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Water and Nutrient Balances of Vegetative Treatment Systems for Feedlots in South Dakota

Daniel T. Ostrem
South Dakota State University

WATER AND NUTRIENT BALANCES OF VEGETATIVE TREATMENT SYSTEMS FOR FEEDLOTS IN SOUTH DAKOTA

BY

Daniel T. Ostrem

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This thesis is approved as a creditable and independent investigation by a candidate for the Master of Science in Engineering degree and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Dr. Todd P. Trooien
Thesis Advisor
Date

Dr. Van C. Kelley
Head, Agricultural and Biosystems Engineering
Date

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ABSTRACT

WATER AND NUTRIENT BALANCES OF VEGETATIVE TREATMENT SYSTEMS FOR FEEDLOTS IN SOUTH DAKOTA

Daniel Thomas Ostrem

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Vegetative treatment systems (VTS) are a possible alternative to storage basins for managing feedlot runoff but have not been researched in South Dakota. This study was conducted to evaluate the performance of VTS within South Dakota. The performance was evaluated by determining water and mass balances on each vegetative treatment area (VTA). The balances were determined by measuring all inflow, outflow, evapotranspiration, precipitation, and both soil and water nutrient concentrations within the VTA. Twelve site-years have been completed in researching VTS from four feedlots in South Dakota. Seven of the twelve site-years VTS were able to prevent water from leaving the VTA. Two of the years that did have VTA outflow were due to rainfalls in excess of a 25 year, 24-hour storm. Any loss in nutrients greater than two percent of the applied nutrients during a site-year was caused by a 25 year, 24-hour storm event. Soil nutrients appear to be accumulating at Miner County and phosphorus appears to be accumulating in front of the VTA inlet at Haakon County. Soil changes however, are not significant at any location at the 95% confidence level. The results show that VTS have potential to become working

systems for the containment of both water and nutrients. Every site had at least one researched site-year that was successful in complete containment. The information learned in this project is valuable to evaluate VTS performance, to calibrate VTS models, and to provide information for further research.

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LIST OF ABBREVIATIONS

CAFO	Concentrated Animal Feeding Operation
ELG	Effluent Limitation Guideline
EPA	Environmental Protection Agency
ET	Evapotranspiration
NPDES	National Pollution Discharge Elimination System
NRCS	Natural Resources Conservation Service
VFS	Vegetative Filter Strip
VIB	Vegetative Infiltration Basin
VTA	Vegetated Treatment Area
VTS	Vegetated Treatment System
TKN	Total Kjeldahl Nitrogen
P	Phosphorus

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Chapter 1 – Introduction and Background

Introduction

While the earth continues to grow in both population and technology, awareness of how people affect their environment grows as well. It is becoming more evident that the quantity and quality of the natural resources that remain on this planet are changing. Because of this, a need is arising to create management practices that mitigate the harmful effects that we may create toward these resources. This is especially true in an agricultural setting, where agricultural practices can have a large effect on the quality of the water, air, and soil. Pollution sources from agriculture are usually non-point source, and may seem insignificant within the scope of a single farm but when accumulated over a large area the total amount of pollutants may be unacceptable to promote a healthy environment.

Concern for agriculture is building as the world populations grow, because agricultural lands are being converted into urban areas. Because this is happening, the agricultural lands will need to become more productive to meet the needs of a growing society. Higher productivity on smaller areas of land might only increase the potential for environmental changes. This may be good or bad. In order to try to make land more productive and sustainable, agricultural land needs alternative forms of management. This allows a producer to choose management practices that can better fit his or her operation for both profit and the betterment of the environment.

One of the newest growing alternative technologies for manure management is the use of Vegetative Treatment Systems (VTS). A VTS can be comprised of solids settling basins, vegetative filter strips (VFS), vegetative treatment areas (VTA), vegetative infiltration basins (VIB), or constructed wetlands (Smith, 2006). A VTS usually utilizes many of these in series.

In 1972, when Congress passed the Clean Water Act, the National Pollutant Discharge Elimination Systems (NPDES) was established. This system became controlled by the state in South Dakota in 1993 and was delegated by the Environmental Protection Agency (EPA) to grant permits to producers whose operations fall under a large confined animal feeding operation (CAFO). A CAFO is defined by the South Dakota Department of Environmental and Natural Resources (DENR) to be a lot or facility that stables or confines and feeds or maintains animals for a total of 45 days or more in any 12-month period and meets criteria for a large (>1,000 animal units), medium (>= 300 and < 999 animal units), or small (< 300 animal units) operation.

The effluent limitation guidelines (ELG) are a set of standards for containment basins. The ELG mandates that the treatment system for a large CAFO must be able to contain all of the water that runs off the feedlots from events not exceeding a 25 year, 24-hour storm. To compare VTS to the baseline ELG standards, site specific monitoring must be done to gather the data needed for calibration of comparison models. Some factors that may change at each site are climate, soils, topography, VTS design, and vegetation. Environmental regulators will use this research to determine if VTS have the potential to achieve "equal to or better than" the current holding basin system based on the amount and the number of occurrences of releases that each model predicts.

A VTS may be more beneficial to a producer because it has the potential to mitigate some of the disadvantages that a holding pond or lagoon may possess. Some of these disadvantages may include:

- water volumes that are stored for extended periods of time, increasing the potential for deep seepage
- containment leakages that can end up in nearby water sources
- labor and management problems that may arise with land application
- unpleasant odors that are intensified by large open surface area
- visual aspects that may be environmentally unsightly
- construction costs that are usually higher than VTS

A benefit of the alternative system is that a VTS may mitigate the potential for deep seepage because water can be applied to one of many components for vegetation use right away or up to 72 hours later. Seventy-two hours is the maximum amount of time that water may be held in an unlined settling basin under DENR enforcement. One of the largest factors in the performance of a VTS is its management. Since producers have more timing control of water application with a VTS than a holding pond, they may be able to avoid containment breeches, especially during the growing season if land application of the manure is not possible.

The large surface area of the free water surface of containment basins has a high potential to release large amounts of ammonia, intensifying the odor problems for nearby areas. This large area is also not as aesthetically pleasing to most people as a field of vegetation may be.

The total cost of construction of a VTS system may be less than a containment basin system. A study of 21 VTS in four different states estimated the average cost of a VTS is $77 per head for a CAFO and $62 per head for an animal feeding operation (AFO), which compares to the cost of a containment basin at $129 per head and $195 per head respectively (Bond, 2009). An AFO is an animal operation with less than 1,000 animal units.

For climates within South Dakota, it is not clear as to whether a VTS design has the potential to contain all water that comes from feedlot runoff within a 25 year, 24-hour storm. It has been hypothesized that four VTS designs within South Dakota will be able to contain all the runoff water that is applied onto the VTA. Site-specific mass and water balances were needed to meet the objectives of the project. These objectives are:

1) To evaluate the performance of a VTA in terms of water containment.
2) To evaluate the performance of the VTA in terms of nutrient containment.

This data will also be useful for the calibration of VTS models and will provide information for use in the future designs of VTS and other research. The models will use the data to determine the ability of the VTS to contain the water within its boundaries in many environments and conditions.

Literature Review

Data have been collected on manure management for nearly four decades at different locations across the nation. This information is valuable to the study of management systems because it allows the consideration of different climates, soil types, and system designs.

Current Manure Management Systems

Containment basins are currently the only permitted manure management option for producers. Much research has been done on these systems. It has been found that they can be very effective in containing runoff from feedlots. A four year study of seepage losses from animal lagoons showed an average of 1.1 mm/day seepage from 20 lagoons (Ham, 2002). The seepage rates are regulated to be 6.3 or 3.1 mm/day depending on the location within Kansas. Also in Kansas, monitoring for a modeling project found that 95.7% containment would be achieved after 10 years of basin life and 97% after 25 years (Koelliker et al., 1975).

There is evidence however, that in some locations there is potential that a basin may not be the best method for manure containment. In North Carolina, 11 lagoon systems were monitored for estimating losses from deep seepage. Out of the 11 lagoon systems investigated in this study, five systems estimated loss rates were low, ranging from 0.17 to 2.5 kg/day nitrogen export. High seepage losses came from four of the systems ranging from 3.4 to 4.6 kg/day of nitrogen export. The last two basin systems had seepage rates that were severe losing 11 and 27 kg/day of nitrogen (Huffman and Westerman, 1995). In Nebraska, a model was developed to determine how seepage is affected by different criteria of the basin. The model obtained valuable information on the variability of the seepage rates in the creation of this model. A total of 50% to 76% of the total water losses from the basin were due to seepage. The model estimated that a basin would need 14 years of sludge accumulation to have seepage rates decline to the Nebraska regulation of 6.3 mm seepage/day (Parker et al., 1999).

This evidence shows that a containment basin system may not always be the best answer for manure management, and it would be beneficial to find alternative technologies that may perform better under the various conditions that compromise the performance of containment basins.

Alternative Manure Management Systems

Infiltration areas, VTA, and VFS, have been studied since the late 1960s in an attempt to determine how well they perform at controlling runoff and nutrients. Some of the research done comes from Kansas where data was collected to calibrate their VTA model. In 2002 they studied three storm events on a 2.7 ha drainage area with 300 head of cattle. They monitored the inflow and outflow of three VTA using ISCO flow meters and samplers. With the collected water samples, they tested for total-P, total-nitrogen, ammonium, and nitrate.

There were three strips that were 15 m wide, with two of them having samplers installed at the inlet, 30 m from the inlet, and 150 m from the inlet for analysis. They found that 85% of the water and 85% of the sediment were absorbed by the VTA or atmosphere within the first 30 m. The total-nitrogen removal was 77% and the phosphorus removal was 84%. Concentration reductions of all nutrients in the water between 30 m and 150 m from the inlet were minimal, suggesting the importance of the quality of the beginning of the vegetative strip or VTA area (Mankin and Okoren, 2003).

Barker and Young (1984) conducted a two year monitoring period of a VTA that prevented 95% of the total inflow from leaving. Spreader berms were placed in the VTA at 9.1 m intervals. The first two berms contained the majority of the nutrients and they found increasing soil nitrates and phosphorus levels. No other soil testing showed any increases. The VTA was able to remove 96% of chemical oxygen demand, 97% of total-nitrogen, and 98% of total-P as measured by concentration (Barker and Young, 1984).

Dickey and Vanderholm (1980) tested four VTA, two of which were overland flow with 100 dairy cows and 450 head of beef cattle, and the others were channelized flow with 500 head of beef cattle and 480 head of swine. The VTA were capable of reducing sample concentrations by 80% and total mass by 95%. The majority of all events were infiltrated entirely by the VTA (Dickey and Vanderholm, 1980).

In Ohio, a 56 head lot with beef steers was tested. The system utilized a solids settling basin and two grass filter strips in series. These filter strips were then compared later to a tiled infiltration bed with reed canary grass growing on the surface. The infiltration bed reduced nutrient concentrations more than just a filter strip of 33 m but not as well as a 66 m strip. Nutrients that were tested for in this project were total solids, chemical oxygen demand, nitrate, ammonium, organic nitrogen, total-P, and potassium (Edwards, 1986).

A study conducted in Virginia utilized dairy manure applied to fields with three different slopes and two different manure application loadings. The pilot lots were 5.5 m wide and 18.3 m long. Each lot had flume with a sampler and stage recorder to determine the flow amount and water concentration. Two filter strips of different lengths were compared to another lot with none. The length of the VFS was 4.6 m for the shorter and 9.1 m for the longer. Both sediment and soluble nutrient removal were studied. It was found that 91% of the sediment was removed from the longer VFS and 81% from the shorter. This is less important to a VTA because most sediment should have been removed in the solids settling basin but, no basin has perfect performance. Much of the nitrogen and phosphorus was removed in the solids. The soluble nutrients however, were not removed as efficiently. Soluble nitrogen removal was 69% and 58% for the long and short VFS respectfully. Soluble phosphorus removed was 74% and 64% for the long and short filters (Dillaha, 1988).

All of these research sites cover feedlots that are smaller in comparison to the large CAFO feedlots that are becoming more common in today's livestock industry. More research is needed in different areas across the nation in order to evaluate the performance of a variety of different larger VTS designs.

Iowa State University has currently been researching six larger feedlots in Iowa. From these site locations they are learning that the performance of the VTA is affected just as much by the operational management rather than its physical characteristics. They have seen a rise in performance of water control each year and attribute this to the experience of the operators as they learn how to maximize the effectiveness of the treatment area. This maximization has been accomplished as the producers have learned to properly release water from the basin at the correct time and rate to avoid outflows from the VTA. Nutrients were able to be reduced in water from the solids settling basins with the addition of gate values to the basin exits. Better established vegetation and the addition of spreader berms also reduced nutrient concentrations within the water on the VTA. Total nutrient mass has been reduced by 65% to 90% as opposed to a system with a solids settling basin only (Andersen, 2009).

Cornell University conducted a study of the use of a VTA for collection and storage of wastewater from silage bunkers. Two VTA at a five percent slope and dimensions of 36 X 66 m were studied. Surface and subsurface runoff was monitored on the VTA with the use of a chloride tracer. Preferential flow was more likely to be created on the surface and subsurface when the soils were saturated. Cornell also studied a mass balance at three different VTA to determine the nutrient removal from the systems. The first VTA had nutrient removals of ammonium at 63%, nitrate at 0%, and soluble reactive phosphorus (SRP) at 39%. VTA two had removals of ammonium at 79%, but nitrate and SRP increased by 200% and 533% respectively. The last VTA had removals of ammonium at 67%, while nitrate removal was at 86% and SRP removal was 88% (Faulkner, 2009).

Research was conducted for passive runoff control onto VTA at the Meat and Animal Research Center in Clay Center Nebraska. Eight pens were selected at about 30 x 90 meters in dimension. The runoff from the feedlots entered a solids settling basin that was designed to distribute the water to the 4.5 ha VTA and to allow a five to eight minute hydraulic retention time. The water distribution from the solids settling basin did not perform as well as they had hoped. Nutrients accumulated in front of the solids settling basin outlet pipes. Nitrate was also found to be accumulating underneath the solids settling basin. No water was found to have left the bottom of the VTA or from beneath the root zone in any of the four monitoring years (Woodbury, 2003).

Chapter 2: Water Balance of Four Feedlots in South Dakota

Abstract

Hydraulic loading of a vegetative treatment system (VTS) is an important factor of its performance. Water is the carrier of the nutrients from the feedlot onto the other components of the system. If a VTS can contain all applied water within a vegetative treatment area (VTA) then it will be able to control the nutrients as well. To determine the performance of VTS designs, four feedlots were studied across the state of South Dakota. Precipitation, VTA inflow, and VTA outflow were measured directly. Evapotranspiration (ET) was estimated using locally-measured weather parameters. Measurements showed that in seven of the twelve site-years, VTS were able to prevent water from leaving the VTA. Two of the years that did have VTA releases were due to rainfalls in excess of a 25 year, 24-hour storm. This leaves three of the site years with releases under the 25 year, 24-hour storm limit and showed some of the possible design flaws that could be improved. Seasonal water releases from the VTA were all 5% or less of the seasonal inflow and precipitation that was applied to the VTA. Ten of the twelve site-years had potential ET values that were high enough to indicate that the VTA should be capable containing all water applied to the VTA.

Introduction

There are many new theories and discussions on how the earth is changing today. These topics are driving a higher awareness of the health and welfare that our world is in. This growing awareness is beginning to have an impact on how some people live as they try to preserve the natural resources that remain on the earth. This is especially true in the areas of agriculture. Agriculture has a large impact on the condition that many of our resources may be in. In order to protect what we have, agricultural practices are starting to be altered to benefit producers as well as keep the environment in as healthy of a state as possible. The research in this project focuses on determining how well a specified field of vegetation or vegetative treatment area (VTA) can contain wastewater from beef feedlots that has been applied to it.

Currently the only acceptable method of runoff containment for the beef lots is to store the water in a lagoon or holding basin (under Effluent Limitation Guidelines). Under these guidelines, producers that have operations over 999 animal units must contain all the water that comes from events not exceeding a 25, year 24-hour storm.

A vegetative treatment system (VTS) may be a viable alternative to the holding basin system currently mandated. Producers that may not have access to fields for crop production to apply the nutrient rich water as fertilizer can instead apply the water to a VTA. The VTA can save on application costs and substitutes an area that produces a harvestable crop for basin space. VTS construction costs have been shown to be lower than holding ponds, monoslope barns, and hoop structures (Bond et al., 2009). The environment may also benefit from the use of VTA by protecting water sources outside the VTS from the higher nutrient concentrations in runoff. With a basin system there is risk of deep nutrient leaching because the water is stored in ponds for long periods of time (Parker et al., 1999). These nutrients that have been leached have the potential to contaminate groundwater sources. The holding ponds also have potential for containment leaks above ground if proper management of the pond is not capable of being conducted. VTS may provide the technology needed to mitigate some of these environmental impacts.

A VTS can contain any or all of the following components: solids settling basin, vegetated infiltration basin, and vegetated treatment area (VTA). The systems in this study consisted of a feedlot, solids settling basin, and a VTA. Runoff water from the feedlot, containing nutrients and other constituents, flows off of the lots and will be contained in the solids settling basin for up to 72 hours, unless it is lined. This is where solids and some associated nutrients are removed from the water by gravity settling. The VTA is the last step in the systems and is area within a VTS in which a perennial crop grows to utilize the incoming nutrients and water.

Design and performance of the VTS depends on site-specific characteristics such as soil types, available areas, expected precipitation, slopes, the method of water release from the sediment basin, and other factors. Most of these factors reduce preferential flow conditions within the VTA. When preferential flow is avoided, infiltration over the VTA is increased and the ability of the VTA to contain the water increases. Cornell University determined that saturated soils also promoted preferential flow conditions with the use of chloride tracers both on the surface and subsurface (Faulkner, 2009). This is why the timing, rate, and volume of emptying the sediment basin are some of the largest controlling factors in the performance of the VTS (Smith, 2006).

The objective of the research reported here was to determine the effectiveness of VTS in containing surface water. The objective was reached by measuring VTA inflows and releases and calculating VTA surface water balances for four animal feeding operations in South Dakota.

Materials and Methods

Hydraulic monitoring of VTS was conducted by calculating a water balance for the surface of the VTA. Water transport was either measured or calculated into or out of the VTA using equation 1. The balance may also be seen in figure 1.

$$R = Q_{in} + P - ET_r - Q_{out} \qquad (1)$$

where

R= Remainder of water balance (mm)

Q_{in}= Depth of water that flowed onto the VTA from the sediment basin (mm)

Q_{out} = Depth of water that flowed off the VTA (mm)

ET_r= Crop evapotranspiration (mm)

P = Precipitation on the VTA (mm)

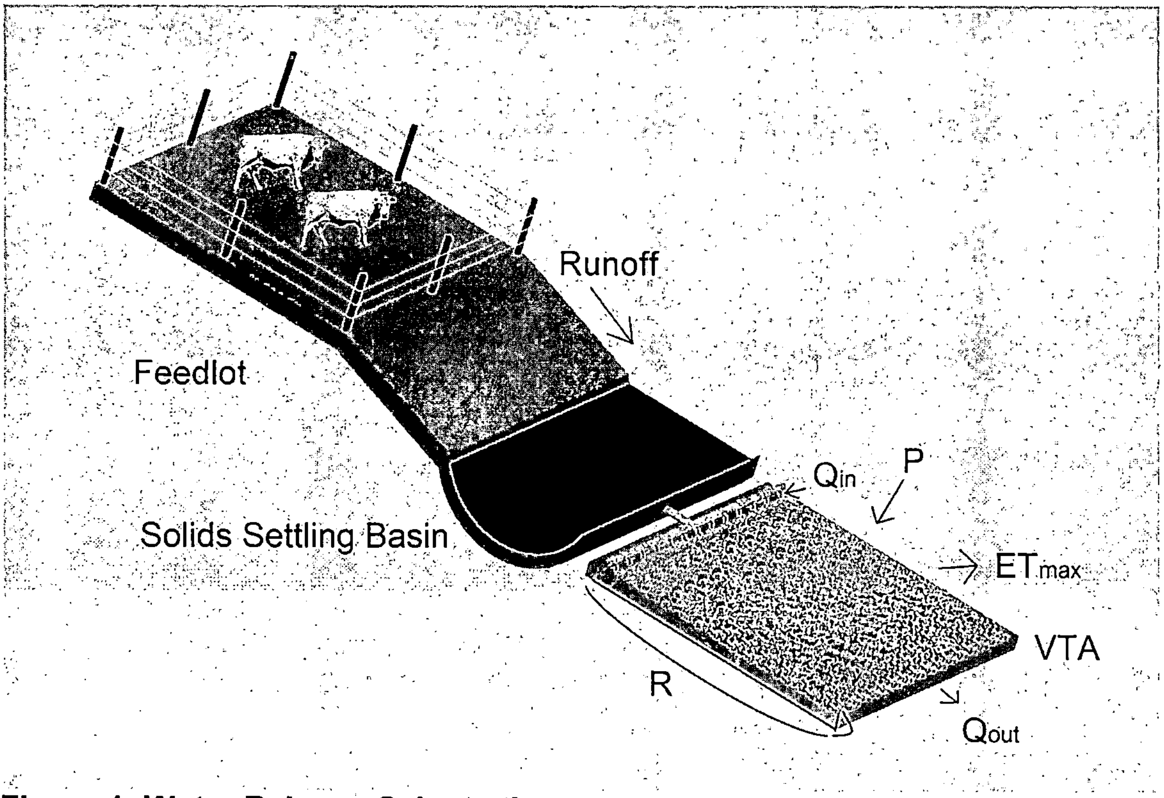

Figure 1: Water Balance Schematic

The values in the project that needed to be measured on site were Q_{in}, Q_{out}, precipitation, temperature, and relative humidity. Equipment that was used included a:

- Hobo tipping bucket with a Hobo H07-002-04 logger for rainfall.
- Hobo H08-032-08 logger for temperature and relative humidity.
- ISCO 730 or 4230 bubbler meters for flow measurements.

Values that were found by using information from nearby weather stations were solar radiation, wind speed, and any missing weather data that may have occurred from collection errors. Missing climate data was collected from South Dakota State University or North Dakota State University station archives. Once a weather data set was complete, daily evapotranspiration values could then be calculated by using a 0.5 m tall reference ASCE Standardized Penman-Monteith equation (eq. 2). The calculated ET_r values were then used as an ET_{max} to show the potential ET that each location could have in order to balance the amount of water on the VTA surface. The calculation was made using an Excel spreadsheet for reference ET that was downloaded from the University of California Davis website (UC Davis, 2009).

$$ET_r = \frac{0.408\,\Delta(R_n - G) + \gamma \frac{1600}{T+273} U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.38\,U_2)} \quad (2)$$

where

ET_r = standardized reference crop evapotranspiration (mm/d)

R_n = calculated net radiation at the crop surface ($MJ/m^2/d$)

G = soil heat flux density at the soil surface ($MJ/m^2/d$)

T = mean daily or hourly air temperature at 1.5 to 2.5-m height (°C)

U_2 = mean daily or hourly wind speed at 2-m height (m/s)

e_s = saturation vapor pressure at 1.5 to 2.5-m height (kPa)

e_a = mean actual vapor pressure at 1.5 to 2.5-m height (kPa)

Δ = slope of the saturation vapor pressure-temperature curve (kPa/°C) γ = psychometric constant (kPa/°C)

In order to determine the amount of water that was applied to each VTA, a hydrograph was made from the data collected by hydraulic instrumentation. The hydrograph could then be graphically integrated to estimate the volume of water that flowed into the VTA. An example of this hydrograph can be seen in figure 2. In the case of a flow meter malfunctioning, the runoff was estimated by the use of a NRCS table that uses inputs of location and month to determine runoff as a percentage of precipitation. This method of estimation is accepted by the SD Department of Environmental and Natural Resources (Bonnema, 2010).

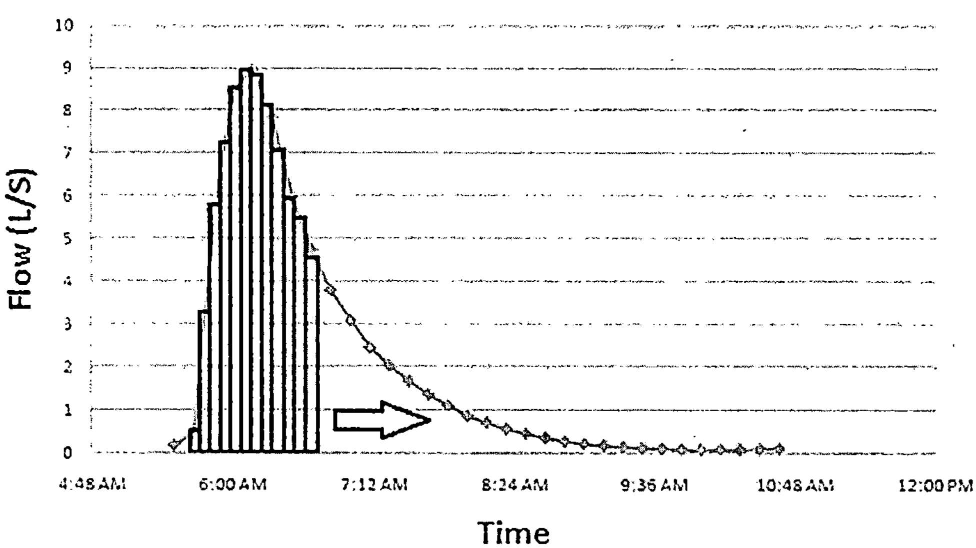

Figure 2: Graphical example of volume calculation

Plots were also made from the measured VTA inflow volumes that show the variability of the amount of runoff that occurs from precipitation amounts. These were plotted with the maximum amount of water that could have run off the feedlots and entered the VTA based on rainfall. This allows the data to be checked for reliability. In the case at Miner County, some of the points did extend beyond what was possible for a rainfall event. Extra runoff water could be counted in a measurement when snowmelt or the drawdown of stored water from a previous event was counted. When the higher points did not associate with either of these exceptions, a new estimate at the maximum runoff level from precipitation data was assumed.

To conduct research on the performance of VTS, sites were needed that would give a representative look at how VTA react in various conditions. South Dakota provided a great landscape for the type of variability needed to research VTA in different conditions. Sites were chosen at different spatially-spread geographical locations. To pick a site location, it was important to look for varying characteristics that could be compared in VTS design as well as having producers that were willing to cooperate with the university on the project. The site locations can be seen in figure 3. All the feedlot site characteristics can be seen in tables 1 and 2. Figure 3 also shows average rainfall values from a thirty year average from 1971 to 2000. Each site location is spread across South Dakota in a different area that has different climate patterns. The town of Sisseton 16 km away from the site and receives 561 mm of rainfall annually. The town of Howard at 1.6 km away from the site and receives 603 mm of precipitation annually. The town of Midland is 5.6 km away from the Haakon County feedlot and has 438 mm of precipitation. The last site is averaged between the towns of Newell and Fort Meade because of the 151 mm difference in rainfall between the two locations that are 33 km apart. The precipitation for the site would be 469 mm annually.

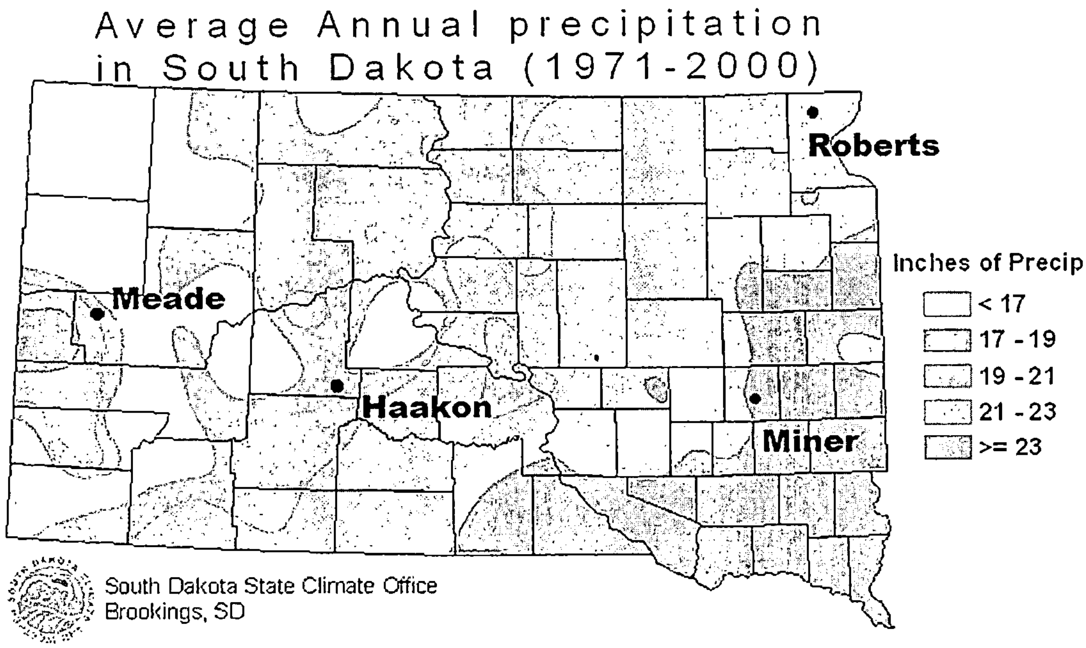

Figure 3: Site locations in South Dakota

Table 1: Site characteristics of two locations west of the Missouri River

Parameter		Site: Haakon	Site: Meade
Monitoring Dates	2005	–	–
	2006	–	1-Jun-30-Nov (182 days)
	2007	3-Apr-Sept 1 (151 days)	16-Mar-Sept 1 (169 days)
	2008	12-Feb-8-Dec (299 days)	8-May-8-Dec (214 days)
	2009	13-Mar-10-Nov (242 days)	13-Mar-Nov 11 (243 days)
Operation type		seasonal cow-calf and back-grounding	seasonal cow-calf
Feedlot Area, m^2		39,254	72,439
Feedlot Surface		Earth	Earth
Feedlot Aspect		South	Northeast
Feedlot Slope %		5	1
Animal Units		665	450
Basin Capacity m^3		8517	1104
VTA area m^2		11,331	102,385
VTA Vegetation		Western Wheatgrass	Alfalfa
VTA Slope, %		1	0.5
VTA Aspect		North	North
Spreader		No	Ditches
VTA : Feedlot Area Ratio		0.289	1.413
VTA Soils		Nimbro silty clay loam (Nb)	Arvada silt loam (AnB) Manvel silt loam (MbB) Savo silty clay (ShA)
VTA containment structure		enclosed berm	gated berm
Nearest Cooperative Weather Station		Midland	Fort Meade
Nearest Automatic Weather Station		Cottonwood	Nisland
VTA Inflow Monitoring Device		0.3 m H-flume	0.3 m H-flume
VTA Outflow Monitoring Device		Standpipe	0.3 m H-flume

Table 2. Site characteristics of two locations east of the Missouri River

Parameter		Site: Miner	Site: Roberts
Monitoring Dates	2005	26-May-20-Oct (147 days)	–
	2006	9-May-16-Nov (191 days)	–
	2007	14-Mar-Sept 1 (171 days)	–
	2008	11-Feb-3-Dec (295 days)	–
	2009	23-Mar-30-Nov (252 days)	15-May-13-Oct (151 days)
Operation type		continuous feeder cattle	continuous feeder cattle
Feedlot Area, m^2		50,586	12,302
Feedlot Surface		Earth	Earth
Feedlot Aspect		East	East
Feedlot Slope %		4	4
Animal Units		675	200
Basin Capacity m^3		1296	2608
VTA area m^2		8,498	13,759
VTA Vegetation		Smooth Brome	Smooth Brome, Intermediate Wheatgrass, Reed Canary grass
VTA Slope, %		2	3.5
VTA Aspect		East	Southeast
Spreader		Gated Pipe	Gated Pipe
VTA:Feedlot Area Ratio		0.167	1.118
VTA Soils		Clarno-Bonilla Loam (CfB), Bon Loam (Bo)	Peever Clay Loam (PeB)
VTA containment structure		none	none
Nearest Cooperative Weather Station		Howard	Sisseton
Nearest Automatic Weather Station		Dell Rapids	Britton
VTA Inflow Monitoring Device		Manning Pipe	Pumping Time
VTA Outflow Monitoring Device		0.15 m H-flume	0.3 m H-flume

Haakon County

Haakon County, which is in a more arid climate, was studied to determine its performance at its location. This site is just south of the town of Midland with coordinates of 101° 10.8'W and 44° 1.1'N. The closest automatic weather station measuring solar radiation and wind was the Cottonwood station. This site contains two VTA but only one of them was monitored to determine VTS performance. The feedlot consists of six pens, three that are drained to the northern sediment basin and VTA and three that are drained to the south basin and VTA. The southernmost system was the one being monitored and can be seen in figure 4. Runoff from the lots dropped into a drop pipe structure inside of the lot where it was then carried underground to the sediment basin. Once in the basin, the water then exited by another pipe to the VTA. Water volume into the VTA was measured with a 0.3 m H-flume, from flow out of the sediment basin. Since the VTA is designed to be completely contained with earthen berms around its perimeter, a bubbler meter was placed at the lowest elevation of the VTA to determine a depth of ponded water. The volume calculated from this depth would give an estimate of the amount of water that may have run off if there had been no berm enclosure. The area is bermed in order to protect Brave Bull Creek which flows very close to the VTA.

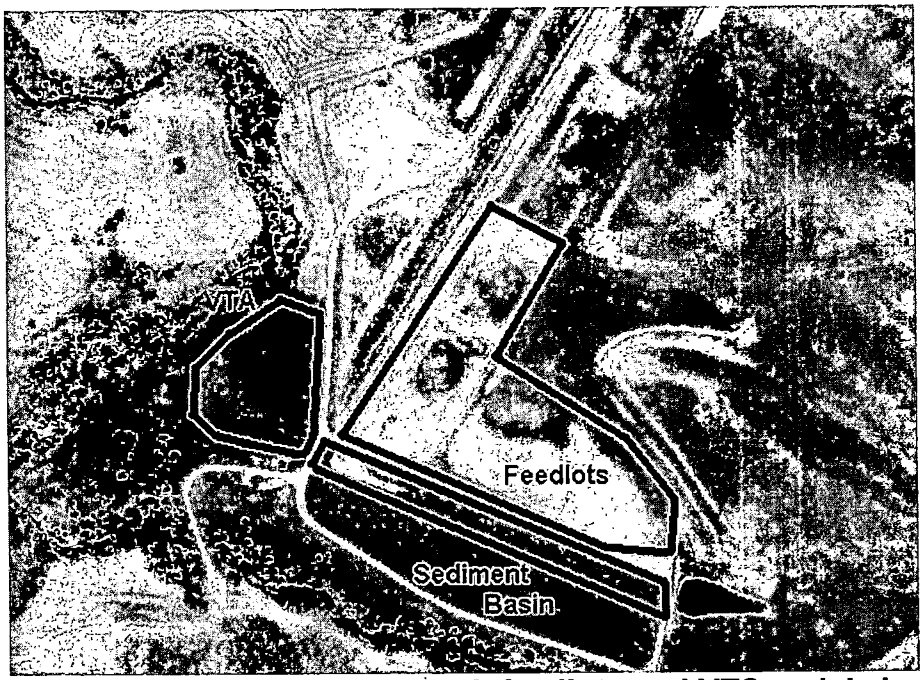

Figure 4: Haakon County south feedlots and VTS aerial view

Meade County

The western side of Meade County has a climate affected by the Black Hills. The hills make a barrier that affects the stability of the air masses that intercept them. This instability has the potential to build large thunderstorms, which often move off the hills before decreasing in intensity and can be directed to nearby regions. Evidence can be seen from this by the annual rainfalls from two locations north and south of the feedlot. Newell, which is 34 kilometers away from Fort Meade to the north, receives 393 mm of rainfall based on a 30 year average. Fort Meade receives 544 mm of rainfall, 151 mm more than Newell. The Meade County VTS site is only a few kilometers north of Bear Butte on Highway 79 directly between Newell and Ft. Meade, where it can still be affected by weather created from the Black Hills' instability. At times when rainfall data at the feedlot wasn't taken, data was adjusted from Nisland and Fort Meade in an attempt to match what was believed to have precipitated. The coordinates of the site are 103° 26.7'W and 44° 32.0'N

The VTA in Meade County is the largest of all monitored VTA. It is divided into three separate cells in which the water can be diverted and distributed into any of the three cells that the producer chooses. This diversion system design is shown in figure 5 shortly after construction.

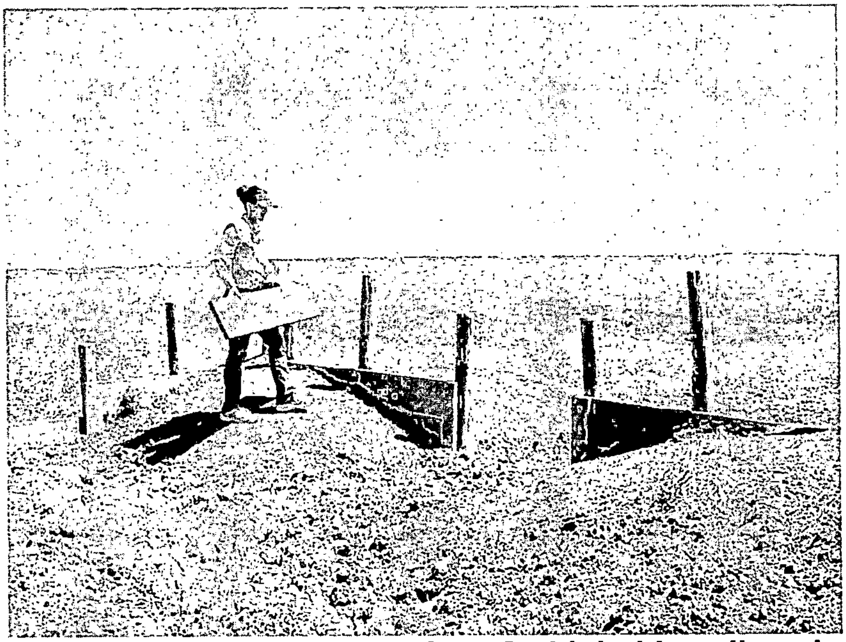

Figure 5: SDSU research student Sara Smith holds a diversion board at a VTA cell inlet.

Water was contained in the VTA unless the water was ponded at the bottom. In this situation, a gate was opened to release the water from the VTA to protect the VTA vegetation. Water was brought to the VTA from an earthen channel after coming out of a pipe from the solids settling basin. Water volume inlet measurement was done at the end of the pipe with a 0.3 m H-flume and Isco bubbler flow-meter. Similarly, a 0.3 m H-flume was used with an Isco bubbler flow meter at the gate on the VTA release point. Flow measurements were available for both inflow and outflow on the VTA. For instances when the rainfall gage was not able to be recorded, rainfall data from Nisland at 19 km away and Ft. Meade at 13 km away were used to fill the gaps. An aerial view of the site can be seen in figure 6.

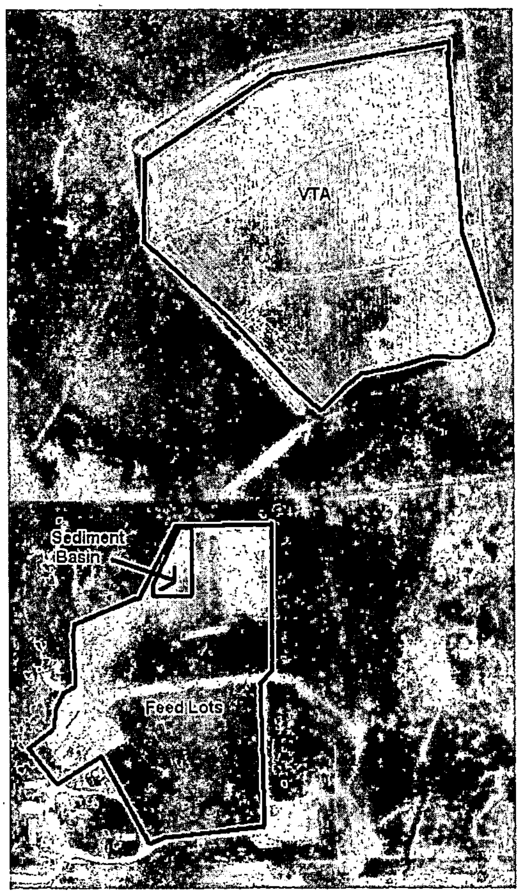

Figure 6: Meade County aerial view

Roberts County

In the most north eastern county of South Dakota lies another VTS research location shown in figure 7. The site is in Roberts County at coordinates of 97° 5.3'W and 45° 48.4'N and brings in cooler temperatures and typically less rainfall than other eastern South Dakota locations. This location had water inflow measured by timing the runtime of a pump that delivered water from the solids settling basin to two higher-gradient sets of gated pipe that ran across the VTA. This runtime was then multiplied with the pump's flow rate to determine water volumes. The VTA here divides into two small sub watersheds in which two 0.3 m H-flumes were installed with Isco bubbler flow meters at the watershed exits from the VTA to measure VTA outflow.

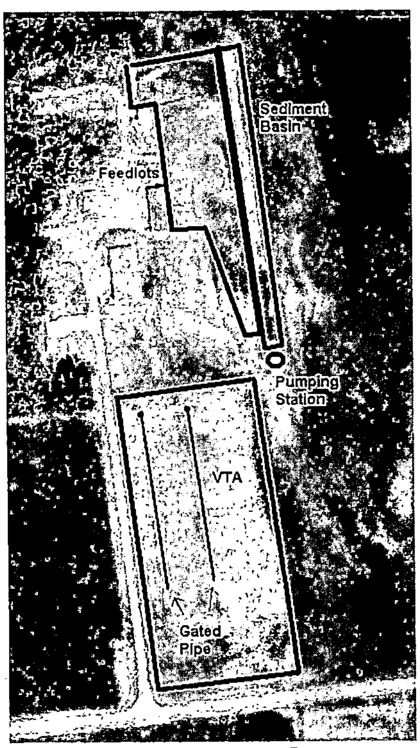

Figure 7: Roberts County aerial view

Miner County

The Miner County location historically has the most precipitation of the sites monitored in this project (fig. 3). It is located just south of the town of

Howard with coordinates of 97° 31.4'W and 43° 59.5'N. The nearest automatic weather station is located at Dell Rapids. There is a coop weather station in Howard that was also used for weather information. These weather stations were utilized to fill missing weather data from the on-site equipment. The VTA here has minimal engineering involved in its design. The sediment basin was dug at the base of the feedlot where space allowed and the VTA was never leveled. Water in the solids settling basin enters the VTA either by the use of a siphon or by entering an overflow pipe near the top of the basin. The siphon needs to be used to drain the water completely from the basin. Both of these drainage methods enter into the same 203 mm pipe in which a bubbler measures the depth of water flowing inside the pipe. The depth can then be used to calculate a flow rate using the Manning's Pipe Equation (eq. 3). The equation used was equation 3.19b found in Open Channel Hydraulics by A. Osman Akan (Akan, 2006).

$$Q = \frac{k_n}{n} AR^{\frac{2}{3}} S_f^{\frac{1}{2}} \qquad (3)$$

where

Q = Flow ($m^3\ s^{-1}$)

k_n = Unit Constant ($1m^{1/3}\ s^{-1}$)

n = Mannings Roughness Factor

R = Hydraulic Radius (m)

A = Cross Sectional Area of Flow (m^2)

S_f = Slope

The water was distributed across the VTA by the use of gated pipe that was added in 2006. The VTA handles the water in two watersheds. The watersheds have a 0.3 m H-flume in the north and a 0.3 m H-flume in the south. Both flumes have Isco bubbers to measure any outflow through the flume if it leaves the VTA. A view of the Miner County feedlot can be seen in figure 8.

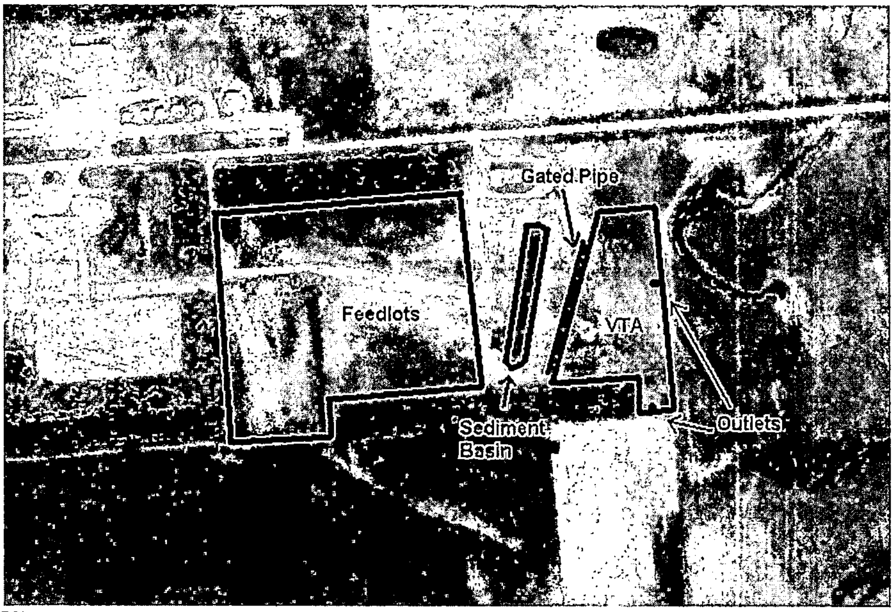

Figure 8: Miner County aerial view

Results

The largest values of inflow are seen in Miner County (fig. 9). These values represent the amount of water that passed through the basin onto the VTA with respect to the surface area of the VTA. The flows were relatively high compared to the other monitored VTA. Regardless of the high inflow to the VTA each year, the VTA was able to prevent water from leaving its boundaries for two of the five monitoring seasons. No monitoring of outflow was done in 2005;

however, it is important to note that there were many outflows during this season. The outflows that occurred during this monitoring season were visually observed. The large amount of water that flowed out of the basin in 2007 was mostly due from snowmelt that occurred in the spring. A summary of each of the site years from the feedlots in South Dakota is shown in figures 9, 10, and 11 as well as table 3. It is important to note that each year had a different monitoring season length. This needs to be taken into thought when comparing the amounts for each site-year.

The Meade and Haakon Counties, which are west of the Missouri River in a typically more arid climate, both received higher than average rainfall for the year of 2008 (fig. 3). The Meade County VTS experienced three 25 year, 24-hour storms in 2007 and 2008. Two of them occurred in 2008. These storms filled the 102,385 m^2 VTA requiring the water to be released in order to save the crop of alfalfa. No 25 year, 24-hour storms occurred in Haakon County during any monitoring season. The design in Haakon County was adequately sized to handle the 155 mm higher than average rainfall that it received in 2008.

The Roberts County feedlot had only been monitored for one season. The site received a few large rainfalls but the design of the solids settling basin contains a pumping system with a large basin such that pumping was only possible twice during the season. The VTA was able to avoid VTA releases in both events. Because of the small dataset collect no further analysis was conducted for the Roberts County VTS.

Figures 9, 10, and 11 show two bars for the inflow and outflow onto or off of the VTA during a monitoring season. Table 3 shows many remainders with negative values. The negatives are important because they show that the VTA have the potential to handle the amount of water that would be applied to the VTA.

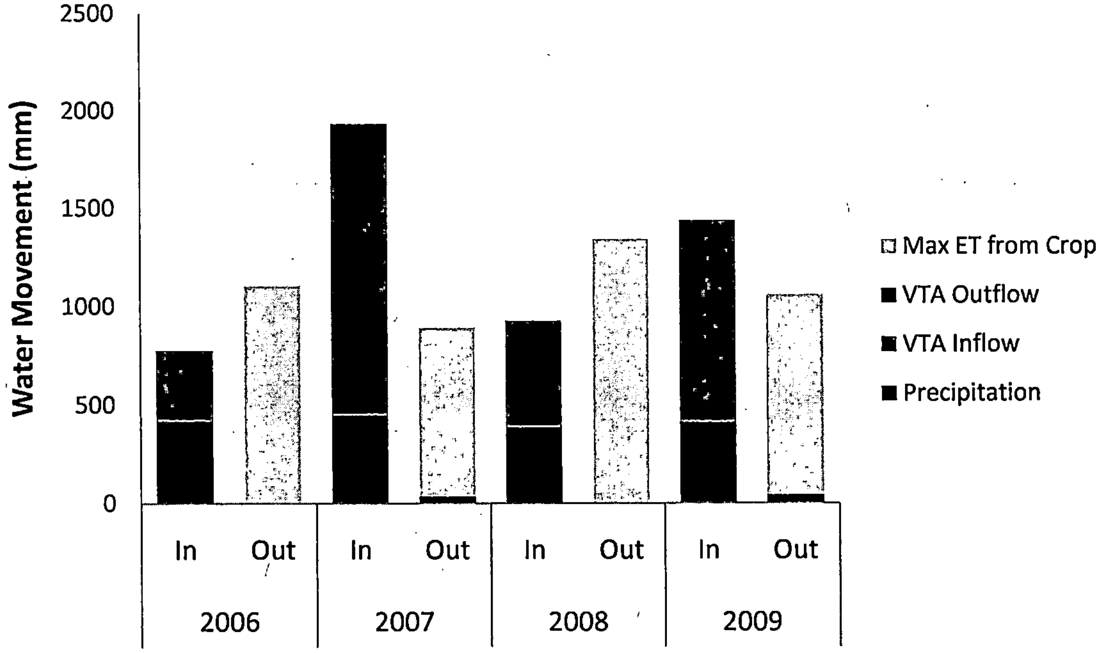

Figure 9: Miner County water balance

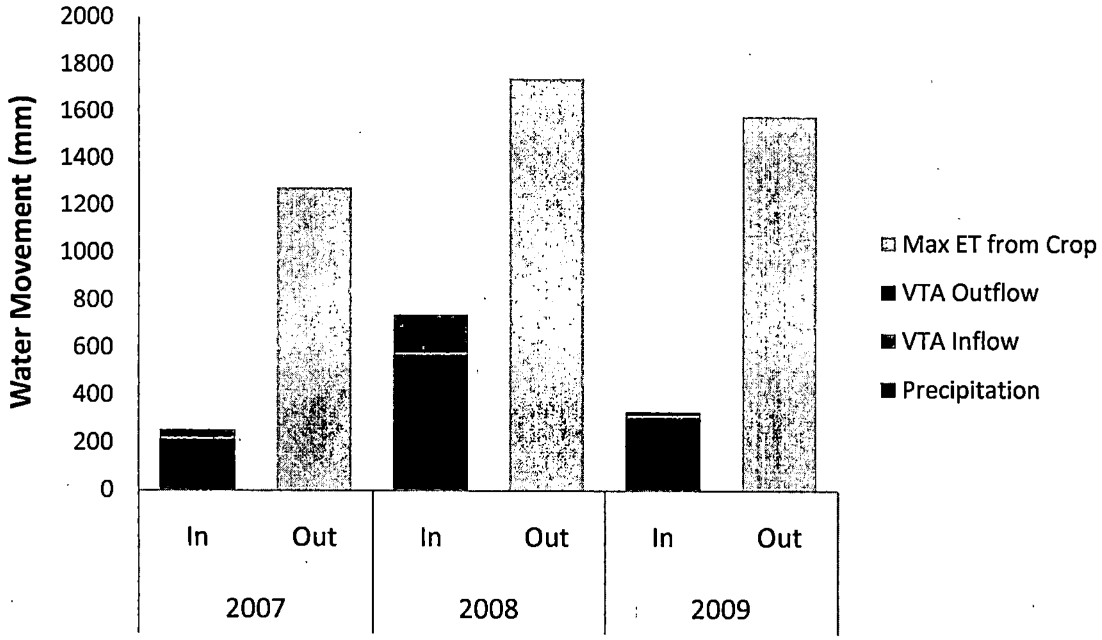

Figure 10: Haakon County water balance

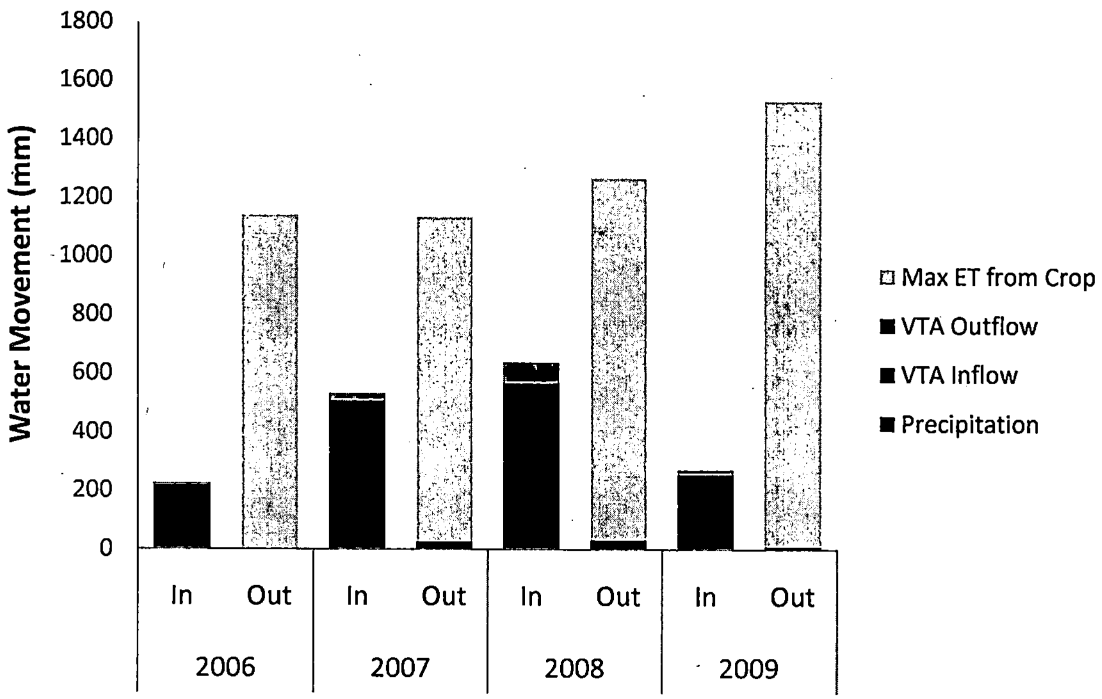

Figure 11: Meade County water balance

Table 3: Seasonal water balance

Site	Number of Days Monitored	Precipitation	VTA Inflow	VTA Outflow	Max ET	Balance Remainder
	mm					
Miner 2006	191	419	356	0	1103	-328
Miner 2007	171	449	1483	35	856	1041
Miner 2008	295	385	538	0	1341	-418
Miner 2009	252	410	1026	43	1014	379
Meade 2006	182	218	8	0	1139	-913
Meade 2007	169	506	27	27	1108	-602
Meade 2008	214	567	72	32	1234	-627
Meade 2009	243	256	18	2	1520	-1248
Haakon 2007	151	214	41	0	1276	-1021
Haakon 2008	299	571	169	0	1742	-1068
Haakon 2009	242	307	23	0	1580	-1250
Koeppe 2009	151	377	2	0	1047	-668

Miner County

Miner County had the most years researched in this project. The site provided information for what many smaller farmers may do in their operations when treatment areas might be limited. High costs of properly designing and building VTA systems may not be in the best interest of producers not under regulations of the NPDES. VTA may still be utilized for the producers with smaller operations to practice good land stewardship with the land characteristics that they have available. Table 4 shows what may happen under conditions where the VTS does not meet all design criteria that would be required of a VTS under state regulations.

Monitoring started in 2005. Total inflow to the VTA measured 2,809 m^3. VTA releases were common from most flow events. This was because there was not a water distribution system installed, and with a VTA that was not leveled, this created preferential flow conditions. To remedy the high outflow problem, gated pipe was installed and was used during the following monitoring seasons.

In the monitoring season of 2006, the gated pipe proved to be successful in preventing any VTA releases. Because of the new change of gated pipe in the system, 2005 was not included in the final analysis of the study. The VTA inflow volume was slightly higher than the previous year at 3,027 m^3 of inflow. This amount of water was capable of being applied without having flow leave the VTA.

This total volume was divided over only four events that all happened later than July during the season.

The year of 2007 had very high inflows during the spring with much snowmelt involved. VTA inflow was over-estimated a few times because values that were recorded were more than what could be estimated as the maximum water applied to the feedlot from precipitation data. The total amount added to the VTA in the season was 12,604 m^3 of water. This large amount caused four days of system outflow totaling 299 m^3.

The solids settling basin overflow pipe changed the inflow into the VTA in 2008. An elbow was placed on the inlet pipe that allowed the solids settling basin to hold a greater volume of water. This elbow cut down on the number of smaller events that came out of the basin. Five events took place over the monitoring season for a total of 4,568 m^3 of water that were applied.

During 2009, the events were evenly spread over the season until October, when a wet fall set in. There were only three major events before October and four events in October and November. The total inflow for 2009 was 9,646 m^3. Total outflow was 351 m^3, slightly higher than 2007.

Table 4: Miner County runoff events

Date	Days in Event	Precipitation (mm)	Inflow (m^3)	Outflow (m^3)
06/12/05	9	108	1353	0
06/24/05	1	28	387	0
08/03/05	1	24	133	0
08/26/05	1	8	71	0
09/08/05	3	77	625	0
09/12/05	1	26	32	0
09/19/05	3	29	167	0
09/24/05	1	17	34	0
10/05/05	2	19	7	0
08/13/06	4	101	781	0
09/02/06	6	86	1098	0
09/23/06	8	56	1126	0
10/19/06	8	6	22	0
03/16/07	snow	0	2399	41
03/26/07	snow	7	1165	65
04/23/07	2	58	2914[a]	141
05/18/07	9	71	3592[a]	52
05/26/07	5	28	2102	0
06/02/07	2	26	1	0
06/09/07	0	0	14	0
06/16/07	1	2	12	0
06/23/07	5	9	7	0
06/30/07	0	0	1	0
08/06/07	2	45	128	0
08/20/07	6	53	256	0
08/24/07	2	27	13	0
04/13/08	13	44	1378	0
04/30/08	17	89	573	0
06/06/08	16	88	684	0
10/15/08	9	65	762	0
10/26/08	11	66	1171	0
03/23/09	snow	0	Ice	139
04/18/09	snow	0	912	0
07/08/09	6	33	1717	0
08/04/09	7	18	729	0
10/02/09	12	47	635	70[b]
10/07/09	5	24	2507	22
10/30/09	2	46	925	102
11/10/09	0	0	1296[a]	38

(a) Adjusted to Max Runoff (b) Estimated

While outflows have been seen in three of the five site years in Miner County, the two years of outflow with gated pipe installed have been rather small in comparison to the amount of water that was added to the VTA. When adding the inflow from the sediment basin and precipitation to the VTA, the outflows that occurred averaged less than 5% of the total volume. This small amount of outflow may also have potential to be reduced if the VTA had been designed longer. Past modeling research in Miner County has shown that a longer, rather than wider VTA have the ability to handle higher water inflows (Smith, 2006).

The plot of precipitation vs. inflow (fig. 12) shows the variability in VTA inflow depending on the amount of precipitation that fell. The variability was dependent on the antecedent moisture content and the texture of the lots within the soil at the time of the event. The texture can change when the pens were last cleaned, whether cattle have been in the pens causing earth disturbances, and the weather. An example of a disturbance would be hoof footprints holding water back in the lot. A couple of the events in the plot are shown above the maximum possible runoff line. These events can be caused by two things. The first was due to snow melting with rainfall to provide more water entering the VTA than what fell on the feedlot. The second was that the siphon was run when there was water still in the solids settling basin from the previous event. This water would then have added to the wrong event and have the appearance of unreal data.

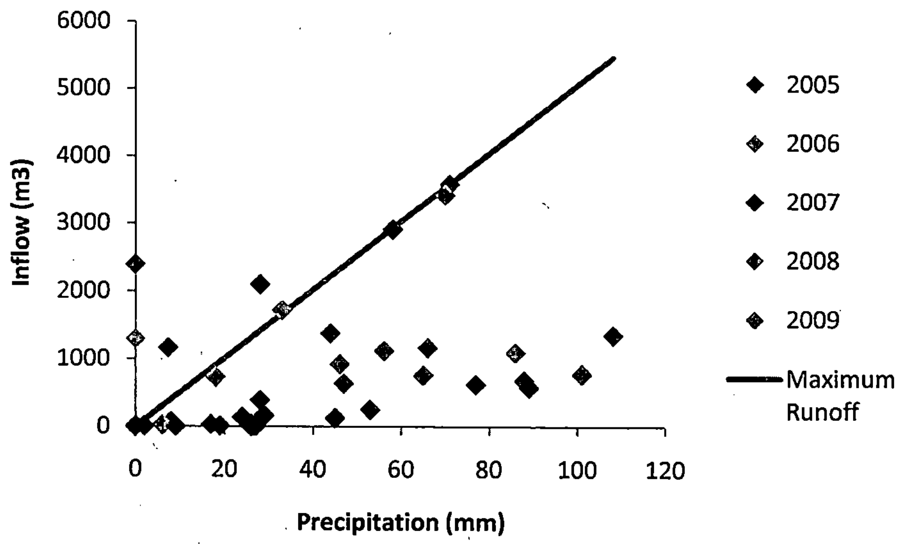

Figure 12: Miner County plot of precipitation versus inflow, this shows trends of runoff from the feedlots dependent on its texture and antecedent moisture condition

Haakon County

The Haakon County data shows the performance of a VTS with a typically drier climate of 438 mm of rainfall annually (fig. 3). The Haakon County VTA had been able to keep all water contained within its boundaries for three consecutive monitoring years. Over those three years the water balance had ended up with an average remainder of -1112 mm. This is evidence that there should be sufficient evapotranspiration to the keep the water from accumulating within the system. Table 5 shows each of the events that happened within those three years.

The first year of monitoring was in 2007. Total rainfall measured on the VTA during the monitoring season was 214 mm. A total of 466 m^3 of water entered the VTA as a result of runoff from that rainfall. This total amount was fairly evenly spread over the season with smaller inflows having been released slowly due to the large size of the solids settling basin.

Table 5: Haakon County run off events

Date	Days in Event	Precipitation (mm)	Inflow (m^3)	Outflow (m^3)
4/14/2007	2	3	184	0
4/21/2007	3	6	6	0
4/28/2007	1	8	5	0
5/5/2007	1	21	10	0
5/12/2007	1	3	13	0
5/22/2007	3	16	78	0
6/2/2007	5	44	121	0
6/9/2007	4	12	38	0
6/16/2007	5	15	3	0
8/4/2007	1	13	1	0
8/18/2007	4	18	1	0
8/25/2007	7	22	5	0
5/02/2008	2	43	185	0
5/10/2008	5	22	211	0
5/23/2008	3	62	475	0
6/06/2008	5	83	830	0
6/25/2008	4	33	218	0
7/15/2009	5	31	224[a]	0
10/22/2009	14	50	32	0

(a) estimated

The 2008 season began with a minimal amount of water ponding from snow melt. The depth was never measured due to equipment error. The months of May and June contributed rainfall amounts that were 122 mm higher than the thirty-year average for the two months at the Midland station. The higher values of inflow were a result. No measurable inflows were recorded the remainder of the monitoring season.

At the beginning of 2009 the clean water diversion failed as fresh water from snowmelt off nearby hills flowed over a containment berm near the road and entered the VTA. The producer pumped the volume out of the contained VTA nearly a month later to protect his grass. From then on, only two VTA inflow events were measureable. One of the events occurred in July and the other in October. The estimated inflow in July had a flow meter malfunction that prevented an actual measurement. Runoff values for these events were then estimated from the methods used by NRCS (Bonnema, 2010) for the use in the total balance.

Figure 13 shows how the total runoff starts to trend upward as precipitation increases. Since 2008 was a wetter season runoff values were higher than other years. This was due not only to higher rainfall amounts but also to the higher antecedent moisture conditions that existed in the soils. Because the months of May and June were so wet the lots didn't have time to dry out and soil infiltration rate was reduced. Other rainfall events were spread out over the summer, which gave the soils time to dry, keeping the runoff levels low or zero.

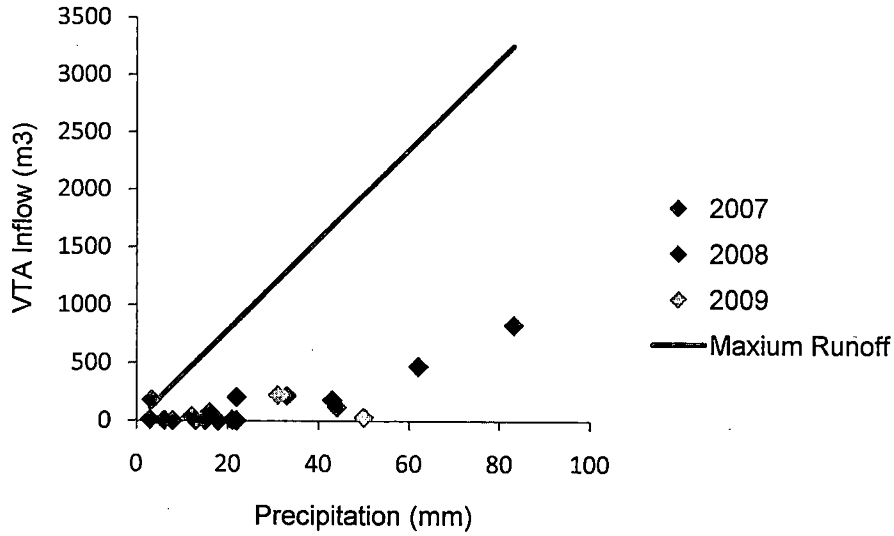

Figure 13: Haakon County plot of precipitation versus inflow, this shows trends of runoff from the feedlots dependent on its texture and antecedent moisture condition

Meade County

The Meade County VTA provided some of the most interesting data that was collected. Because it was in what traditionally is a drier climate compared to eastern South Dakota, it was surprising to have three 25 year, 24-hour storms associated with the monitoring of the project (fig. 3). These storms yielded the largest volumes of outflow from the VTA measured in the research project. Each event in the monitoring of the Meade County site can be seen in table 6.

Monitoring in Meade County began in June of 2006. This year was drier than the years to follow. No inflow events were measured until late September, when a total of nearly 676 m^3 of water entered the VTA. No outflows were measured during this monitoring season, and with ET_{max} measuring 1.139 m, there was a balance remainder of -913 mm. ET_{max} was the largest amount of ET that the site may have produced during the monitoring season. The site seemed to be sufficiently sized from a negative remainder and only needed to handle three events that were added to the 102,385 m^2 VTA. Figure 14 shows the trends in inflow when compared to precipitation.

The 2007 monitoring season started with a few inflows during the end of March. Heavy rain followed in May and June. The only site that had a 25 year, 24-hour storm was in Meade County. The criterion for a 25 year 24 hour storm at this site is 83.8 mm of rainfall in one day or 24 consecutive hours. This happened at this feedlot three times in two years while being monitored. The first happened on 18 June, 2007, receiving 108 mm of rainfall. The VTA had already been wet, accumulating 149 mm of rainfall over eight days. With the VTA already holding water, the addition of the 25 year 24-hour storm created ponding within the VTA. A water volume of 2,747 m^3 needed to be released to save the alfalfa crop growing within. This volume was estimated to be 23% of the total water added to the VTA during the event.

Table 6: Meade County runoff events

Event Date	Days in Event	Precipitation (mm)	Inflow (m^3)	Outflow (m^3)
09/22/06	7	47	130	0
09/23/06	1	35	207	0
10/11/06	1	6	339	0
03/29/07	2	23	60	0
03/30/07	1	9	302	0
04/21/07	3	12	16	0
05/05/07	2	55	81.5	0
05/31/07	14	101	145	0
06/07/07	3	36	42	0
06/16/07	1	93[b]	1691	0
06/17/07	1	2	290	2747
05/21/08	9	56	0	0
05/22/08	1	91[b]	1222	0
05/24/08	2	41	597	0
05/27/08	2	34	292	>3313
06/04/08	9	179[b]	3717	-
09/10/08	10	19	350	0
09/16/08	6	5[c]	516	0
10/12/08	8	52[c]	63	0
10/23/08	1	2[c]	759	0
03/15/09	1	1	68	0
04/15/09	1	8	81[a]	0
04/21/09	6	6	61[a]	0
05/07/09	14	35	362	0
06/15/09	15	80[d]	1113[a]	247
07/13/09	1	11	131[a]	0

(a) estimated (b) exceeds 25yr 24hr rainfall amount (c) Nisland (d) Fort Meade

The first recorded inflow event of 2008 was the second 25 year, 24-hour storm of the project. This storm yielded 91 mm of rainfall on May 22nd. More rain came in the next few days, bringing the total rainfall to 166 mm. This too filled the VTA, ponded the water and threatened the crop. To save the vegetation more than 3,313 m^3 were released from the VTA. It is believed to be more than 3,313 m^3 because the recording tape used by the sampler ran out before the flow ceased in the flume. With these estimates, the outflow from the VTA was calculated to be at least 13% of the total water additions. The last 25 year, 24-hour storm came at the start of the next month, on 4 June. A 179 mm rainfall over nine days brought in the largest VTA inflow recorded with 3,717 m^3 of water. The inflow was probably this large due to the system still recovering from the last events. No outflow was measured from this event because travel to the site had not been possible, and the tape from the previous event had not been replaced. The VTA was capable of handling the remainder of the inflows in the 2008 season.

The weather in the 2009 season was very similar to the 2007 season in that the majority of the rainfall happened in the spring with no events in late summer or fall. The inflow sampler during this year had many malfunctions due to power issues. Missing flow data was replaced with estimates from a NRCS runoff estimation procedure based on runoff maps from the Ag Waste Field Manual (Bonnema, 2010). A smaller outflow in comparison to the ones previous did occur during this monitoring season. A total of 247 m^3 left the VTA. The inflow and precipitation data that would match this outflow event needed to be estimated because the sampler had lost power and the rain gage was broken due to a hail storm that occurred before the rain events. Rainfall data taken from Ft. Meade was used to fill in missing data at the VTA. The rainfall was estimated to be 80 mm and total inflow was estimated from NRCS to be 1,113 m^3.

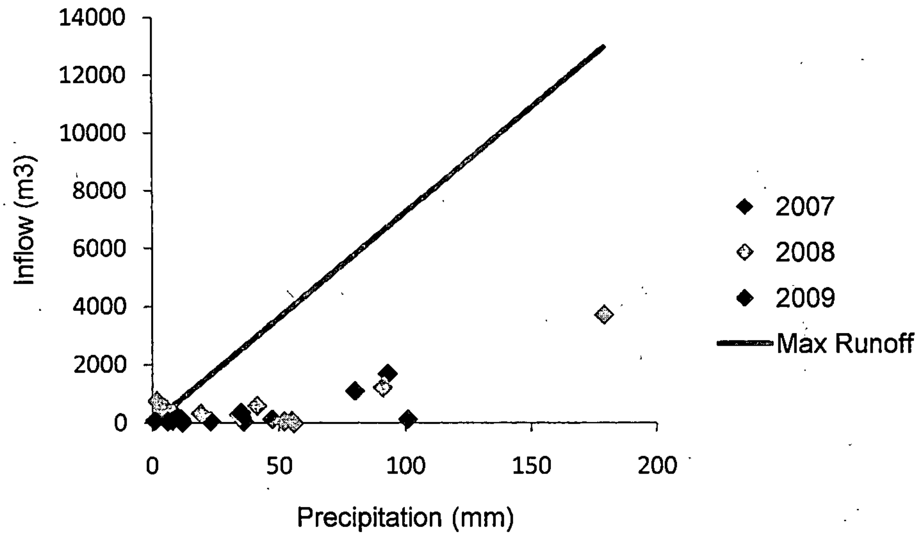

Figure 14: Meade County plot of precipitation versus inflow. This shows trends of runoff from the feedlots dependent on its texture and antecedent moisture condition

Roberts County

Completion of the construction of the Roberts County VTA ended in late 2008 once the grasses were established. Monitoring began in May of 2009. The pump for the solids settling basin only needed to be run twice during the whole season. The first pumping event was in early July. The pump ran for a total of 25 minutes, the equivalent of applying 25 m^3 of water to the VTA. This volume was applied to only the farther set of gated pipe from the basin, and the water was taken in by the soil very quickly. The second flow was much smaller than the first. The pump was run for six minutes and applied a total volume of six m^3 of water to the vegetative area. Water was applied to the same location as before. Once again, there was no potential for a VTA outflow. Table 7 shows only the two events from the 2009 monitoring season. Research is planned to continue at this location to build a larger data set for a year to year comparison.

Table 7: Roberts County runoff events

Event Date	Days in Event	Rainfall (mm)	Estimated Inflow (m^3)	Estimated Outflow (m^3)
07/07/2009	22	89	25	0
10/13/2009	10	67	6	0

Discussion

Factors that contributed to the success of the VTA at Haakon County were the large solids settling basin, smaller pipe that connected the system components, and the berm around the bottom of the VTA. The large solids settling basin was helpful because it could store the entire runoff volume from an event and hold it long enough to allow the VTA to gain more capacity as it dried. The flow restricting pipe slowed the flow rate of water onto the VTA allowing more time for infiltration on the VTA. The berm was the final reassurance that water would stay contained within the system. Although water was never measured to be ponded within the VTA due to the feedlot system, a VTS system will need a backup plan to remove the water if long term ponding is evident. This will protect the integrity of the vegetation, keeping the system functional.

The backup plan proved useful in Meade County in both 2007 and 2008 when they saved the alfalfa crop by releasing the water from the VTA, although it would have been better to pump the water back into the solids settling basin.

Events at the Meade County site show the importance of soil type within a VTS system. The tight clay soils on the VTA kept infiltration rates lower creating ponding on the entire VTA threatening the crop. The quick method of solids settling basin water release in Meade County also attributed to the large amounts of ponded water on the VTA. The 254 mm pipe released water too quickly onto the VTA adding to the ponded water volumes.

The Miner County site performed well when considering the undersized solids settling basin and VTA. It is speculated that the largest contributor to the excellent performance of the VTA, was the siphon that pulled water out of the solids settling basin and into the gated pipe. The slow rate of water application the siphon created, increased water infiltration within the smaller VTA. This evidence when combined with the fast sediment basin outflow in Meade County shows that a VTS may increase performance by having a design that slows the release from the solids settling basin.

Water spreading is also an important factor in VTA design. Adding the gate pipe in to the VTA in Miner County showed how preferential flow could be diminished and greater infiltration could be obtained over a larger area. Research at Iowa State has found the same evidence of improved performance with the addition of spreader berms (Andersen, 2009). Even though water distribution is important, water application should not be designed like an irrigation system. A surface irrigation system the design normally wants to apply water quickly to cover the whole application area evenly. This usually requires the waste of some water at the end of the field. A goal of a VTA is to prevent water from leaving the VTA. The probability of obtaining no release is increased as water is applied slowly. The Meade County VTA was designed as a furrow irrigation system that moved water more quickly toward the end of the VTA. This design possibly led to an unnecessary outflow that happened in 2009.

Conclusions

Feedlot runoff was completely controlled within the VTA for 6 of the 12 site-years in this study. For all of the remaining five site-years, at least 95% of the total seasonal water was controlled within the VTS. Out of the four sites studied, Haakon and Roberts Counties were the only two that were able to successfully contain all VTA inflows during their monitoring seasons. The Meade County VTS had three years of research in which an outflow event occurred. Only one outflow occurred that was not a result of a 25 year, 24-hour storm. This outflow was measured to account for 2.5% of the total VTA inflow amount that includes precipitation and is only for that particular storm. Outflow events that were a result of 25 year, 24-hour storms accounted for an estimated 23% and more than 13% of the total inflows from their attributed events. The Miner County VTA had many outflows in 2005 but no data was able to be collected. From events during the 2007 season, snowmelt and spring rains created outflows that contributed to 5% of the inflows that caused the releases. Release events in 2009 from the

Miner County VTA yielded 8% of event inflows that contributed to releases in that year.

During the site-years monitored, ten of the twelve years had ET_{max} values from the crop that were higher than both the precipitation and VTA inflow combined. This indicated that the calculated ET_{max} was large enough to remove the amount of water that was applied onto the VTA area. This means that there is less of a chance for water to be percolated deeper than the root zone.

VTS Design Recommendations

1) Design the solids settling basin with a volume capable of containing all runoff from a 25 year, 24-hour storm as a minimum. Greater storage can delay water flow to the VTA, helping to prevent releases.

2) Restrict the water flow rate from the solids settling basin by using small pipe or a valve. Slower water flow to the VTA can help prevent releases.

3) Line the solids settling basin with clay, concrete, or a synthetic liner to allow water to be retained for greater than 72 hours. Longer retention time can help prevent releases.

4) Construct a berm at the bottom of the VTA. The berm will help prevent the release of water.

5) Remove water from the bottom of the VTA by pumping it back to the solids settling basin. This can help prevent release and damage to the vegetation.

6) Spread the water laterally across the VTA with gated pipe or other methods. Lateral spreading will allow utilization of the entire VTA and slows the advancement of water down the VTA.

Chapter 3: Nutrient Balance of Three Feedlots in South Dakota

Abstract

A concern of vegetative treatment systems (VTS) is that the specified vegetative treatment areas (VTA) will not be capable of containing the potentially large amounts of nutrients that may be applied. Research on three South Dakota VTA at different geographic locations within the state, was conducted to determine the ability of the VTS to perform in the containment of Kjeldahl nitrogen and total phosphorus. This was done by creating a mass balance of nutrients within the VTA to compare year by year. Samples for nutrient concentration were taken from solids settling basins and VTA outflows and combined with hydraulic inflow and outflow data to determine the total mass of nitrogen and phosphorus that was added or left the VTA. Vegetation samples were also taken to determine nutrients that left the VTA from crop production. Six of the eleven site-years monitored were able to contain all the nutrients in the soil profile. Any loss in the nutrients greater than 2% of the applied nutrients was caused by a 25 year, 24-hours storm event. All soil nutrients appear to be accumulating at Miner County and phosphorus appears to be accumulating in front of the VTA inlet at Haakon County. However, there is not enough evidence to show that the soils actually are accumulating. It is recommended that the solids settling basin be designed to hold all runoff from a 25 year, 24-hour storm and to have the inlet as far from the outlet as possible to provide adequate solids removal. The VTA should also have an area that is maximized to disperse the

nutrients that are applied as much as possible as well as remove more nutrients within the crop.

Introduction

Farmers and producers in agriculture are discovering the importance of nutrient management as they learn how to protect the environment as well as make their operations more profitable. There have been many studies in the value of manure as a source of fertilizer for other crops. In order to efficiently utilize the manure as a nutrient source, it needs to be collected and managed in an environmentally safe and economically feasible way. Some feedlots under confined animal feeding operations (CAFO) regulations do not have the best site conditions to properly handle and distribute the manure under the current holding basin system. VTS have been proposed as a possible alternative to the current system that will offer producers a different option for use with their nutrient management plan.

A VTA may provide benefit to a producer when the producer may have difficulty finding land that is open for land application. The fields that need the nutrients the most are usually only able to accept nutrients a short time of the year. Typically, nutrients are only able to be applied during the spring or fall of each year either before or after the crop had been planted or harvested. These two times are also typically when more of the annual rainfall occurs; creating conditions that may be too wet to apply the manure. During the dry times, most producers need to work longer hours to get both nutrients and crops into the fields. This makes VTS an advantage for time management because the nutrients in the water can be applied during most of the growing season while the producers may be less busy. Another advantage for time management as well as expenses is the lack of water transport that may be needed with a system that requires off-site land application. The VTA is usually either gravity flowed or the water may be pumped nearby for application to the VTA.

A VTA may mitigate the amount of nutrient losses to the environment. Because the runoff from the feedlot will usually be applied within three days after the event, a VTS may create less potential for nitrogen to be lost due to volatilization. Each manure management system has the potential for nitrogen loss during the application of manure onto the field. A VTS, however, has the advantage of having one less step in the storage of the manure. Studies have shown that 20% to 40% of the nitrogen was lost in a holding basin system and 70% to 85% of the nitrogen was lost in an anaerobic lagoon system (MWPS-18). A mass balance will be able to give insight to the possible losses of nitrogen in a VTS.

The opposite condition to nutrient loss, nutrient buildup, can become a problem. The producers may need large amounts of land to protect from the accumulation of phosphorus in specific fields. A properly designed VTA will be able to keep the nutrients that are applied in balance with the amount of nutrients that will be removed. A mass balance from this study will be able to give insight to see if the VTA can handle the nutrient inflows and prevent nutrient accumulation.

Because it is unknown how well VTS can perform when trying to compare them to a containment basin, more research on VTS is needed in varying site conditions and designs. This will allow for the quantification of performance as well as aid in the design of future VTS for use in a producer's nutrient management plan.

The objective of this research was to evaluate the performance of a VTS in containing nutrients with its boundaries. A goal of creating a mass balance of all nutrients applied and nutrients removed was completed in order to meet the objective.

Materials and Methods

In order to evaluate the performance of a VTS system, a nutrient mass balance was calculated. Equation 4 shows the terms that were used in the calculation for the balance. The balance is also shown in figure 15 with the term M_s (Mass soil). This term is the actual amount of nutrients that were measured in the soil profile.

$$\Delta M = M_{in} - M_{out} - M_{p} \tag{4}$$

where

ΔM = Calculated change of nutrient mass per area (kg ha $^{-1}$)

M_{in}= Inflow mass per area onto VTA from basin loading concentrations and volume (kg ha $^{-1}$)

M_{out}= Outflow mass per area from VTA as discharge concentrations and volume (kg ha^{-1})

M_p= Nutrient mass per area use by crop (kg ha^{-1})

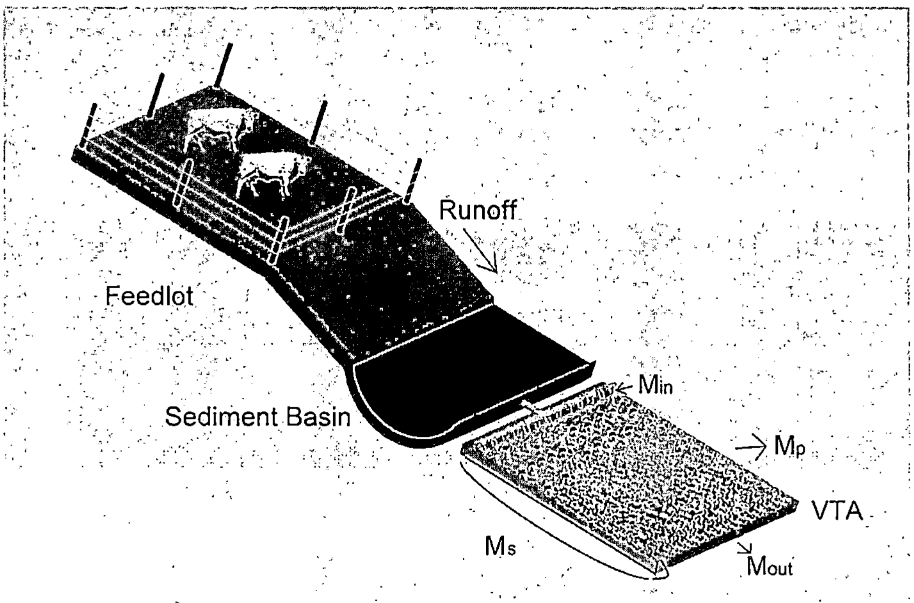

Figure 15: Mass balance schematic

Water Collection and Nutrient Concentration Analysis

The measured values of nutrient inflow and outflow were determined by combining known volumes of water that would enter or leave the VTA with the nutrient concentration of samples from their respected flow. Water samples were taken either by hand or with the use of an automatic sampler. The majority of the samples were taken compositely over the term of the flow event. Some samplers pump water into a single jug (Isco GLS Sampler), while others had a set of 24 sequential bottles for water collection (Isco 6712). The 24-bottle system allowed for the ability to test the water concentration change over the duration of the event if desired; otherwise, the separated samples were mixed together to create a composite sample. Samples were tested for total Kjeldahl nitrogen, total phosphorus, and total solids. Two bottles of at least 500 mL were collected for each event. This allowed one sample to be acidified to a pH < 2 using 2 mL/L of analytical grade concentrated sulfuric acid. This sample was used for testing Kjeldahl nitrogen. Analysis was conducted by the Oscar E. Olsen Biochemistry Laboratory on the campus of South Dakota State University. Total Kjeldahl nitrogen was determined using EPA method 351.3 (Nesslerization). Total Phosphorus was determined using Standard Methods for the Examination of Water, Method #4500-P B&E. When no sample was able to be collected during an event because of equipment failure or other reasons that a created a sample that was unrepresentative of reality, the sample concentration needed to be estimated. Concentrations that were accepted to be real were plotted against event precipitation, intensity, and inflow. *T-tests* were then conducted in an attempt to find the best correlation between each of the independent variables and nutrient concentration. Regression was then run and the best correlating variable was used to estimate the concentration to use with the event for total nutrient mass determination. The Meade County VTA only had one outflow event that was able to be sampled. The one sample that was collected was used to apply concentrations to the other events. The Miner County site had missing data filled in with an average of all outflow concentrations and water concentrations from samples that were ponded in the front of exit flumes.

Soil Collection and Analysis

Soils were measured by collecting core samples from the VTA in locations where the largest change in nutrient concentration was expected. Soil samples were taken by hand with a probe to a depth of at least 0.3 m. When access to a Giddings Rig was possible, soil cores were able to be taken to a depth of 1.2 m. The samples were tested for total phosphorus, total Kjeldahl nitrogen, and nitrate. The Haakon County site had 11 soil core samples taken from the VTA in 2007 and 2008. In 2009 only three 0.3 m samples were taken where the highest and lowest changes were thought to occur. The two locations that were thought to receive the highest changes were directly in front of the inlet and at lowest elevation of the VTA. The last sample was located on a higher portion of the VTA for comparison to the other sampler locations. In Meade County 28 soil cores were taken to 1.2 m in 2007 and 2008. In 2009 only the top 0.3 m of soil were sampled at six locations. The six samples were taken at the top and bottom of each of the three cells in the VTA. The Miner County site had 17 core samples dug to 1.2 m in 2006 and 2008. The year of 2007 only sampled to the 0.3 m depth. Analysis was done on all 17 sample locations in Miner County because of the very high water inflow and concentrations that entered the VTA in comparison to the other site locations.

Years that took samples to 1.2 m were used to determine the total mass of nutrients within a unit area at each soil core location. The averages of these masses were compared with a t-Test by year to determine if any significant changes at the 95% confidence level occurred.

Vegetation Collection and Analysis

Vegetation samples were taken at each of the three sites after each cutting. Total mass, phosphorus, and nitrogen usage were measured from each of the samples taken. The Miner County site was the only location that used latin square treatments in the analysis (Similien, 2010). The Miner County VTA had two sampling locations, one at the top of the VTA and one at the bottom. Nutrient removal data were averaged between the two when possible. There were some harvests where the grasses had insufficient re-growth for testing, but never from both sampling locations. Only one plot was then able to be sampled in this condition. The other sites had samples that were randomly collected over the surface of the VTA after cuttings.

The producers from the Meade and Haakon County sites weighed the total masses of each of their harvests and reported the results back to South Dakota State University. The masses were then multiplied by the percentage of nitrogen and phosphorus in the samples to obtain the mass of nutrient that was removed. Each research site's VTA utilized a different type of vegetation. The

Miner County VTA had brome grass, while the Meade County VTA grew alfalfa, and the Haakon County VTA utilized western wheatgrass.

All nutrient analysis was completed at the South Dakota State University Forage Quality Laboratory. Nutrient masses for nitrogen and phosphorus from the Miner County site were reported in Mg/ha while the results from the other sites were reported as a percentage of dry matter forage.

Results

When considering the nutrient loading of the VTA it is important to look at the feedlot and solids settling basin characteristics. It has been shown that many factors may influence the concentration of incoming water to the VTA. Some of these factors include the ratio of lot area to basin volume, ratio of lot area to animal units, basin dimensions, and the basin and lot construction material. Many of these criteria are based on or related to the solids settling basin. The highest average concentrations in nutrients that were found came from Miner County as is shown in figure 16. After flowing through the VTA, TKN concentrations were diminished by 69% of the inflow at Miner County. Phosphorus concentrations were diminished at Miner by 66%. Water from Meade County had nutrient concentration reductions of 81% and 82% for TKN and total-P respectfully. The concentration changes in Meade County were due to dilution of water from the high intensity rainfalls that fell on the VTA when the

VTA outflows occurred. The VTA outflow concentrations can be seen in figure 16.

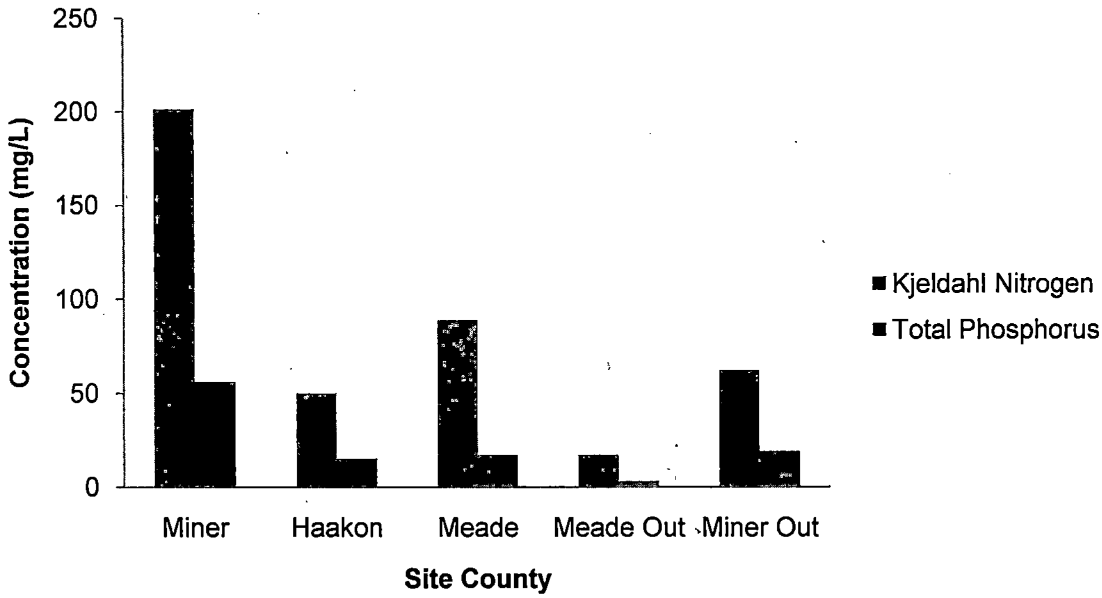

Figure 16: Average nutrient concentrations in VTA water

There are many factors pertaining to the feedlot and solids settling basin that determines what the concentration of nutrients in the water entering the VTA will be. One of the largest contributors to the high concentrations at Miner County is the low feedlot area to solids settling basin volume ratio. The small basin was quickly filled with solids, leaving less room for new incoming solids to drop out of suspension. Less depth in the basin also leads to higher flow velocities that may bring more solids up into suspension. The same principles must be applied when designing the dimensions of the solid settling basin. A solids settling basin that has water enter close to the water outlet has the potential for short circuiting through the basin and may not give the solids a chance to subside. The oversized solids settling basin in Haakon County was capable of keeping the concentrations of the water far lower than nutrient concentrations in Miner County. The number of animal units in the pens also had a role in the higher average concentrations. The Miner County site had animals in the lots year round, while the other sites had cattle grazing for a large portion of the monitoring season.

Nutrient Concentration Analysis

To determine the total mass of nutrients that enter the VTA, hydraulic data was combined with the concentrations of the water flowing into the VTA. Water concentration is dependent on many of the influences that the environment creates and can be very variable. In order to determine if regression of the sample concentrations were significant to another factor, *t* statistics were calculated to test that slope did not equal zero. In table 8, only the test for inflow was significant. Using inflow as the most significant variable, nutrient concentration was estimated from regression equation 5 for nitrogen and equation 6 was used for phosphorus.

$$y = .0269 \times x + 166.55 \tag{5}$$

$$y = .0044 \times x + 51.031 \tag{6}$$

Where

y = nutrient concentration (mg/L)

x = the independent variable being tested

Table 9 shows that there was a very low correlation for inflow and precipitation in Haakon County. The only significant test at Haakon County was related to rainfall intensity and nitrogen. While not significant, the phosphorus also had a much higher *t-test* value for intensity as compared to the other tests, reinforcing the choice of intensity. Estimations of nutrients were then based on the regression equations for intensity. The equation for nitrogen used was equation 7 and the equation used for phosphorus was equation 8.

$$y = 1.925 \times x + 24.78 \tag{7}$$

$$y = .2842 \times x + 11.59 \tag{8}$$

Where

y = nutrient concentration (mg/L)

x = the independent variable being tested

The Meade County VTS had no significant tests to relate a correlation between nutrient concentration and other variables. The insignificant test results can be seen in table 10. Because there was no correlation, missing concentration data were filled with averages calculated from the samples that were able to be collected.

Table 8: Miner County "t" values testing Ho: Slope = 0

Test Method	Inflow	Precipitation	Intensity
Kjeldahl-N	*2.42	-0.82	-1.37
Total-P	0.93	-0.81	-1.89

(*) H_o is rejected at the 0.05 confidence level

Table 9: Haakon County "t" values testing Ho: Slope = 0

Test Method	Inflow	Precipitation	Intensity
Kjeldahl-N	-0.13	0.07	*2.5
Total-P	-0.56	-0.59	1.43

(*) H_o is rejected at the 0.05 confidence level

Table 10: Meade County "t" values testing Ho: Slope = 0

Test Method	Inflow	Precipitation	Intensity
Kjeldahl-N	-0.89	-0.7	-0.29
Total-P	0.37	0.61	0.2

(*) H_o is rejected at the 0.05 confidence level

The variability seen in the different tests demonstrates the importance of researching different geographic locations and design criteria because they can behave so differently. With concentrations following different trends based on different variables, it shows how each site is unique.

Soil Nutrient Analysis

Nutrients have the appearance of accumulation at the Miner County VTA in both nitrogen and phosphorus. In Haakon County, nitrogen has the appearance of accumulating phosphorus and the depletion of nitrogen. The VTA in Meade County seems to be depleting both nitrogen and phosphorus. Tables 11 and 12 show that although these sites appear to have changes for some yearly comparisons, statistically there is not enough evidence at the 95% confidence level to determine that changes do exists.

Table 11: Average soil profile mass to a 1.2 m depth of TKN and yearly evaluation of change significance at 95%

	2006	2007 TKN kg/ha	2008	T - test P Value	Degrees Freedom
Miner	24,768	-	26,492	0.3784	22
Meade	-	29,924	20,696	0.1464	10
Haakon	-	26,030	24,963	0.6866	4

Table 12: Average soil profile mass to a 1.2 m depth of Tot-P and yearly evaluation of change significance at 95%

	2006	2007 Tot-P kg/ha	2008	T - test P Value	Degrees Freedom
Miner	250	-	383	0.0852	22
Meade	-	69	65	0.8362	10
Haakon	-	101	116	0.4237	4

In Miner County, the feedlot had been supplying the VTA with more nitrogen than had been being removed. Based on the soil profile from the years of 2006 to 2008 in figure 17, no large changes in Kjeldahl nitrogen have occurred when compared to the amount of nutrients that were applied to the landscape. This shows that natural processes in the nitrogen cycle, including the denitrification and volatilization into nitrogen gas and ammonia, have kept the nitrogen from accumulating in the profile.

While the nitrogen has the potential to be lost to the atmosphere phosphorus does not. This nutrient had the lowest P-value of all comparisons on the Miner County VTA. Phosphorus losses only came from the removal of vegetation when the VTA was harvested for years that didn't have outflow. Figure 18 shows the changes in phosphorus concentration within the soil profile from the years of 2006 to 2008.

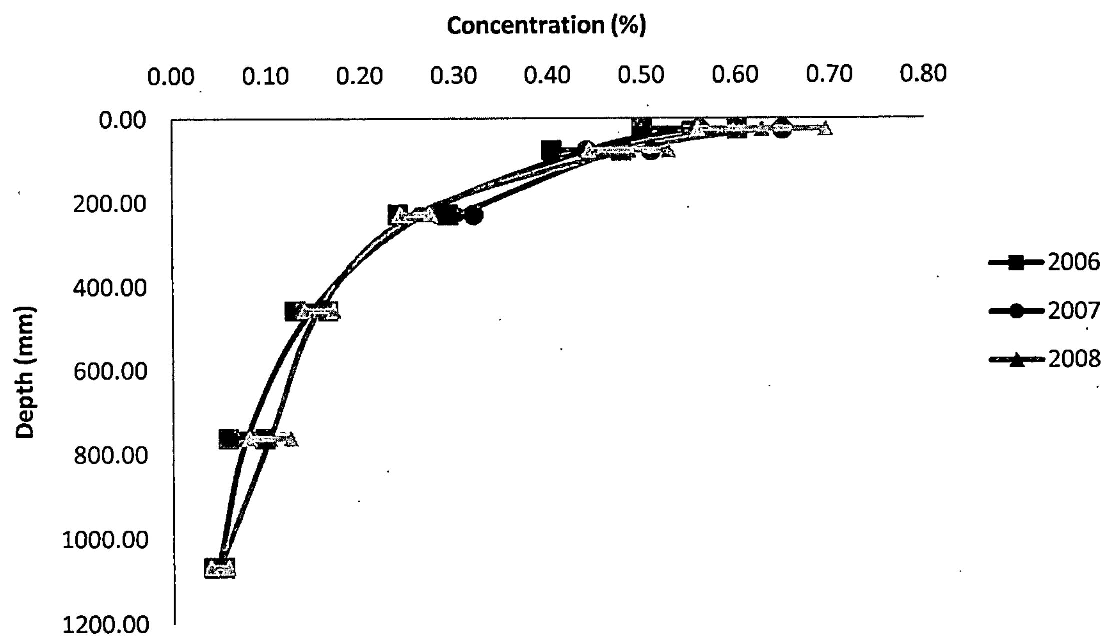

Figure 17: Kjeldahl nitrogen concentrations in the soil profile at the Miner County site, 2006 through 2008

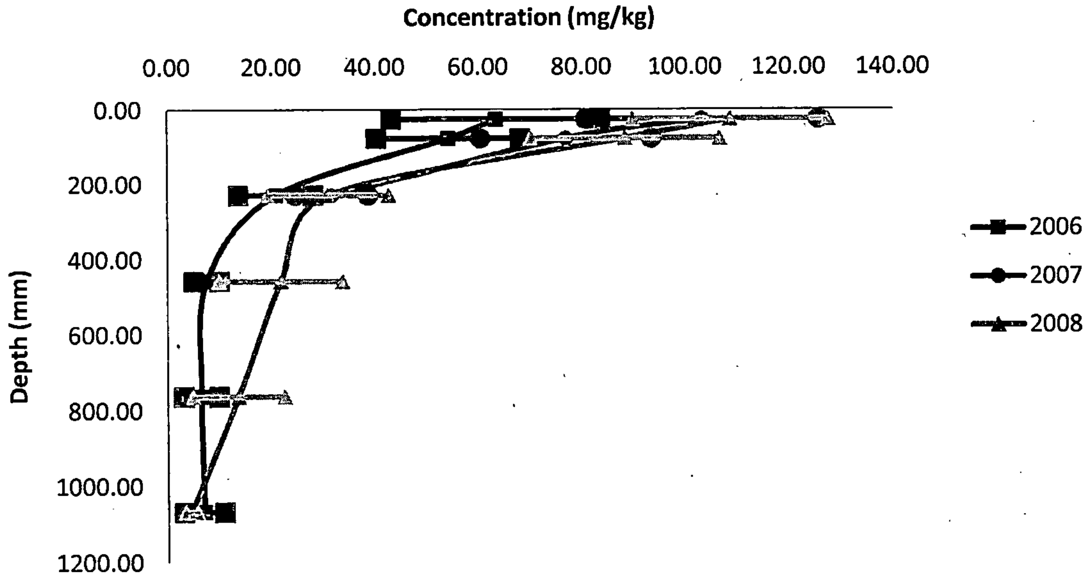

Figure 18: Total phosphorus concentrations in the soil profile at the Miner County site, 2006 through 2008

Meade County VTA soil profiles can be seen in figures 19 and 20. Kjeldahl nitrogen levels here dropped at all depths in 2008 compared to 2007. Some of this was possibly due to losses volatilization and denitrification, but is speculated to be largely due to deep seepage losses from when the VTA became flooded after the 25 year, 24-hour storms that came during the spring of 2008. A small rise near the surface can be seen in the following year of 2009 as added nutrients start to recover in the soil profile. The phosphorus profiles do not show much change in the deeper portions of soil but do rise slightly in 2008 near the surface. The lower inflows in 2009 allowed the soil phosphorus concentrations to drop again as vegetation utilized the nutrients.

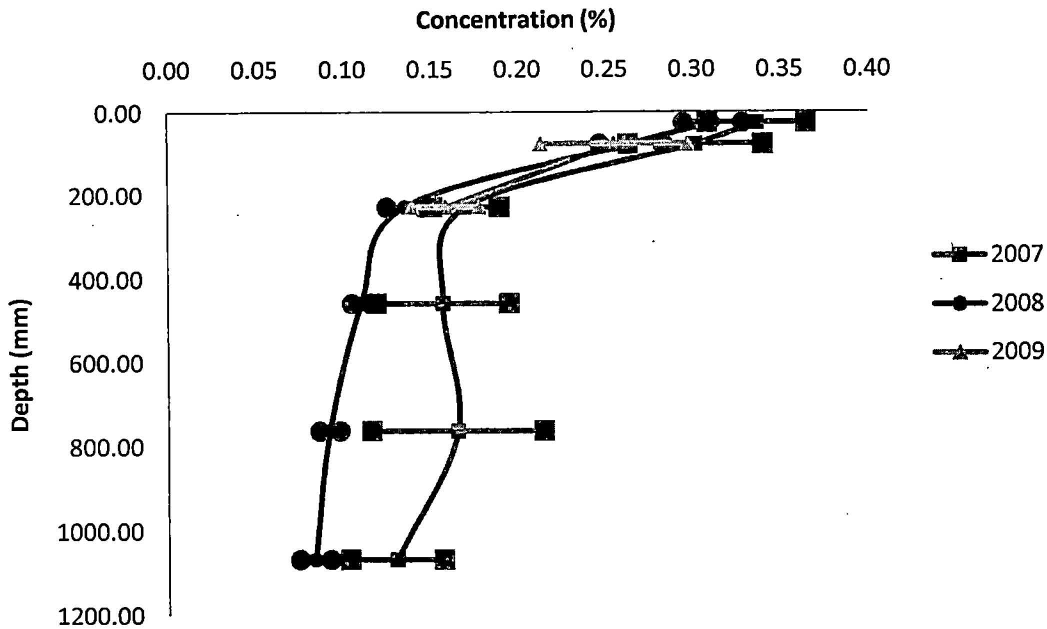

Figure 19: Kjeldahl nitrogen concentrations in the soil profile at the Meade County site, 2007 through 2009

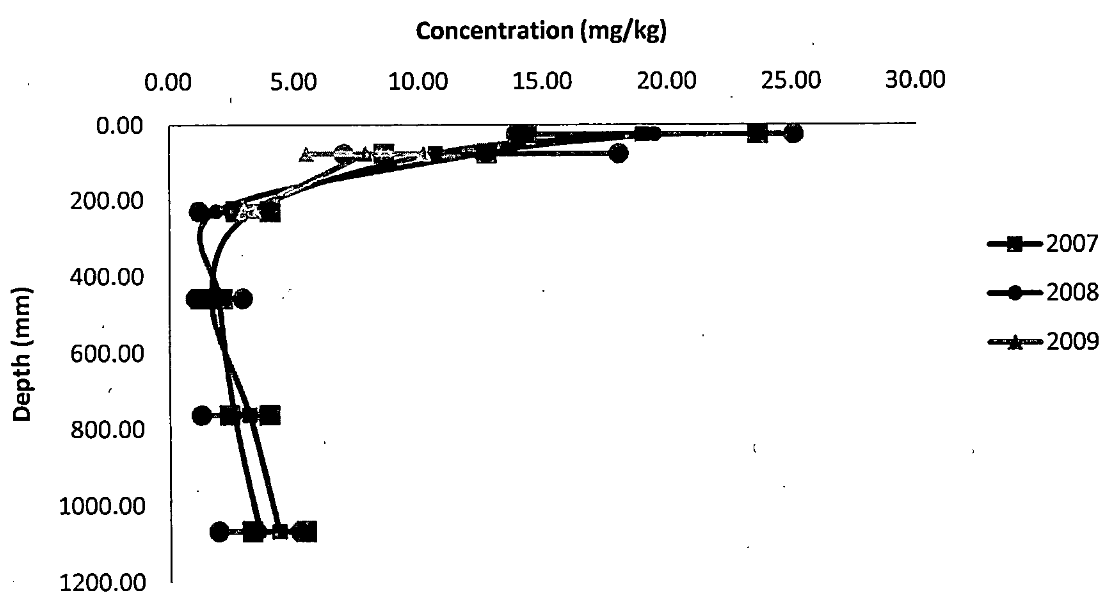

Figure 20: Total phosphorus concentrations in the soil profile at the Meade County site, 2007 through 2009

The Haakon County VTS received the lowest volumes of water applied each season as well as the lowest water concentrations. The additional Kjeldahl nitrogen does not appear to be accumulating in the profile at this site. This was also likely due to natural responses of the nitrogen cycle releasing nitrogen to the atmosphere, keeping the nitrogen level in balance. Phosphorus levels appear to be rising each season. This was especially true directly in front of the inlet, where water ponds in a 4 m diameter area and does not flow to other areas of the VTA, as shown in figure 21. Figures 22 and 23 represent the soil profiles of Kjeldahl-N and total phosphorus respectively in Haakon County.

Figure 21: Water ponded in front of the VTA inlet at Haakon County. Vegetation growth around the inlet also shows the higher moisture conditions that exist

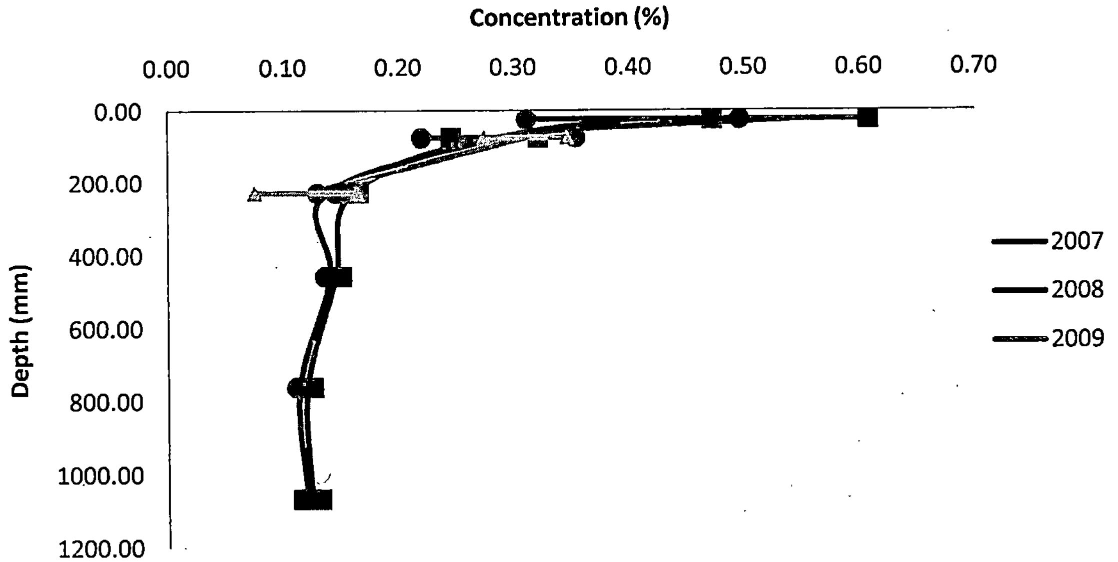

Figure 22: Kjeldahl nitrogen concentrations in the soil profile at the Haakon County site, 2007 through 2009

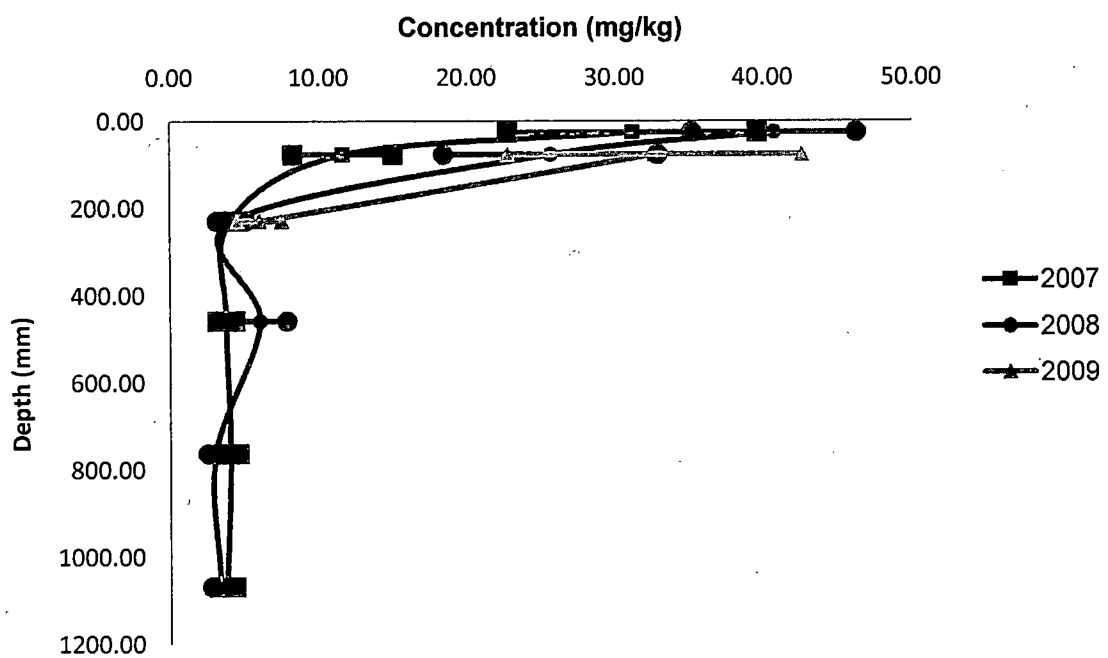

Figure 23: Total phosphorus concentrations in the soil profile at the Haakon County site, 2007 through 2009

Mass Balance

To calculate a mass balance, multiple sets of data were brought together to determine the final nutrient masses that were added to each VTA site-year. For these tables to be constructed, all the hydraulic data, concentration data, and vegetation data were needed. Tables 14 and 15, show the additions and removals of nutrients in each county for each site-year.

It can be seen that the highest amounts of nutrient inflow come from Miner County. This was due to there being a VTA to feedlot ratio that is undersized as well as an undersized basin for the area of the feedlot. The 0.167 ratio for the VTA to feedlot, allows more water to be applied to the VTA than what might be desired. The basin is about a 25% of the volume that the NRCS would recommend. This factor promotes the higher concentrations that come onto the VTA.

The calculated change in mass in tables 13 and 14, differ from the values that were measured in the soils after three years of soil sampling. The differences can be seen while comparing tables 13 and 14 with table 15. Table 15 contains the mass of nutrients that changed in a volume of soil that was one hectare in area and 0.3 m deep during three years of monitoring.

Table 13: Mass balance - Kjeldahl Nitrogen

Site	In	Out	Vegetation Out	ΔM
	kg/Ha			
Miner 2005	614	NA	583	31
Miner 2006	661	0	410	251
Miner 2007	4229	11	422	3797
Miner 2008	1043	0	614	429
Miner 2009	2278	19	524	1735
Meade 2006	10	0	-	-
Meade 2007	18	4	-	-
Meade 2008	61	5	129	-74
Meade 2009	16	1	72	-57
Haakon 2007	9	0	-	-
Haakon 2008	93	0	-	-
Haakon 2009	8	0	-	-

Table 14: Mass balance - Total Phosphorus

Site	In	Out	Vegetation Out	ΔM
	kg/Ha			
Miner 2005	164	NA	53	111
Miner 2006	169	0	45	124
Miner 2007	876	4	38	834
Miner 2008	299	0	58	241
Miner 2009	705	8	78	619
Meade 2006	1	0	-	-
Meade 2007	4	1	-	-
Meade 2008	13	1	9	3
Meade 2009	4	1	5	-2
Haakon 2007	4	0	-	-
Haakon 2008	26	0	-	-
Haakon 2009	3	0	-	-

Miner County had a net mass of 3797 kg of TKN added to the VTA in 2007 alone but over the three years the only build-up of nutrients seen was 782 kg/ha. The nutrients that are uncounted for are most likely lost from releases to the atmosphere and from leaching deeper than our sampling protocol.

Table 15. M_s - Change in soil concentration over three years

Site	Years	TKN change in soil	Total-P change in soil
		kg/ha	
Miner	2006-2008	782	95
Haakon	2007-2009	-282	45
Meade	2007-2010	-1173	-6

Table 16 shows the percentage of reduction of nutrients the VTA were capable of during each site-year. The percentages were based on the amounts of nutrients that left the containment areas of the VTA compared to what the total nutrient application was from the sediment basin.

The VTA in Haakon County was 100% successful in nutrient reductions each season mostly because of the large berm on the perimeter of the VTA which kept water in. Berms were not able to contain the water at Meade County. Nutrients escaped the system due to the ponded water inside the bermed area that needed to be released to save the alfalfa crop. The Miner County VTA performed very well containing all or 99% of nutrients each season, even though it was undersized.

Table 16: Percent reductions of nutrients during site-years by the VTA

Site	Kjeldahl-N	Total-P
	%	
Miner 2006	100	100
Miner 2007	99	99
Miner 2008	100	100
Miner 2009	99	99
Meade 2006	100	100
Meade 2007	76	82
Meade 2008	91	92
Meade 2009	98	97
Haakon 2007	100	100
Haakon 2008	100	100
Haakon 2009	100	100

Discussion

The performance of a VTS was based on its ability to contain all of the nutrients within the area. This is ultimately determined by the ability of the VTA to contain water, but the system needs to able to control the nutrients to prevent nutrient accumulation within the soil profile and lower the concentrations of nutrients within release water should a release occur.

When considering VTS design it is important to think about the relationship of water volume and concentration. If locations are limited on VTA area, the design of the sediment basin becomes much more important. This was because there was not much area to handle large amounts of water that may be applied. A sediment basin needs to be able to lower water concentrations in the effluent so you don't over apply nutrients from the higher volumes of water that will be applied on the smaller area. Water volumes applied cannot be reduced by the sediment basin; they can however, slow the flow of water to allow the VTA more time for infiltration. VTA with greater areas can accept less performance from a sediment basin. This is because the higher concentration water will be dispersed over the soil when the water is spread over large areas adding fewer nutrients per hectare.

The Miner County VTA had greatest apparent buildup of nutrients within the soil profile. Although the concentrations appear to be increasing, statistically there is not enough evidence to be confident at the 95% level that the increases are due to the nutrient additions. Nutrient concentrations in the water were also the highest in Miner County. This was largely determined by the undersized solids settling basin. Had the solids settling basin been large enough to allow more settling of solids, the lower concentrations would have reduced the amount of nutrients building up in the soils. Another factor of the solids settling basin that lead to the higher nutrient concentrations was the locations of the inlets and outlets of the basin. Since the inlet was located close to the outlet, higher nutrient concentration water was less likely to slow flow velocity for a long enough time period to settle solids before exiting the basin.

The Meade County VTS had a smaller solids settling basin compared to the area of feedlot associated with it. This would normally create higher concentrations than what was seen at other sites but other factors kept the concentrations down. These factors were the lower slope of the feedlot and not having any cattle within the feedlot during the monitoring period. It is appropriate for a location with a small solids settling basin in comparison to feedlot area, to have a large VTA to allow the spreading of nutrients over the VTA area. The larger VTA also provides more area for crop growth allowing a greater nutrient removal within vegetation.

Conclusions

With the completion of the mass table, it was determined that the VTS were able to contain nutrients to very high amounts. Six of the eleven site-years that were analyzed for nutrient containment had 100% reduction of nutrients preventing them from leaving the system. The other site-years that had reductions of less than 99% were from Meade County and were due to the 25 year, 24-hour storm events. The amount of nutrients that were applied was far greater than what was evident in the change of soil concentration. All three VTA have not changed enough to be statistically confident at the 95% level that nutrients are accumulating or diminishing. It is speculated that the process of denitrification and the volatilization of nitrogen into the atmosphere added to vegetation removal have kept nitrogen levels from accumulating. These processes have actually helped lower soil nitrogen concentrations in Meade and Haakon Counties, even with the applications of feedlot runoff.

VTS Design Recommendations

1) Design the solids settling basin with a volume capable of containing all runoff from a 25 year, 24-hour storm as a minimum. Greater storage can delay and slow water flow to the VTA, helping improve solids removal.

2) Design the solids settling basin inlet to be far away from the outlet to allow the most time for solid settling and avoid short circuiting of flow.

3) Design the VTA as large as possible to maximize nutrient removal from the VTA. This decreases the probability of nutrient accumulation in the soil profile.

Recommendations for Future Research

1) To conduct more extensive soils research to determine if the apparent accumulation of nutrients is significant.

2) To conduct more research on the VTS at Roberts County. More data is needed to conduct useful water and mass balances.

References

Andersen, D. S., R. T. Burns, L. B. Moody, I. K. Khanijo, M. J. Helmers, C. Pederson, J. Lawrence. 2009. Performance of six vegetative treatment systems for controlling runoff from open beef feedlots in Iowa. Paper Number 097054. St. Joseph, Mich.: ASAE.

Akan, A. O. 2006. Open Channel Hydraulics. Burlington, M.A. : Butterworth-Heinemann.

Barker, J. C. and B. A. Young. 1984. Evaluation of a vegetative filter for dairy wastewater treatment in southern Appalachia. North Carolina State University research report. Published by US Department of Commerce, National Technical Information Service. 69 pages.

Bond, B. J., R. T. Burns, T. P. Trooien, S. H. Pohl, C. G. Henry, L. B. Moody, M. J. Helmers, J. Lawrence. 2009. Comparison of Construction Costs for Vegetated Treatment Systems in the Midwest. Paper No. 096524. St. Joseph, Mich.: ASAE.

Bonnema, J. 2010. Personal communication. NRCS Agricultural Engineer. 11 January.

Brakensiek, D.L., H.B. Osborn, and W.J. Rawls. 1979. Field Manual for Research in Agricultural Hydrology. Agriculture Handbook No. 224. Washington, D.C.: United States Department of Agriculture.

Dickey, E.C. and D.H. Vanderholm. 1981a. Performance and design of vegetative filters for feedlot runoff treatment. *Livestock Waste: A Renewable Resource. Proc. of the 4th International Symposium on Livestock Wastes, 1980.* ASAE. St. Joseph, MI. 49085. pp 257-260.

Dillaha, T. A., J. H. Sherrard, D. Lee, S. Mostaghimi, V. O. Shanholtz. 1988. Evaluation of vegetative filter strips as a best management practice for feed lots. *J. Water Pollution Control Federation.* 60(7): 1231-1238.

Edwards, W.M., L.B. Owens, R.K. White and Fausey, N. R. 1986. Managing feedlot runoff with a settling basin plus tiled infiltration bed. *Transactions of the ASAE.* 29(1): 243-247.

Faulkner, F.W. 2009. Monitoring and modeling of hydrology and subsurface nutrients within vegetative treatment areas. PhD Dissertation. Ithaca, New York: Cornell University.

Ham. J.M. 2002b. Seepage losses from animal waste lagoons: A summary of a four-year investigationin Kansas. Trans. ASAE. 45:983-992.

Huffman R.L. and P.W. Westerman. 1995. Estimated seepage losses from established swine waste lagoons in the lower coastal plain of North Carolina. *Transactions of the ASAE.* 38(2): 449-453.

Koelliker, J. K., H. L. Manges, and R. I. Lipper. 1975. Modeling the performance of feedlot-runoff-control facilities. *Transactions of the ASAE* 18(6): 1118-1121.

Koelsch, R., J. Lorimor, and K. Mankin. 2006. Vegetative treatment systems for management of open lot runoff: review of literature. Applied Eng. in Agric. 22(1): 141-153.

Mankin, K. R. and C. G. Okoren. 2003. Field evaluation of bacteria removal in a VFS. Paper No.032150. Presented at 2003 ASAE Annual International Meeting, Las Vegas, NV. 9 pages.

MidWest Plan Service. 1993 Livestock Waste Facilities Handbook. Ames IA: Iowa State University.

North Dakota State University. 2009. North Dakota Agricultural Weather Network. Fargo, ND. Available online at: http://ndawn.ndsu.nodak.edu/

Michael, N.O. 2007. Water and nutrient use evaluation of South Dakota vegetated treatment systems. MS thesis. Brookings, South Dakota: South Dakota State University, Department of Agricultural and Biosystems Engineering.

Parker, D. B., D. E. Eisenhauer, D. D. Schulte, D. L. Martin. 1999. Modeling Seepage from an Unlined Beef Cattle Feedlot Runoff Storage Pond. Trans. ASAE. 42(5):1437-1446

Similien, R. M. 2010. Forage production of bromegrass under internsive management with applications to vegetated treatement areas in the Northern Great Plains. PhD diss. Brookings, S.D.: South Dakota State University, Department of Plant Science.

Smith, S.M., T.P. Trooien, S.D. Pohl, R.A. Persyn, and H.D. Werner. 2007. Performance of a vegetated treatment system simulation model. In Proceedings of the International Symposium on Air Quality and Waste Management for Agriculture,CD-ROM. September, 2007. St. Joseph, Mich.: ASAE.

South Dakota Department of Environmental and Natural Resources. 2010. Permits: Surface Water Quality: CAFOS. Available at: http://denr.sd.gov/des/sw/cafoFAQ.aspx#CAFO

South Dakota State University. 2009. South Dakota Climate and Weather. Brookings, SD. Available online at http://climate.sdstate.edu/climate_site/climate.htm

University of California Davis. 2009. UC Davis Biometeorology Program, Evapotranspiration. Available at: http://biomet.ucdavis.edu/evapotranspiration.html

USDA-NRCS. 2009. Web soil survey. Available online at: http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx

Woodbury, B.L., J.A. Nienaber, and R.A. Eigenberg. 2003. Performance of a passive feedlot runoff control and treatment system. *Transactions of the ASAE* 46(6): 1525-1530