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Evaluating the cost and performance of vegetative treatment systems on open beef feedlots in the Midwestern United States

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Abstract

Runoff from open beef feedlots has become an important environmental concern over the last decade. Feedlot runoff has the potential to degrade surface water and groundwater. For these reasons, the U.S. Environmental Protection Agency required concentrated animal feeding operations (CAFOs) to control feedlot runoff resulting from up to and including a 25 year, 24 hour rainfall event. Typical feedlot runoff control systems utilize a containment basin to collect and store feedlot runoff.

In 2003, federal regulations allowed the use of alternative technologies to control feedlot runoff that performed equal to or better than a conventional runoff storage basin on a pollutant mass released basis. Vegetative treatment systems (VTS) are one alternative technology system of interest to researchers and producers across the Midwest. These systems utilize a solid settling basin (SSB), vegetative treatment area (VTA), and an optional vegetative infiltration basin (VIB). During a runoff event, earthen berms collect and convey feedlot runoff (i.e., effluent) into a SSB where a fraction of the solids are removed via settling. After solids are settled, the effluent is then applied to a VTA where it is infiltrated into the soil where plant uptake and treatment occur. Beef producers in the Midwestern United States have shown an increasing interest in using VTSs as a perceived lower cost option to traditional containment basin systems.

This thesis includes two papers for journal submission and one supplemental chapter providing further analysis of the first paper. Chapter two consists of the first paper titled “Comparison of construction costs for vegetative treatment systems in the Midwestern United States” while chapter three is titled “Evaluating the annualized vegetative treatment system cost.” Chapter four consists of the second paper is titled “Evaluating the performance of vegetative treatment systems on open beef feedlots in the Midwestern United States.”

Chapter two, including the first paper, reports the construction cost associated with 23 VTSs located in the Midwestern United States. The cost comparison for VTSs were presented on a per head space of cattle basis adjusted to 2009 dollars

for animal feeding operations (AFOs) containing less than 1,000 head of cattle and CAFOs containing more than 1,000 head of cattle.

VTS construction costs were compared to estimated construction costs associated with conventional basins, monoslope barns, hoop structures, and earthen feedlots with a basin system. Results from the cost comparison indicated VTSs on average were the least expensive runoff control system to construct compared to conventional containment basins on both AFO ($77 per head space for VTS, $205 per head space for containment basin) and CAFO ($85 per head space for VTS, $136 per head space for containment basin) facilities. The construction cost of a VTS implemented on an open feedlot was compared to a monoslope barn, hoop structure, and open feedlot with a containment basin. In this analysis, the VTS constructed with an open earthen feedlot was, on average, the least expensive feedlot system to construct at $282 per head space of cattle (average of feedlot size) followed by an open lot with containment basin ($361 per head space of cattle), hoop structure ($395 per head space of cattle), and monoslope barn ($655 per head space of cattle).

The third chapter reports the annualized cost associated with the initial construction of a VTS compared to a containment basin. Operation and maintenance costs were not included for either VTSs or containment basins in this analysis due to availability of data. Results from this analysis showed VTSs, on average, cost approximately $13 per head space on an annualized basis. This value assumes a life expectancy of 10 years. An estimated conventional basin designed for the same VTSs would cost approximately $11 per head space on an annualized basis for a basin life expectancy of 25 years and an irrigation equipment life expectancy of 10 years. A VTS break even life expectancy of greater than 14 years was needed to create an annualized system cost less than a conventional basin. Annualized system cost was found to be largely influenced by life expectancy.

Chapter four consisting of the second paper reports the 2009 VTS performance data collected from nine CAFO feedlots located in Iowa, Nebraska, and Minnesota. The nine VTSs were compared on the total runoff volumes from the SSB and VTA, pollutant concentrations in the effluent released from the VTA, and the mass of five monitored parameters released from each VTS component.

In 2009, five of the nine monitored VTSs did not report a release from the VTS. The percent runoff controlled varied by site ranging from a low of -6 percent to a high of 100 percent. The overall average percent of mass reduced from the five monitored parameters ranged from 72 to 100 percent. Vegetative treatment systems performance varied depending on site specific rainfall, stocking densities, feedlot to VTA ratio, and system design. The concentrations of five runoff parameters were monitored leaving each VTS component. These five parameters were total Kjeldahl nitrogen, ammonia, total phosphorus, chemical oxygen demand, and total solids. The 2009 overall average concentration reduction for each VTS ranged from 35% to 84%. This range in concentration reductions was due to VTS design, weather conditions, site variation (i.e., soils, vegetation, etc.), and management practices.

CHAPTER 1. GENERAL INTRODUCTION

Introduction

The United States Environmental Protection Agency (USEPA) identified pollution from agricultural land as one of the leading sources of impaired waters of the United States (USEPA, 2000). An impaired water source is considered any body of water not meeting its designated use such as drinking water supply, the ability to sustain aquatic life, or recreational activities.

Agricultural pollution is a broad term used to describe many of the environmental impacts in modern farming practices. Common agricultural pollutants are nitrogen and phosphorus, both commonly found in animal waste (manure). Animal manure from feedlots is typically deposited by the animals on the feedlot surface. Manure typically remains on the feedlot until it is mechanically collected and stored as a solid until land application. However, the manure deposited on the feedlot surface becomes a potential pollutant source when runoff caused by rainfall contacts the manure and flows away from the feedlot. The main components of manure that impact surface waters are organic matter, nutrients (such as: nitrogen, phosphorus, ammonia, etc.), and fecal bacteria (USDA, 1992). Each of these components may cause water degradation or impairment depending on the concentration in a water body. The following section briefly reviews how organic matter and nutrients released into a body of water may lead to water quality impairment or degradation.

Organic matter is defined as any material capable of decaying into a simpler form. The organic matter located in animal manure consists of undigested feed material the animals did not utilize and convert into energy. When organic matter enters a water source, aerobic micro-organisms begin to consume this matter as an energy source. While doing so, these aerobic micro-organisms consume dissolved oxygen within the water and release carbon dioxide. This in turn reduces oxygen in the water that is available to fish and other aquatic life.

Nutrients, such as nitrogen and phosphorus, can enter a water body and create a food source for algae and other aquatic plants to grow. This process is called eutrophication and refers to an increase of nutrients within an ecosystem causing excessive plant growth and decay. When the plants die, micro-organisms begin to consume the organic matter (plants), thus following the same process described for organic matter. Water quality is affected by both organic matter and nutrients by reducing the amount of oxygen available to aquatic animals living within the water source. In addition to low oxygen levels, some nutrients, (e.g., un-ionized ammonia (NH_3)) can be toxic to fish and other aquatic life (USDA, 1992). Degradation of fishing and other recreational activities may result from an increase in nutrients or organic matter in water bodies. As a result, water quality degradation and impairment to surface waters has led to the creation of federal and state regulations governing the acceptable release of pollutants from not only agriculture but industries as well.

In 1972, congress passed the Clean Water Act (CWA) to restore and maintain the chemical, physical, and biological integrity of the Nation's waters (Sweeten et al., 2003). Section 502 of the CWA specifically defined concentrated animal feeding operations (CAFOs) as point sources along with other manufacturing industries (FWPCA, 2002). In section 402 of the CWA, the National Pollution Discharge Elimination System (NPDES) was created to permit point source pollution discharges to federal waters (Sweeten et al., 2003). Water quality standards termed effluent limitation guidelines (ELGs) were developed to provide specific guidelines regulating the amount of pollutants discharged from a particular point source. Currently, only feedlots designated as CAFOs are required to apply for NPDES permits and follow specific CAFO ELGs. Various feedlot classifications and regulatory requirements are discussed in the following sections.

The United States Environmental Protection Agency (USEPA) defined animal feeding operations (AFOs) as an operation where animals are confined on a lot or in a facility that does not sustain vegetation for at least 45 days in a 12 month period (Federal Register, 2003). These facilities concentrate animals on areas of land where feed is brought to the animals instead of seeking food located in pastures (i.e., grazing). When a feedlot AFO reaches 1,000 head of beef cattle, the facility is then defined as a large concentrated animal feeding operation (CAFO). In addition to large CAFOs, small (less than 300 head) and medium (300 to 999 head) AFOs may be classified as a CAFO on a site by site basis if one of the following conditions is met: facility discharges manure or wastewater through manmade conveyances directly to surface water, or found to be a significant contributor of pollutants to local water sources (Sweeten et al., 2003). Animal feeding operations that do not meet the requirements of a CAFO are still required to meet state regulations.

USEPA rules require feedlots designated as CAFOs to contain all of the wastewater and runoff produced up to and including a 25-year, 24-hour design storm (USEPA, 2008). Animal feeding operations that meet the regulatory definition of a CAFO may be regulated under the NPDES permitting program (USEPA, 2008). Concentrated feeding operations that have 1,000 head of cattle or more are typically permitted under the NPDES program.

To meet the current EPA regulations requiring feedlot runoff control for a 25-year, 24-hour storm event, many CAFO producers constructed containment basins to store feedlot runoff. Containment basin systems consist of earthen berms used to direct feedlot runoff into an earthen or concrete storage structure. The effluent in these structures periodically must be land applied to allow enough storage for up to and including the 25-year, 24-hour rain event. The difficulty with a basin system lies when farmlands are growing crops, therefore limiting field application of effluent during the row crop growing season. As a result, producers must construct large containment basins to enable enough effluent storage to meet federal and state requirements along with conforming to their own land application periods.

In 2003, the EPA revised the CAFO rules by allowing the use of alternative technologies for runoff control measures that meet or exceed the performance of a traditional containment basin on a pollutant mass release basis (Federal Register, 2003). One alternative technology of interest to researchers and producers is a vegetative treatment system (VTS) which utilizes a solid settling basin (SSB) and vegetation as a means to treat feedlot effluent.

Objectives

The objective of this thesis was to evaluate the cost and performance of vegetative treatment systems (VTS) as an alternative to traditional containment basins for runoff control from beef feedlots.

VTS construction costs were collected for 9 permitted CAFOs and 14 non permitted animal feeding operations (AFOs) located in Iowa, Nebraska, and South Dakota, and Minnesota. The VTS construction cost associated with CAFOs and AFOs were compared in 2009 dollars by system type based on a per head space of cattle basis and on an annualized dollars per head space basis. Traditional containment basins, hoop structures, and monoslope barn construction costs were also included in this comparison. Conclusions were drawn on the economics of these facilities.

System performance was monitored at six concentrated animal feeding operations (CAFAO's) utilizing VTSs in Iowa were monitored by Iowa State University (ISU) along with three additional sites monitored by South Dakota State University and the University of Nebraska-Lincoln. Each feedlot was permitted with a NPDES permit and the partnering universities were responsible for data collection and upkeep of instrumentation at their sites. Quarterly reports were provided to ISU containing the effluent inflows and outflows from each component, concentration of the effluent from each component, and the associated climate data for each VTS location. Effluent samples were required for each runoff event and were analyzed at a commercial testing facility.

Literature Review

The organization of this literature review consists of three sections: general VTS and runoff control information, cost analysis, and VTS performance. The general information section describes typical VTS components along with various design related considerations. This section also contains general information regarding the various types of runoff control systems. The cost analysis section describes current literature associated with VTS construction cost. Limited data was found representing the cost of these systems especially when implemented to control runoff from CAFO facilities. The VTS performance section describes research literature using VTSs to control and treat runoff for both AFOs and CAFOs. Performance data collected from the review of literature is provided for both the SSB and VTA components.

General Runoff Control and VTS Information

Murphy and Harner (2001) reported two basic categories of runoff control systems for open feedlots; containment and discharge systems. Containment systems collect and store all of the runoff leaving a feedlot while a discharge system releases runoff typically after performing some sort of treatment (Murphy and Harner, 2001). Murphy and Harner (2001) also reported five different types of runoff control systems consisting of wetlands, grass filters, infiltration fields, terraces, and containment systems. These five systems can further be reduced to three categories consisting of vegetative systems, containment ponds (basins), and evaporation ponds (Khanijo, 2008).

A review of literature for vegetative treatment systems was compiled by Koelsch, Lorimor, and Mankin in 2005 and reported four general conclusions about using VTSs to treat and control runoff from livestock operations: 1.) VTSs designed for runoff control had the potential to achieve equivalent performance compared to conventional technologies 2.) important VTS design factors to maximize pollutant reduction were pre-treatment of effluent, maintaining sheet flow within the VTA, discharge control of volume from the SSB, system size, and site location 3.) sedimentation and infiltration were the two primary mechanisms for pollutant reduction from a VTS 4.) research was confined to non-CAFO applications likely due to regulatory limits (Koelsch et al., 2006). Prior to 2003, research on vegetative systems were performed on AFOs smaller than 1,000 head since federal regulations did not allow these systems on larger feedlots until 2003.

Typical components of a VTS (Figure 1) consist of a solid settling basin (SSB), optional vegetative infiltration basin (VIB), and a vegetative treatment area

(VTA) (Koelsch et al., 2006a). During a precipitation event, runoff (effluent) occurring within the feedlot and feed processing area is conveyed into a SSB where a fraction of the solids are removed through settling. The SSB provides temporary effluent storage, up to seven days (IDNR, 2006) until soil conditions within the VTA allow effluent application. The Iowa Department of Natural Resources (IDNR) defined appropriate weather and soil conditions for effluent application if the following conditions are met: land application area is not frozen or snow covered, temperature is greater than 32 degrees Fahrenheit, and the site did not receive more than 0.05 inches of rain per day for the previous three days prior to application (IDNR, 2007). During an effluent application event meeting the IDNR criteria, effluent is released from the SSB and applied evenly across the top width of a VTA. Typical effluent application methods include but are not limited to gated pipe, earthen & concrete spreaders, or irrigation sprinkler systems (Woodbury et al., 2006, Gross and Henry, 2007). A VTA is level in one dimension with less than a 5% percent slope in the other dimension (Moody et al., 2006). Some systems utilize an optional VIB to provide further effluent treatment before VTA application. A properly designed VIB will perform two functions; provide additional effluent treatment before entering a VTA, delay and reduce the peak flow of runoff applied to a VTA (Lorimor et al., 2006). Vegetative infiltration basin systems contain an independent grid of tile lines located underneath the VIB to collect and encourage effluent infiltration through the soil profile (Moody et al., 2006). The soil profile serves as a filter to further remove solids and nutrients present within the effluent. After the effluent infiltrates through the soil profile and is collected within the tile lines, it is then pumped onto a VTA where the treatment process continues.

Clark et al. (1975) reported runoff characteristics for two types of containment basins; holding ponds and playas. Playas were defined as a natural occurring, shallow, wet weather lake that does not contain a drainage outlet (Clark et al., 1975). Playas are typically located in Texas while holding ponds are constructed in the Midwest. Playas are similar in concept to a holding pond or containment basin where effluent is stored long term until appropriate conditions enable dewatering of the basing through land application. The only exception to the previous statement is when a playa is dewatered by evaporation especially in arid climates.

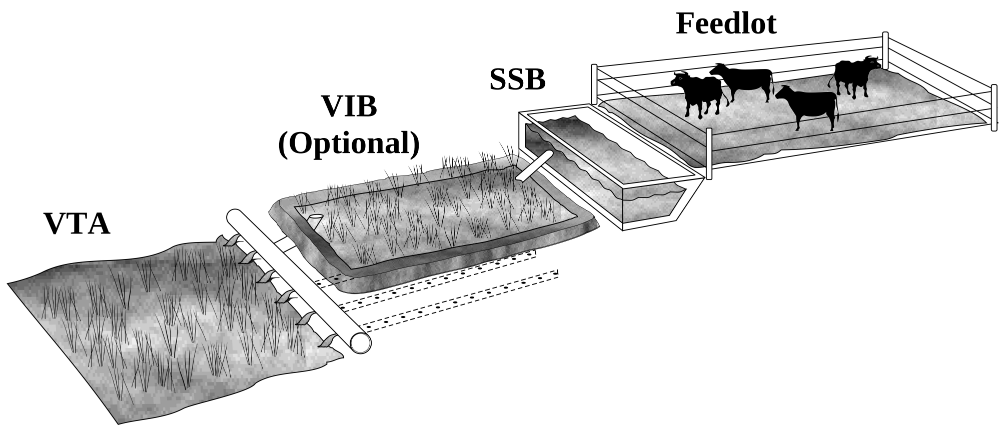

Figure 1. A typical VIB-VTA gravity flow vegetative treatment system (Henry, 2004)

A previous literature review by Koelsch (2006c) did not report any studies investigating actual containment basin performance. While containment basins are assumed to be zero discharge systems, in reality these systems have the potential and do discharge under certain conditions. A report to the USDA Risk Management Agency (RMA, 2003) investigated the modeled risk associated with failures from various waste storage systems. A risk model simulation was performed on five waste management systems located throughout the United States representing current waste management systems for swine, beef, and dairy cattle. Simulation scenarios were modeled on each of the five sites representing various management conditions. Results from the modeled simulations showed releases do occur from containment basins and weather, management and system upkeep are important elements in minimizing containment basin failure (RMA, 2003).

Cost Analysis

Typical manure management systems for CAFO beef feedlot facilities consist of a containment basin designed to collect feedlot runoff (effluent) into an earthen or lined storage structure. Periodically, the effluent in these structures needs to be land applied to maintain sufficient storage capacity for a 25-year, 24-hour rain event. Five containment basin systems were described by IDNR to meet the storage requirements of a CAFO NPDES permit (IDNR, 2007). These five systems vary with the containment basin design volume based on the frequency of effluent application. For example, system 1 must provide enough runoff storage capacity to contain effluent up to 12 months; the effluent is land applied at the end of the 12 month period. System 2 requires enough storage capacity (nine months) to land apply effluent runoff twice a year (July and October) while system 3 requires enough storage capacity (six months) to land apply three times a year (April, July, and October) (IDNR, 2007). System 4 must provide enough storage capacity to land apply effluent after every precipitation event, therefore requiring smaller storage basins. System 5 requires enough storage capacity for eight months with effluent application at least twice a year in either April/May or October/November (IDNR, 2007). Therefore, the size of the containment basin (i.e., storage volume) depends on the producer's effluent application scheme. This potentially results in larger containment basins to enable greater storage between application periods which in turn increases the construction cost associated with the manure handling system. For these reasons, beef producers in the Midwestern United States have shown an increasing interest in using vegetative treatment systems (VTSs) as a lower cost option to larger containment basins.

Literature suggests (Edwards et al., 1996, Melvin et al., 2007, Woodbury et al., 2003 & 2005) that VTSs are a lower cost option for runoff control compared to a conventional storage basin even though very little data is available to support this claim. Limited construction cost data is available to researchers and produces to provide insight on the actual overall cost of a VTS. Three research papers investigating the cost of VTSs are included in this review and represent the cost associated with implementing a VTS onto an AFO. A discussion of additional economic (i.e., cost) considerations are provided along with general description of the VTS.

Kizil (2010) reported the estimated construction cost for two VTSs and two containment basin systems designed to control runoff from two feedlots located in

North Dakota containing less than 1,000 head of beef cattle. Kizil reported the estimated construction cost of a VTS ($410 and $337 per head space) was more than the estimated cost to construct a containment basin ($334 and $299 per head space) on a per head of cattle basis (Kizil, 2010). These results may not be a complete comparison since the SSB cost did not include effluent application costs. In order to accurately compare the construction cost of both systems, the containment basin system should include the equipment cost associated with some sort of effluent land application method since the cost of VTS includes the cost of application onto a vegetative area. Therefore, a more accurate cost analysis between the two systems should include the cost associated with equipment needed for land application along with the construction cost. Engineering design cost should also be considered for both systems since design costs may be different between system types. Engineering design cost may be more important when analyzing CAFO systems since more design and regulation considerations need to be considered.

Cayley and Toombs (1997) reported the actual construction cost associated with constructing a vegetative filter strip (VFS) for a 20 head cow-calf operation in Ontario, Canada. The system consisted of a solid settling area, a gravel spreader, and a vegetated filter strip. The VFS was designed for a 2 year, 2 hour design storm and included an earthen berm surrounding the VFS to divert clean water away from the system. The total construction cost reported in 1994 Canadian dollars was $2,400 (Cayley and Toombs, 1997). In 1994 U.S. dollars, this value converts to approximately $1,764 and equates to approximately $88 per head of cattle. The construction cost included initial construction, gravel, plumbing, and electrical work. No engineering cost was presented in this analysis. The construction cost of $88 per head space reported in this paper may represent the cost associated with smaller scale VFSs but may not be representative of larger feedlots requiring a larger design storm standard.

Gross and Henry (2007) reported the design and construction cost for a sprinkler VTS and three gravity VTS located in Nebraska. These four VTSs were also compared to estimated construction costs for a conventional holding pond. The sprinkler VTS design utilized irrigation equipment (i.e., sprinklers) as a means to apply feedlot runoff to a VTA. This system was designed to control and treat runoff from a 40 cow-calf operation in conjunction with a 40 head feeder calf operation. A 25 year, 24 hour design storm standard was used to design this system. The actual VTS construction cost for a sprinkler VTS was reported by Gross and Henry (2007) at $63 per head space excluding engineering cost. The cost associated with three gravity VTSs ranged from $17 to $30 per head space excluding engineering cost. These four systems were compared to five different estimated conventional holding pond cost ranging from $44 to $170 per head space depending on the type of liner, size, and the inclusion of a pump station. The cost associated with all five holding ponds did not include the cost of land application equipment.

Economic analysis of various beef feedlot designs were documented by Honeyman, et al. (2008) and Lawrence et al. (2006). Honeyman, et al. (2008) reported a cost of $395 per head space of cattle for a hoop structure while Lawrence et al. (2006) reported the estimated annual operation cost along with the initial construction cost for five different AFO and CAFO beef feedlot systems; earthen lot with windbreak, earthen lot with shed, concrete lot with shed, confinement with solid floor, and confinement with slatted floor. The estimated costs for each system were based off of 2006 construction prices and were designed to meet all state and federal regulations at the time of publication. The construction cost associated with these five feedlot systems for both AFO and CAFO feedlots in 2006 dollars is as follows: earthen lot with windbreak (AFO,$249 per head space, CAFO, $289 per head space), earthen lot with shed (AFO,$511 per head space, CAFO, $586 per head space), concrete lot with shed (AFO,$651 per head space, CAFO, $705 per head space), confinement with solid floor (AFO,$618 per head space, CAFO, $600 per head space), and confinement with slatted floor(AFO,$707 per head space, CAFO, $693 per head space). This document did not include construction costs associated with VTSs.

The limited research literature presented above reported the construction cost of VTSs designed to control and treat runoff from feedlots containing less than 1,000 head of beef cattle. All three systems reported previously were constructed on smaller lots and did not include engineering design cost. Kizil (2010) reported the estimated cost per head space associated with the construction of a new feedlot with a VTS as the runoff control system while Cayley and Toombs (1997) and Gross and Henry (2007) reported the construction cost per head space associated with only a VTS. The conclusions drawn from this review of literature showed VTSs constructed without a feedlot ranged from $17 to $88 per head space while a complete VTS and feedlot system was estimated at $410 and $337 per head space. All of these studies did not account for engineering design cost which could prove to be a significant cost addition to the system. Due to VTSs application to CAFO feedlots to control and treat runoff, very little data was available on the construction cost associated with these systems. Therefore, additional research is needed to document the VTS construction cost and compare them to a conventional basin system.

VTS Performance

The research literature provided within this section discusses the performance data for both the SSB and VTA. One key component of a VTS to improve the overall performance of the system lies in the SSB design. A properly designed SSB serves two important functions within a VTS: delay and reduce the peak flow of the hydrograph, and reduce the organic material entering the VTA (Moody et al., 2007). Delaying and reducing the peak flow of runoff improves the overall VTS performance by creating more time for settleable solids to settle out of suspension. The removal of settleable solids are required by the IDNR and is achieved by reducing effluent flow to less than 0.5 feet per second for a minimum of five minutes (IDNR, 2007). Settleable solids include both soil particulates and organic matter where organic matter is associated with nutrients either bound to the surface or contained as part of their biological makeup. By reducing the nutrient loading to the VTA, the overall VTS performance increases since more nutrients are removed from the system. Lower nutrient loading may also result in lower nutrient concentrations leaving a VTA during a release event. Therefore, the SSB performance is a very important factor in the overall VTS treatment capabilities. The SSB and VTA literature review performance data collected from feedlots utilizing a VTS to control runoff is reported in this section.

The SSB performance data associated with 12 feedlots located in Iowa, Nebraska, South Dakota, Minnesota, and Ontario, Canada utilizing a VTS was reported by Andersen et al. (2009), Woodbury et al. (2003), Ostrem et al. (2009), and Cayley and Toombs (1997). Six out of the twelve feedlots contained less than 1,000 head (AFO) while the other six contained more than 1,000 head (CAFO). All 12 SSBs were constructed in different years; therefore the monitoring period ranged from 2005 to 2008 depending on the site. The VTS monitoring period and feedlot capacity is provided in Table 1 for all 12 sites along with five monitored parameters consisting of the following: total Kjeldahl nitrogen (TKN), phosphorus (P), potassium (K), chemical oxygen demand (COD), and total suspended solids (TSS).

The concentration results displayed in Table 1 represent the average nutrient concentration monitored leaving the SSB during the associated monitoring period. The average nutrient concentrations from the feedlots (Table 1) containing less than 1000 head of beef cattle for TKN, P, K, COD, and TSS were 209 mg/L, 40 mg/L, 470 mg/L, 4389 mg/L, and 1412 mg/L respectively. The average nutrient concentrations for the feedlots containing more than 1000 head of beef cattle for TKN, P, K, COD, and TSS were 527 mg/L, 97 mg/L, 689 mg/L, 11612 mg/L, and 5990 mg/L for. Based solely on the concentration averages, AFOs appeared to produce lower concentrations leaving the SSB than a CAFO site. This could potentially be due to differences in stocking densities or the total number of cattle residing on each system. For example, beef finishing cattle excrete 780 lb/day of TS, 0.42 lb/day of nitrogen (N), 0.097 lb/day phosphorus (P), and 0.30 lb/day potassium (K) (ASABE, 2005). Therefore the more cattle confined on a particular lot will excrete more manure (or nutrients) compared to a lot containing less cattle. If these nutrients are not removed from the lot surface periodically, then a buildup of nutrients will take place in the feedlot potentially resulting in larger concentrations during runoff events.

Table 1. Average concentration released from the solid settling basin

Reference	Site Location	Monitoring Period	Capacity Head	TKN mg/L	P mg/L	K mg/L	COD mg/L	TSS mg/L
Ostrem et al., 2009	SD	2005-2008	675	301	42	542	---	---
Ostrem et al., 2009	SD	2006-2008	450	102	18	398	---	---
Ostrem et al., 2009	SD	2007-2008	665	58	17	417	---	---
Cayley and Toombs, 1997	ON*	2 years	20	225	17	523	---	415
Woodbury et al., 2003	NE	1999-2001	600	---	---	---	2,311	849
Andersen et al., 2009	IA	2006-2008	650	361	109	---	6,466	2,972
Ostrem et al., 2009	MN	2008	2,250	231	58	689	---	---
Andersen et al., 2009	IA	2006-2008	1,000	326	83	---	5,602	1,640
Andersen et al., 2009	IA	2006-2008	1,400	561	86	---	11,379	5,595
Andersen et al., 2009	IA	2006-2008	4,000	1,635	222	---	34,933	17,016
Andersen et al., 2009	IA	2007-2008	2,300	126	53	---	1,609	1,052
Andersen et al., 2009	IA	2007-2008	1,200	288	83	---	4,539	4,647

* ON = Ontario, Canada

Research literature using vegetative filter strips (VFS) to treat feedlot runoff can be found dating back to 1980 (Young et al., 1980). VFSs are similar to VTAs in the sense they both use vegetation to treat polluted runoff. A VTA consists of a clean water diversion (i.e., a berm) surrounding the vegetated area to keep clean runoff out of the system while a VFS typically does not have a berm and is designed to discharge after performing some sort of treatment. Researchers using VFSs or VTAs to control and treat runoff from AFOs less than 1,000 head of cattle were reported by Dillaha et al. (1988), Cayley and Toombs (1997), Murphy and Bogovich (2001), Ostrem et al. (2009), Woodbury et al. (2002, 2003, 2005). Woodbury et al. (2002, 2003, 2005) reported performance data from 1999 to 2003 from a passive VTS (i.e., no SSB outlet control) constructed on a feedlot containing approximately 600 head of finishing cattle located in Nebraska. Results showed a VTS reduced total mass by 59% to 80% for chemical oxygen demand and total solids respectively (Woodbury et al., 2003). Other findings by Woodbury et al. (2005) showed effluent distribution throughout the VTA was not uniform and no flow was recorded leaving the VTA. Murphy and Bogovich (2001) reported a need to modify current VFS design to improve overall system performance. Key areas of improvement were SSB performance and sheet flow effluent application to filter strips. One potential design modification to improve these key areas was to provide variable VFS application rates through controlled SSB release. Dillaha et al. (1988) performed a VFS study on a field plot scale and investigated the transport of sediment, nitrogen and phosphate through a VFS of two different lengths (4.6m and 9.1m) and three different slopes (11%, 16%, 5%). Results showed VFS removed 81% and 91% of incoming sediment for lengths of 4.6m and 9.1m respectively. Total nitrogen percent reductions were 64% and 74% while total phosphorus reductions were 58% and 69% for filters lengths of 4.6m and 9.1m respectively. In addition to researching filter length, the effects of channeling and uneven flow distribution within a VFS was also studied on a plot with a 4% cross slope. The authors concluded channelized flow through a FVS resulted in concentration reductions that were less than non-channelized FVS. Based on the research projects cited above, general conclusions may be drawn on the importance of uniform sheet flow throughout a VFS and the need to control SSB release in order to promote better SSB and VFS performance.

The VTS design and monitoring systems implemented on six CAFO feedlots in Iowa were reported by Melvin et al. (2007), Moody et al. (2006), Khanijo et al. (2006), Khanijo (2008), Andersen (2008), and Pepple et al. (2008). These papers reported the VTS design process, monitoring methods and systems for rainfall, temperature, ground water, surface water, soil sampling, and system discharge from each VTS component. General VTS design criteria for a SSB, VTA, and VIB system was described and reported in section 5, 6, and 7 of the Vegetative Treatment Systems for Open Lot Runoff (Nienaber et al., 2006, Woodbury et al., 2006).

Research data collected on VTSs designed to control and treat runoff from open beef CAFOs in Iowa were documented by Andersen et al. (2009), Khanijo (2008). Khanijo (2008) reported VTS performance data collected from four feedlots located in Iowa. Results from this study found SSB performance improved solid settling after installing a valve on the SSB outlet to control effluent application to a VTA. In 2006, all four SSBs did not have a valve installed on the SSB outlet while in 2007 three out of the four SSBs were modified to utilize a valve to control effluent application. From 2006 to 2007, the total solids concentration leaving the SSB was reduced by 59% and 69% at two of the sites while the third site experienced an increase of total solids by 453 percent. The site that increased in total solids from 2006 to 2007 changed its SSB management practices in 2007 by removing a hay bale filter lining the entrance of the SSB. This filter was used to remove solids during the 2006 monitoring season. Therefore, only two out of the four sites can accurately be used to determine the effect of installing a value on the SSB outlet and these two sites experienced total solids concentration reductions of 59% and 69%.

Factors affecting the overall performance of VTSs were limited storage capacity of the SSB, ponded conditions in the VIB, low VTA infiltration rates, high water tables, and management techniques (Khanijo, 2008). Research initially performed on these four VTS sites by Khanijo was continued through 2009 with the addition of two VTS sites. Andersen et al. (2009) reported 2008 performance data from all six VTS sites located in Iowa along with data collected by Khanijo in 2006 to 2007. Results from this study showed VTSs were capable of reducing the concentrations and mass of nutrients exiting a VTS by 50 to 90% and 65 to 99% respectively, varying by both site and year (Andersen et al., 2009).

The research information provided within this review of literature showed VTSs possess the ability to reduce the concentration and mass of nutrients to treat runoff from CAFOs. Vegetative treatment system performance conclusions drawn from the presented research literature showed SSBs are key components to improve the overall performance of a VTS. Solid settling basins were found to attenuate the runoff hydrograph and reduce the organic material loading into the VTA through solid settling. Average concentrations leaving a SSB appeared to vary within and between both the AFO and CAFO runoff control systems. Research presented on VTSs used for open feedlot runoff control showed typical nutrient reductions ranging from 58% to 91% for AFOs and 50% to 90% for CAFOs. Performance varied based on weather conditions and management practices. Common design and operational requirements concluded from the literature for VTSs were improved SSB performance, control over SSB application, and maintaining sheet flow within a VFS or VTA. Limited full scale performance data using VTSs to control runoff from beef CAFOs was available for review.

Thesis Organization

The papers format was used for the organization of this thesis. Two papers were written for the requirement of this Master of Science degree. The first paper is titled “Comparison of Construction Costs for Vegetative Treatment Systems in the Midwestern United States.” This paper was submitted to the Transactions of ASABE and compared the actual and estimated construction costs for both CAFO and AFO runoff control facilities across the Midwest. The co-authors gathered VTS construction cost data from VTS sites located within their corresponding state and submitted this data to Iowa State University (myself) for analysis between the sites. I was the primary author for the paper and responsible for the data analysis, interpretation, and paper writing.

The second paper titled “Evaluating the Performance of Vegetative Treatment Systems on Open Beef Feedlots in the Midwestern United States” reported the 2009 performance data from nine feedlots utilizing a VTS in the Midwest and will be submitted to Transactions of the ASABE. My responsibilities for this paper were to collect performance data from six VTS feedlots located in Iowa along with data analysis from three additional sites located in the surrounding states. The co-authors affiliated with the University of Nebraska-Lincoln and South Dakota State University monitored these four “out-of-state” (i.e., outside of Iowa) VTSs and submitted performance data to Iowa State University (myself) for analysis between all nine sites.

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CHAPTER 2. COMPARISON OF CONSTRUCTION COSTS FOR VEGETATIVE TREATMENT SYSTEMS IN THE MIDWESTERN UNITED STATES

A paper submitted to *Transactions of the ASABE* for publication

B. J. Bond, R. T. Burns, C. G. Henry, T. P. Trooien, S. H. Pohl, L. B. Moody, M. J. Helmers, J. D. Lawrence

Abstract

Vegetative treatment systems (VTSs) provide an alternative to containment basin systems for beef feedlot runoff control. Beef producers in the Midwestern United States have shown an increasing interest in using VTSs as a perceived lower cost option to containment basin systems. This paper reports the actual construction costs associated with 23 VTSs (nine on permitted Concentrated Animal Feeding Operations (CAFOs) and 14 on non permitted Animal Feeding Operations (AFOs)) and four containment basins located throughout Iowa, Minnesota, South Dakota, and Nebraska. The VTS construction costs are reported on a per head space of cattle basis in 2009 adjusted dollars for each system. Cost comparisons are presented between CAFO and AFO facilities and by system type. Additionally, estimated construction cost comparisons between open feedlots with VTS systems, open feedlots with containment basins, monoslope barns and hoop structures for beef production systems are provided. Results from the cost comparison indicate the average cost in 2009 dollars for an AFO or CAFO is $655 per head space for animals housed in a monoslope barn with a concrete floor and $395 per head space for animals housed in a hoop structure. For AFOs and CAFOs, the average cost of an earthen lot with a containment basin costs is $361 per head space, while the average cost of an earthen lot implemented with a VTS is $282 per head space. If only the feedlot runoff control system is considered, VTAs designed for CAFO facilities are less expensive to construct ($85 per head space on average) than

traditional containment basins ($136 per head space on average). Similarly for AFO feedlot runoff control systems, a VTS was less expensive to build ($77 per head space on average.) than a containment basin on a similar facility ($205 per head space). The data indicated the least expensive VTS for an AFO is a sloped or sloped and level VTA ($50 per head space average.) followed by a sprinkler VTS ($94 per head space average.) and a pump sloped VTA ($101 per head space average).

Introduction

US Environmental Protection Agency (USEPA) rules have required concentrated animal feeding operations (CAFOs) to contain all of the wastewater and runoff produced from a 25-year, 24-hour design storm (USEPA, 2008). The 2003 CAFO rule allowed the use of alternative technologies that meet or exceed the performance of traditional containment basin systems. Manure containment systems can be costly to construct and require manure storage over a long period of time. Generally, runoff collected and stored in containment basins are land applied twice a year (spring and fall) as either fertilizer or irrigation water when field conditions allow manure application (MWPS-18, 2001). Beef producers have expressed interest in non-basin technology systems that eliminate the need for the long term storage of feedlot manure runoff (Woodbury et al., 2005).

Current manure management systems for CAFO beef feedlot facilities consist of a containment basin designed to collect feedlot runoff (effluent) into an earthen or lined storage structure. Periodically, the effluent in these structures needs to be land applied to maintain sufficient storage capacity for a 25-year, 24-hour rain event. One difficulty with this system occurs when land application areas contain growing crops, making manure field application difficult. The result is larger containment basins to enable greater storage between application periods which in turn raises the construction cost associated with the manure handling systems. For these reasons, beef producers in the Midwestern United States have shown an increasing interest in using vegetative treatment systems (VTSs) as a lower cost option to containment basins.

Beef animal feeding operations (AFOs) were defined by the EPA as a facility where animals are confined on a lot or in a facility that does not sustain vegetation for at least 45 days in a 12 month period. Animal Feeding Operations that meet the regulatory definition of a CAFO may be regulated under the National Pollutant Discharge Elimination System (NPDES) permitting program (USEPA, 2008). Concentrated animal feeding operations that have 1,000 head of cattle or greater are typically permitted under the NPDES program. Animal Feeding Operations may be designated as a CAFO by the permitting authority and be required to obtain an NPDES permit; thus these producers have an incentive to manage their runoff to avoid violations.

This paper reports the actual construction costs associated with 23 VTSs (nine on permitted CAFOs and 14 on non-permitted AFOs) and four containment basins located throughout Iowa, Minnesota, South Dakota, and Nebraska. Additionally, estimated cost comparisons were made between open feedlots with VTSs, open feedlots with a containment basin system, monoslope barns, and hoop structures for beef production systems.

Site Descriptions

Vegetative Treatment Systems

Vegetative treatment systems provide an alternative to containment basins for feedlot runoff control. Typical components of a VTS are shown in Figure 2 and consist of a solid settling basin (SSB), optional vegetative infiltration basin (VIB), and a vegetative treatment area (VTA). During a rainfall event, feedlot runoff is contained by berms surrounding the lot and conveyed into a solid settling basin where solids are allowed to settle out of suspension. The effluent is then pumped or allowed to gravity flow evenly across a VTA where it is infiltrated into the ground keeping it from entering nearby surface water sources. Some systems contain an optional VIB between the solid settling basin and the VTA. The VIB receives effluent from the SSB and is constructed with an independent grid of tile lines buried approximately 1.2 meters (4 feet) under the ground surface to encourage effluent infiltration. The soil above the tile lines acts as a filter to further remove solids and nutrients still in suspension. The effluent collected from the tiles then enters a sump where a pump transports the effluent to a VTA. Gated pipe and concrete spreaders are typical devices used to evenly apply effluent to a VTA. VTAs can be either sloped (1-5%) or level (0-1%). Sloped VTAs use overland flow to distribute effluent across the VTA, while level VTAs use a flooding effect to obtain even distribution.

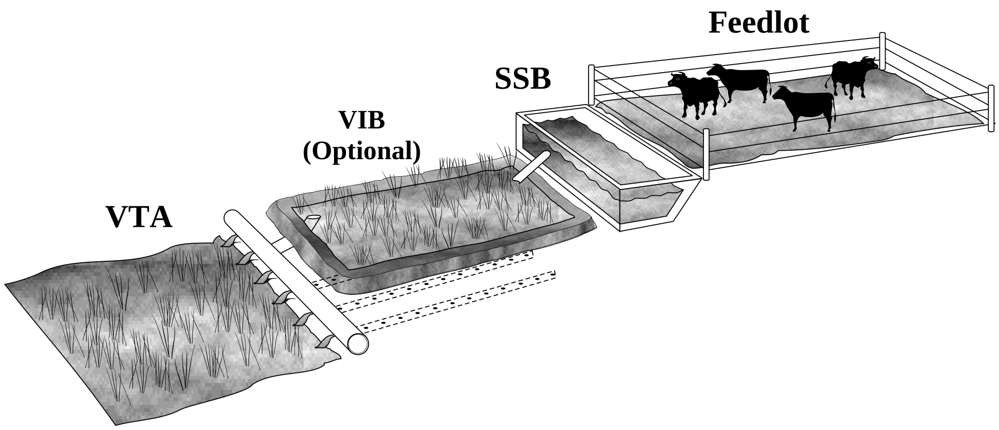

Figure 2. A typical VIB-VTA gravity flow vegetative treatment system (Henry, 2004)

Pump VTSs (Figure 3) are a variation of the gravity sloped VTS and have the advantage of being used on sites that cannot accommodate a gravity system. Like a gravity flow system, these rely on even distribution and overland flow across a gravity sloped or level VTA. Some pump VTSs are designed to re-circulate effluent from the bottom of a VTA back into the sump. This essentially creates a closed system where releases from the VTS are less likely to occur.

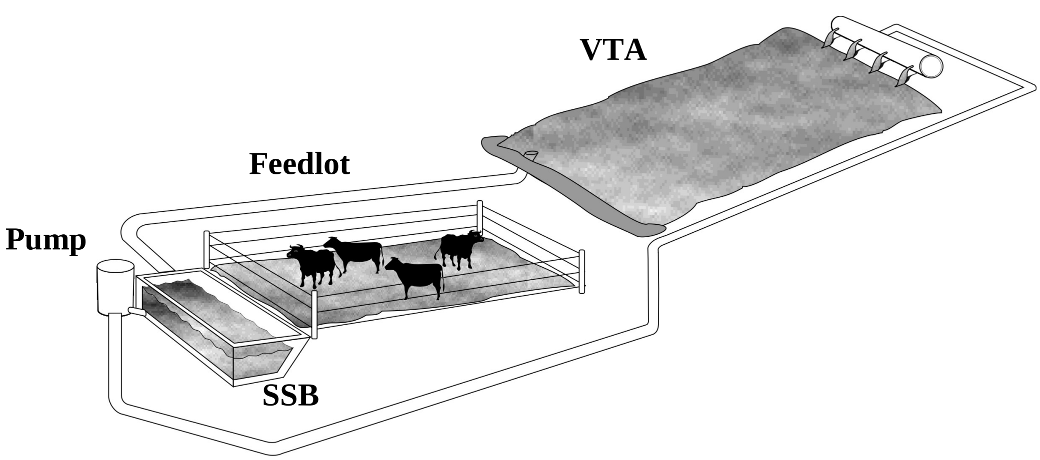

Figure 3. A typical pump VTS system (Henry, 2004)

Some VTSs utilize an irrigation system to apply effluent to a VTA. These VTSs utilize various irrigation equipment, including solid set sprinklers, traveling gun systems and towline systems to apply effluent to a vegetated area. Examples include the sprinkler irrigation of dairy parlor water to a sod filter area using a solid-set sprinkler system (Winker, 1989) and solid set sprinkler irrigation of milk-house waste water to a vegetative infiltration area (Christopherson et al., 2003). More recently this same approach has been used to apply beef feedlot run-off to vegetative treatment areas in Nebraska (Gross and Henry, 2007). These systems are constructed similar to a gravity flow VTS described above except for the addition of a pump and irrigation sprinklers (Gross and Henry, 2007). Irrigation systems allow effluent disposal on rolling and irregular land and generally cost more to construct than other manure application systems but overcome topographical challenges where gravity systems would not work. The irrigation VTS cost information presented in this paper is for the Sprinkler VTS (Figure 4) developed in Nebraska for beef feedlot runoff (Gross and Henry, 2007).

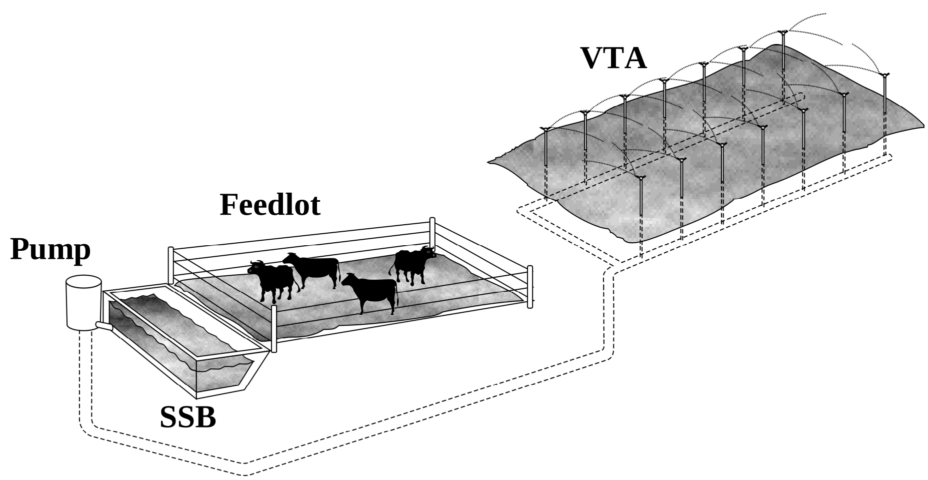

Figure 4. VTS sprinkler system (Henry, 2004)

VTS designs and terminology vary depending on the location and local regulations. In some Midwestern states, VTS systems utilize a level VTA at the end of the system to minimize the risk of runoff leaving the system. These level VTA's are similar to VIB's, except they do not include a tile drain system. The coupling of more than one style of VTA has been reported to enhance the performance of VTS systems (Koelsch, 2006).

Containment Basin System

Open feedlots with manure containment basins usually consist of an earthen or concrete lot, a solid settling basin, and a detention basin (Figure 5).The lots are typically designed for 23.2 square meters (250 square feet) of pen space per animal space (Lawrence et al., 2006). During a rainfall event, effluent travels down the feedlot gradient and collects in the solid settling basin where solids are allowed to settle out of suspension. After adequate time has passed for solid settling, the effluent is released into a detention basin to be stored until land application.

Containment basin systems produce both solid and liquid manure. The solid manure comes from cleaning out the settled particles in the settling basin and cleaning the feedlot itself. The manure from these two components needs to be removed periodically and either land applied or stockpiled until appropriate field conditions occur.

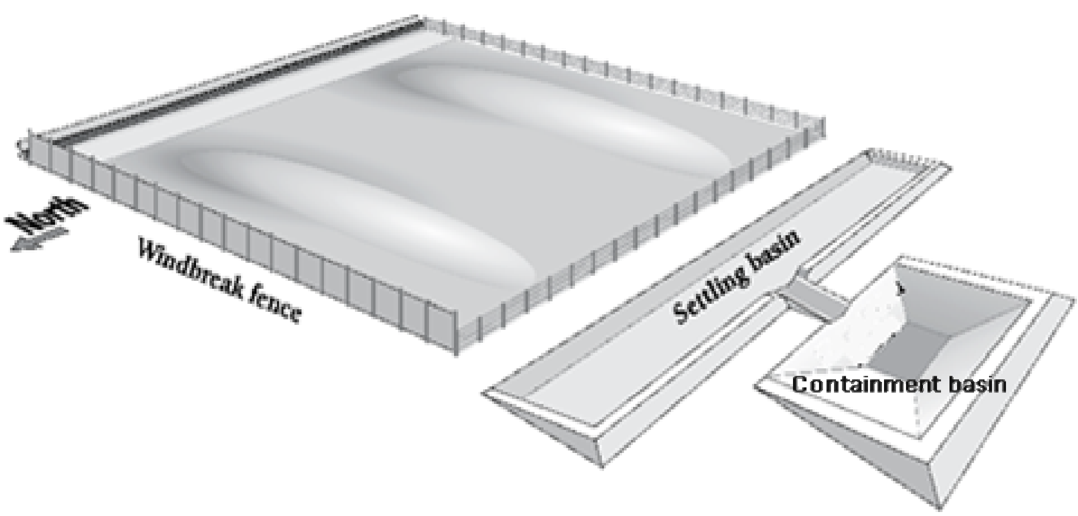

Figure 5. Open feedlot with a containment basin system (Lawrence et al., 2006)

Roofed Systems with Manure Storage

Monoslope barns feature complete animal confinement with solid concrete floors (Figure 6). These barns are designed for approximately 3.7 square meters (40 square feet) of open space per animal (Lawrence et al., 2006). Bedding is placed in the middle of the pens forming a bedding pack to absorb manure and is typically collected twice a week depending on management practices. Manure from these facilities is handled as a solid and stockpiled for field application when conditions are appropriate. Feeding bunks are typically located on both sides of the barn to allow 0.3 meters (one foot) of bunk space per head (Lawrence et al., 2006).

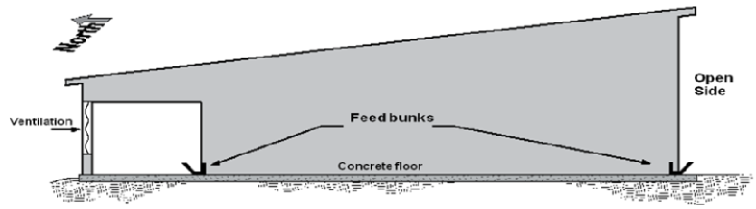

Figure 6. Monoslope barn with a solid concrete floor (Lawrence et al., 2006)

Hoop barns were first developed in Canada during the early 1990's (Connor, 1993) and were introduced to the United States in the mid- 1990s (Honeyman, 2005). These structures were rapidly accepted by many farmers due to their low cost and versatility in agricultural production systems. The framework of these structures (Figure 7) consists of tubular steel arches (trusses) spanning across the sidewalls of the barn (Honeyman, 2005). These arches are attached to posts on each side of the structure creating a steel framework to support a UV-resistant, polyvinyl tarp (Shouse et al., 2004). The floor covering in this system is either concrete or a dirt floor depending on the producer's decision. Hoop barns are designed for natural ventilation and contain curtains on the sidewalls to adjust ventilation rates especially in the summer months. These facilities are typically designed with an overhang covering the feed bunks to exclude any rainfall that might enter the system.

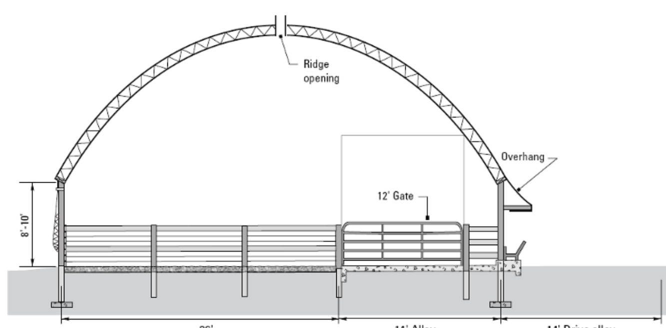

Figure 7. Hoop barn with feed bunk overhang (Honeyman, 2008)

Manure management for hoop barns is handled by selectively cleaning portions of the barn or by applying additional layers of bedding to soak up moisture (Shouse et al., 2004). Bedding typically consists of corn stalks applied evenly throughout the facility's flooring. If selective cleaning (i.e., cleaning based on visual inspections) is chosen, the collected manure needs to be stockpiled in a way that meets state and federal regulations. Typically the manure is then spread directly on fields when appropriate conditions are met.

Methods

Actual Cost Evaluation for Vegetative Treatment and Containment Basin Systems

The VTS feedlot construction data for this paper was provided by Iowa State University, University of Nebraska-Lincoln, and South Dakota State University. The feedlots were located throughout Iowa, Nebraska, Minnesota, and South Dakota representing both AFO and CAFO feeding operations. The presented costs were actual system costs paid by producers and represent the as built cost associated with integrating a VTS system into an existing feedlot.

The VTS construction costs are reported on a per head space of cattle basis for each system based on actual cost in the year they were constructed and were adjusted to 2009 dollars. The average yearly inflation rate was calculated from the Producer Price Index compiled by the Bureau of Labor Statistics for the years 2001 through 2009 (United States Department of Labor, 2009); the calculated rates were used in conjunction with the future worth equation to adjust the construction cost for inflation to a common 2009 base year.

The cost analysis for each site was based only on the VTS construction and engineering design cost and did not include the following items: feedlot construction, feed and cattle handling facilities, fencing, feeding equipment, or operation and maintenance costs. The operation and maintenance cost associated with a VTS was not collected due to inadequate operator records. The in-kind costs (i.e., material and labor supplied or performed by the producer) were also not included within the analysis. The values reported in this paper represent the amount a producer might expect to pay to implement a VTS on an existing feedlot.

Some feedlots reported in this paper were designed by public entities while others were designed by private consultants. In order to create a fair comparison between sites designed by different entities, the engineering design cost was normalized with an average billing rate of $84 per hour. This engineering rate was calculated from a 2009 phone survey of 7 agricultural engineering consulting firms located in the Midwest. The average billing rates were categorized into the following occupational categories: licensed and non-licensed engineers, drafting & technology, and surveying personnel. These billing rates were then weighted by the average percent of employee time allocated for a typical engineering project located in the Midwest. The average billing rates for each occupation and the average percent of employee time per project is located in Table 2.

Table 2. The average billing rate and percent of time per engineering project reported from 7 consulting firms located in the Midwest.

Firm Occupations	Average Billing Rate, $/hr	% of Time Per Project	$/hr
Licensed Engineer	109	25	27
Non-Licensed Engineer	77	43	33
Drafting/Technology	68	22	15
Surveying	90	10	9
	Total	**100**	**84**

The actual containment basin construction data for this paper was provided by the Nebraska Natural Resource Conservation Service (Reedy, 2009) and producer interviews by the University of Nebraska (Henry, 2009) which represented four holding basins and land application systems installed between 2003 and 2007 by NRCS. The containment basin systems were located throughout Nebraska representing three AFO and one CAFO feeding operation. The presented construction costs were paid by the producer and represent the cost associated with construction and materials while the design cost was normalized using the weighted average billing rate of $84 per hour for the design hours reported. Some producers used a combination of existing irrigation equipment while others purchased used or new equipment to apply effluent. For each feedlot, an estimated cost of implementing new irrigation equipment was reported along with the actual cost paid by the producer. To accurately report the overall basin cost per head space of cattle, the estimated new irrigation cost was used since producers may not have access to used irrigation equipment.

Cost Estimation for Containment Basins and Roofed Facilities

The estimated construction cost information for traditional open beef feedlots and monoslope facilities was collected from the ISU Beef Feedlot Systems Manual produced by Iowa State University and the Iowa Beef Center. This publication reported feedlot cost based on new feedlot construction and current Iowa regulations at the time of publication. Additional items included in the cost of a new feedlot are feed storage structures, cattle handling facilities, and feeding equipment. For the purpose of this paper, these items were removed from the analysis since existing feedlots already contain these items.

Basic assumptions for both the open feedlot and monoslope facilities are as follows based on the ISU Beef Feedlot Systems Manual (Lawrence et al., 2006):

- Each pen contains 150 head spaces
- 0.3 meters (one foot) of bunk space per head space for all systems
- Earthen lots have 4.9 meters (16 feet) wide concrete aprons placed along the feed bunks
- Outdoor lots over 1,000 head have settling and detention basins designed for a 132 mm (5.2 inch) storm
- All lots assume fence and gates at $33 per meter ($10 per foot)

For comparison purposes, the construction cost for an AFO with a containment system was estimated based on the following assumptions; CAFO engineering costs/efforts would remain constant for an AFO system of the same type, the feedlot area, run-off volume, and basin size would be proportional to a 1,500 head space operation. According to the ISU Beef Feedlot Systems Manual (2006), the engineering costs for a 1,500 and 5,000 head operation are reported as the same value since the design time will be approximately the same for both feedlot sizes (i.e., the same calculations are performed just different numbers). In order to justify the estimate using proportions between a 750 and 1,500 head feedlot, the AFO is assumed to be designed for a 25 year, 24 hour rain event. Accounting for these assumptions, the construction cost and irrigation was calculated for the 1,500 head CAFO facility on a per head space basis, and multiplied by 0.5 to yield the estimated total cost for each system component (SSB, containment basin, and irrigation system) for a 750 head feedlot.

Results and Discussion

AFO Vegetative Treatment Systems

The AFO VTS facilities were separated into three categories: sloped or sloped and level VTA, pumped sloped VTA, and sprinkler VTS. The sloped or sloped and level VTAs are gravity flow systems where effluent is applied via gated pipe or concrete spreaders. These systems may contain a level VTA to prevent a discharge. The pump sloped VTA category is similar to the sloped and level VTAs except for the need to pump effluent to the VTA (i.e., gravity flow is not utilized). These systems are more expensive due to the additional expense of a pump and have a slightly higher operating cost compared to a gravity flow VTA system. The sprinkler VTS category consists of a pump and irrigation equipment to apply effluent to a VTA. The VTS construction cost data for AFO facilities is provided in Table 3.

Table 3 shows the lowest VTS design cost for a beef feedlot was a gravity flow VTA. These systems averaged $50 per head space with a range of $25 to $74 per head space. The feedlots ranged in size from 120 to 700 head space of cattle. Compared to the other two systems, the sloped or sloped and level VTA had the fewest components to design and construct which results in a lower overall cost.

The sprinkler VTS systems averaged $94 per head space with a range of $67 to $110 per head space. These systems were more expensive than a sloped and level VTA due to the additions of a pump and irrigation equipment. These four systems ranged from feedlots containing 210 to 800 head of cattle. Three of the four sites used a towable sprinkler distribution system and the other used a solid set system. These sprinkler VTSs costs almost twice as much as a gravity flow VTSs to construct.

The pump sloped VTA systems averaged $101 per head space with a range of $46 to $173 per head space. These facilities ranged from 285 to 780 head of cattle. The pump sloped VTA were on average an additional $51 more per head space than a sloped and level VTA making this the most expensive VTA system to construct per head space for AFOs. The additional cost per head space was due to the addition of a pump and pump station to transport effluent to the top of a VTA. While looking at the engineering design costs for a pump sloped VTA, one site displayed an extremely high engineering design cost compared to other systems similar in size. If this site was excluded from the average cost per head space calculation, the new overall average for these systems would be reduced to $77 per head space of cattle making these systems less expensive per head space than a sprinkler system. Since the only difference between a pump sloped VTA and a sprinkler VTA was the addition of irrigation equipment, it could easily be assumed that the average overall cost would be more for a sprinkler VTA. However, other factors affect the overall cost of a pumping system including the pumping distance from the SSB to the VTA and the number of cattle utilizing the system.

Within each category, the lowest system cost per animal space corresponded with the largest number of animals but the highest cost was not necessarily associated with the smallest number of animals. The overall cost of a VTS depends on several site specific design variables such as the amount of earthwork, the type of pump and sprinkler system, the pumping distance from the SSB to the VTA, and the design costs (hours) associated with different consulting firms. These variables were determined to be the main factors affecting the various overall costs per head space between the VTS facilities.

Table 3. Vegetative treatment system construction costs for 14 animal feeding operations located throughout Nebraska, Minnesota, and South Dakota in 2009 inflation adjusted dollars.

AFO < 1,000 Head of Cattle											
		Number	VTA		Engineering Costs			Construction[3]		Total Cost[4]	2009 Dollars
VTS Type	Location	Of Head Space	Area, ha	Year	Hours	Actual[1]	Normalized[2]	Earthwork	Supplies/labor	2009 Dollars	Per Head Space
Sloped or sloped and level VTA	NE	359	1.5	2005	36	NA	$ 3,024	$ 6,655	$ 1,345	$ 13,608	$ 38
Sloped or sloped and level VTA	NE	290	1.0	2006	66	NA	$ 5,544	$ -	$ 8,597	$ 16,447	$ 57
Sloped or sloped and level VTA	NE	700	2.9	2006	45	NA	$ 3,780	$ 9,988	$ 1,500	$ 17,757	$ 25
Sloped or sloped and level VTA	NE	450	1.2	2007	53	NA	$ 4,452	$ 7,500	$ 4,690	$ 18,144	$ 40
Sloped or sloped and level VTA	NE	120	0.2	2007	59	NA	$ 4,956	$ 1,991	$ 400	$ 8,010	$ 67
Sloped or sloped and level VTA	SD	450	10.2	2005	110	NA	$ 9,240	$ 21,078	$ 5,912	$ 33,315	$ 74
Pump sloped VTA	NE	285	2.0	2006	52	NA	$ 4,368	$ 4,137	$ 17,994	$ 30,820	$ 108
Pump sloped VTA	NE	780	2.0	2009	70	NA	$ 5,880	$ 27,852	$ 2,024	$ 35,755	$ 46
Pump sloped VTA	SD	300	1.2	2007	239	$ 11,979	$ 20,076	$ -	$ 27,519	$ 51,889	$ 173
Pump sloped VTA	SD	665	3.8	2006	90	NA	$ 7,560	$ 8,496	$ 28,191	$ 51,462	$ 77
Sprinkler VTS	NE	210	0.9	2009	64	NA	$ 5,376	$ 3,250	$ 12,203	$ 20,829	$ 99
Sprinkler VTS	NE	800	3.0	2009	88	NA	$ 7,392	$ 5,700	$ 40,565	$ 53,657	$ 67
Sprinkler VTS	NE	450	1.9	2007	72	NA	$ 6,048	$ -	$ 35,115	$ 44,877	$ 100
Sprinkler VTS	NE	720	3.4	2009	88	NA	$ 7,392	$ 14,735	$ 57,060	$ 79,187	$ 110

[1] Actual engineering design costs

[2] Normalized design cost based on $84 per hour

[3] Cost as provided for the year the system was built

[4] Total cost associated with normalized engineering rate; for comparison, all totals were converted to 2009 using the Producer Price Index

CAFO Vegetative Treatment Systems

The CAFO VTSs were split into three categories: sloped or sloped and level VTA, pump sloped VTA, and a VIB-VTA system. The sloped or sloped and level VTA used gravity to transport the effluent through the system while the pumped sloped VTA used a pump to transport effluent to the top of the VTA. Therefore the pumped sloped VTA contains extra construction costs compared to the sloped or sloped and level VTA systems. Additional costs associated with a VIB-VTA system included a pump and the design/construction costs for an extra basin (the VIB). The construction costs associated with nine CAFOs are provided in Table 4. The engineering design hours for two out of the nine VTSs (one in Iowa, one in South Dakota) were unavailable. Therefore the actual engineering design cost for these systems was used instead of a normalized design cost.

The average CAFO construction cost for a gravity flow system is $79 per head and approximately $83 per head for a VIB-VTA system. The VIB-VTA system has a slightly higher cost per head for two reasons: installation of tile lines in the VIB, and purchasing a pump to transport infiltrated effluent from the VIB to the VTA. The pump sloped VTA site showed a greater cost per head compared to the VIB-VTA systems; effluent at the pumped slope VTA site was transported a longer distance from the SSB to the top of the VTA due to site layout. An additional return pipe connecting the VTA to the SSB sump collected ponded effluent in the VTA and returned it back to the system. The additional piping and trenching costs associated with this type of system could be the primary factor for this higher cost per head. The South Dakota site produced the largest sloped and level VTS cost per head at $107. Explanations for this high value are potentially due to having greater earthwork cost than the other sites since the VTA was located the farthest away from the feedlot. For the site, a long earthen channel was designed to transport SSB effluent to the VTA.

Vegetative treatment system design and overall construction cost depends heavily on the location of the planned VTS. Certain VTS types, such as sprinkler or pump sloped VTSs, are typically constructed in locations where gravity cannot be used to transport effluent to a VTA (i.e., VTA is located at a higher elevation). At these locations a sprinkler system may be a more appropriate design than a gravity flow system and end up costing less to construct. Therefore, depending on location, some sites may be limited to a certain VTS type. Although VTSs can be implemented at locations with less than ideal conditions, these sites typically will have larger construction costs associated with the design. For example if a feedlot is located at the bottom of a hill, then a pump sloped VTA might be a more appropriate VTS than a gravity flow system since a considerable amount of earthwork might be needed to create a VTA below the feedlot. This extra earthwork results in a more expensive VTS and could potentially cost more than implementing a sprinkler system. Many site limitations for various VTS designs include but are not limited to the topography of the site, water table depth, soil characteristics, and producer management practices. Therefore, VTSs are designed on a site by site basis and the overall construction cost between different systems may be difficult to draw conclusions about the which system is the least expensive to construct.

Containment Basins

The actual containment basin cost data provided by the University of Nebraska-Lincoln (Table 5) resulted in an average cost of $206 per head space for an AFO facility. Data for one CAFO facility was reported resulting in a cost of $103 per head space. One of the three AFO sites purchased all new irrigation equipment, therefore the actual and new irrigation costs were reported with the same value located in Table 5. As mentioned previously, the total basin cost included the estimated values for new irrigation equipment as well as normalized engineering costs.

Based on economic analysis data from Lawrence (2006) that have been updated to 2009 inflation adjusted dollars, an estimated containment basin system (Table 6) designed for a 1,500 head beef operation would cost approximately $167 per head space and a 750 head operation would cost $205 per head space.

Table 4. Vegetative treatment system construction costs for nine confined feeding operations in 2009 inflation adjusted dollars.

CAFO > 1,000 Head of Cattle											
		Number	VTA		Engineering Costs			Construction Cost[3]		Total Cost[4]	2009 Dollars
VTS Type	Location	Of Head	Area, ha	Year	Hours	Actual[1]	Normalized[2]	Earthwork	Supplies/labor	2009 Dollars	Per Head Space
Sloped or sloped and level VTA	IA	1,500	2.1	2005	246	$ 22,522	$ 20,664	$ 19,483	$ 38,734	$ 97,369	$ 65
Sloped or sloped and level VTA	IA	3,400	5.4	2005	222	$ 39,379	$ 18,669	$ 111,422	$ 102,360	$ 286,931	$ 84
Sloped or sloped and level VTA	IA	2,300	4.0	2007	208	$ 32,000	$ 17,510	$ 32,655	$ 44,326	$ 103,017	$ 45
Sloped or sloped and level VTA	IA	5,500	18.4	2006	NA	$ 179,507	NA	$ 107,495	$ 55,872	$ 398,790	$ 73
Sloped or sloped and level VTA	SD	2,000	6.4	2009	260	$ 27,181	$ 21,843	$ 118,950	$ 60,157	$ 214,416	$ 107
Sloped or sloped and level VTA	MN	2,750	4.6	2005	NA	$ 46,816	NA	$ 19,601	$ 150,881	$ 268,227	$ 98
VIB-VTA system	IA	4,000	1.5	2005	231	$ 29,411	$ 19,383	$ 36,963	$ 206,231	$ 322,217	$ 81
VIB-VTA system	IA	2,500	0.5	2005	318	$ 21,822	$ 26,712	$ 32,000	$ 115,658	$ 215,237	$ 86
Pump Sloped VTA	NE	1,200	4.5	2007	650	NA	$ 54,600	$ 15,493	$ 68,121	$ 150,686	$ 126

[1] Actual engineering design costs

[2] Normalized design cost based on $84 per hour

[3] Cost as provided for the year the system was built

[4] Total cost associated with normalized engineering rate; for comparison, all totals were converted to 2009 using the Producer Price Index

Table 5. Containment basin costs associated with three AFOs and one CAFO in 2009 inflation adjusted dollars

Containment Basin									
	Number		Engineering Costs		Construction	Irrigation Costs		Total Cost[3]	Dollars
Location	Of Head	Year	Hours	Normalized[1]	Cost[2]	Actual	New	2009 Dollars	Per Head
NE	800	2003	560	$ 47,040	$ 47,060	$ 55,000	$ 55,000	$ 202,413	$ 253
NE	900	2007	580	$ 48,720	$ 18,185	$ 9,800	$ 56,800	$ 134,867	$ 150
NE	800	2006	500	$ 42,000	$ 54,465	$ 25,600	$ 61,000	$ 171,642	$ 215
NE	2500	2007	560	$ 47,040	$ 99,880	$ 34,400	$ 106,160	$ 258,588	$ 103

The construction cost on a per head space of cattle basis decreased as the cattle numbers increased since the cost was spread over a larger cattle population. The general trend shown in this paper suggested an increase in animal numbers would produce a lower overall SSB cost per head space since the extra design regulations were already accounted for in the system.

Table 6. Estimated construction costs for a containment basin system consisting of a SSB, detention basin, and irrigation system adjusted for inflation in 2009 dollars.

Containment Basin Systems						
		750 Head		1500 Head		5000 Head
Engineering Costs	$	58,154	$	58,154	$	58,154
Construction Costs	$	52,339	$	104,677	$	348,924
Irrigation System	$	43,616	$	87,231	$	116,308
Total	**$**	**154,108**	**$**	**250,062**	**$**	**523,386**
$ per head	**$**	**205**	**$**	**167**	**$**	**105**

Source: Lawrence et al., 2006

Vegetative treatment systems designed for CAFOs cost less to construct per head space than a traditional containment basin. If all nine of the reported VTSs were averaged regardless of type, the total CAFO VTS cost was approximately $85 per head space. This value is considerably less than a containment basin constructed for a 1,500 to 5,000 head of cattle feedlot at $167 and $105 per head space respectively. AFOs show similar results with a total system average of $77 per head space (regardless of type) and an estimated 750 head containment system costing $205 per head space.

VTS Comparison to Confinement Buildings and Feedlot Systems

In order to compare the construction cost of VTSs with monoslope barns, open feedlots with containment basins, and hoop structures, a cost estimate needed to be added to the VTS to account for the area occupied by the cattle. This cost addition was necessary since monoslope and hoop structure facilities confined cattle in the same area as the solid manure. In order to get an estimate of the costs associated with the construction of a new earthen feedlot, the VTS cost per head space was added to the feedlot cost per head space from the ISU Beef Feedlot

Systems Manual adjusted for inflation to 2009 dollars. After adjusting for inflation, the cost of a 750 head open feedlot (earthen) without any manure management system was $208 per head space while the costs of a 1,500 and 5,000 head feedlot were $200 and $197 per head space, respectively (Table 7). The accuracy of this calculation is dependent upon how close the interested feedlot is to the number of cattle reported for each feedlot size in the Beef Feedlot Systems Manual. For instance, if the 720 head VTS sprinkler system costs $110 per head space, an additional feedlot cost of $208 per head space would yield a total system cost of $318 per head space.

Table 7. Earthen feedlot construction costs adjusted for inflation in 2009 dollars.

Earthen Lot With Windbreak						
Facilities and Equipment		750 Head		1500 Head		5000 Head
Building	$	-	$	-	$	-
Concrete	$	80,253	$	157,016	$	523,386
Feed Bunks	$	13,085	$	26,169	$	87,231
Fencing	$	43,616	$	78,508	$	247,155
Site Preparation	$	8,723	$	17,446	$	58,154
Windbreaks	$	10,468	$	20,935	$	69,785
Building engineering cost	$	-	$	-	$	-
Total System Cost	**$**	**156,144**	**$**	**300,075**	**$**	**985,711**
Total System Cost per head	**$**	**208**	**$**	**200**	**$**	**197**

Source: Lawrence et al., 2006

Based on economic analysis data from Lawrence (2006) that have been updated to 2009 inflation adjusted dollars, concrete monoslope facilities cost $662, $655, and $649 per head space for a 750, 1,500, and 5,000 head operations respectively (Table 8). Monoslope barns were the most expensive form of cattle feeding operations in both the AFO and CAFO categories. The total system cost for a CAFO was slightly lower than an AFO facility due to the cost being spread over a larger number of cattle.

Table 8. Concrete monoslope barn construction costs adjusted for inflation in 2009 dollars.

Monoslope Barn - Cattle						
Facilities and Equipment		750 Head		1500 Head		5000 Head
Building	$	261,693	$	523,386	$	1,744,621
Concrete	$	207,610	$	408,241	$	,349,173
Feed Bunks	$	13,085	$	26,169	$	87,231
Fencing	$	12,212	$	17,446	$	46,523
Site Preparation	$	1,745	$	3,308	$	11,631
Windbreaks	$	-	$	-	$	-
Building engineering cost	$	-	$	3,489	$	3,489
Total System Cost	**$**	**496,345**	**$**	**982,040**	**$**	**3,242,668**
Total System Cost per head	**$**	**662**	**$**	**655**	**$**	**649**

Source: Lawrence et al., 2006

Beef hoop structures cost approximately $395 per head space in inflation adjusted 2009 dollars based on assumptions for a hoop structure as described in the system descriptions (Honeyman et al., 2008). The cost estimate reported above assumes flooring constructed primarily of limestone screenings with a small concrete pad located in front of the feed bunk and a manure scrape alley extending the length of the barn. This system was designed for approximately 4.6 square meters (50 square feet) of floor space per head (Honeyman et al., 2008).

Even though monoslope barns and hoop structures may initially cost more per head space to construct than open feedlots, advantages of confined cattle facilities were reported in research studies over open feedlots. Research has shown cattle performance may increase under confinement conditions compared to open feedlots. Lawrence et al. (2006) reported that beef confinement facilities reduced feed consumption and were more efficient with the feed consumed per pound of weight gained. Open feedlots constructed with a shelter also improved cattle efficacy (Lawrence et al., 2006). Similar results were shown by Mader, 2003. Another advantage of a complete confinement system is the ability to reduce or potentially eliminate feedlot runoff. Reducing or eliminating feedlot runoff could be an important factor influencing producers to construct these facilities.

Conclusion

The animal feeding operation vegetative treatment system (VTS) with the lowest cost per head space to construct was a sloped or a sloped and level VTA ($50 per head space average.) followed by the sprinkler VTS ($94 per head space average.) and the pump sloped VTA ($101 per head space average.). The major factors affecting the overall price of these systems was dependent upon the amount of earthwork, type of pump and sprinkler system, and pumping distance from the SSB to the VTA. Systems which use gravity to transport effluent through the VTS are generally lower cost to construct per head space. Within each category, the lowest system cost per head space corresponded with the largest animal numbers, but the highest cost was not necessarily associated with the smallest number of animals.

The least expensive VTS design for a CAFO facility was a sloped or sloped and level VTA ($79 per head space average.) followed by a VIB-VTA system ($83 per head space average.) The four dollar per head increase for a VIB-VTA compared to a sloped and level system was primarily due to the addition of a pump and the design/construction costs associated with an extra basin (VIB).

Vegetative treatment systems designed for CAFOs cost on average $85 per head space (averaged regardless of type) and range from $45 to $126 per head space depending on the type of VTS system while the estimated cost of a containment basin was $105 to $167 per head space depending on the number of animals. The average cost of a VTS system designed for an AFO facility was $77 per head space (averaged regardless of type) ranging from $25 to $173 per head space while an estimated containment system for a 750 head facility would cost $205 per head space. In both cases the VTS was the lowest cost option compared to a containment system.

Monoslope barns were reported to be approximately $662 per head space for a 750 head AFO and $655 per head space for a 1,500 head CAFO facility (Lawrence et al., 2006) and were the most expensive system to construct for a beef manure system. Hoop structures were the next highest cost per head space and could be built for approximately $395 per head space (Honeyman et al., 2008). The average cost of an earthen lot with a containment basin was $361 per head space while a feedlot implemented with a VTS would cost approximately $282 per head space on average. Although monoslope barns and hoop structures were more expensive to construct per head, these systems handle only solid manure and are not required to handle feedlot runoff since the cattle are confined indoors.

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CHAPTER 3. EVALUATING THE ANNUILIZED VEGETATIVE TREATEMENT SYSTEM COST

Introduction

Chapter two reported the actual construction and engineering design cost associated with implementing a VTS onto a pre-existing feedlot. While this initial cost analysis is important to feedlot producers, another important analysis is the annualized cost of these systems over the expected life span of the VTS. This annualized cost takes into account the value of land for the VTS area taken out of production along with spreading the construction and engineering design cost over the expected life of the system. The annualized VTS cost was then compared to the estimated annualized containment basin cost designed to stored effluent for each of the nine site specific CAFOs reported in chapter two. Comparisons are provided between VTS types on an annualized dollar per kilogram of pollutant removed from the VTS and annualized dollars per head space. Comparisons between VTSs and containment basins are provided on an annualized cost per cattle head space.

Methods

The annualize cost for the 23 VTSs located in Iowa, South Dakota, Nebraska, and Minnesota was calculated for each system excluding operation and maintenance cost. This annualized cost included the value of purchasing the land required to cover the VTS footprint. The oportunity cost of removing the land associated with the VTS footprint from crop production was assumed to be reflected by the value of the land per acre (i.e., land with higher yields and crop productivity will be worth more money per acre, therefore the value of land per acre incorporates the productivity of the land). Land values for the farm locations in Iowa, Nebraska, South Dakota, and Minnesota were collected from the Ag. Decsion Maker Farmland Value Survey, Conrnhusker Economics, Minnesota Land Economics, and South Dakota Farm Realestate Market Survey report in 2009 (for complete citation see Table 10). A long term design interest rate of 5 percent was used along with the annualized cost Equation 1 (Qiu, 2003) where r is the interest rate, I is the installation VTS cost (including land value), n represents the life expectancy of the system in years. An estimated VTS life expectancy of 10 years was assumed in this analysis. As mentioned previously, operation and maintenance costs were not included within this analsis due to the unavialablity of the data for each of the 23 VTSs.

Equation 1. Annualized vegetative treatment system cost equation

$$Annualized\ \cos t = \frac{rI}{1-(1+r)^{-n}}$$

Results

VTS Annualized Cost per Head Space of Cattle

The annualized VTS cost is shown in Table 9 and Table 10 for 14 AFO and nine CAFO sites. Since many Midwestern feedlots produce two turns of cattle a year, the annualized cost is shown on a per head space of cattle basis for both one and two turns of cattle. The annualized cost for two turns of cattle was calculated by dividing one turn of cattle by two turns. The following discussion is based on the cost associated with one turn of catte. Results indicated the annualized AFO cost ranged from approximately $5 per head space per year to $24 per head space per year. The South Dakota site with the $24 per head space had a larger engineering design cost compared to the other 13 sites, which in turn, created a larger annulaized cost. The slope or sloped and level VTA had the lowest average annualized cost per head at $10 per head space followed by the sprinkler VTS at $14 per head space and lastly the pump slope system at $15 per head space. The annualized cost for the CAFO VTSs displayed similar values as the AFO sites ranging from a low of $8 per head space to a high of $18 per head space. The CAFO slope or sloped and level VTA cost on average $13 per head space followed by a VIB-VTA system at $11 per head space and lastly a pump slope system at $18 per head space. Based solely on averages, the annualized cost of constructing a VTS on a CAFO was less expensive than a AFO facility. The overal combined average annual cost for an AFO and CAFO slope or sloped and level VTAs was approximately $11 per head space while the overal average cost for an AFO and CAFO pump sloped VTA was $16 per head space. Note that the operation and maintenance costs were not included within this analysis. Therefore the overal annualized cost for a sprinkler, pump slope, and VIB-VTA system may be larger than the values presented in this analysis when additional operation and maintenance cost are considered.

VTS Annualized Cost per Kilogram of Pollutant Removed

The anualized dollars per kilogram of pollutant removed for the 2009 monitoring season is displayed in Table 11 for the nine monitored CAFO VTSs. Since the mass of the five potential pollutants released from the 14 AFOs were not available for this analysis, the dollars per kg of pollutant removal could only be calculated for the nine CAFO VTSs. Results showed totals solids (TS) removed from CAFO VTSs during the 2009 monitoring season were on average the least expensive potential pollutant to remove at $1.29 per kilogram of TS followed by chemical oxygen demand (COD) ($1.60 per kg of COD), total Kjeldahl nitroten (TKN) ($27 per kg of TKN), ammonia nitrogen (NH_3-N) ($72 per kg of NH_3-N), and total phosphorus (TP) ($85 per kg of TP). On a whole system basis (i.e., average cost of pollutant removed for all five parameters), Southwest IA 1 and Northwest IA 2 produced the lowest dollars per kilogram of pollutant removed. This indicates these two systems removed the most mass of nutrients per annualized dollar of total system cost. The cost of pollutant removal is related to the mass released to the VTA (Figure 8). A linear relationship is shown in Figure 8 as the mass released from the SSB increases, the mass removed per dollar also increases. Therefore sites that release more mass from the SSB will remove more potential pollutant mass per annualized dollar spent on the VTS excluding the operation and maintenance cost.

Table 9. Annualized cost for 14 vegetative treatment systems constructed on animal feeding operations

VTS Type	Location	Number Of Head	Feedlot Size, acre	VTA Area Acres	Total System[1] Cost, Dollars	Annualized Cost, Dollars	Annualized Cost, $/head space	
							1 Turn Per Year	2 Turns Per Year
Sloped or sloped and level VTA	NE	359	NA	3.7	$ 18,877	$ 2,445	$ 6.81	$ 3.40
Sloped or sloped and level VTA	NE	290	1.8	2.5	$ 20,007	$ 2,591	$ 8.93	$ 4.47
Sloped or sloped and level VTA	NE	700	7.1	7.1	$ 27,868	$ 3,609	$ 5.16	$ 2.58
Sloped or sloped and level VTA	NE	450	2.8	3	$ 22,416	$ 2,903	$ 6.45	$ 3.23
Sloped or sloped and level VTA	NE	120	0.47	0.57	$ 8,821	$ 1,142	$ 9.52	$ 4.76
Sloped or sloped and level VTA	SD	450	17.9	25.3	$ 73,213	$ 9,481	$ 21.07	$ 10.53
Pump sloped VTA	NE	285	2.5	5	$ 37,940	$ 4,913	$ 17.24	$ 8.62
Pump sloped VTA	NE	780	6.7	5	$ 42,875	$ 5,553	$ 7.12	$ 3.56
Pump sloped VTA	SD	300	3.04	2.96	$ 56,557	$ 7,324	$ 24.41	$ 12.21
Pump sloped VTA	SD	665	14.75	9.35	$ 66,207	$ 8,574	$ 12.89	$ 6.45
Sprinkler VTS	NE	210	2.3	2.3	$ 24,104	$ 3,122	$ 14.86	$ 7.43
Sprinkler VTS	NE	800	6.4	7.4	$ 64,194	$ 8,313	$ 10.39	$ 5.20
Sprinkler VTS	NE	450	2.8	4.6	$ 51,428	$ 6,660	$ 14.80	$ 7.40
Sprinkler VTS	NE	720	5.7	8.5	$ 91,291	$ 11,823	$ 16.42	$ 8.21

[1] Includes construction, engineering, and land value costs reported in 2009 dollars

[2] 1 turn indicates one group of cattle feed per year, 2 turns inidcates two groups of cattle feed per year

Land Value Sources:

Ag. Decision Maker, Iowa State University Extension, 2009
www.extension.iastate.edu/agdm
Cornhusker Economics, University of Nebraska-Lincoln Extension, 2009
http://www.agecon.unl.edu/Cornhuskereconomics/2009cornhusker/3-25-09.pdf
Minnesota Land Economics, University of Minnesota, 2009
http://www.landeconomics.umn.edu/MLE/landdata/LandValue/Statistics.aspx?RI=604945
South Dakota Farm Real Estate Market Survey, SDSU, 2009 and earlier
http://sdces.sdstate.edu/Brown/FarmlandMarketTrends.pdf

Table 10. Annualized cost for nine vegetative treatment systems constructed on concentrated animal feeding operations

	CAFO > 1,000 Head of Cattle								
			Head	Feedlot	VTA Area	Total System[1]	Annualized	Annualized Cost, $/head space	
Site	VTS Type	Location	Of Cattle	Area, Acre	Acres	Cost, Dollars	Cost, Dollars	1 Turn Per Year	2 Turns Per Year
Central IA 1	Sloped or sloped and level VTA	IA	1500	7.6	5.29	$ 121,914	$ 15,788	$ 10.53	$ 5.26
Northwest IA 1	Sloped or sloped and level VTA	IA	3400	22.05	13.4	$ 350,005	$ 45,327	$ 13.33	$ 6.67
Southwest IA 1	Sloped or sloped and level VTA	IA	2300	18.46	10	$ 142,037	$ 18,394	$ 8.00	$ 4.00
Southwest IA 2	Sloped or sloped and level VTA	IA	5500	48.6	45.36	$ 575,785	$ 74,567	$ 13.56	$ 6.78
Southeast SD 1	Sloped or sloped and level VTA	SD	2000	16.2	15.8	$ 257,724	$ 33,376	$ 16.69	$ 8.34
Western MN 1	Sloped or sloped and level VTA	MN	2750	8.8	11.32	$ 297,693	$ 38,553	$ 14.02	$ 7.01
Northwest IA 2	VIB-VTA system	IA	4000	7.3	3.8	$ 344,339	$ 44,594	$ 11.15	$ 5.57
Central IA 2	VIB-VTA system	IA	2500	8.05	1.19	$ 221,341	$ 28,665	$ 11.47	$ 5.73
Central NE 1	Pump Sloped VTA	NE	1200	11.4	11	$ 168,407	$ 21,809	$ 18.17	$ 9.09

[1] Includes construction, engineering, and land value costs reported in 2009 dollars

[2] 1 turn indicates one group of cattle feed per year, 2 turns inidcates two groups of cattle feed per year

Land Value Sources:

Ag. Decision Maker, Iowa State University Extension, 2009

www.extension.iastate.edu/agdm

Cornhusker Economics, University of Nebraska-Lincoln Extension, 2009

http://www.agecon.unl.edu/Cornhuskereconomics/2009cornhusker/3-25-09.pdf

Minnesota Land Economics, University of Minnesota, 2009

http://www.landeconomics.umn.edu/MLE/landdata/LandValue/Statistics.aspx?RI=604945

South Dakota Farm Real Estate Market Survey, SDSU, 2009 and earlier

http://sdces.sdstate.edu/Brown/FarmlandMarketTrends.pdf

Table 11. Annualized dollars per kilogram of pollutant removed for nine CAFO vegetative treatment systems

	CAFO > 1,000 Head of Cattle	Mass Removed by VTS					Annualized Dollars Per Kilogram of Pollutant Removed[1]				
		NH_3-N	COD	Total P	TKN	TS	NH_3-N	COD	Total P	TKN	TS
Site	VTS Type	kg	kg	kg	kg	kg	$/kg	$/kg	$/kg	$/kg	$/kg
Central IA 1	Sloped or sloped and level VTA	290	20,195	362	913	22,605	$ 54.38	$ 0.78	$ 43.56	$ 17.30	$ 0.70
Northwest IA 1	Sloped or sloped and level VTA	1,223	35,520	530	2,437	56,200	$ 37.08	$ 1.28	$ 85.52	$ 18.60	$ 0.81
Southwest IA 1	Sloped or sloped and level VTA	1,190	33,494	864	2,403	68,792	$ 15.46	$ 0.55	$ 21.29	$ 7.65	$ 0.27
Southwest IA 2	Sloped or sloped and level VTA	838	40,655	703	2,159	73,539	$ 88.97	$ 1.83	$ 106.09	$ 34.53	$ 1.01
Southeast SD 1	Sloped or sloped and level VTA	---	---	---	---	---	---	---	---	---	---
Western MN 1	Sloped or sloped and level VTA	353	19,810	259	1,114	20,275	$ 109.21	$ 1.95	$ 148.85	$ 34.61	$ 1.90
Northwest IA 2	VIB-VTA system	3,195	220,635	1,541	9,514	237,180	$ 13.96	$ 0.20	$ 28.94	$ 4.69	$ 0.19
Central IA 2	VIB-VTA system	126	6,096	149	356	6,445	$ 227.08	$ 4.70	$ 192.44	$ 80.51	$ 4.45
Central NE 1	Pump Sloped VTA	672	14,214	396	1,235	22,666	$ 32.45	$ 1.53	$ 55.07	$ 17.66	$ 0.96
						Average	$ 72.32	$ 1.60	$ 85.22	$ 26.94	$ 1.29

[1] Annualized cost does not include operational and maintenance cost
---No Data Available

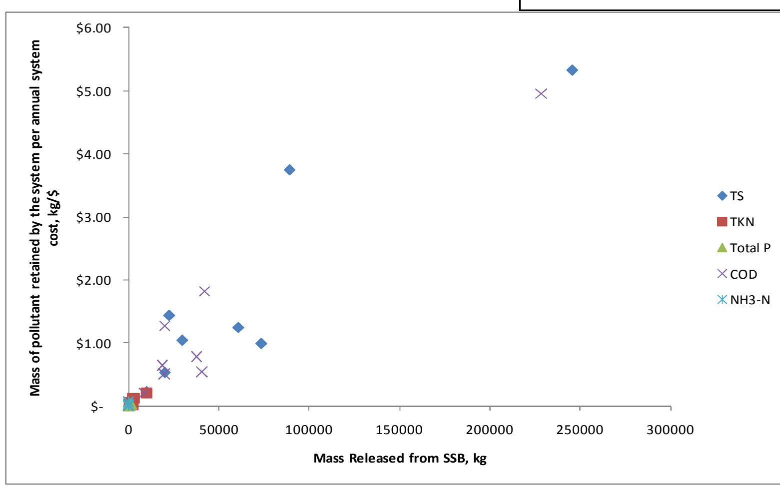

Figure 8. Mass of pollutant retained by the vegetative treatment system per annualize system cost

Containment Basin Estimated Annualized Cost per Head Space of Cattle

The estimated annualized cost of a conventional containment basin designed for each of the nine CAFO feedlots was also calculated and compared with the actual annualized VTS cost. The containment basins were designed using the Natural Resources Conservation Service Animal Waste Management program Version 2.30 (NRCS, 2007) for the design and sizing of each basin. Each basin design used preloaded weather files specific for the location of the basin (i.e., the location of the basin was the same location as the corresponding VTS). Since the footprint area of the basin was the main focus of designing these basins, the following design assumptions were used for all nine basin design: basin depth designed at 10 feet, side slopes were 2:1, and effluent was applied twice a year in April/May and October/November. The containment basin construction cost was estimated using the per head values reported by Lawrence et al. (2006) and adjusted to 2009 dollars. The life expectancy of the containment basin was estimated at 25 years (Lawrence et al., 2006) and the irrigation application equipment life expectancy was estimated at 10 years (Wichelns, 1996) with a 5 percent design interest rate.

The actual VTS area at each of the nine CAFOs was compared to the estimated design area for a containment basin located at the same location. This analysis is shown in Table 12. Results show the area of a VTS is 3.9 times larger than a conventional containment basin for all VTSs except for a VIB-VTA system which is on average 0.67 of the size.

Table 12. Annualized containment basin cost for nine feedlots located in Iowa, Minnesota, South Dakota, and Nebraska

Site	VTS Type	Head Of Cattle	Feedlot Area, Acre	VTA Area Acres	AWM Program Basin Area Acres	Total Annualized[1] Cost	Annualized Cost, $/head space	
							1 Turn Per Year	2 Turns Per Year
Central IA 1	Sloped or sloped and level VTA	1,500	7.6	5.29	2.02	$ 16,053	10.70	5.35
Northwest IA 1	Sloped or sloped and level VTA	3,400	22.05	13.4	4.66	$ 36,435	10.72	5.36
Southwest IA 1	Sloped or sloped and level VTA	2,300	18.46	10	4.51	$ 24,843	10.80	5.40
Southwest IA 2	Sloped or sloped and level VTA	5,500	48.6	45.36	11.50	$ 59,605	10.84	5.42
Southeast SD 1	Sloped or sloped and level VTA	2,000	16.2	15.8	2.83	$ 20,517	10.26	5.13
Western MN 1	Sloped or sloped and level VTA	2,750	8.8	11.32	2.46	$ 28,211	10.26	5.13
Northwest IA 2	VIB-VTA system	4,000	7.3	3.8	4.18	$ 42,430	10.61	5.30
Central IA 2	VIB-VTA system	2,500	8.05	1.19	2.77	$ 26,515	10.61	5.30
Central NE 1	Pump Sloped VTA	1,200	11.4	11	1.95	$ 12,310	10.26	5.13
						Average	10.56	5.28

[1] Includes construction, engineering, and land value costs reported in 2009 dollars
Analysis does not include operational and maintenance cost

The basin surface area does however, directly depend on the design depth and side slope of the containment basin walls. Depending on the design depth or side slope, the basin surface area could be modified in such a way to minimize or maximize the total footprint (surface area) of the basin. Therefore, the results of the analysis provided above may or may not be correct depending on specific site criteria or design standards.

The results from the annualized cost of a containment basin showed the estimated annualized system cost (excluding operation and maintenance cost) for a containment basin with a 25 year life expectancy averaged $11 per head space for one turn of beef cattle per year. This estimated annualized cost was less than the average annualized cost for a VTS ($13 per head) with a life expectancy of 10 years. The annualized system cost greatly depends on the estimated life expectancy of both systems; therefore a more accurate estimate of the life of a VTS is needed to provide a closing economic conclusion between the two systems. This analysis did, however, provide insight on how long the VTS life expectancy needs to be to provide an economical advantage over a containment basin with a 25 year life expectancy. A VTS life expectancy greater than 14 years is needed to create an annualized system cost less than $11 per head space (Figure 9). A more accurate estimate of the VTS life expectancy and operation and maintenance costs are needed to provide an economical conclusion between these two systems.

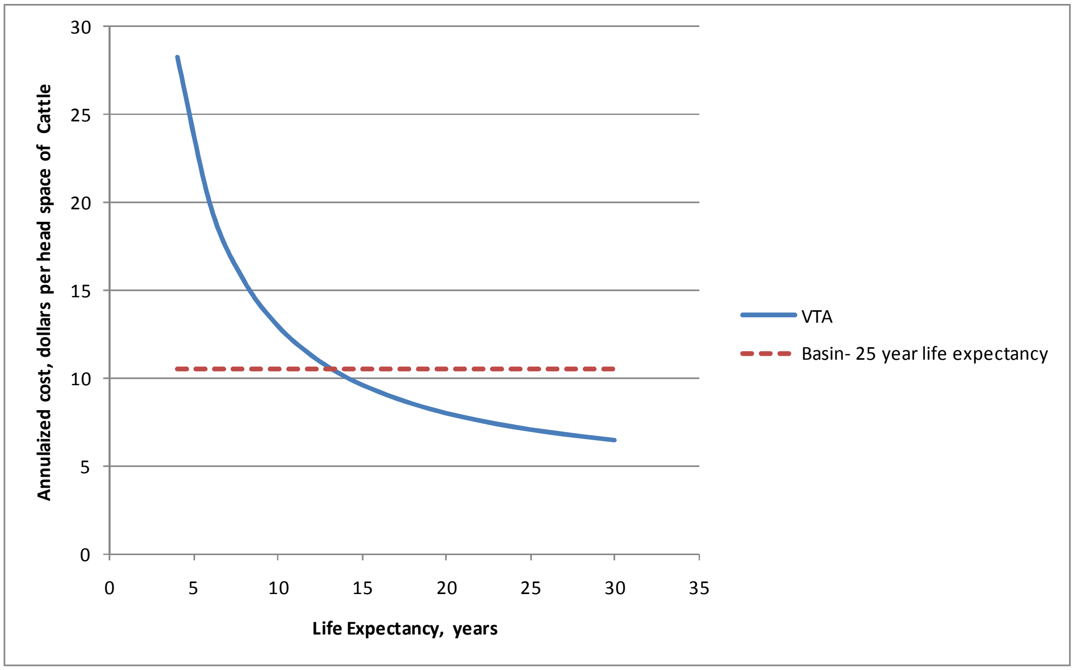

Figure 9. Vegetative treatment system life expectancy compared to containment basin with a 25 year life expectancy.

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CHAPTER 4. EVALUATING THE PERFORMANCE OF VEGETATIVE TREATMENT SYSTEMS ON OPEN BEEF FEEDLOTS IN THE MIDWESTERN UNITED STATES

To be submitted to Transactions of *ASABE* for publication

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Abstract

United States Environmental Protection Agency (US EPA) regulations require concentrated animal feeding operations (CAFOs) to control open feedlot runoff resulting from storms up to and including a 25 year-24 hour storm event. Runoff collection systems commonly used in the United States for open beef feedlots consists of a basin designed to intercept runoff and provide storage until field conditions exist for land application. An alternative system evaluated by a three-state research team is a vegetated treatment system (VTS) designed to infiltrate all of the feedlot runoff. This paper reports the runoff volumes, concentration, and the mass of five physical parameters released from nine CAFO's utilizing VTS's located in the Midwestern United States (six sites in Iowa, two in Nebraska, one in Minnesota). Comparisons between sites were made based on the volume, concentration, and mass of these parameters retained within the system. The performances of the nine VTSs varied depending on site specific rainfall, stocking densities, feedlot to VTA ratio, and system design. Five of the nine VTAs monitored in 2009 did not report an actual release from their system. The percent runoff controlled varied by site ranging from a low of -6 percent to a high of 100 percent. The overall average percent of mass reduced from five tested parameters varied from 72 to 100 percent.

Introduction

Animal feeding operations (AFOs) with greater than 1,000 head of cattle are required by the United States Environmental Protection Agency (US EPA) to contain the runoff produced from storms up to and including a 25 year, 24 hour storm event (US EPA, 2008). AFOs are defined by the US EPA as animals confined on a lot or a facility containing no vegetation for at least 45 days per year. Based on the regulatory definition, a beef AFO is defined as a large concentrated animal feeding operation (CAFO) when the facility contains greater than 1,000 head of beef cattle. Historically, the only runoff control option available for large CAFOs consisted of a containment basin designed to collect and store feedlot runoff. In 2003, the US EPA revised the CAFO rules allowing the use of alternative technologies that meet or exceed the performance of traditional containment basins. One alternative technology of interest for producers and researchers is vegetative treatment systems (VTS). The majority of the previous research on these vegetative systems were performed on animal feeding operations smaller than 1,000 head since federal regulations did not recognize these systems for use on CAFOs until 2003 (Koelsch et al., 2006). Khanijo et al. (2008) and Andersen et al. (2009) have reported monitoring and performance data from six VTSs in Iowa designed to control and treat runoff from large beef CAFOs. Additional research is needed to test and confirm the performance of these systems in the Midwestern United States.

The 2006 to 2008 VTS performance data for six large CAFO facilities located in Iowa was reported by Andersen et al. (2009). In 2009, an additional year of monitoring was performed at these same six sites located in Iowa with three additional sites located in Minnesota and Nebraska. This paper evaluates the 2009 VTS performance data for nine sites located in the Midwestern United States. The nine locations represented various configurations of vegetative treatment systems, weather conditions, and geographical characteristics.

Materials and Methods

The nine VTSs analyzed were constructed on animal feeding operations containing greater than 1,000 head of beef cattle. All of the feedlots reported in this paper were permitted under National Pollution Discharge Elimination System (NPDES) permits and complied with state and federal regulations during the time of construction. The location of each feedlot reported within this paper is displayed in Figure 10.

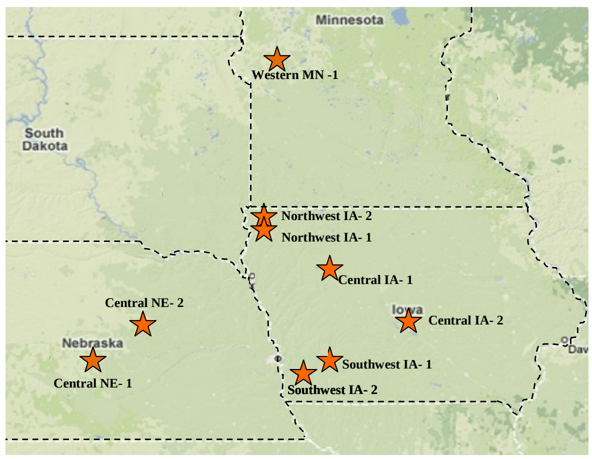

Figure 10. Nine VTSs monitored on large CAFOs in the Midwest.

Various combinations of VTS designs were located on the nine feedlots reported within this paper. Typical VTS designs have consisted of the following components: a solid settling basin (SSB), optional vegetative infiltration basin (VIB), and a vegetative treatment area (VTA). The designs varied from site to site depending on topography, land availability, and feedlot management considerations. Examples of various VTSs include but are not limited to sloped or sloped and level VTAs and pump sloped VTAs; descriptions for the VTS alternatives are provided in Bond et al. (2009). Some of the CAFOs reported within this paper contained multiple VTSs while others utilized only one VTS for the entire feedlot. Sites containing multiple VTSs and outlets typically contained one intensively monitored system for research data collection. Only the performance data collected from these research systems was reported within this paper. The individual research VTS information is provided in Table 13.

Table 13. 2009 CAFO research VTS information by site

2009 Research VTS Information

Parameter	Central IA 1	Central IA 2	Northwest IA 1	Northwest IA 2	Southwest IA 1	Southwest IA 2	Western MN 1	Central NE 1	Central NE 2
Capacity, head	1,000	650*	1,400	4,000	2,300	1,200	1,750	1,200	1,700
Feedlot Area, ha	3.09	1.07	2.91	2.96	7.49	3.72	3.56	4.8	4.76
Feedlot Surface	Earthen	Earthen	Earthen	Concrete	Earthen	Earthen	Earthen	Earthen	Earthen
Stocking Density‡	31	16	21	7.4	33	31	20	40	28
Feedlot Slope, %	2.3	0.6	4.0	3.0	7.5	8.6	4.0	2.5	0.2
SSB Volume, m^3	4,289	51	3,710	110	11,550	6,275	807	5,029	NA†
VIB Area, ha	-	0.32	-	1.01	-	-	-	-	-
VTA Area, ha	1.53	0.24	1.68	0.91	4.0	3.46	3.524	4.45	3.8
VTA Length, m	313.9	76.2	478.5	109.7	121.9	298.7	91.4	243.8	365.8
VTA Width, m	48.7	31.7	35.1	54.9	329.2	115.8	385.6	19.5	142.3
Feedlot:VTA ratio	2 : 1	1.9 : 1	1.5 : 1	1.8 : 1	1.9 : 1	1.1 : 1	1 : 1	1.1 : 1	1.3 : 1

* Old permit was 800 Head

† This site utilizes a settling bench

‡ m^2 per head

The data reported in this paper represents the flow volume, concentration, and mass of five monitored parameters leaving each VTS component for the 2009 monitoring season. The 2009 monitoring season was site specific and depended on location and local weather conditions. The season typically began mid March and extended through the middle of November. Runoff samples were collected from either an automated sampler or by collecting grab samples during site visits. These samples were collected after each component of the VTS (i.e. SSB, VIB and VTA).

To compare the flow volumes and mass of each monitored parameter released from each VTS component across the nine sites, the data was normalized to account for variability in feedlot size (i.e. head space of cattle, feedlot area) and annual precipitation. Therefore, the flow volumes (m^3) and mass release data (kg) were reported two ways, on the basis of 100 head space of cattle per cm of annual rainfall and on the basis of feedlot area (hectare) per cm of annual rainfall. Some systems contained a monitored VTA outlet while others contained a level VTA or an earthen berm to minimize the chance of a release event from the system but not to a stream. For the purpose of this paper, a release from the VTA implies effluent leaving the system (i.e., ponding behind the berm and recycling events do not count toward an actual release). Effluent volume and mass data calculated during VTA recycling events were reported within this paper but were noted as not leaving the system.

The concentration data represented effluent samples collected from the SSB and VTA outlet during the 2009 monitoring season. Samples were collected during each release event and shipped overnight on ice to a testing laboratory. The laboratory analyzed each sample for total Kjeldahl nitrogen (TKN), ammonia (NH_3-N), total phosphorus (TP), chemical oxygen demand (COD), and total solids (TS). Effluent samples were reported for two sites utilizing an effluent recycle pipe. These samples represent effluent measured at the end of the VTS and do not leave the system.

Statistical analysis software, SAS 9.2, was used to analyze the concentration data collected from each site. An analysis of variance (ANOVA) procedure was used within SAS to compare the means of each site for the five tested parameters. The concentration data did not follow a normal distribution which violated the normal distribution assumption of an ANOVA procedure. Therefore, a log transformation was performed for each concentration sample to attain a normal distribution for each of the five parameters tested. An alpha value of 0.05 was used to determine significant differences between each site. Statistical analysis could not be performed on annual flow volume or mass data since this paper reports only one year of data.

Site Descriptions

Site descriptions of the nine VTSs reported within this paper are provided in the following paragraphs. A complete description of the six VTSs located in Iowa along with the monitoring protocols implemented from 2006 to 2008 was reported by Andersen et al. (2009). The Iowa site descriptions reported below provide a brief summary of the system including any site modifications made during the 2009 monitoring season.

Central Iowa 1

The VTS research portion consisted of one SSB and two VTAs to handle and treat runoff from 3.09 ha of earthen feedlot area. Earthen berms located around the feedlot conveyed effluent into the SSB where solids were allowed to settle out of suspension. The SSB outlet control structure consisted of a V-notch weir and a knife-gate allowing the producer to control the rate and amount of effluent applied to the VTA (Andersen et. al., 2009). Two pipes located in the outlet structure divided the effluent stream to produce similar effluent VTA loadings delivered to each of the VTAs. Concrete spreaders were used at the top of the VTA to evenly distribute effluent across the VTA inlet. Three earthen spreaders were constructed across each VTA to slow down the flow and redistribute the effluent across the VTA (Andersen et. al., 2009). Automated monitoring equipment located at the VTA H-flume outlet was used to measure flow and to sample release events leaving the system. A release from the system does not imply a direct release to surface waters of the state.

Central Iowa 2

The research portion of the VTS consisted of one SSB, one VIB, and one VTA. The SSB at this site utilized a porous dam constructed with round bales of hay to slow the feedlot runoff and filter the effluent reducing the amount of solids traveling through the SSB (Andersen et. al., 2009). A manually operated gate valve was used to release effluent from the SSB to the VIB. A network of independent tile drainage pipes was installed beneath the VIB soil to encourage drainage through the soil profile. The tile lines transported the infiltrated effluent to a sump, and a pump was then used to apply the effluent to a VTA through gated pipe. VTA releases were monitored using automated sampling equipment and an H-flume. A release from the system does not imply a direct release to surface waters of the state.

Northwest Iowa 1

The research portion of the VTS consisted of one SSB releasing effluent onto one VTA. Concrete spreaders were used to evenly apply effluent across the top of the VTA. Monitoring equipment was installed at the SSB and VTA outlet to measure and sample flow leaving each component. An earthen berm was constructed before the VTA outlet during June of 2009 to minimize releases resulting from direct rainfall onto the VTA. The berm was approximately 0.3 meters (12 inches) tall and contained two separate effluent outflow pipes to safely release ponded effluent located within the VTA (Figure 11a). The first pipe contained a gate valve allowing the producer to control the amount of runoff ponded in the bottom of the VTA to minimize vegetation stress from saturated soil conditions. The second pipe served as an emergency overflow system to safely remove effluent in the case of a large ponding event. Runoff released from either of these pipes did not necessarily mean a release to surface waters. Effluent from this VTA received further vegetative treatment before leaving the system through a monitored H-flume outlet.

Northwest Iowa 2

The VTS research portion at this site consisted of one SSB, one VIB, and two VTAs. The feedlot surface at this site was concrete. Effluent collected in the SSB where solids were allowed to settle. PVC stop logs were installed at the SSB outlet to provide flow control for the effluent released into the VIB. The flow leaving the SSB was measured in an H-flume. The effluent then entered a VIB where a grid of drainage tile pipes collected infiltrated effluent and conveyed it into a sump. A pump was used to transfer the effluent to a gated pipe at the top of the VTAs. In 2009, an additional VTA was constructed increasing, the VTA total to three. The new VTA was constructed to provide a larger application area to treat feedlot runoff. The additional VTA was constructed to the east of the original VTAs and utilized the same effluent application system as the original two VTAs. The total VTA plus VIB area increased from 1.61 to 1.91 hectares and changed the feedlot to VTA ratio from 1.84:1 to 1.5:1. The new VTA became fully operational and began accepting effluent from the VIB in August 2009. The SSB outlet structure was also modified in 2009 to utilize an organic filter to provide further effluent treatment before entering the VIB. The filter design consisted of a 6.1 by 9.1 meter (20 by 30 foot) concrete structure (Figure 11b) with a sloped entrance ramp for solids and filter removal. Two steel fabricated fences extended across the structure to confine the filter material and to keep it from floating away with the effluent. After the filter was operational, square wooden posts were bolted together and placed on top of the filter material to compact the material and help keep it in place. The producer has experimented with various filter materials, including corn cobs and soy bean stover.

Southwest Iowa 1

Ten VTAs and one SSB provided runoff control and treatment for 7.49 ha of feedlot area. Earthen berms constructed around the feedlot conveyed runoff into the SSB where solids were allowed to settle out of suspension. A butterfly valve released effluent from the SSB into a system of gated pipe extending across the top of all ten VTAs. In 2009, two additional VTAs were constructed to provide additional application area to treat effluent. These new VTAs were located to the west of the original system. However, to establish vegetation, they were nonoperational during the 2009 monitoring season.

Figure 11a. Northwest IA 1 constructed an earthen berm located in front of the VTA outlet.

Figure 11b. Northwest Iowa 2 SSB filter design

Southwest Iowa 2

The research portion of the VTS consisted of one SSB and one VTA. During a rainfall event, effluent from the feedlot was collected in the SSB and was then applied to a VTA through gated pipe. A knife-valve was used to control the effluent leaving the SSB. The management practices in 2009 were modified to include closing a gate valve located at the VTA outlet. During the 2006 to 2008 monitoring seasons, this valve was left open allowing a release to occur from the VTA. The entire 2009 monitoring period was operated with the valve closed. This modification was instrumented to retain direct rainfall runoff within the system especially during larger rainfall events.

Western Minnesota 1

The research VTS consisted of a 3.56 hectare feedlot permitted for 1,750 head of beef cattle. Runoff from the feedlot’s 7 pens was drained into three concrete settling basins located on the east side of the pens (Ostrem, et al., 2009). The release structure at each basin consisted of a boarded gate operated manually by the producer. The boarded gate was used to release effluent into an H-flume where an automated sampler was used to collect samples and record flow leaving the basin. If research personal were present during a release, grab samples were collected from the H-flume. Effluent from the H-flume entered concrete spreaders extending the entire length of each basin. The spreaders evenly applied effluent across the top of the VTA. An earthen berm surrounded the VTA to contain any effluent reaching the end of the system.

Central Nebraska 1

This site contained an earthen feedlot permitted for 1,200 head of beef cattle. During a precipitation event, feedlot runoff collected within four SSBs located within the feedlot. An underground pipe network connected all four SSBs and gravity conveyed the effluent from the three upper SSBs into the fourth, lower SSB. During VTA application events, the producer released effluent from the fourth SSB into a concrete sump. A pump transported the effluent through an underground pipe to the top of the VTA where it was applied to one of eight VTA distribution areas. The applied effluent then traveled down the VTA and was allowed to infiltrate into the soil profile where vegetation utilized the nutrients contained within the effluent. An earthen berm located at the bottom of the VTA caught excess runoff which was then conveyed along a vegetated channel to a collection pipe where effluent was recycled back to the pumping station to create a closed system. Samples and flow measurements were collected by two automated samplers stationed in the sump and runoff return line. Effluent at this site was applied to the VTA until runoff was produced through the VTA return line. Therefore a VTA release was recorded for each application event.

Central Nebraska 2

This site maintained one VTA (3.8 hectares) centrally located between two feedlot pens containing a combined 3,000 head of beef cattle. This site utilized settling benches instead of settling basins to settle solids. A settling bench consisted of a level area located below a feedlot designed to reduce the velocity of the runoff leaving the feedlot allowing solids to settle out of suspension. The settling bench located at this site extended the entire length of the feedlot and was designed to have even flow across the entire bench. Since the feedlot runoff did not converge to a common point before entering the VTA, difficulties with monitoring and sampling this runoff were experienced. An automated sampler located at the VTA outlet pipe was used to collect runoff samples leaving the system.

Results and Discussion

Flow Volume Controlled

The total number of 2009 release events recorded leaving the SSB and VTA are shown in Table 14 while the total volume of effluent released from each component is shown in Table 15. Monitored release events from the SSB ranged from a high of 45 events (Northwest IA 1) to a low of 18 events (Western MN1). The site with the least amount of rainfall had the least total number of SSB release events while the site with the largest total rainfall did not necessarily result in the largest number of release events. Three sites did not record a release from the VTA while release events from the other six sites ranged from a low of 11 (Central NE 2) events to a high of 38 events (Central NE 1). Reasons for such a large number of release events at Central NE 1 were due to the recycling effluent management practices implemented at this site. Under this management system, effluent was applied to the VTA until the saturation limit of the soil was reached ultimately causing runoff from the VTA. The researchers were able to use this management system at this site since an effluent recycle pipe would return the excess runoff back into the pump station (i.e., no effluent would leave the system). The performance data from this site could represent the worst case scenario of a poorly managed VTS.

The 2009 flow data displayed in Table 15 shows the effluent released from the SSB ranged from a low of 2,098 cubic meters (Central IA 2) to a high of 19,963 cubic meters (Southwest IA1) across the nine sites. The site with the largest SSB

Table 14. Number of release events by site per VTS component

Site	Rainfall cm	Number of Release Events SSB	VTA
Central IA 1	63.2	38	0
Central IA 2	82.4	25	16
Northwest IA 1	68.1	45	13
Northwest IA 2	70.3	33	17
Southwest IA 1	79.8	29	3
Southwest IA 2	70.0	22	0
Western MN 1	56.7	18	0
Central NE 1	79.0	36	38
Central NE 2	57.7	---	11

--- No data available

Table 15. Effluent released from each VTS component

Site	Cattle Head	Feedlot Area Hectares	VTS Area Hectares	2009 Rainfall cm	Effluent Released m^3 SSB	VTA
Central IA 1	1,000	3.09	1.53	63.2	6,804	0
Southwest IA 2	1,200	3.72	3.46	70.0	9,616	0
Western MN 1	1,750	3.56	3.52	56.7	2,634	0
Northwest IA 1	1,400	2.91	1.68	68.1	9,296	1,099
Northwest IA 2*	4,000	2.96	1.91	70.3	7,686	1,496
Central NE 1*	1,200	4.8	4.45	79.0	9,394	2,572
Southwest IA 1	2,300	7.49	4.0	79.8	19,963	6,376
Central IA 2	650	1.07	0.56	82.4	2,098	2,226
Central NE 2	1,700	4.8	3.8	57.7	---	2,581

* Site utilizes an effluent recycle pipe resulting in zero discharge from the system. reported values represent effluent recycled from the VTA
--- No data available

from the VTA ranged from a low of 0 cubic meters (Central IA 1, Southwest IA 2, Western MN1) to a high of 6,376 cubic meters (Southwest IA 1). Although Southwest IA 1 released the most effluent from the VTA compared to the other eight sites, this site recorded the least number of VTA release events out of the six sites that did monitor release from the system. Ninety-four percent of the VTA effluent released from Southwest IA 1came from one release event. This release event was a management decision due to a full SSB and additional expected rainfall. Even though this effluent was monitored exiting the VTA, the effluent was contained within two additional non-operational VTA cells constructed next to the research VTA.

The normalized 2009 flow data (Table 16) represents the total flow recorded leaving or entering each VTS component analyzed on both a per 100 head of cattle space per cm of rain (cattle basis) and a per feedlot area per cm of rain basis (area basis). Normalizing the flow data two different ways (i.e., cattle based, area based) exposed certain facilities' traits while suppressing others in such way that may not be not have been shown using only one method. On the basis of cattle number, Central IA 2, Northwest IA 2, and Western MN 1 displayed the lowest volume of SSB release (3.9, 2.7, 2.7 cubic meters per 100 head of cattle per cm of rainfall). Northwest IA 2 was a concrete feedlot and had the largest stocking density; this spread the flow volume over a large number of animals and resulted in the lowest flow volumes on a per animal basis. Conversely, when the same site was analyzed based on feedlot area, it had the second largest SSB volume released per feedlot area. However, Central IA 2 and Western MN 1 both still had the lowest flow volumes when analyzed based on feedlot area. The SSB flow at Central IA 2 was calculated using stage storage curves due to a leaky gate valve allowing effluent to seep out of the basin. Therefore, error could be associated with the release volumes monitored at this site. Another interesting point, Western MN 1 received 56 cm of rainfall while Central IA 2 received 82 cm. These totals represent the lowest and highest 2009 rainfall totals reported across the nine sites.

The sites were also ranked based on the percent runoff controlled by the VTS. Three VTS sites (Central IA 1, Southwest IA 2, Western MN 1) maintained 100 percent control of the 2009 runoff from the feedlot (i.e. no VTA release event). Out of the six remaining sites that recorded a release event, two of the sites (Northwest IA 2, Central NE 1) utilized an effluent recycle pipe confining the effluent within the system. The percent runoff control calculated for Central NE 1 (73%) may not represent the overall performance of the VTS due to the management practices of this recycle system. This type of management produced a lower percent runoff control value since a "release" was expected during each VTA application event.

Central IA 2 produced a negative percent runoff control (-6%). A negative value indicated more flow left the VTA than was applied from the SSB. Explanations for this negative value were due to a combination of rainfall landing on the VTA and VIB surface along with background tile flow collected from the VIB. Due to SSB monitoring difficulties experienced at Central NE 2, a percent runoff control value could not be calculated.

Table 16. 2009 percent runoff controlled and volume released from VTS component
(† m^3/100 head of cattle space-cm rain, ‡ m^3/ lot ha-cm rain)

					Effluent Released				
	Cattle	Feedlot Area	VTS Area	2009 Rainfall	Cattle Basis †		Area Basis‡		Percent Runoff
Site	Head	Hectares	Hectares	cm	SSB	VTA	SSB	VTA	Controlled
Central IA 1	1,000	3.09	1.53	63.2	10.8	0.0	34.8	0.0	100
Southwest IA 2	1,200	3.72	3.46	70.0	11.5	0.0	37.0	0.0	100
Western MN 1	1,750	3.56	3.52	56.7	2.7	0.0	13.1	0.0	100
Northwest IA 1	1,400	2.91	1.68	68.1	9.8	1.2	46.9	5.5	88
Northwest IA 2*	4,000	2.96	1.91	70.3	2.7	0.5	36.9	7.2	81/100
Central NE 1*	1,200	4.8	4.45	79.0	9.9	3.0	24.8	7.6	73/100
Southwest IA 1	2,300	7.49	4.0	79.8	10.9	3.5	33.4	10.7	68
Central IA 2	650	1.07	0.56	82.4	3.9	4.2	23.8	25.3	-6
Central NE 2	1,700	4.8	3.8	57.7	---	2.6	---	9.4	---

* Site utilizes an effluent recycle pipe resulting in zero discharge from the system. Reported values represent effluent recycled from the VTA
--- No data available

Five of the nine VTAs monitored in 2009 did not report an actual release from their VTS. Two of the VTS systems (Central NE 1, Northwest IA 2) utilized an effluent recycle line at the end of their VTA allowing the producer to “recycle” effluent from the bottom of the VTA back into the system creating a closed circuit. Both of these systems had similar monitored “release” volumes per feedlot area at 7.6 m^3 for Central NE 1 and 7.2 m^3 for Northwest IA 2.

SSB Concentration Data

The average effluent concentrations for five analyzed parameters leaving the SSB nine feedlots are displayed in Table 17. The statistical analysis of each tested parameter per site is provided in Table 1a and Table 2a located in appendix A. The concentration data leaving the SSB was unavailable for one site due to monitoring difficulties experienced during the 2009 monitoring season. As shown in Table 17, SSB concentrations released from Northwest IA 2 were larger on average than the other seven sites for all five parameters analyzed. On the log transformed scale, this site was significantly different than the other sites for each tested parameter. This site utilized a concrete feedlot and a higher stocking density (7.4 square meters per head of cattle) compared to the other sites. Western MN 1 was also consistently higher in SSB concentration than the other sites (excluding Northwest IA 2). Western MN 1 experienced sedimentation issues around the outlet flume which may have led to higher TS concentrations collected in their samples. Two distinct groups appeared in TS concentrations. The first group consisted of Central IA1, Southwest IA 1, Central NE 1 and displayed TS concentrations of 3842, 3830, 3464 mg/L. The second group consisted of Northwest IA 1, Southwest IA 2, Western MN1 and displayed TS concentrations of 6863, 7211, and 7012 mg/L. According to the log transformed data, the sites within each group were not significantly different but were significantly different between the two groups. Explanations for these two groups could be based on feedlot slope along with SSB design. The three sites with larger TS concentrations have larger feedlot slopes thus potentially resulting in larger runoff velocities able to transport more solids. Two of the sites within the group with lower TS concentrations have feedlot slopes less than 2.5% while one site (Southwest IA 1) has a slope of 7.5%. Based on the assumption that feedlot slope effects TS concentrations, one would assume Southwest IA 1 to contain similar TS values as Southwest IA 2 with a feedlot slope of 8.6%. Based on visual inspection throughout the 2009 monitoring season, Southwest IA 1 appeared to settle more solids in a flatter area located before the SSB while Southwest IA 2 did not have a flat area located at the SSB inlet. The concentration data leaving the solid settling basins for all tested parameters were highly variable within each site as well as between sites.

Table 17. Average monitored concentration data leaving the solids settling basin by site including the standard deviation in parentheses.

SSB-2009

Site	# of Samples	NH_3-N mg/L		COD mg/L		Total P mg/L		TKN mg/L		TS mg/L	
Central IA 1	26	56	(43)	3,673	(2,168)	63	(33)	166	(85)	3,842	(1,700)
Central IA 2	27	70	(58)	4,030	(2,159)	82	(41)	227	(139)	5,131	(1,597)
Northwest IA 1	16	140	(56)	4,046	(1,296)	66	(23)	287	(104)	6,863	(2,559)
Northwest IA 2	19	379	(183)	26,872	(19,283)	184	(129)	1,162	(474)	26,961	(27,464)
Southwest IA 1	26	78	(44)	2,074	(814)	56	(10)	141	(53)	3,830	(935)
Southwest IA 2	20	88	(45)	4,518	(4,338)	73	(39)	226	(117)	7,211	(4,953)
Western MN 1	39	145	(107)	7,247	(3,371)	89	(44)	505	(674)	7,012	(2,522)
Central NE 1	28	99	(45)	2,135	(1,284)	59	(17)	184	(88)	3,464	(1,835)
Central NE 2	---	---	---	---	---	---	---	---	---	---	---

--- No data available

VTA Concentration Data

The flow weighted average VTA concentration data was presented for six sites recording a release during the 2009 monitored season (Table 18). As mentioned previously, Northwest IA 2 and Central NE 1 both utilize an effluent recycle line. Therefore a release from the VTA does not mean a release from the system. The concentration data showed Central NE 2 and Northwest IA 2 both contained higher concentrations on average for all of the tested parameters. Recall that Northwest IA 2 initially started with larger nutrient concentrations leaving the SSB. These initial larger concentrations appeared to carry over into the VTA effluent even though concentration reduction did take place. Unlike the SSB concentration data, Northwest IA 2 was not significantly different on the log transformed scale between each site for every parameter tested. The high concentrations monitored at Central NE 2 were due to the utilization of a settling bench to settle runoff solids along with collecting only one sample for the monitoring season. Settling benches are designed to be a passive system (i.e., no control over released effluent) where the effluent runs off the feedlot during a storm and immediately into the VTA. Depending on the storm intensity and soil moisture condition within the VTA, the effluent retention time within the VTA may not provide complete treatment before exiting through the VTA outlet. The VTS system constructed at Central IA 2 produced the lowest VTA concentration across all the parameters tested. As reported in chapter 3, this site recorded a negative percent runoff control (i.e., more runoff left the system than entered). Therefore the lower concentrations could be due to dilution from outside water. The other sites produced similar nutrient concentrations.

Table 18. Average monitored concentration data leaving the vegetative treatment area by site including the standard deviation in parentheses.

VTA-2009

Site	# of Samples	NH_3-N mg/L		COD mg/L		Total P mg/L		TKN mg/L		TS mg/L	
Central IA 1	0	------------------------------No Release Occurred In 2009------------------------------									
Central IA 2	18	8	(11)	702	(1,004)	11	(14)	36	(44)	1,492	(834)
Northwest IA 1	11	47	(38)	1,863	(1,235)	65	(52)	129	(118)	3,786	(3,551)
Northwest IA 2	10	118	(57)	4,101	(2,708)	48	(24)	267	(146)	4,332	(2,683)
Southwest IA 1	6	16	(12)	823	(733)	21	(9)	47	(41)	2,127	(1,583)
Southwest IA 2	0	------------------------------No Release Occurred In 2009------------------------------									
Western MN 1	0	-----------------------------No Release Occurred In 2009------------------------------									
Central NE 1	28	61	(38)	1,339	(1,278)	39	(20)	136	(87)	2,198	(1,825)
Central NE 2	1	191	---	5,758	---	130	---	378	---	10,767	---

--- No data available

Table 19 displays the concentration reductions produced by the VTA. Three sites did not monitor a VTA release during the 2009 monitoring season; therefore a percent reduction could not be calculated. Excluding these three sites, Central IA 2 and Northwest IA 2 produced the highest percent concentration reduction at 84 and 78 percent while Central NE 1 produced the lowest percent reduction at 35 percent. Central IA 2 and Northwest IA 2 both utilized a VIB which provided further effluent treatment by infiltrating through the soil profile before collected in tiles lines to be applied to a VTA. Central NE 1 produced the smallest concentration reduction due to the effluent recycling management system (i.e., effluent applied to the VTA until runoff occurred). Since this producer intentionally applied effluent until runoff occurred form the VTA, this site could represent the worst case scenario of overall VTS performance. This type of management practice resulted in larger concentrations released from the VTA since the effluent had a lower retention time within the treatment area.

Table 19. Vegetative treatment system nutrient concentration reductions

2009 Concentration Reductions

Site	NH_3-N %	COD %	Total P %	TKN %	TS %	Average Performance, %
Central IA 1	------------------------------No Release Occurred In 2009---------------------					
Southwest IA 2	------------------------------No Release Occurred In 2009---------------------					
Western MN 1	------------------------------No Release Occurred In 2009---------------------					
Central IA 2	89	83	87	85	74	84
Northwest IA 2	69	85	74	77	84	78
Southwest IA 1	83	60	62	67	44	63
Northwest IA 1	67	54	3	55	44	45
Central NE 1	38	37	34	26	37	35
Central NE 2	---	---	---	---	---	---

--- No data available

Mass Data

The mass of five parameters released from the SSB per site is displayed in Table 20 and Table 21 and represents the total mass entering the VTS. The mass data calculated for each site was ranked on TS as this parameter accounted for particulate and dissolved transport relating to the other four parameters tested. Northwest IA 2 released the most mass of all five parameters analyzed compared the other eight sites. Central IA 2 released the least amount of mass from the five monitored parameters even though this site received the most rainfall in 2009. The rest of the six sites displayed two sets three sites with similar mass of total solids released from the SSB (Set one: Western MN1, Central IA 1, Central NE 1 Set 2: Northwest IA 1, Southwest IA 2, Southwest IA 1).

Mass was also analyzed on both a 100 head space of cattle per cm of rain and a per feedlot area per cm of rain basis. Unlike the flow volume analysis, the mass analysis appeared to make more sense when analyzing the data on a per head space basis since each animal will excrete a certain amount of nutrients. A feedlot with a larger stocking density should produce more nutrients per area which is shown at Northwest IA 2. Central IA 2 produced the least amount of mass per 100 head per cm of rainfall for all five parameters tested with the exception of Total P. This site also utilized a filter constructed from round hay bales placed in front of the SSB to assist in removing solids before entering the basin. The total solids data analyzed on a per head space basis (i.e. kg per 100 head per cm of rain) showed a relatively steady increase in mass released across the eight sites. If the data was analyzed on a feedlot area basis (i.e. kg per lot hectare per cm rain), three sites (Northwest IA 1 & 2, and Southwest IA 2) released approximately twice as much mass from the SSB (307, 1180, 283 kg/hd/cm-rain) as the other five sites. These three sites had relatively large feedlot slopes (4, 3, 8.6 percent) resulting in effluent flowing at an increased rate allowing more solid transportation. Northwest IA 2 was also the only concrete feedlot reported within this paper.

Table 20. Mass released from the solid settling basin during the 2009 monitoring season

SSB-2009

Site	2009 Rainfall cm	TS kg	NH_3-N kg	COD kg	Total P kg	TKN kg
Central IA 2	82.4	10,198	160	8,656	186	478
Western MN 1	56.7	20,275	353	19,810	259	1,114
Central IA 1	63.2	22,605	290	20,195	362	913
Central NE 1	79.0	29,852	861	18,727	528	1,647
Northwest IA 1	68.1	60,892	1,285	37,935	625	2,628
Southwest IA 2	70.0	73,539	838	40,655	703	2,159
Southwest IA 1	79.8	89,226	1,346	42,027	1,037	2,886
Northwest IA 2	70.3	245,511	3,412	228,478	1,634	10,010
Central NE2	57.7	---	---	---	---	---

--- No data available

Table 21. Normalized mass of analyzed parameters released from the solid settling basin per site
(† kg/100 head of cattle-cm rain, ‡ kg/ lot ha-cm rain)

SSB-2009

Site	TS†	TS‡	NH_3-N†	NH_3-N‡	COD†	COD‡	Total P†	Total P‡	TKN†	TKN‡
Central IA 2	19	116	0.30	1.8	16	98	0.35	2.1	0.9	5.4
Western MN 1	20	101	0.36	1.8	20	98	0.26	1.3	1.1	5.5
Central NE 1	31	79	0.91	2.3	20	49	0.56	1.4	1.7	4.3
Central IA 1	36	116	0.46	1.5	32	103	0.57	1.9	1.4	4.7
Southwest IA 1	49	149	0.73	2.3	23	70	0.56	1.7	1.6	4.8
Northwest IA 1	64	307	1.35	6.5	40	191	0.66	3.2	2.8	13.3
Northwest IA 2	87	1,180	1.21	16.4	81	1,098	0.58	7.9	3.6	48.1
Southwest IA 2	88	283	1.00	3.2	48	156	0.84	2.7	2.6	8.3
Central NE 2	---	---	---	---	---	---	---	---	---	---

--- No data available

Three sites recorded no VTA mass released in 2009 while six sites recorded a release from the system (Table 22 and Table 23). Central NE 2 released the most mass of all five monitored parameters from the VTA. This site only collected one VTA sample during the entire 2009 monitoring season, therefore the mass released from the VTA was dependent on the concentration of one sample. This collected sample contained high concentrations of all five measured parameters and therefore displayed a large amount of mass leaving the VTA. Central IA 2 released the least amount of mass from the five measured parameters. This site utilizes a VIB system where the effluent is filtered through the soil profile, therefore reducing the amount of total suspended solids. The other VIB system (Northwest IA 2) displayed higher total solids mass released (8,331 kg) than Central IA 2 (3,753 kg). This is due to Northwest IA 2 starting with a larger total solids concentration entering the VTA as discussed previously in the concentration section.

Central NE 2 produced the largest mass released on a normalized basis for both a per head space and per feedlot area basis. Only one sample was collected for the 2009 monitoring season, therefore this single sample may not accurately represent the entire VTA flow leaving the system. Northwest IA 2 produced the least amount of total solids (3 kg/100hd/cm-rain) leaving the VTA. This site utilizes a VIB to filter the effluent by infiltrating through the soil.

Table 22. Mass released from the vegetative treatment area during the 2009 monitoring season

VTA-2009						
Site	2009 Rainfall cm	NH_3-N kg	COD kg	Total P kg	TKN kg	TS kg
Central IA 1	63.2	-----No Release Occurred In 2009-----				
Southwest IA 2	70.0	-----No Release Occurred In 2009-----				
Western MN 1	56.7	-----No Release Occurred In 2009-----				
Central IA 2	82.4	34	2,560	37	122	3,753
Northwest IA 1	68.1	62	2,414	95	191	4,691
Central NE 1	79.0	189	4,513	132	412	7,186
Northwest IA 2	70.3	217	7,843	93	495	8,331
Southwest IA 1	79.8	156	8,533	173	483	20,435
Central NE2	57.7	481	14,486	327	951	27,090

Table 23. Normalized mass of analyzed parameters released from the vegetative treatment area per site
(† kg/100 head of cattle-cm rain, ‡ kg/ lot ha-cm rain)

					VTA-2009					
Site	TS†	TS‡	NH_3-N†	NH_3-N ‡	COD†	COD‡	Total P†	Total P‡	TKN†	TKN‡
Northwest IA 2*	3.0	40	0.08	1.04	2.8	38	0.03	0.45	0.18	2.38
Northwest IA 1	4.9	24	0.07	0.31	2.5	12	0.10	0.48	0.20	0.96
Central IA 2	7.0	43	0.06	0.38	4.8	29	0.07	0.42	0.23	1.38
Central NE 1*	7.6	19	0.20	0.50	4.8	12	0.14	0.35	0.43	1.09
Southwest IA 1	11.1	34	0.09	0.26	4.7	14	0.09	0.29	0.26	0.81
Central NE 2**	27.6	99	0.49	1.75	14.8	53	0.33	1.19	0.97	3.47
Central IA 1	---No Release Occurred In 2009--------------------------------------									
Southwest IA 2	---No Release Occurred In 2009--------------------------------------									
Western MN 1	---No Release Occurred In 2009--------------------------------------									

* Site utilizes an effluent recycle pipe
** Only one VTA sample was collected

Table 24 displays the percent mass reductions produced by each site. Sites displaying a 100 percent mass reduction did not have a monitored VTA release during the 2009 monitoring season. Excluding the sites without a monitored release, Northwest IA 2 produced the largest mass reduction (i.e., average reduction across all five parameters) while Central NE 2 produced the lowest percent mass reduction. As mentioned previously, Northwest IA 2 and Central NE 1 both contained an effluent recycling pipe. Therefore a release does not mean a release leaving the system. Due to the VTS management practices of Central NE 1, the percent mass reductions may not reflect the actual performance of the system. One would expect the mass reductions to increase for this system if the effluent was not applied until a VTA release occurred.

Table 24. Percent vegetative treatment system mass reductions

		2009 Percent Mass Reductions					
Site	2009 Rainfall cm	NH_3-N	COD	Total P	TKN	TS	Average
Central IA 1	63.2	100	100	100	100	100	100
Southwest IA 2	82.4	100	100	100	100	100	100
Western MN 1	68.1	100	100	100	100	100	100
Northwest IA 2†	70.3	94	97	94	95	97	95/100
Northwest IA 1	79.8	95	94	85	93	92	92
Southwest IA 1	70.0	88	80	83	83	77	82
Central NE 1†	56.7	78	76	75	75	76	76/100
Central IA 2	79.0	79	70	80	75	63	72
Central NE2	57.7	---	---	---	---	---	---

--- No data available
† Site utilizes an effluent recycle pipe resulting in zero discharge from the system. Reported values represent effluent recycled from the VTA

Conclusion

The performances of the nine monitored VTSs varied depending on feedlot area, VTS design and management practices. In 2009, five of the nine VTSs recorded no VTA release from the system; two of the five sites did not have a VTA release due to the utilization of a recycling pipe. The volume released from the SSB ranged from a low of 2,098 cubic meters to a high of 19,963 cubic meters. The VTA volume released ranged from a low of 0 cubic meters to a high of 6,376 cubic meters. The system with the best performance on a volume of effluent released from both the VTA and SSB was Western MN 1. This site did not monitor a release from the VTA and calculated the least amount of effluent volume released from the SSB at 13.1 cubic meters per feedlot area per cm of rainfall. Central IA 2 produced the next lowest runoff volume leaving the SSB at 23.8 cubic meters per feedlot area per cm of rainfall. This value is twice as much as Western MN 1. For these reasons, the VTS constructed at Western MN 1 produced the best performance on a volume of effluent released from both the SSB and VTA.

The VTS percent runoff control ranged from -6 percent to 100 percent. By excluding the site associated with the -6 percent runoff control, the next lowest percent runoff control was Southwest IA 1 at 68 percent control. System management, VTS designs, and weather were important factors in the percent runoff controlled. Out of the five systems that did not monitor a release from the VTA, three of the systems were slope or sloped and level VTAs while the other two contained effluent recycle lines. Depending on the topography of the feedlot site, effluent recycle lines provided an effective way to prevent an actual release from the VTA if all of the effluent is not infiltrated within the VTA.

The concentration data collected from the VTA and SSB varied between sites and between release events. The effluent concentration released from the SSB in NW IA 2 was significantly different from the other sites for each of the five tested parameters. This site utilized a concrete feedlot which enables the producer to use a larger cattle stocking density. Feedlot slope and type (i.e., earthen or concrete) appears to affect the performance of the SSB. Steeper feedlot slopes have the potential to carry more sediment resulting in larger TS concentrations. Larger initial concentrations exiting the SSB appear to result in larger concentrations released from the VTA. Therefore the performance of the SSB appeared to be an important factor dictating the performance of the whole system. Concentration variability between sites could be due to different weather conditions, management practices, or different VTSs. The overall average 2009 VTS concentration reductions per site ranged from 35% to 84%. These percent reductions were due to differences in VTSs, weather conditions, and management practices. The VTS management practices of effluent application performed at Central NE 1 could represent the worst case scenario of a poorly managed system. The vegetative treatment system with the best concentration reduction performance was Central IA 2 at 84 percent followed by Northwest IA 2 at 78 percent. Although Northwest IA 2 had the second largest percent concentration reduction, this site also monitored the second largest effluent concentration leaving the VTA while Central IA 2 monitored the lowest VTA concentration across all five tested parameters. Both of these sites utilize a VIB to pretreat effluent before VTA application. Therefore the advantage of these particular systems provides pretreatment of effluent before VTA application.

The analysis of the average mass released for five tested parameters from the SSB and VTA showed contrasting results for certain sites when analyzed on both a kg per 100 head space per cm of rainfall and on a kg per feedlot area per cm of rainfall basis. The overall average percent of mass reduction based on five monitored parameters through the VTS ranged from a low of 72 percent to a high of 100 percent (i.e., 100 percent means no monitored 2009 VTA release). The two sites with the best overall VTS performance on a mass released basis were Western MN 1 and Central IA1. Both sites did not monitor a release from the VTA and produced a similar amount of mass released from the SSB. Although Southwest IA 2 did not monitor a release from the VTA, this site released a larger mass of total solids (73,539 kg of TS) into the VTA as compared to Western MN 1 (20,275 kg of TS) and Central IA 1 (22,605 kg of TS).

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CHAPTER 5. GENERAL CONCLUSIONS

Implications of VTS Construction Costs

Four important conclusions were drawn from the research presented in chapters two and three. The first conclusion showed the average initial construction cost of VTSs were less expensive to construct on a per head space basis than containment basins in both the AFO and CAFO categories. The second conclusion drawn from this research showed VTSs constructed on AFOs may provide a more economical benefit than a VTS constructed on a CAFO when compared to a containment basin. This information supported the initial perceived idea that VTSs were less expensive to construct than containment basins. The third conclusion showed VTS cost cannot be predicted based off of feedlot head space. The fourth conclusion drawn in chapter three showed the initial annualized construction cost between a VTS and a containment basin. Conclusions in this chapter showed containment basins may or may not cost less than a VTS on an annualized cost basis depending on VTS life expectancy.

The first conclusion showed on average, the initial construction cost of VTSs were less expensive to construct on a per head space basis than containment basins in both the AFO and CAFO categories. Since this analysis only reported the initial construction cost for both AFOs and CAFOs, (i.e., construction and engineering design for both VTS and basins), overall conclusions may not be drawn between theses systems without including operation and maintenance cost associated with each system. Examples of operational and maintenance cost associated with both systems consist of system maintenance, life expectancy, and management labor, and opportunity cost for removing potential row crop production land by constructing VTSs. Additional research is needed to compare each of the previously mentioned operation and maintenance cost for each system in order to provide insight on the long term overall annualized cost of both systems.

The second conclusion drawn from the paper showed the initial construction cost on average for VTSs constructed for AFO facilities produced a larger cost saving per head space than CAFO facilities when compared to a containment basin for feedlot runoff control. Although the average VTS cost savings depends on the site location and type of system, an AFO implemented with a VTS displayed a larger cost advantage than a CAFO compared to a conventional basin. The overall average cost to construct a VTS for an AFO facility was $77 per head space (average of all types) while a basin constructed for an AFO facility was $205 per head space on average. This resulted in a construction cost savings of $128 dollars per head space for an AFO. When compared to a CAFO, the overall average VTS construction cost for a CAFO facility was $85 per head space (average of all types) while the cost associated with constructing a basin ranged from $103 per head space (actual cost) to $136 per head space (estimated average, Lawrence et. al., 2006). This resulted in a cost saving of $18 to $51 per head space depending on using actual or estimated basin cost values. The cost of a VTS constructed on a CAFO feedlot ranged from a low of $45 per head space of cattle to a high of $126 per head space. Since the CAFO cost per head space for a VTS overlapped into the cost for a containment basin, a CAFO VTS may not always be the lowest cost option for runoff control depending on site location and system type. Therefore, VTSs implemented on AFOs may provide a larger cost savings per animal space on average than VTSs implemented on CAFOs.

The third conclusion showed the cost of VTSs cannot be predicted based off of feedlot head space. Statistical analysis software, SAS 9.2, was used to analyze the construction cost data collected from each site. An analysis of variance (ANOVA) procedure was used within SAS to compare the means of the construction cost per head space between beef AFO and CAFO facilities and between each system type (i.e., sloped or sloped and level VTA, pump sloped VTA, sprinkler VTA, and VIB-VTA system). The statistical analysis showed no significant difference between the VTS construction cost per head space of cattle for an AFO compared to a CAFO ($p=0.07$, alpha= 0.05) while there was a statistical difference between system type ($p=0.02$, alpha=0.05). Therefore, the variation of the sample average (on a cost per head space of cattle) for an AFO is statistically the same as a CAFO even though a difference of $8 per head was reported between the average cost per head space of the two feedlot sizes. Therefore, feedlot capacity may not be used as an indicator to predict the cost of a VTS. Figure 12 supports this claim by graphically showing no visible trend between the cost per head space compared to the total feedlot size (R^2=0.0001).

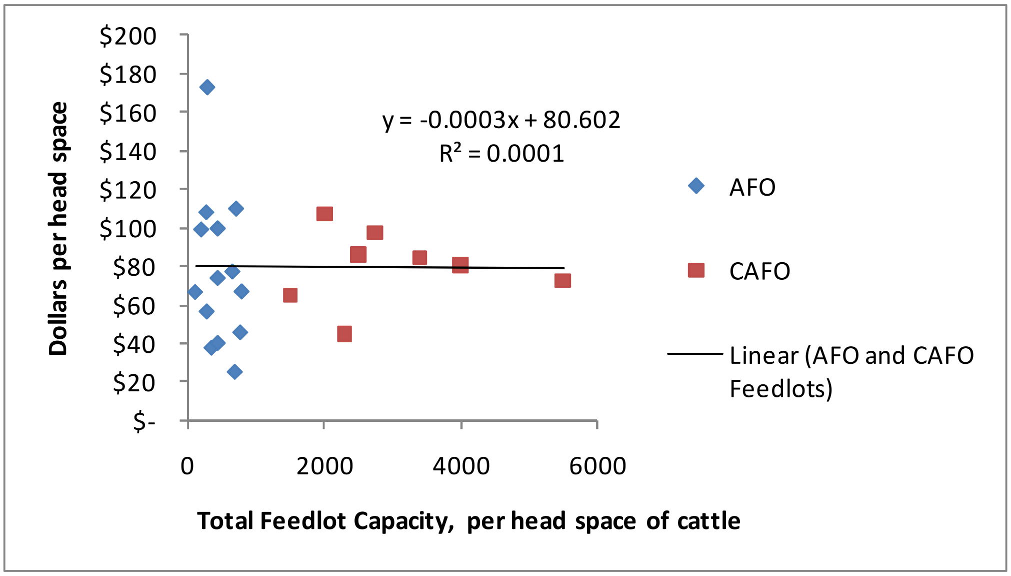


Figure 12. Graphical representation of dollars per head space verses total feedlot capacity.

The results of the ANOVA procedure comparing the means of each system type (AFO and CAFO VTS type combined) on a per head space of cattle showed a statistical difference between two of the system types (sloped and sloped and level VTA, pump sloped VTA) using an alpha value of 0.05. This analysis showed the cost per head space for a slope and sloped and level VTA was significantly different from the cost per head space for a pump sloped VTA. If the data is analyzed with an alpha value of 0.1, a statistical difference is shown between three system types; a sloped or sloped and level VTA with both a sprinkler VTA and pump sloped VTA. This means the cost per head space for a sloped or sloped and level VTA was significantly different than the cost per head space for a sprinkler VTA and pump sloped VTA. The statistical analysis between system type could be slightly misleading at the 0.05 alpha level since one pump sloped VTA system recorded a system cost approximately $47 per head larger than the next largest pump sloped site. Including this site in the analysis raises the average of the pump sloped VTA cost per head to a value larger than the cost of a sprinkler VTS. Figure 13 displays all 23 VTS sites for both AFO and CAFOs separated by system type. All four system types did not show a clear trend in relation to feedlot capacity.

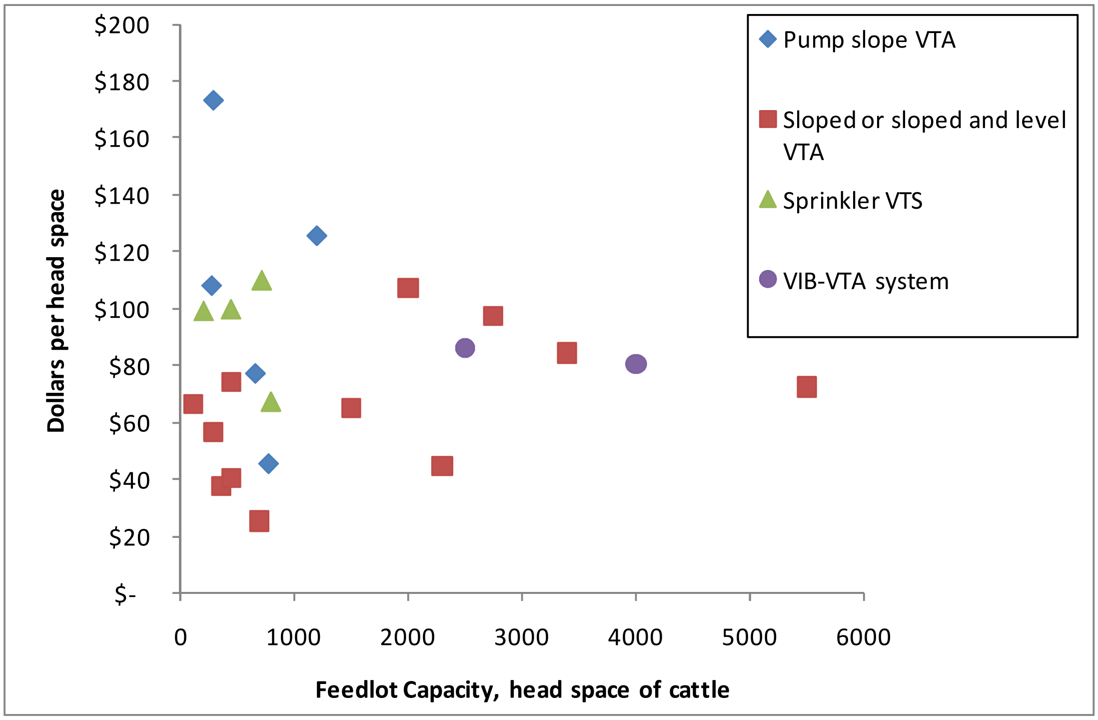
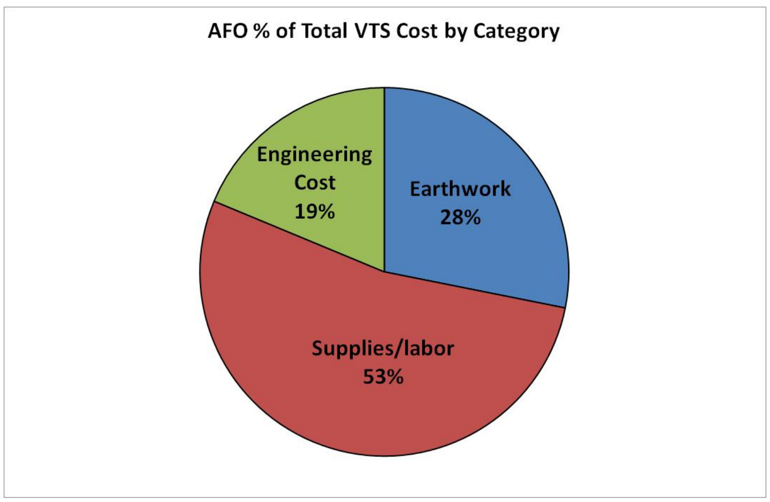


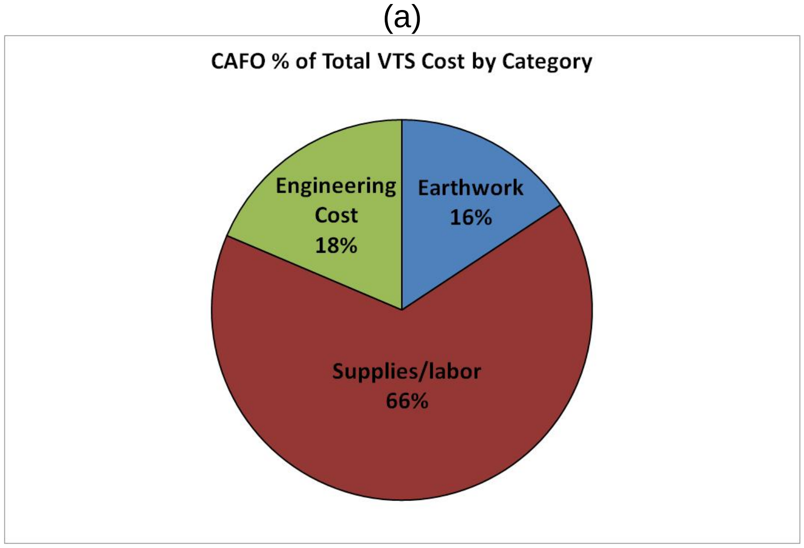
Figure 13. Graphical representation of dollars per head space verses feedlot capacity separated by system type.

The fourth conclusion drawn from the research presented in chapter three showed the initial annualized cost of a VTS may or may not cost less than a conventional containment basin depending on the VTS life expectancy. This conclusion was based on a basin expected life of 25 years and a VTA expected life of 10 years and does not include operation and maintenance cost for either system. The break even life expectancy of a VTS is 14 years when compared to a 25 year containment basin life expectancy.

The total construction cost of VTSs varied on the type of system and the topography of the area. Chapter two reported the total engineering and construction cost for each VTS site. The construction cost was further broken down into two categories: earthwork, supplies/labor. Earthwork cost consisted of general excavation, trenching, and site leveling while the supplies/labor category consisted of the materials used for the VTS construction (i.e., valves, concrete, labor, inlets and outlets) and construction labor charged by the contracting companies. As mentioned previously, the in-kind costs were not included within this analysis. The construction cost for certain sites could not be broken down into smaller categories due to construction bills combining cost into broad categories. Therefore, the construction costs associated with only nine AFO sites and four CAFO sites were used to calculate the percent of construction cost. The 2009 AFO and CAFO construction cost by category is displayed in Figure 14.



(a)



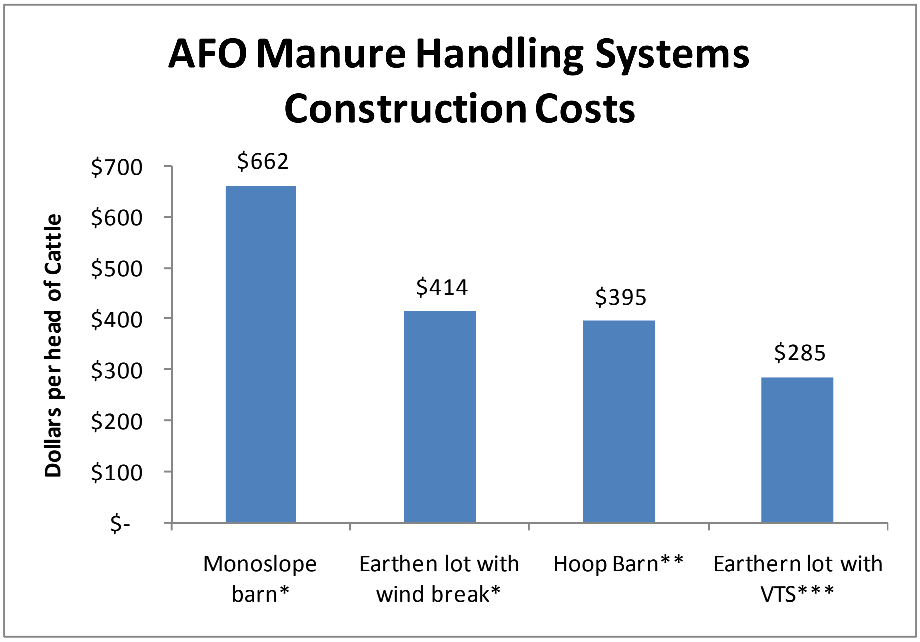
(b)

Figure 14. Percent of total VTS cost by category. AFO (a), CAFO (b)

The cost data from nine AFO VTSs were used to calculate the percent of each category. Based on these nines sites, the supplies/labor (53%) category was the largest cost associated with constructing a VTS on an AFO followed by earthwork (28%), and engineering design (19%). The CAFO analysis displayed similar results when compared to the AFO categories. Four CAFO VTSs were used to calculate the percent of each category. Results from these four CAFO sites showed the largest cost category associated with a VTS was supplies/labor (66%) followed by engineering design (18%), and earthwork (16%). An explanation for the increase in supplies/labor between an AFO and CAFO might be due to the cost associated with concrete work. The CAFOs reported in this paper typically used more concrete in their VTS designs than AFOs possibly due to their larger scale and regulatory requirements. Engineering design remained approximately the same between an AFO and a CAFO (19%, 18%).

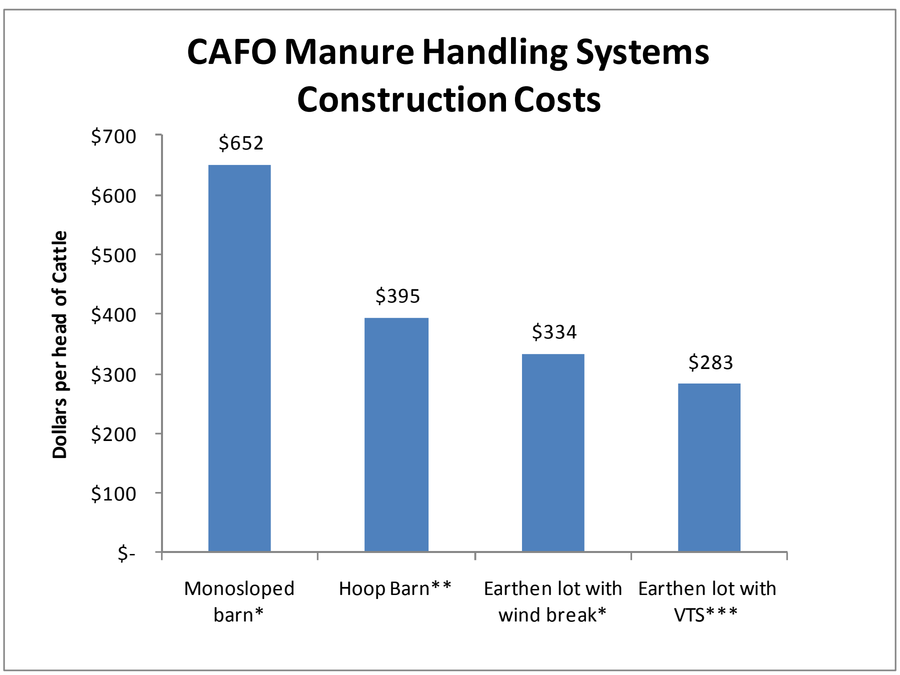
The paper also compared the construction cost associated with constructing a VTS to other types of beef production systems. The results displayed in Figure 15 showed construction costs for an AFO open feedlot coupled with a VTS ($285 per head space) were least expensive to construct on a per head of cattle basis compared to a monoslope barn ($662 per head space), open feedlot with a containment basin ($414 per head space), and a hoop structure ($395 per head space). Since this analysis only looked at the construction cost of each system, additional research is needed to provide insight on the annual operating cost including labor, maintenance, and opportunity cost for land taken out of row crop production.

The results displayed in Figure 16 showed a VTS constructed on a CAFO earthen feedlot ($283 per head space) was least expensive to construct per head of cattle than a monosloped barn ($652 per head space), hoop barn ($395 head space), and earthen feedlot with a basin ($334 per head space). As mentioned previously, additional research is needed on the annual operation and maintenance costs for each system to create a fair long term comparision between each system.



* System cost estimated from Lawrence et al., 2006
** System cost estimated from Honeyman et al., 2008
*** Estimated earthen lot (Lawrence et al., 2006) plus actual VTS cost

Figure 15. AFO manure handling systems construction cost



* System cost estimated from Lawrence et al., 2006
** System cost estimated from Honeyman et al., 2008
*** Estimated earthen lot (Lawrence et al., 2006) plus actual VTS cost

Figure 16. CAFO manure handling systems construction cost

Implications of CAFO VTS Performance data

Two conclusions were drawn from analyzing the performance of a VTS to control and treat the runoff associated from beef feedlots in the Midwestern United States. The first conclusion indicated a VTS has the potential to equal the performance of a traditional containment basin. The second conclusion showed large variations in the performance data of VTSs.

The first conclusion drawn from the VTS performance data analyzed from nine beef feedlots located in the Midwestern United States indicated VTSs have the potential to equal the performance of a traditional containment basin. In 2009, five out of the nine monitored VTS did not report a release from the VTS while the other four sites demonstrated potential for complete runoff control except for discrete release events. These discrete release events were potentially due to management issues regarding effluent application to the VTA.

The second conclusion showed large variations in the VTS performance data collect during the 2009 monitoring season. The VTS performance data for the SSB and VTA showed large variation in concentration samples collected throughout the monitoring season. These large concentration variations in the SSB and VTA were also reported by Andersen et al. (2009) for the same six sites monitored in Iowa from 2006 to 2008. A side by side comparison of the 2006 to 2008 VTS data analyzed by Andersen et al. 2009 and the 2009 data reported within this thesis is provided in Table 25 and Table 26. The 2009 SSB concentrations were consistently lower than the 2006-2008 monitoring period at the same Iowa sites except for Southwest IA 1. This site experienced larger concentrations for all parameters except total solids. Potential reasons for this concentration increase in 2009 could be due to a large amount of settled solids located within the basin coupled with receiving the second largest rainfall amount (79.8 cm) in 2009. Due to wet conditions within the SSB, the producer was unable to remove the settled solids from the basin which potentially creates an additional source of nutrients in addition to the feedlot runoff. The two VTSs located in Nebraska and Minnesota (Central NE 1, Western MN 1) both

Table 25. 2006-2008 & 2009 average monitored concentration data leaving the solid settling basin by site including the standard deviation in parentheses.

SSB-2006-2009

Site	NH_3-N mg/L		COD mg/L		Total P mg/L		TKN mg/L		TS mg/L	
	'06-'08*	2009	'06-'08*	2009	'06-'08*	2009	'06-'08*	2009	'06-'08*	2009
Central IA 1	142 (57)	56 (43)	5,602 (2,447)	3,673 (2,168)	83 (23)	63 (33)	326 (117)	166 (85)	6,394 (3,041)	3,842 (1,700)
Central IA 2	120 (126)	70 (58)	6,466 (6,597)	4,030 (2,159)	109 (95)	82 (41)	361 (363)	227 (139)	8,402 (6,522)	5,131 (1,597)
Northwest IA 1	187 (55)	140 (56)	11,379 (11,257)	4,046 (1,296)	86 (46)	66 (23)	561 (401)	287 (104)	12,965 (8,753)	6,863 (2,559)
Northwest IA 2	492 (209)	379 (183)	34,933 (15,751)	26,872 (19,283)	222 (61)	184 (129)	1,635 (545)	1,162 (474)	32,281 (14,227)	26,961 (27,464)
Southwest IA 1	68 (20)	78 (44)	1,609 (119)	2,074 (814)	53 (8)	56 (10)	126 (34)	141 (53)	4,049 (1,412)	3,830 (935)
Southwest IA 2	99 (54)	88 (45)	4,539 (1,511)	4,518 (4,338)	83 (12)	73 (39)	288 (144)	226 (117)	12,800 (4,694)	7,211 (4,953)
Western MN 1	---	145 (107)	---	7,247 (3,371)	---	89 (44)	---	505 (674)	---	7,012 (2,522)
Central NE 1	---	99 (45)	---	2,135 (1,284)	---	59 (17)	---	184 (88)	---	3,464 (1,835)
Central NE 2	---	--	---	---	---	---	---	---	---	---

* Data from Andersen et al., 2009 and represents the average concentration and standard deviations for sites constructed during the 2006 to 2008 monitoring period.

---Concentration data from this site is unavailable due to monitoring difficulties

Table 26. 2006-2008 & 2009 average monitored concentration data leaving the vegetative treatment area by site including the standard deviation in parentheses.

	VTA 2006-2009 Concentration									
Site	**NH_3-N mg/L**		**COD mg/L**		**Total P mg/L**		**TKN mg/L**		**TS mg/L**	
	'06-'08*	**2009**	**'06-'08***	**2009**	**'06-'08***	**2009**	**'06-'08***	**2009**	**'06-'08***	**2009**
Central IA 1	52 (26)	NR	2,984 (2,947)	NR	51 (29)	NR	181 (164)	NR	4,215 (4,154)	NR
Central IA 2	8 (6)	8 (11)	441 (286)	702 (1,004)	7 (3)	11 (14)	26 (16)	36 (44)	1,336 (453)	1,492 (834)
Northwest IA 1	63 (21)	47 (38)	2,415 (515)	1,863 (1,235)	41 (4)	65 (52)	167 (20)	129 (118)	4,604 (740)	3,786 (3,551)
Northwest IA 2	152 (51)	118 (57)	7,352 (956)	4,101 (2,708)	101 (70)	48 (24)	456 (75)	267 (146)	7,580 (1,673)	4,332 (2,683)
Southwest IA 1	14 (19)	16 (12)	625 (785)	823 (733)	17 (20)	21 (9)	40 (52)	47 (41)	2,384 (1,873)	2,127 (1,583)
Southwest IA 2	23 (10)	NR	1,036 (814)	NR	29 (13)	NR	66 (39)	NR	2,323 (1,417)	NR
Western MN 1	---	NR	---	NR	---	NR	---	NR	---	NR
Central NE 1	---	61 (38)	---	1,339 (1,278)	---	39 (20)	---	136 (87)	---	2,198 (1,825)
Central NE 2	---	191 ---	---	5,758 ---	---	130 ---	---	378 ---	---	10,767 ---

* Data from Andersen et al., 2009 and represents the average concentration and standard deviations for sites constructed during the 2006 to 2008 monitoring period.
---Concentration data represents one sample
NR – No VTA release

produced SSB concentrations similar to those found at the Iowa sites. Western MN 1 appeared to have slightly higher concentrations for all tested parameters when excluding Northwest IA 2. Northwest IA 2 recorded the largest concentrations for all five of the monitored parameters in all four years of monitoring along with the largest standard deviations for all parameters except TKN in 2009. This site is the only concrete feedlot and the concentration and consistency of the effluent varied more than the other sites from release event to release event.

The 2009 VTA performance data displayed in Table 26 shows on average four out of the six Iowa sites displayed a decrease in pollutant concentrations for the 2009 monitoring period. Southwest IA 1 and Central IA 2 both experienced higher pollutant concentrations released from the VTA in 2009 compared to the previous monitored years. Reasons for higher pollutant concentrations leaving the VTA from Southwest IA 1 were due to one large release event where the producer needed to empty his basin to create storage for predicted rainfall. As a result this corresponded in less treatment time within the VTA to treat and reduce the nutrient concentrations of the effluent.

The 2009 VTS percent mass reduced per site is displayed in Table 27 along with the 2006-2008 percent mass data reported by Andersen et al. (2009). Results showed all of the Iowa sites, except for Central IA 2 and Northwest IA 1, improved on a percent mass reduction basis from the 2006-2008 monitoring period compared to the 2009 period. The VTS percent of nutrient mass reduction by site ranged from a low of 2 percent (Southwest IA 1, TS) to a high of 100 percent (Central IA1, Southwest IA 2, Western MN1, for all 5 parameters). Although Northwest IA 2 and Central NE1 did not have an actual release from the system, both sites did experience effluent runoff through their recycle pipe. This effluent represents the concentrations that “might have” released if a recycle pipe was not used. Therefore the actual percent mass reduced value was presented in Table 27 along with a 100 percent designation (e.g., 82/100 means 82 percent mass reduction from the VTA and 100 percent mass reduction from overall VTS system). The overall average percent nutrient reduction for all nine sites (including 2006-2008 data were applicable) showed nutrient reductions of 87%, 83%, 82%, 83%, 81% for NH_3-N, COD, Total P, TKN, and TS respectively.

Table 27. 2006-2008 & 2009 average VTS percent mass reduced per site.

VTS 2006 to 2009 Percent Mass Reductions

Site	NH_3-N %		COD %		Total P %		TKN %		TS %	
	'06-08*	2009	'06-08*	2009	'06-08*	2009	'06-08*	2009	'06-08*	2009
Central IA 1	72	100	71	100	66	100	71	100	66	100
Southwest IA 2	95	100	95	100	91	100	94	100	95	100
Western MN 1	---	100	---	100	---	100	---	100	---	100
Northwest IA 2†	82/100	94/100	93/100	97/100	93/100	94/100	89/100	95/100	93/100	97/100
Northwest IA 1	93	95	92	94	91	85	93	93	93	92
Southwest IA 1	60	88	11	80	4	83	8	83	2	77
Central NE 1†	---	78/100	---	76/100	---	75/100	---	75/100	---	76/100
Central IA 2	87	79	88	70	88	80	88	75	76	63
Central NE2	---	---	---	---	---	---	---	---	---	---
Average, %	87		83		82		83		81	

* Data from Andersen et al., 2009 and represents the average concentration and standard deviations for sites constructed during the 2006 to 2008 monitoring period.
--- Percent mass reduction could not be calculated due to minimal SSB volume measurements
† Site utilizes an effluent recycle pipe resulting in zero discharge from the system. Reported values represent effluent recycled from the VTA

Data collected and presented within this thesis provided important insight on the initial cost and performance of VTSs implemented on large CAFOs to control and treat feedlot runoff. The initial cost of a VTS constructed for an AFO was on average $128 less per head than a containment basin while a CAFO VTS was $51 per head less on average than a containment basin. Previous VTS research was restricted to feedlots containing less than 1,000 head of cattle due to current regulations at the time of the research. In 2009, five out of the nine feedlots did not report an effluent release from the VTS system. Vegetative treatment systems were found to effectively reduce the mass of nutrients by approximately 81 to 87 percent. Based on the research presented, VTS have the potential to be a cost effective viable option to treat and control runoff from permitted CAFO facilities.

Conclusions

The performance of three different vegetative treatment systems designed to control and treat runoff from large CAFOs were investigated within this thesis. The best type of vegetative treatment system is dependent on site specific variables such as rainfall, soil properties, topography, and management practices. Since all of these variables were different for each of the three monitored VTS types, a clear conclusion may not be drawn on which type of system performs the best. Therefore, a discussion of the advantages and disadvantages of each system type reported in this paper is provided along with performance data based on the information collected during this research.

The slope or sloped and level VTS was the lowest cost system per head for initial construction cost compared to a VIB-VTA system and a pump sloped system. However, on an annualized cost basis, these systems were not the least expensive. Advantages of a slope or sloped and level system use gravity to distribute effluent throughout a VTS. By using gravity to transport effluent, there are no additional construction and maintenance costs associated with a pump and pumping station. Three out of the six slope or sloped and level VTS sites did not monitor a VTS release from the system. The other three slope or sloped and level VTS sites demonstrated potential for complete runoff control except for discrete release events potentially due to management issues.

Vegetative infiltration basins combined with a vegetative treatment area are excellent systems to reduce effluent concentrations of pollutants from feedlot runoff. These systems had the highest concentration reductions at 84 and 78 percent out of the five sites that monitored a VTA release during the 2009 monitoring season. The VIB-VTA systems were the least expensive VTS on an annualized cost per head space at $11 per head space without including operation and maintenance costs. If the annual operation and maintenance cost was included in the annualized cost analysis, the cost per head space could potentially increase more than a slope or sloped and level VTA due to the addition of a pump and pumping station. Therefore, the total system cost analysis is difficult to compare between VTS types.

Based on the cost data collected, a pump sloped VTA was the most expensive system to construct on both an annualized and initial construction cost per head comparison. This cost analysis contained only one pump sloped VTA site, therefore no variability in this particular system cost could be analyzed. Pump sloped VTAs operate similar to a slope or sloped and level VTA. The only difference between these two systems is how effluent is transported to the VTA. Pump sloped VTAs allow VTSs to be operated in areas where the feedlot topography inhibits VTA construction down gradient from the feedlot. Pump sloped VTAs may also utilize an effluent recycle pipe allowing the return of effluent that was not infiltrated within the VTA.

The ability to recycle effluent released from a VTA is an excellent way to manage VTA releases. This option allows operators additional protection against effluent releases from the feedlot and production areas. This system also protects the vegetation from water stress due to ponding at the end of the VTA by recycling this effluent back through the system. Although not researched within this paper, recycled effluent would have the potential to provide further concentration reductions with a second cycle through the system. When a VTS is managed and designed properly, these recycle systems would not be needed. However, certain effluent application events may occur throughout the year under non-optimal soil conditions especially during periods of large rainfall events.

Future Research

The long term operating and maintenance cost should be a major topic of future VTS research. The cost data reported within this thesis represented only the initial construction cost associated with a VTS. In order to perform a complete economic analysis between a VTS and conventional containment basin, the annual operating and maintenance cost of both systems should be included in the comparison. The annual operating and maintenance cost should include the following components: labor required to operate the system, maintenance and upkeep of the system, land opportunity cost, and the life expectancy of the system.

The life expectancy of both systems is very important in an economic analysis since the initial investment cost may be larger for one system type but it may even out if the system has a longer life expectancy. This will spread the cost over a longer service life and potentially normalizing the overall annual cost.

The life expectancy of a VTS is also an important component for future management decisions regarding the operation and cost of these systems. For example, research is needed to understand and implement proper closure methods or reclamation methods to reduce future contamination of old discontinued systems. Once the approximate life expectancy of VTSs is estimated, then insight may be drawn on methods or management practices to maximize the life expectancy of the system. Vegetative treatment system management practices that may positively affect the life expectancy may include but not limited to the rate of effluent application, nutrient reductions in cattle rations, additional SSB pretreatment, more efficient nutrient uptake in forage, and continuing to modify and improve VTS design criteria.

APPENDIX. STATISTICAL RESULTS

Table 1a. Statistical Analysis for five SSB parameters analyzed between sites. Sites significantly different (p=0.05) are denoted in the table as "significant" while sites not significantly different are denoted with "NS."

		NH3-N							
		CN IA 1	CN IA 2	NW IA 1	NW IA 2	SW IA 2	SW IA 1	W MN 1	CN NE 1
NH3-N	CN IA 1		NS	Significant	Significant	Significant	Significant	Significant	Significant
	CN IA 2	NS		Significant	Significant	NS	NS	Significant	Significant
	NW IA 1	Significant	Significant		Significant	Significant	Significant	NS	NS
	NW IA 2	Significant	Significant	Significant		Significant	Significant	Significant	Significant
	SW IA 2	Significant	NS	Significant	Significant		NS	NS	NS
	SW IA 1	Significant	NS	Significant	Significant	NS		Significant	NS
	W MN 1	Significant	Significant	NS	Significant	NS	Significant		NS
	CN NE 1	Significant	Significant	NS	Significant	NS	NS	NS	

		COD							
		CN IA 1	CN IA 2	NW IA 1	NW IA 2	SW IA 2	SW IA 1	W MN 1	CN NE 1
COD	CN IA 1		NS	NS	Significant	NS	Significant	Significant	Significant
	CN IA 2	NS		NS	Significant	NS	Significant	Significant	Significant
	NW IA 1	NS	NS		Significant	NS	Significant	Significant	Significant
	NW IA 2	Significant	Significant	Significant		Significant	Significant	Significant	Significant
	SW IA 2	NS	NS	NS	Significant		Significant	Significant	Significant
	SW IA 1	Significant	Significant	Significant	Significant	Significant		Significant	NS
	W MN 1	Significant	Significant	Significant	Significant	Significant	Significant		Significant
	CN NE 1	Significant	Significant	Significant	Significant	Significant	NS	Significant	

		Total P							
		CN IA 1	CN IA 2	NW IA 1	NW IA 2	SW IA 2	SW IA 1	W MN 1	CN NE 1
Total P	CN IA 1		Significant	NS	Significant	NS	NS	Significant	NS
	CN IA 2	Significant		NS	Significant	NS	Significant	NS	Significant
	NW IA 1	NS	NS		Significant	NS	NS	NS	NS
	NW IA 2	Significant	Significant	Significant		Significant	Significant	Significant	Significant
	SW IA 2	NS	NS	NS	Significant		NS	NS	NS
	SW IA 1	NS	Significant	NS	Significant	NS		Significant	NS
	W MN 1	Significant	NS	NS	Significant	NS	Significant		Significant
	CN NE 1	NS	Significant	NS	Significant	NS	NS	Significant	

		TKN							
		CN IA 1	CN IA 2	NW IA 1	NW IA 2	SW IA 2	SW IA 1	W MN 1	CN NE 1
TKN	CN IA 1		Significant	Significant	Significant	Significant	NS	Significant	NS
	CN IA 2	Significant		NS	Significant	NS	Significant	Significant	NS
	NW IA 1	Significant	NS		Significant	NS	Significant	NS	Significant
	NW IA 2	Significant	Significant	Significant		Significant	Significant	Significant	Significant
	SW IA 2	Significant	NS	NS	Significant		Significant	Significant	NS
	SW IA 1	NS	Significant	Significant	Significant	Significant		Significant	NS
	W MN 1	Significant	Significant	NS	Significant	Significant	Significant		Significant
	CN NE 1	NS	NS	Significant	Significant	NS	NS	Significant	

		TS							
		CN IA 1	CN IA 2	NW IA 1	NW IA 2	SW IA 2	SW IA 1	W MN 1	CN NE 1
TS	CN IA 1		Significant	Significant	Significant	Significant	NS	Significant	NS
	CN IA 2	Significant		NS	Significant	NS	Significant	NS	Significant
	NW IA 1	Significant	NS		Significant	NS	Significant	NS	Significant
	NW IA 2	Significant	Significant	Significant		Significant	Significant	Significant	Significant
	SW IA 2	Significant	NS	NS	Significant		Significant	NS	Significant
	SW IA 1	NS	Significant	Significant	Significant	Significant		Significant	NS
	W MN 1	Significant	NS	NS	Significant	NS	Significant		Significant
	CN NE 1	NS	Significant	Significant	Significant	Significant	NS	Significant	

Table 2a. Statistical Analysis for five VTA parameters analyzed between sites. Sites significantly different are denoted in the table as "significant" while sites not significantly different are denoted with "NS."

		NH3-N							
		CN IA 1	CN IA 2	NW IA 1	NW IA 2	SW IA 2	SW IA 1	W MN 1	CN NE 1
NH3-N	CN IA 1		---	---	---	---	---	---	---
	CN IA 2	---		Significant	Significant	---	Significant	---	Significant
	NW IA 1	---	Significant		Significant	---	Significant	---	NS
	NW IA 2	---	Significant	Significant		---	Significant	---	NS
	SW IA 2	---	---	---	---		---	---	---
	SW IA 1	---	Significant	Significant	Significant	---		---	Significant
	W MN 1	---	---	---	---	---	---		---
	CN NE 1	---	Significant	NS	NS	---	Significant	---	

		COD							
		CN IA 1	CN IA 2	NW IA 1	NW IA 2	SW IA 2	SW IA 1	W MN 1	CN NE 1
COD	CN IA 1		---	---	---	---	---	---	---
	CN IA 2	---		Significant	Significant	---	NS	---	Significant
	NW IA 1	---	Significant		NS	---	NS	---	NS
	NW IA 2	---	Significant	NS		---	Significant	---	Significant
	SW IA 2	---	---	---	---		---	---	---
	SW IA 1	---	NS	NS	Significant	---		---	NS
	W MN 1	---	---	---	---	---	---		---
	CN NE 1	---	Significant	NS	Significant	---	NS	---	

		Total P							
		CN IA 1	CN IA 2	NW IA 1	NW IA 2	SW IA 2	SW IA 1	W MN 1	CN NE 1
Total P	CN IA 1		---	---	---	---	---	---	---
	CN IA 2	---		Significant	Significant	---	Significant	---	Significant
	NW IA 1	---	Significant		NS	---	NS	---	NS
	NW IA 2	---	Significant	NS		---	NS	---	NS
	SW IA 2	---	---	---	---		---	---	---
	SW IA 1	---	Significant	NS	NS	---		---	NS
	W MN 1	---	---	---	---	---	---		---
	CN NE 1	---	Significant	NS	NS	---	NS	---	

		TKN							
		CN IA 1	CN IA 2	NW IA 1	NW IA 2	SW IA 2	SW IA 1	W MN 1	CN NE 1
TKN	CN IA 1		---	---	---	---	---	---	---
	CN IA 2	---		Significant	Significant	---	NS	---	Significant
	NW IA 1	---	Significant		Significant	---	NS	---	NS
	NW IA 2	---	Significant	Significant		---	Significant	---	NS
	SW IA 2	---	---	---	---		---	---	---
	SW IA 1	---	NS	NS	Significant	---		---	Significant
	W MN 1	---	---	---	---	---	---		---
	CN NE 1	---	Significant	NS	NS	---	Significant	---	

		TS							
		CN IA 1	CN IA 2	NW IA 1	NW IA 2	SW IA 2	SW IA 1	W MN 1	CN NE 1
TS	CN IA 1		---	---	---	---	---	---	---
	CN IA 2	---		Significant	Significant	---	NS	---	NS
	NW IA 1	---	Significant		NS	---	NS	---	NS
	NW IA 2	---	Significant	NS		---	NS	---	Significant
	SW IA 2	---	---	---	---		---	---	---
	SW IA 1	---	NS	NS	NS	---		---	NS
	W MN 1	---	---	---	---	---	---		---
	CN NE 1	---	NS	NS	Significant	---	NS	---	