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Monitoring vegetative treatment system performance for open beef feedlot runoff control

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by

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Abstract

Vegetative treatment systems (VTS) are an alterative technology designed to control runoff from open beef feedlots. A VTS consists of a solids settling basin (SSB) followed by a vegetative treatment area (VTA) or a combination of vegetative infiltration basin (VIB) and a VTA. Four sites were monitored in 2006 and 2007 to evaluate the performance of the VTSs in Iowa. In 2006, the systems were managed with unrestricted SSB releases. The percent runoff control at Central IA 1 & 2 and Northwest IA 1 & 2 was measured as 99, 74, 96, and 98 respectively. The percent TKN mass retained in the systems for Central IA 1 & 2 and Northwest IA 1 & 2 was 97, 78, 97, and 99 respectively. In 2007, the SSB outlets were valved and SSB releases were controlled depending upon the VTA saturation conditions. In 2007, the percent runoff control at Central IA 1 & 2 and Northwest IA 1 & 2 was measured as 55, 80, 85, and 99 respectively. The percent TKN mass retained in the systems for Central IA 1 & 2 and Northwest IA 1 & 2 was 44, 95, 82, and 99 respectively. The SSB performance in terms of settling solids improved in 2007 after the installation of the gate valves. The VIBs at Central IA 2 and NW IA 2 were ponded for most of the 2006 and 2007 monitoring period. As a result, a good stand of vegetation could not be established in the VIBs, thereby affecting their ability to reduce nutrients. Channeling was observed in the Central IA 1, Central IA 2 and NW IA 1 VTAs. Channeling resulted in under-utilization of the VTA area which affected the runoff control and nutrient reduction performance of the VTAs. Limited SSB storage capacity, ponded conditions in the VIBs, lower infiltrations rates of the VTA soil, high water table under the VTAs and SSB management techniques were identified as some of the key factors affecting the overall VTS performance in Iowa. The measured VTS performance for two years was compared to the containment system performance (predicted by the ELG models) as required by each site's permit requirements. The VTSs at the four sites did not perform equal or better than traditional containment system performance predicted by the effluent limitation guidelines (ELG) model. The measured performance for the four sites was also compared to the modeled performance (predicted by the VTS models) for 2006 data. The VTS models over estimated the VIB and VTA performance at the four sites.

1: Introduction

Iowa's beef industry represents a major economic activity in the state's economy. In 2004, cattle marketing in Iowa represented 20 % of all agricultural marketing (includes crops and livestock) and 37% of livestock and poultry marketing (Lawrence and Otto, 2006). The beef cow inventory in Iowa was 1.013 million head at the start of 2005 and is expected to increase in the coming years (Lawrence and Otto, 2006).

Beef feedlots in Iowa are generally classified into five different categories: earthen lots with windbreak, earthen lots with shed, concrete lot with shed, complete confinement building with solid floor and complete confinement building with slatted floor (Lawrence et al, 2006). According to the United States Environmental Protection Agency's (US EPA) revised 2003 rules and regulations (US EPA Federal Register, 2003), beef feedlots or animal feeding operations (AFOs) with more than 1,000 head are classified as large concentrated animal feeding operations (CAFOs), feedlots with 300-999 head as medium CAFOs and feedlots with less than 300 head as small CAFOs. Iowa has higher number of small and medium CAFOs compared to the large CAFOs. According to NASS agricultural statistics (2002), only 20% of the total feedlots in Iowa have more than 500 head.

Runoff from open feedlots contains nutrients including ammonia, organic matter, solids, pathogens and oxygen depleting pollutants; and if not handled properly can degrade surface water and ground water quality. Large CAFOs are required to control feedlot runoff and maintain a National Pollution Discharge Elimination System (NPDES) permit. A large CAFO is not allowed to discharge feedlot runoff except under the terms of the permit. The NPDES permit contains the US EPA's CAFO effluent limitation guidelines (ELGs). The ELGs are minimum requirements that put limitations on discharge of pollutants, total volume discharged and use of certain management practices. According to the US EPA Federal Register (2003), all large CAFOs are required maintain a NPDES permit, develop a nutrient management plan and identify best management practices necessary to implement the ELGs. The ELGs also require large CAFOs to contain runoff from a 25 year - 24 hour rainfall by application of best available technology (BAT).

Containment systems or holding ponds have been used to contain runoff from feedlots. Other methods to control runoff from feedlots are called alternative technologies. According to NPDES permit, any alternative technology used for large CAFOs must meet or exceed performance of baseline technologies (containment systems). The US EPA CAFO regulations states that median annual overflow volume based on 25 years of data along with the mass of pollutants discharged from the alternative technology must be equal or less that the baseline technology. These regulations place the burden of proof on individual producers for comparing the baseline technologies to alternative technologies. The vegetative treatment systems (VTSs) tested in this project are an alternative technology to control open feedlot runoff from large CAFOs and also provide an option for meeting the CAFO ELGs under the NPDES permit.

2: Literature Review and Objectives

2.1 Literature Review

Runoff from open feedlots contains pollutants and uncontrolled runoff, which can be a source of water pollution. To reduce the risk of surface water and ground water pollution, animal feeding operations (AFOs) need to control the runoff leaving their systems. Murphy and Harner (2001) studied various runoff control options for controlling and treating runoff from open feedlots. The runoff control options included vegetative systems, containment systems and evaporation ponds. The vegetative systems can include grass filters, wetlands, infiltration areas, and terraces. The evaporation ponds are used mostly in low rainfall areas, where the annual evaporation is more than twice the annual precipitation. The containment systems are one of the most popular methods used for controlling open feedlot runoff.

A containment system usually consists of a settling basin that intercepts the feedlot runoff and removes solids. The effluent from the settling basin then flows into a holding pond/detention basin for storage until it can be land applied depending upon soil conditions. Researchers have studied the designing of the containment systems and developed computer models to design and predict performance of the systems (Wensink and Miner, 1977; Koelliker et al., 1975; Anschutz et al., 1979; and Wulf et al., 2003). However, little literature was found on monitoring the performance of these systems for controlling runoff. A case study was done on design and installation of a feedlot runoff control system for a 100 head feedlot by Gilbertson and Nienaber (1973). The runoff control system included a debris basin or settling basin for settling solids, holding pond for storage and disposal area for land application of runoff. The debris basin removed an estimated 50 % of total solids in this study and no overflow was recorded during the one year study period.

The containment systems are designed for controlling runoff from a 25 year – 24 hour rainfall plus an allowance of sediment deposit and freeboard. The containment system should be designed according to the state regulations (Murphy and Harner, 2001).

Seepage from containment systems can lead to groundwater contamination which is one of the major concerns of using these systems. Parker et al. (1999) studied seepage losses from unlined holding pond used for runoff control. A seepage rate of 0.86 cm/day (0.34

in/day) following an extended dry period was measured in this study. The contaminant plume was measured to have exceeded a depth of 6.1 m (20 feet) below the surface indicating seepage of nutrients and contaminants from the holding pond. Other disadvantages of using containment systems include unpleasant odors, labor intensive management practices (land application), high construction and operation cost, safety hazard for animals and children and environmental unsightliness. The containment systems provide runoff control from a 25 year -24 hour rainfall (according to NPDES permit requirements) but may prove to be an expensive option especially for small operations. As a result, alternative non-basin technologies are considered as an option for controlling runoff from open feedlots.

Non-basin alternative technologies used to control and treat feedlot runoff have been studied for two decades. One such technology is vegetative filter strips (VFS), which have been researched for reducing pollutants in runoff from AFOs (Young et al., 1980; Dickey and Vanderholm, 1981; Edwards et al., 1983; Adam et al., 1986; Magette et al., 1989; Dillaha et al., 1988; Schwer and Clausen, 1989; Hawkins et al., 1998; and Shrivastava et al., 1996).

The VFS are a band of planted vegetation usually situated down slope of an animal facility and are used to reduce contaminant levels in the runoff generated from the animal facilities. The feedlot runoff is usually pre-treated (using settling basins) to reduce solids before being released onto a VFS. The VFS treats feedlot runoff through infiltration, settling, adsorption and aeration (Lorimor et al., 2002). The VFS can be designed on the following criteria: length, area ratio, hydraulic loading or nutrient loading (Lorimor et al., 2002). The performance of the VFS is evaluated by its ability to reduce pollutant levels in the runoff leaving the system. Maintenance of the VFS involves maintaining a good stand of vegetation, prevent channeling and periodic harvesting.

Ikenberry and Mankin (2002) reviewed literature on use of vegetative filter strips for treating agricultural wastewater. The reviewed studies show that use of filter strips removed 70-90% total solids (TS), 70-95% total phosphorous (TP) and reduced more than 85% percent of total kjeldahl nitrogen (TKN) and ammonia (NH_4-N). The factors affecting the performance of the VFS were identified as follows: formation of gullies or channels, length of the filter strip, and age of the VFS. The reviewed studies show that pollutant removal efficiency of the VFS is reduced by channeling and increased age of the VFA. Young et al.

(1980), Dickey and Vanderholm (1981) and Lim et al. (1998) studied the relationship between the length of VFS and concentration reduction in pollutants coming in. Lim et al. (1998) concluded that approximately 75 % of TKN, TP, ortho –P and total suspended solids were removed with in first 6.1 m (20 feet) of the filter strip.

According to the Natural Resources Conservation Service (NRCS) conservation practice standard, a wastewater treatment strip can be used to treat wastewater from livestock facilities. A wastewater treatment strip is defined as an area of herbaceous vegetation used to reduce nutrient loading, pathogens and other contaminants associated with animal manure or agricultural wastewater or runoff from livestock holding areas. Pre- treatment of runoff is recommended before being released onto the treatment strip (Boyd, 2002). The wastewater treatment strip is similar to the VFS in terms of operation and maintenance.

The ELGs for large CAFO require that runoff from a 25 year - 24hour rainfall should be controlled by application of BAT and its performance should meet or exceed the baseline technology performance. The containment systems meet the requirements for CAFO ELGs but they prove to be labor and cost intensive method for the producers. As a result, the producers have expressed interest in using alternative runoff control technologies that eliminate the need for long term storage (Woodbury et al., 2005). The VFS is an alternative non- basin technology, but it is not designed for meeting CAFO ELGs requirements. However, vegetative treatment systems (VTS) are an alternative technology that have a potential of meeting CAFO ELGs and also eliminate the need of long term storage of feedlot runoff as compared to containment systems.

The vegetative treatment systems (VTSs) are designed as a combination of individual treatment components: solid settling basin (SSB), vegetative infiltration basin (VIB) and vegetative treatment area (VTA). A VTS can be of two types: a stand alone VTA system in which a SSB followed by a VTA and a VIB-VTA system in which a SSB is followed by VIB followed by a VTA. Figure 1 shows a schematic of two types of VTSs.

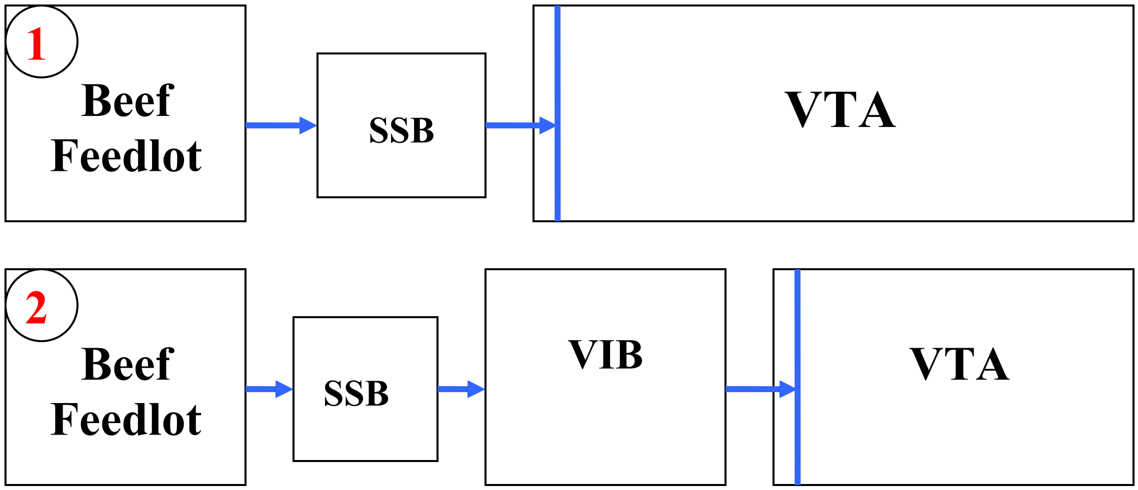

Figure 1: Schematic showing two types of vegetative treatment systems

A SSB is a concrete or an earthen basin designed to reduce the velocity of runoff coming from the feedlot and to settle solids before discharging to further components of the system. According to Lorimor et al. (2002), settling basins for open feedlots must be designed to settle solids from a 1-hour, 10 year storm. The liquid velocity leaving the basin must be reduced to 0.15 m/s (0.5 ft/s) or less. The three most important criteria for designing a SSB are storm size, basin surface area and feasibility in cleaning (Lorimor et al., 2002).

Maintenance of the SSBs includes scraping the solids and management of release of SSB effluent. According to Koelsch et al. (2006), SSB releases can be managed in the following three ways: unrestricted runoff release option in which SSB outlet is not restricted; passive runoff release control in which SSB outlet is restricted to release effluent slowly over a 36-72 hour period; and active runoff release control in which SSB outlet is physically controlled to release effluent depending upon VTA/VIB saturation conditions. For the passive and active runoff release control options, the SSB should be designed to handle a 25 year-24 hour storm.

A VTA is a vegetated area that is level in one dimension and has a less than 5% slope in the other dimension. Vegetation usually consists of perennial grass species. Pollutant removal can occur by several methods including filtration as the runoff flows through the vegetation, attachment of pollutants to roots and soil during infiltration, settling and plant uptake of nutrients. The settling basin / VIB effluent is spread evenly across the top width of the VTA using level spreaders and the effluent is allowed to slowly flow down slope through the vegetation. A good VTA design must address issues like: proper distribution of flow and nutrients in the VTA, proper selection of grass, limiting the potential of unplanned release of runoff, minimizing excess nutrient leaching within the VTA (Woodbury et al., 2006). The VTAs are usually sized based on nutrient balance or water balance. Maintenance of the VTA includes harvesting at least once a year, maintaining a good stand of vegetation, weed control, maintenance of level spreaders, leveling the VTA and preventing channeling in the VTA (Kuenstler and Koelsch, 2006).

A VIB is relatively flat area which is bermed to prevent outflow of effluent. It is planted with perennial grass species. The VIBs have tiles typically placed 1.2-1.5 m (4 to 5 feet) below the soil surface to allow movement of water through the treatment system. Pollutant removal from these systems can occur through filtration of runoff waters through the soil, plant uptake of nutrients, and pollutant degradation. A VIB after the SSB and before the VTA performs following functions: it is an additional source of pollutant concentration reduction prior to release to the VTA, it delays the runoff release and spreads the release over an extended period of time and it reduces the VTA influent volume through evapotranspiration and storage of water within the VIB soil profile (Lorimor et al., 2006). The VIBs for CAFOs are designed to retain 25-year, 24-hour storm with an additional six inches of freeboard. The time to drain the 25-year, 24-hour storm including runoff from the feedlot should be compatible with tolerance of the VIB vegetation to flooding which usually should not exceed 72 hours (Lorimor et al., 2006). Drainage rates in the VIB are affected by tile drain size and spacing. Maintenance of the VIB includes harvesting at least once a year, maintaining a good stand of vegetation, weed control and active management of release of VIB effluent onto the VTA (Kuenstler and Koelsch, 2006).

Researchers have studied the performance of the VTSs in controlling runoff from the open feedlots. Koelsch et al. (2006) reviewed the literature on use of VTSs for management of open feedlot runoff. Performance data for SSB, VIB and VTA was reviewed from 16 research citations. The VTA performance was estimated by comparing reduction of pollutant concentration or mass entering and leaving of the VTA. Studies showed that VTAs removed 70-90% of total solids, more than 80% of TKN and NH_4-N, 70 % of phosphorus and 75 %

BOD. Studies reviewed also show that the VIBs removed 80% of total solids, TKN, and TP and about 85% of NH_4-N. Based on the literature review, it was concluded that pre-treatment of the runoff, maintaining of vegetation and sheet flow in the VTA, and proper sizing of the VTS are some of key factors that affect the VTS performance.

Woodbury et al. (2002) designed, constructed and evaluated a passive vegetated runoff control system. The runoff control system consisted of a grass approach, a terrace with a flat bottom debris basin and a vegetated filter strip. The flat bottom debris basin with terrace was designed to collect runoff, accumulate solids and release effluent to the VFS. The nutrients totals originating from feedlot pens were estimated using Nutrient Fate Model for Beef Cattle Feedlots (Eigenberg et al, 1995). The debris basin with terrace removed 80% of total suspended solids (TSS). No discharge was recorded leaving the vegetative filter strip. Woodbury et al. (2003) used the same vegetative filter strip system to evaluate its performance in reducing contaminant discharge. Average reductions in TSS, volatile suspended solids (VSS) and chemical oxygen demand (COD) leaving the debris basin were measured as 80, 67 and 59 % respectively. No discharge was recorded leaving the filter strip during the three year study.

Woodbury et al. (2005) evaluated a vegetative treatment area (modified from the earlier study) to determine the mass balance of total nitrogen (TN) and map the solids basin discharge water distribution system using electromagnetic induction and map interpretation methods. The VTA was sized on nutrient balance using the Nutrient Fate Model for Beef Cattle Feedlots (Eigenberg et.al., 1995). Net removal of TN was quantified by doing nitrogen balance of discharge samples and estimating nitrogen removal by brome grass. Higher nitrate-N concentrations were found near the debris basin outlet. Soil tests also indicated movement of nitrate-N and seepage beneath the solids basin. Distribution of solids basin discharge was not uniform over the VTA area. No discharge was measured leaving the VTA during the study period.

2.2 Objectives

A study to evaluate the performance of the VTS for controlling runoff from large CAFOs in Iowa was initiated by Iowa State University (ISU) in 2004. The VTS models were developed by ISU to predict the performance of site-specific VTS (Wulf et al., 2005). The ELG model was developed based on Koelliker et al. (1975) to predict the performance of traditional containment systems. This model was used to compare the measured performance of the VTS with the baseline containment systems as required by the CAFO ELGs under the NPDES permit.

The performance of the VTSs constructed on four large CAFOs in Iowa was studied for two years. The objectives of this study are:

1) Evaluate the performance of the vegetative treatment systems by evaluating the measured data for the four Iowa sites during the two year research.
2) Compare the monitored performance of VTSs and modeled performance of containment systems for a two year study period.
3) Compare the modeled system performance (predicted by the VTS models) to the measured VTS performance for the first year of the study.

3: Methods and Materials

3.1 Site Descriptions

Four NPDES permitted CAFO beef feedlots in Iowa were included in this study. The vegetated treatment systems on these feedlots were designed by an engineering consulting firm using the ISU VTS models and 25 years of historical weather data. These sites were monitored under this study for two years based on NPDES permit requirements. Some of these sites were designed to have more than one VTS per site to accommodate site specific needs. In such a case only one VTS was chosen as a research portion for monitoring as a part of this study. The non-research portion of the VTS was monitored by the producers as required to meet their NPDES permit requirements. This study reports the results from the research portion of the system. Table 1 provides the size and VTS components for the research and non-research portion for the four sites. The monitoring periods for the four sites were initiated according to each site's NPDES permit initiation date.

Table 1 Size and VTS components for the five sites

	Number of Cattle		VTS Components	
	On-Site	**Research Portion**	**On-Site**	**Research Portion**
Central IA 1	1400	1000	2 SSB – 3 VTA	1 SSB – 2 VTA
Central IA 2	2400	800	3 SSB – 5 VIB – 3 VTA	1 SSB – 1 VIB – 1 VTA
Northwest IA 1	1400	800	3 SSB – 5 VTA	1 SSB – 1 VTA
Northwest IA 2	4000	4000	1 SSB – 1 VIB – 1 VTA	1 SSB – 1 VIB – 1 VTA

A detailed description of the research VTSs at the four sites included in this study is as follows:

Central IA 1: Central IA 1 has two VTSs designed to control runoff from a 4 ha (10 acre) earthen feedlot. The research portion of the VTS consists of one SSB followed by two VTAs. The non-research portion consists of a SSB and a VTA. A 3 ha (7.6 acre) feedlot area out of total 10 acres discharges into the research portion of the VTS. The research portion of the feedlot drains into a 4,276 m^3 (151,000 ft^3) concrete solid settling basin. According to the engineering reports, the 1.2 m (4 feet) deep SSB is designed to conform to NRCS Conservation Practice Standard 350 as well as IDNR requirements for storage capacity of liquids and solids. A gate valve controls the release of water from the SSB. Water released from the gate valve is collected into a flow distribution box. Two outlets in the walls of the flow distribution box (figure 2) allow the release of SSB effluent to the two VTAs. Two 0.2 m (8 inch) PVC pipes connected to these outlets release SSB effluent onto the two concrete pads. The SSB effluent released onto the concrete pads flow into two 3 m (10 feet) wide and 0.2 m (6 inch) deep concrete level spreaders (shown in figure 2), which are level across the top width of the two VTAs.

Figure 2: (L to R) Two settling basin outlets; a concrete flow pad leading to concrete flow spreader at Central IA 1

The complete VTS has three bermed VTAs running parallel starting with west monitored VTA (figure 3) at the highest elevation. The research portion consists of first two VTAs (figure 3) which are about 311 m (1020 feet) long and 25 m (80 feet) wide with a total VTA area of about 1.5 ha (3.7 acres). Geotextile flow spreaders (made from woven geotextile fabric) are located every 61 m (200 feet) along the VTA length to maintain uniform flow and prevent channelization in the VTAs (figure 6). The VTAs were seeded with reed canary grass and brome grass. The closest creek to the VTS is the Camp Creek which is approximately 229 m (750 feet) from the VTA outlet. The VTA area: feedlot area ratio for the research portion for central IA 1 is 0.5. The soil series present at this site are Clarion Laom, Cylinder Loam and Wadena Loam.

Figure 3: Aerial view of the Central IA 1 VTS with highlighted research VTS portion

Central IA 2: Central IA 2 has three VIB-VTA systems handling runoff from a 3.3 ha (8 acre) earthen feedlot. The first system is the North system which has a SSB discharging into three parallel VIBs that further discharges onto a VTA. The south system has one SSB discharging into a VIB. The effluent from the VIB is released into a corn field which serves as a land application area. The third system at this site is the middle system (figure 4) which is the monitored VTS. The other two systems are monitored by the producer.

The research VTS handles runoff from a one ha (2.6 acre) feedlot, which is a part of the 8 acre feedlot area. Feedlot runoff is discharged into a 0.9 m (3 feet) deep concrete SSB with a volume of 560 m^3 (19,800 ft^3). The settling basin is designed to store a 25 year – 24 hour storm (5.1 inch storm for Central IA 2) according to the engineering reports. A 0.3 m (12 inch) SSB outlet pipe discharges the SSB effluent into a VIB. The 0.3 ha (0.8 acre) VIB is designed to hold a liquid depth of 12.3 inches (7.2 inch runoff + 5.1 inch direct precipitation). The VIB has 0.1 m (4 inch) diameter perforated tiles installed 1.2 m (4 feet) deep and spaced 6.1 m (20 feet) apart under the soil surface.

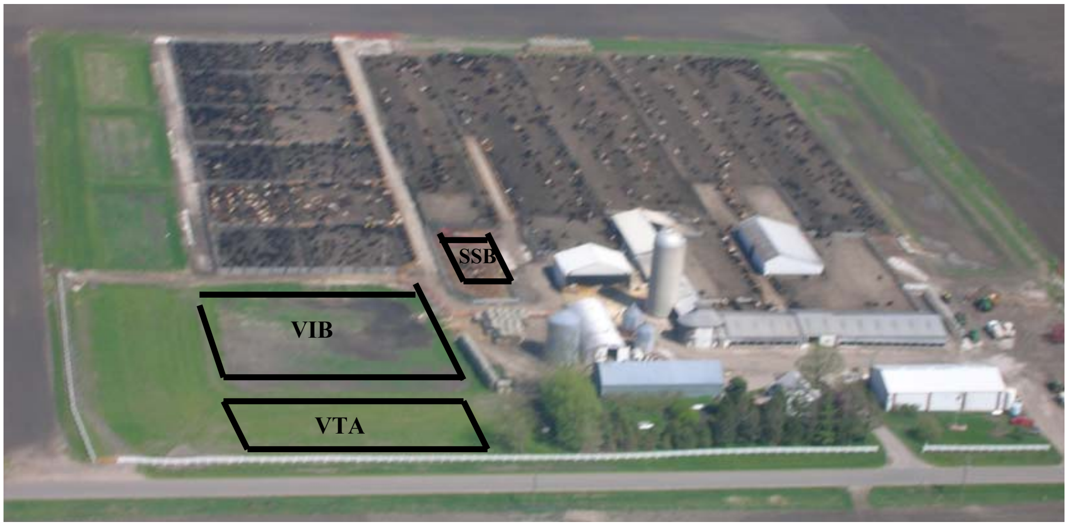

Figure 4: Aerial view of Central IA 2 VTS with highlighted research VTS portion

Flow from the tiles lines is collected in a concrete sump from where it is pumped onto 0.2 ha (0.5 acre) VTA. A gated pipe is used to spread VIB effluent evenly across the top width of the VTA (figure 5). Both VIB and VTA are planted with reed canary grass and brome grass. The VTA: VIB area ratio for the research potion is 0.6 and VTS area: feedlot area ratio is 0.5. The closest creek to the VTS is a perennial stream which is approximately 1,676 m (5,500 feet) from the VTA outlet. The soil series found at this site are Clarion Loam, Webster Clay Loam and Nicollet Loam.

Figure 5: Gated pipe at top end of the Central IA 2 VTA

Figure 6:Geotextile flow spreader in the Central IA 1 VTA

Northwest IA 1: This site has three stand alone VTA systems receiving a total feedlot area of 6.9 ha (17 acres). The first system has a SSB which discharges into three parallel VTAs. The second system has one SSB and one VTA. The third system is the research system with a 2.9 ha (7.2 acre) earthen feedlot. Feedlot runoff is collected into a 1.2 m (4 feet) deep concrete SSB having a volume of 3,710 m^3 (131,000 ft^3). The SSB is designed to store a 25 year-24 hour storm (5 inch storm for NW IA 1) according to the engineering reports. A 0.2 m (6 inch) SSB outlet pipe discharges water onto a 1.4 m (54 inch) wide concrete level spreader which is level across top width of the VTA (figure 7). A gate valve controls the release of effluent in the SSB outlet pipe.

Figure 7: SSB outlet pipe flowing into the concrete level spreader at Northwest IA 1

The five VTAs run parallel and are "stair stepped" down the slope starting with first VTA at the highest elevation. The monitoring VTA is shown in Figure 8. All VTAs have 0.3 m (1 foot) high berms to prevent overflow. All VTAs are level along the width and are sloped along the length of the VTA. The 1.6 ha (4 acre) monitoring VTA has geotextile flow spreaders located every 61 m (200 feet) along its length to maintain uniform flow and prevent channelization. All the VTAs were planted with reed canary grass and brome grass. The closest creek to the VTS is an unnamed tributary of Spring Creek which is approximately 518 m (1,700 feet) from the VTA outlet. The VTA area: feedlot area ratio for the research VTS is 0.5. The soils present at this site are Afton and Redford.

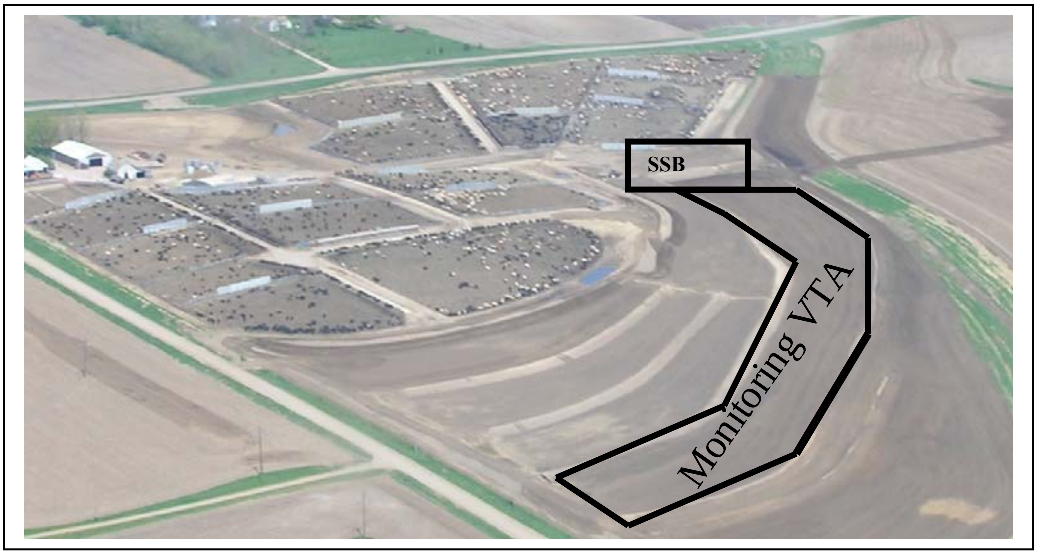

Figure 8: Aerial view of the Northwest IA 1 VTS with highlighted research VTS portion

Northwest IA 2: Northwest IA 2 has a VIB-VTA system designed to control runoff from a 2.8 ha (7 acre) concrete feedlot, which is the research VTS as shown in Figure 9. A concrete settling basin of 1,105 m^3 (39,000 ft^3) capacity collects the runoff from the feedlot. The 0.6 m (2 feet) deep SSB has a V-notch as a SSB outlet (functions as a V-notch weir) as shown in figure 10. The SSB effluent from the V-notch is discharged into a one ha (2.5 acre) VIB. The VIB has 0.1 m (4 inch) diameter perforated tiles installed 1.2 m (4 feet) deep and spaced 4.5 m (15 feet) apart under the soil surface. The 0.9 m (3 feet) deep VIB is designed to hold the 25-year, 24-hour storm runoff plus 12 inches of freeboard, assuming no infiltration occurs during the 24-hour duration of the storm.

Flow from the tile lines is collected in a manhole sump and pumped onto the VTA. A gated pipe is used to spread flow evenly cross the top width of the VTA. The 0.3 ha (0.7 acre) VTA was split into two 27 m (90 feet) wide VTAs (figure 9). At a given time, water is pumped onto only one VTA channel. The geotextile flow spreaders are located at 30 m (100 foot) intervals from the top of the channels to maintain uniform flow. Topographically, the VTA is at higher elevation to the VIB. As a result, a 0.2 m (6 inch) pipe installed at the VTA outlet gravity drains the VTA effluent back into the VIB. Both VIB and VTA are planted with reed canary and brome grass. The distance from the VTA outlet to a nearby classified stream is about 2,012 m (6,600 feet) but since the VTA discharge is recycled back into the

VIB so the effluent does not leave the system. The VTA: VIB area ratio is 0.6 and the VTS area: feedlot area ratio is 0.5. The soils present at this site are Moody silty clay loam and Ackmore silty clay loam.

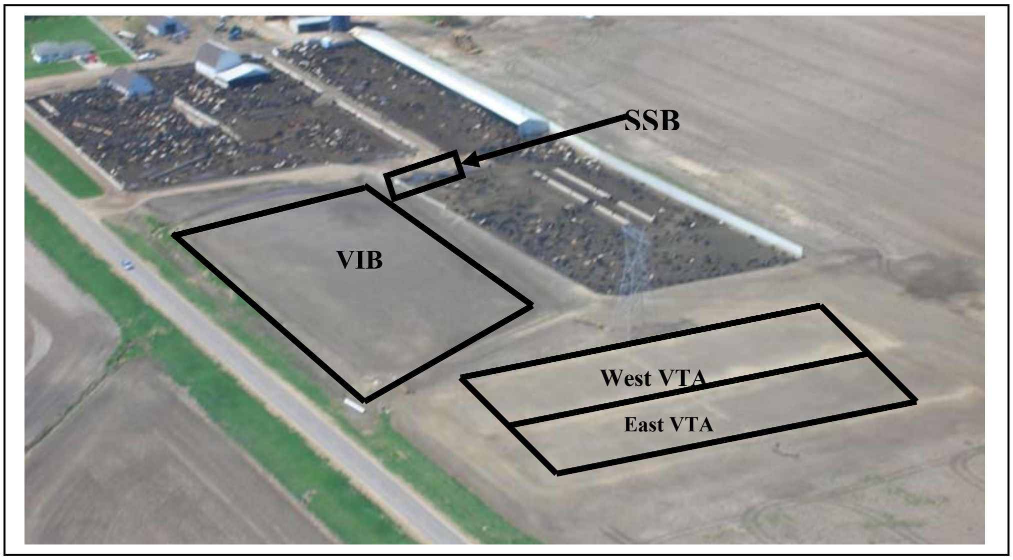

Figure 9: Aerial view of the Northwest IA 2 VTS with highlighted research VTS portion

Figure 10: V-notch SSB outlet at Northwest IA 2

3.2 IDNR VTS Design and Siting Criteria

The Iowa Department of Natural Resources (IDNR) has given design and siting criteria for a site for construction of a VTS (AFO rules, 2006). The design criteria for overall system are:

- Capacity to hold runoff from Nov. 1 – Mar. 30 or hold a 25 yr - 24 hr event (whichever is greater)
    - Containment in settling basin does not have to meet liner design and construction requirements when holding liquid for < 7 days following an event between Mar. 30 & Nov. 1

The design criteria for SSB are:

- Have capacity to store solids between cleanouts
- Provide flow-velocity reduction from a 10 yr -1 hr storm (less than 0.5 ft/sec for minimum of 5 minutes)

The design criteria for VIB and VTA are:

- Maximum slope of the constructed VIB should not exceed 1 percent
- Maximum slope of the constructed VTA should not exceed 5 percent (in one dimension
- Size of the VIB shall not be less than 30% of feedlot area
- Size of the VTA shall not be less than 30% of VIB surface area
- Tile system may be installed to enhance infiltration within the VTA
    - Tile lines shall be installed at the centerline of the berms of the VTA cells
    - No settled open effluent can enter tile lines except though infiltration through the soil profile

The siting criteria for VIB and VTA are:

- Depth to Water Table
    - Seasonal high must be capable of being lowered to 1.2 – 1.5 m (4-5 ft) below surface with a perimeter tile line installed outside of the VIB or VTA
- Subsoil / Geology
    - If in Karst terrain, must have a soil core to 7.6 m (25 ft)

    - Depth to sand / gravel / glacial outwash must be > 3 m (10 ft) for a VIB and > 1.8 m (6 ft) for a VTA
    - Depth to fractured or carbonated bedrock > 10 ft
- Soil permeability
    - 1.5 – 5 cm/ h (0.6 – 2.0 in/h) to depth of 1.5 m (5 ft) for VIB – VTA system
    - 0.5 – 5 cm/h (0.2 – 2.0 in/h) to depth for 5 ft for a stand alone VTA system
- No construction in areas subject to flooding more than once in 25 yrs
- Proximity to waters of the state
    - Classified waters or perennial streams
        - Discharge flow path of > 152 m (500 ft) or 0.5 ft / animal unit capacity
    - Un-crossable intermittent streams
        - Discharge flow path > 61 m (200 ft)

3.3 NPDES Permit Requirements

The NPDES permits issued to these sites by the IDNR, lists design criteria, operation and maintenance requirements of the each component of the system, monitoring requirements for the system, reporting requirements and the (nutrient management plan) NMP plan requirements. Some of the major operational and maintenance requirements for SSB, VIB and VTAs for both research and non- research portions of the systems are:

- Whenever possible, manure and settled feedlot effluent in the SSBs should be completely emptied during the growing season (April 1 thru October 31).
- Accumulation of solids must be monitored and solids that disrupt the flow in the VIB and VTA must be removed.
- During the non- growing season (November 1 thru March 31), all the feedlot runoff must be collected in the SSB and should not be released into the VIB/VTA.
- Dense vegetation is required to be maintained on VIBs and VTAs during the growing season. The VIB and VTA vegetation should be periodically mowed to maintain a healthy stand of vegetation.

- Photos of the vegetation cover on the VIB and VTAs should be submitted at least three times per year.
- Regular maintenance should be carried out for both VIBs and VTAs. Animals should not be allowed to graze on VIBs and VTAs.

The following monitoring was conducted on the research section of each site in accordance with the NPDES permit requirements. The NPDES monitoring requirements for the research portion of the sites are as follows:

- After the completion of construction of the sites and before the system is fully operational, background data from soil, surface and groundwater sources should be collected and submitted to the permitting agency.
- Daily temperature, daily precipitation and liquid levels in the SSB should be recorded.
- Surface water sampling: Surface water samples are collected upstream and downstream of the main tile line (or point of entry to the creek) and where the VTS release would enter the creek through the main tile line. Surface waters samples should be collected annually each spring. These samples should be analyzed for chemical oxygen demand (COD), total Kjeldahl nitrogen (TKN), ammonia (NH_4-N), total phosphorus(TP), total suspended solids (TSS), five day biochemical oxygen demand (BOD_5), nitrates (NO_3-N), ortho phosphorus (ortho P), chloride (Cl), total dissolved solids (TDS), pH and fecal coliforms. The dates and times of sampling were recorded along with the stream sampling locations using a global positioning system (GPS). The analytical methods used for analysis of the surface water samples are listed in Table 6 A.
- Groundwater sampling: Piezometers (4 cm I.D. PVC) have been installed to an average depth of 6.1 m (20 ft) to monitor groundwater quality. One piezometer is installed in the VTA, one up gradient of the system and one down gradient of the system. The samples are sent to a commercial laboratory to be tested for NO_3-N, NH_4-N, fecal coliform, and chloride. The locations of the piezometers once installed are recorded using the GPS. Groundwater samples are collected monthly at the beginning of each month. The analytical methods used for analysis of the groundwater samples are listed in Table 6 A

- Soil sampling:
    - *Surface soil sampling*: A 0-0.2 m (0-6 inch) deep soil sample should be collected annually. Soil samples should be collected at the point where the SSB discharges into the VIB, VTA inlet, within the VTA and at the outlet of VTA. If the length of the VTA is greater than 122 m (400 ft), an additional soil sample will be taken every 61 m (200 ft) along the length. The sample from each point will be a composite of 10-12 cores taken within a 3 m (10 ft) radius of the sample point. Points will be identified using GPS coordinates. Soil samples are analyzed by Iowa State University Department of Agronomy Soil Laboratory for NO_3-N, NH_4-N, P, K and pH.
    - *Deep soil sampling*: A 0-1.2 m (0-4 feet) deep soil sample should be collected biennially. The soil profile will be separated in the following increments for analysis: 0-6”, 6-12”, 12-24”, 24-36” and 36-48”. Deep soil samples should be collected at the point where the SSB discharges into the VIB, VTA inlet and outlet. Points will be identified using GPS coordinates. Soil samples are analyzed by Iowa State University Department of Agronomy Soil Laboratory for NO_3-N, NH_4-N, P, K and pH. The analytical methods used for analysis of the deep and surface soil samples are listed in Table 7 A
- Effluent sampling: Samples were collected from the SSB outflow, VIB outflow and VTA outflow. Event based samples are collected over a variable time period as determined by continuous flow measurements. Flow weighted composite samples were used for analysis. The samples were sent to a commercial laboratory to be tested for COD, TKN, NH_4-N, Total P, BOD_5, NO_3-N, PO_4, Cl_2, pH, fecal coliform, TSS, and TDS. Table 2 shows the number of sampling points per site. Figures 11, 12, 13 and 14 show the all the sampling locations on the schematic diagrams of the VTSs at Central 1 & 2 and Northwest IA 2 & 1 respectively. The analytical methods used for analysis of the effluent samples are listed in Table 8 A.

Table 2 Sampling points for each site

Site Name and Research Portion VTS	Groundwater	Surface water	Surface Soil Samples	Deep Soil Samples	Settling Basin Discharge	VIB Discharge	VTA Discharge
Central IA 1 1 SSB – 2 VTA	3	3	13	4	1	0	1
Central IA 2 1 SSB – 1 VIB – 1 VTA	3	3	8	3	1	1	1
Northwest IA 1 1 SSB – 1 VTA	3	3	8	2	1	0	1
Northwest IA 2 1 SSB – 1 VIB – 2 VTA	2	3	5	5	1	1	1

- Photos of vegetative cover of the VTA/VIB should be submitted at least three times year in May, August and October. Harvest dates should also be submitted.

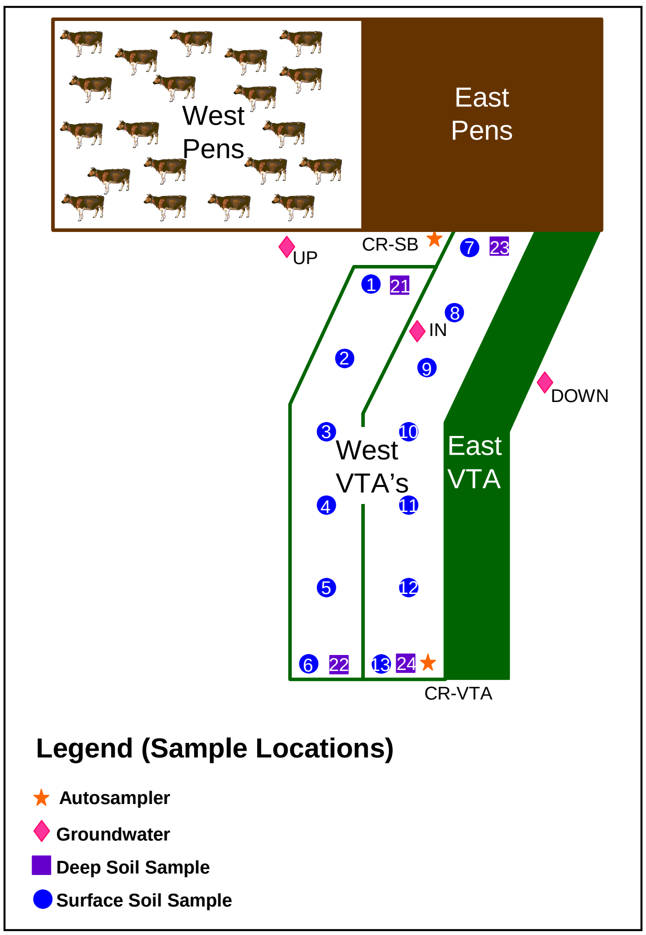

Figure 11: Sampling locations at Central IA 1

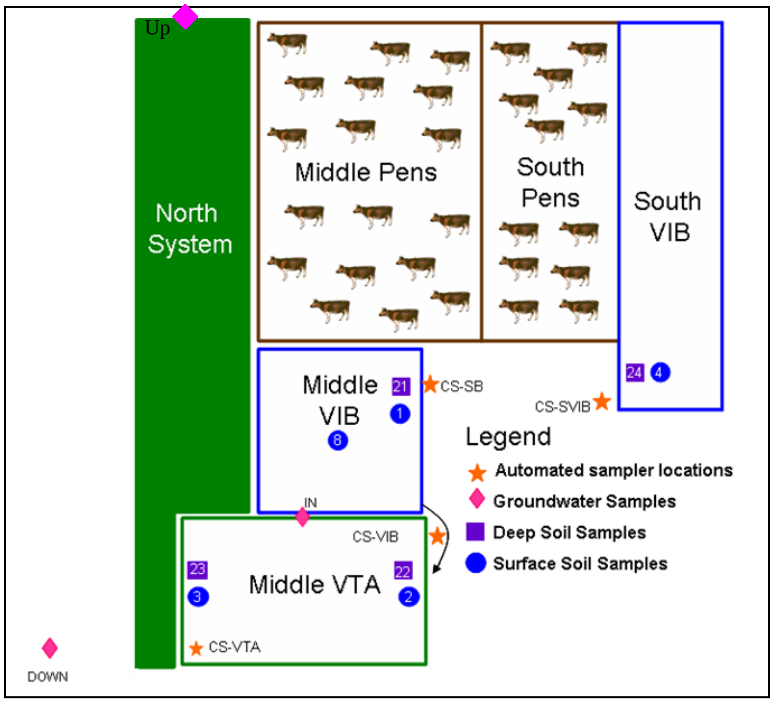

Figure 12: Sampling locations at Central IA 2

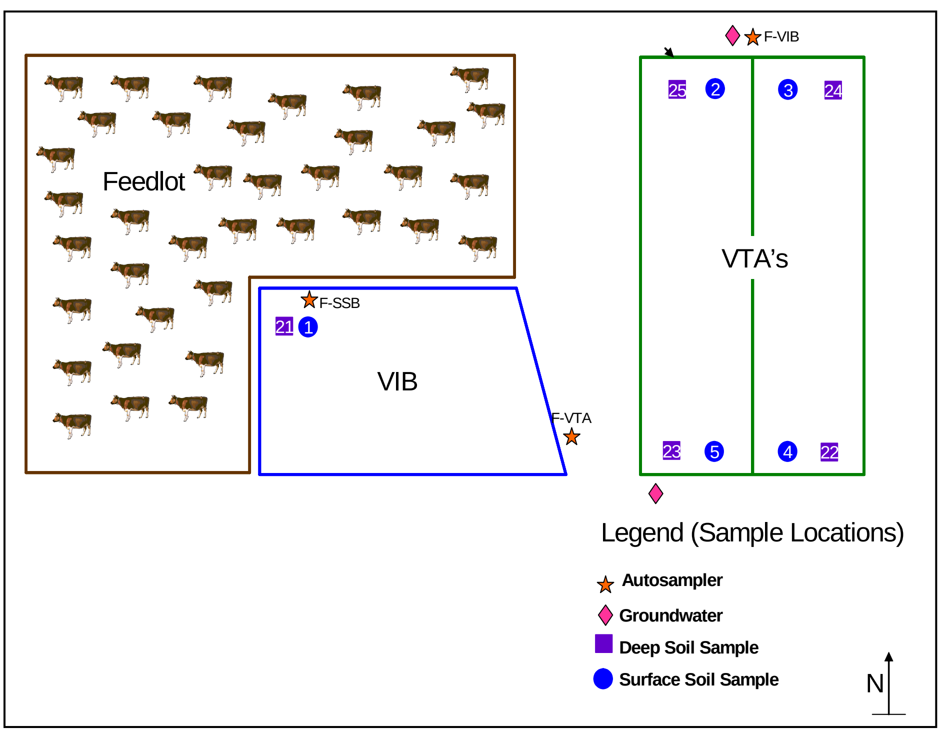

Figure 13: Sampling locations at Northwest IA 2

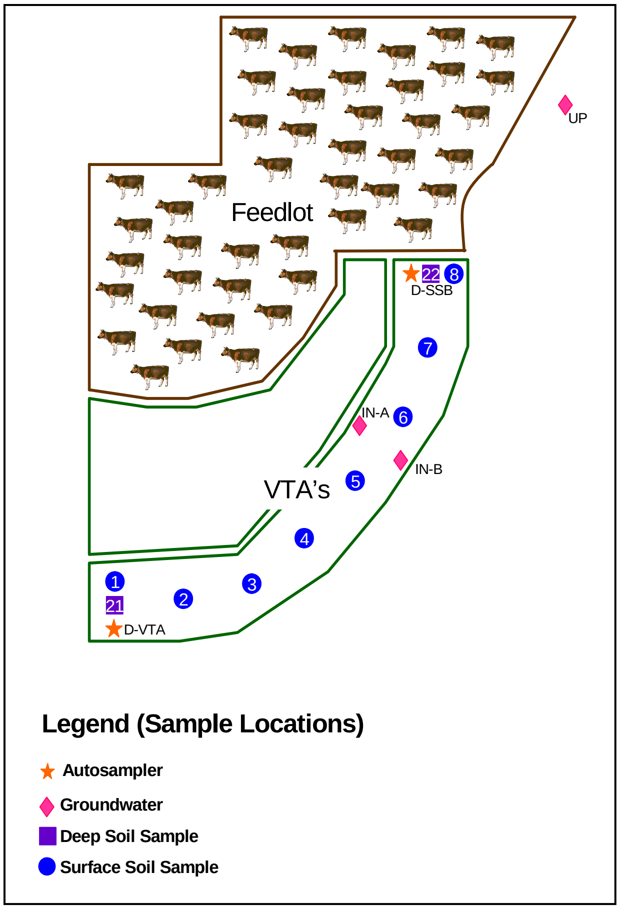

Figure 14: Sampling locations at Northwest IA 1

The monitoring requirements for non- research portion of the VTS are as follows:

- Date, time, duration, measured volume and nutrient mass of any release from the VTA must be recorded. Discharge samples must be collected and should be analyzed for COD, TKN, NH_4-N, Total P, BOD_5, NO_3-N, PO_4, Cl_2, pH, fecal coliform, TSS, and TDS.
- Groundwater samples must be collected quarterly from the groundwater monitoring wells and analyzed for NO_3-N, NH_4-N, fecal coliform, and chloride.
- Manure, feedlot effluent, SSB effluent and settleable solids must be analyzed at least once a year for nitrogen and phosphorus.
- Soil sampling requirements are same as the research portion requirements listed in the previous section.

- Photos of vegetative cover of the VTA/VIB should be submitted at least three times year in May, August and October. Harvest dates should also be submitted.

3.4 Monitoring System Description

Rainfall and Temperature: Precipitation depth and intensity were measured using an ISCO 674 tipping bucket rain gauge (Teledyne ISCO, Lincoln, NE). A standard passive rain gauge was also installed at all the sites as a back-up and for use during extreme cold weather conditions. Hourly temperature was measured at the sites using Hobo temperature loggers (Onset, Bourne, MA). The ISCO rain gauge and the temperature logger are shown in Figure 15.

Figure 15: ISCO 674 tipping bucket rain gauge and Hobo temperature logger

Settling basin release volume measurement and sampling: Depending upon whether the SSB outlet is a round pipe or a 0.5 m (1.5 foot) H-flume; an ISCO 750 low profile area velocity sensor or an ISCO 720 submerged probe (Teledyne ISCO, Lincoln, NE) was used to measure flow coming out of the SSB. Flow was measured every two minutes and flow based samples of SSB effluent are collected using an ISCO 6712 automated sampler (Teledyne ISCO, Lincoln, NE).

VIB release volume measurement and sampling: The effluent from the VIB is collected in a sump and is further pumped onto the VTA. Pumped volume was measured continuously using Neptune 0.5 m (2 inch) turbine flow meters (Neptune, Tallassee, AL). Flow based samples were collected using ISCO 6712 automated samplers (figure 16). The

Neptune turbine meter was interfaced with the automated sampler using an ISCO 780 smart 4-20 Module (Teledyne ISCO, Lincoln, NE). The ISCO 6712 sampler has the capability to interpret analog data from flow meters that output a 4-20 mA signal. The 780 Module allows the flow signal to pace the sampler. The 6712 sampler is able to convert the flow-proportional signal into selectable flow units, which can be displayed as flow rate and totalized flow.

VTA release volume measurement and sampling: Depending upon whether the VTA outlet is a round pipe or a 1.5 foot H-flume, an ISCO 750 low profile area velocity sensor or an ISCO 720 submerged probe was used to measure flow coming out of the VTA. Flow is measured every two minutes and flow based samples are collected using an ISCO 6712 automated sampler.

Instrumentation: The ISCO 750 low profile area velocity sensor uses Doppler technology to measure the average velocity in a full or partially flowing pipe. An integral pressure transducer measures depth of water flowing in the pipe to determine the flow area. Flow rate is calculated as a product of velocity and flow area by the ISCO 6712 sampler.

The ISCO 720 probe (figure 16) uses a differential pressure transducer to measure the level of water above the sensor placed in the stilling well of the flume. The ISCO 6712 sampler calculates flow rate using stage flow rate relationship for an H-flume. The 1.5 foot H-flume coupled with the ISCO 720 submerged probe will record a wide range of flow volumes (0.2 to 5 ft^3/s).

The ISCO 6712 automated sampler is a portable sampler used to collect flow or time based samples. It is powered with a 12 V deep cycle battery and recharged with local AC power or with a solar panel. The sampler has the versatility to integrate a large range of modular sensors with various flow measurement devices and to sample according to various monitoring protocols. Each sampler is equipped with 24 one liter bottles. The sampler can be programmed with up to 4 different programs at one time to collect samples according to required situations. The ISCO samplers at SSB location are connected with an ISCO 6712 digital cell phone modem (figure 16). The cell phone modem retrieves and transfers stored data digitally to a computer in the lab. The modem also has an ability to send alarms to the user when certain conditions are met within the programs. An ISCO 581 rapid transfer device (RTD) is used to download data stored in the sampler. The RTD is a self contained data shuttle with a non-volatile memory to store data from up to 20 samplers.

Figure 16: (L to R) ISCO 6712 digital cell phone modem, ISCO 6712 Sampler, ISCO 720 submerged probe, and Neptune turbine flow meter

The Neptune turbine flow meter shown in figure 16 is designed for full pipe flow and is capable of measuring flow up to 12.6 lps (200 gpm). The Tricon/E3 encoder (Neptune, Tallassee, AL) is attached to a register that will output an analog 4-20 mA signal. This allows integration with the ISCO 780 4-20 mA module attached to the 6712 sampler to collect flow paced samples proportional to the flow events.

At Central IA 1, an ISCO 750 sensor was installed at one of the two SSB outlet pipes because equal amounts of water flow through both the outlet pipes. Therefore, total flow coming out of the SSB is double the flow measured by the ISCO 720 sensor. Water flowing from both the VTAs is measured at the end of the second VTA using a 1.5 foot H-flume. The ISCO 750 sensor was used to measure flow out of the SSB outlet pipe at Central IA 2 and NW IA 1. An H-flume was installed at the NW IA 2 SSB outlet and an ISCO 720 probe was used for measuring flow out of the SSB. Table 3 provides the list of monitoring equipment used at each component of the research portion of the VTS.

Table 3: Instrumentation description for the research VTSs at each site

Site	SSB	VIB	VTA
Central IA 1	6712 sampler, 674 Rain gauge, Cellular modem, 750 ISCO velocity flow meter	-	720 ISCO + H Flume
Central IA 2	6712 sampler, 674 Rain gauge, Cellular modem, 750 ISCO velocity flow meter	Neptune turbine flow meter, 780 ISCO module	720 ISCO + H Flume
Northwest IA 1	6712 sampler, 674 Rain gauge, Cellular modem, 750 ISCO velocity flow meter	-	720 ISCO + H Flume
Northwest IA 2	6712 sampler, 674 Rain gauge, Cellular modem, 720 ISCO + H-Flume	Neptune turbine flow meter, 780 ISCO module	750 ISCO velocity flow meter

3.5 Data Collection

After a rainfall event, water flows through the system and the flow data was recorded every two minutes by the ISCO samplers. Samples are collected based on flow volume recorded at the SSB, VIB and VTA outlets. The flow data was retrieved from the samplers and processed in Flowlink software (Teledyne ISCO, Lincoln Nebraska). Data from Flowlink was transported into MS Excel for further analysis.

The ISCO samplers were programmed with site-specific programs which were different for the SSB, VIB, and VTA at each site. The samplers were programmed in such a way that most of the samples would be collected close to peak of the hydrograph. Figure 17 shows an example of Central IA 1 hydrograph (May 6-7, 2007) for a VTA release event, where 12 samples were collected by the ISCO sampler over two days. Figure 18 shows the same hydrograph plotted in MS Excel showing the two samples closest to hydrograph peaks that were selected to be sent for analysis.

For a release event, one sample closest to the peak of the hydrograph was selected per day to be sent for analysis to Test America laboratory, which is a commercial laboratory that analyzes samples for nutrients listed in the monitoring requirements of the permit. Test America requires that two 1 liter bottles with no treatment, one 1 liter H_2SO_4 treated bottle and one 100 ml sterile bottle should be filled for analysis of one sample.

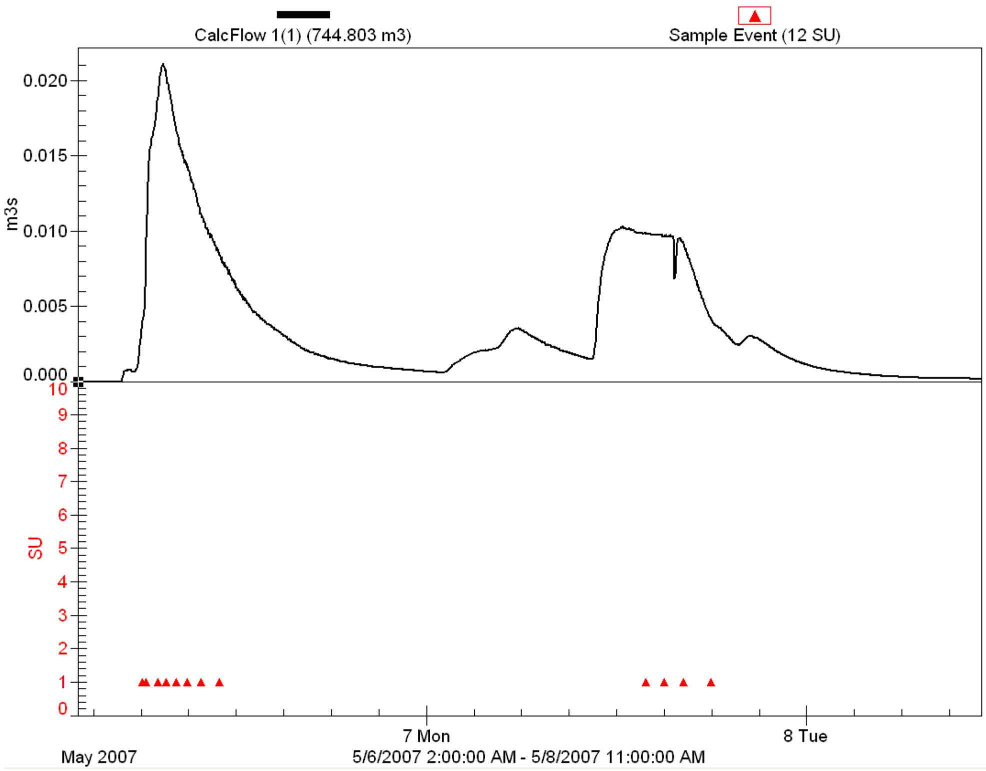

Figure 17: Flow hydrograph in Flowlink with samples collected for the Central IA 1 VTA event on May 6-7 2007

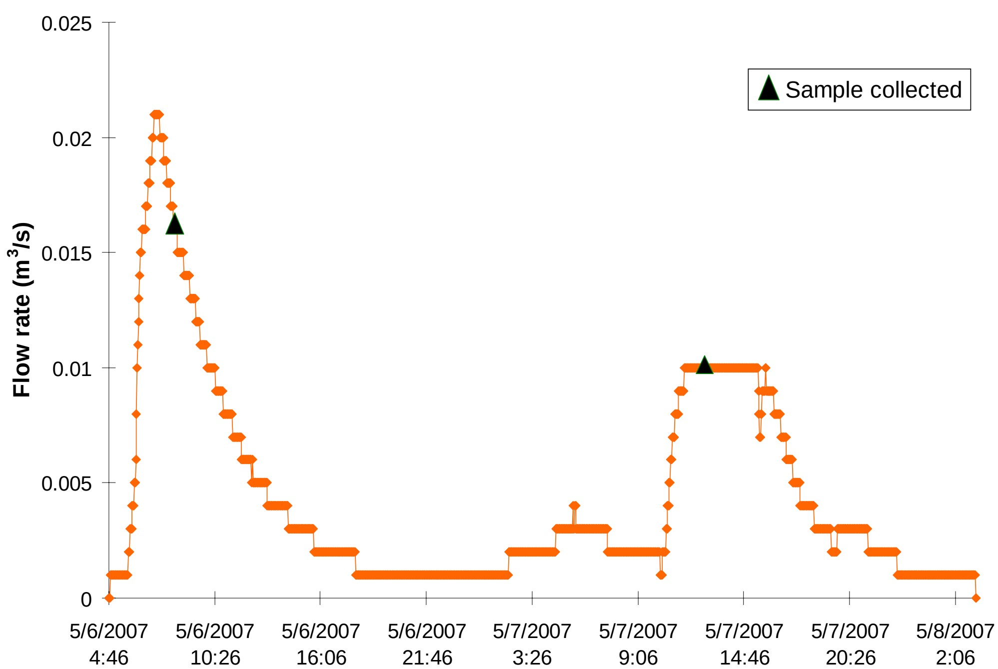

Figure 18: Flow hydrograph and two samples selected for the Central IA 1 VTA event on May 6-7 2007 in Excel

Since the ISCO sampler can collect only 24 one liter samples per program, therefore all the ISCO samplers were programmed to fill three bottles per sample. Three 1 liter ISCO bottles filled per sample were used to fill four Test America bottles (3100 ml). A Test America chain of custody protocol was followed to ship the samples. Samples were shipped within 24 hours of collection and they were packed with enough ice to maintain temperature below 4^{o}C during the shipping process.

The ISCO programs can be written in one or two parts depending upon sampling requirements. Sampling intervals for the programs were set to collect samples from high and low intensity storms for both short and long durations. For instance, the first part of program was set to take first two samples after 10 m^3 of flow (for low intensity storms) and the second part of the program was set to take next six samples after 30 m^3 of flow (for high intensity storms). Each sampler was programmed with four programs for different flow events: low flow, medium flow, two high flow programs. For large flow events, high flow 1 & 2 programs were used; for medium events, medium flow programs were used and for low flow events, low flow programs were used. Tables 4, 5, 6, and 7 show sampling intervals used in ISCO programs for SSB, VIB and VTA for Central IA 1 & 2 and NW IA 1 & 2 respectively.

During the 2006 monitoring period, medium flow programs were used for Central IA 1 and 2 and high flow 1 program was used for NW IA 1 and 2 at the SSB, VIB and VTA. In 2007, SSBs were valved at Central IA 1 & 2 and NW IA 1. For the VTA and VIB, medium flow programs were used for Central IA 1 and 2; high flow 1 program was used for NW IA 1 and 2. High flow 2 programs were used for valved SSBs at Central IA 1 & 2 and NW IA 1. The high flow 1 program was used for NW IA 2 SSB because high flow volumes were expected to be released from a 2.8 ha (7 acre) concrete feedlot.

Table 4: ISCO program settings for central IA 1

SSB	VTA
Two part program • *Part A*: Enable at 0.08 ft flow depth • *Part B*: Enable when part A complete	Two part program • *Part A*: Enable at 0.05 ft flow depth *Part B*: Enable when part A complete
low flow • First two samples after every 5m^3 • Next six samples every 10m^3	**low flow** • First two samples after every 5m^3 • Next six samples every 10m^3
med flow • First two samples after every 5m^3 • Next six samples every 20m^3	**med flow** • First two samples after every 5m^3 • Next six samples every 50m^3
high flow 1 • First two samples after every 10 m^3 • Next six samples every 50m^3	**high flow 1** • First two samples after every 10 m^3 • Next six samples every 70m^3
high flow 2 • First four samples after every 30m^3 • Next four samples every 60m^3	**high flow 2** • First four samples after every 40m^3 • Next four samples every 100m^3

Table 5: ISCO program setting for Central IA 2

SSB	VIB	VTA
Two part program • *Part A*: Enable at 0.03 ft/s velocity • *Part B*: Enable when part A complete	One part program • ~ 40 gal/pulse	Two part program • *Part A*: Enable at 0.05 ft flow depth *Part B*: Enable when part A complete
low flow • First two samples after every 5m^3 • Next six samples every 10m^3	**low flow** • Eight samples every 100 pulses	**low flow** • First two samples after every 5m^3 • Next six samples every 10m^3
med flow • First two samples after every 5m^3 • Next six samples every 20m^3	**med flow** • Eight samples every 200 pulses	**med flow** • First two samples after every 5m^3 • Next six samples every 30m^3
high flow 1 • First two samples after every 10 m^3 • Next six samples every 50m^3	**high flow 1** • Eight samples every 400 pulses	**high flow 1** • First two samples after every 10 m^3 • Next six samples every 70m^3
high flow 2 • First four samples after every 30m^3 • Next four samples every 60m^3	**high flow 2** • Eight samples every 600 pulses	**high flow 2** • First four samples after every 40m^3 • Next four samples every 100m^3

Table 6: ISCO program settings for NW IA 1

SSB	VTA
Two part program • *Part A*: Enable at 0.08 ft flow depth • *Part B*: Enable when part A complete	Two part program • *Part A*: Enable at 0.05 ft flow depth *Part B*: Enable when part A complete
low flow • First two samples after every $5m^3$ • Next six samples every $30m^3$	**low flow** • First two samples after every $5m^3$ • Next six samples every $30m^3$
med flow • First two samples after every $10m^3$ • Next six samples every $50m^3$	**med flow** • First two samples after every $10m^3$ • Next six samples every $70m^3$
high flow 1 • First two samples after every 10 m^3 • Next six samples every $100m^3$	**high flow 2** • First two samples after every 10 m^3 • Next six samples every 150 m^3
high flow 2 • First four samples after every $50m^3$ • Next four samples every $150m^3$	**high flow 2** • First four samples after every $50m^3$ • Next four samples every $150m^3$

Table 7: ISCO program setting for NW IA 2

SSB	VIB	VTA
Two part program • *Part A*: Enable at 0.25 ft flow depth • *Part B*: Enable when part A complete	One part program • ~ 40 gal/pulse	Two part program • *Part A*: Enable at 1 ft/s flow velocity *Part B*: Enable when part A complete
low flow • First two samples after every $10m^3$ • Next six samples every $50m^3$	**low flow** • Eight samples every 200 pulses	**low flow** • First two samples after every $5m^3$ • Next six samples every $30m^3$
med flow • First two samples after every $50m^3$ • Next six samples every $100m^3$	**med flow** • Eight samples every 400 pulses	**med flow** • First two samples after every $10m^3$ • Next six samples every $100m^3$
high flow 1 • First four samples after every 100 m^3 • Next four samples every $200m^3$	**high flow 1** • Eight samples every 800 pulses	**high flow 1** • First two samples after every 50 m^3 • Next six samples every $150m^3$
high flow 2 • First four samples after every $150m^3$ • Next four samples every $250m^3$	**high flow 2** • Eight samples every 1000 pulses	**high flow 2** • First four samples after every $50m^3$ • Next four samples every $200m^3$

3.6 Data Analysis

The data reported in this thesis is for the four sites that were monitored for different durations in 2006 and 2007. Central IA 1 was monitored during June thru Oct 2006 and April thru Oct 2007; Central IA 2 was monitored during May thru Oct 2006 and April thru Oct 2007; and NW IA 1 & 2 were monitored during August thru Oct 2006 and April thru Oct 2007. The data was collected according to permit monitoring requirements of the sites. Table

8 shows the total monitoring period, 25 year- 24 hour storm and the largest storm recorded at each site. The largest storm was recorded over a 24 hour period.

Table 8: Monitoring period, 25-year 24-hour design storm size and largest storm recorded at each site

Site	Monitoring period (days)	25 year 24 hour design storm in cm (inches)	Largest storm in cm (inches)
Central IA 1	367	12.7 (5.0)	13.2 (5.2)
Central IA 2	398	12.9 (5.1)	8.1 (3.2)
Northwest IA 1	337	12.7 (5.0)	5.4 (2.1)
Northwest IA 2	337	12.4 (4.9)	6.4 (2.5)

To achieve the objectives of this study, flow volume and nutrient mass released for each release event from the SSB, VIB and VTA were required. The flow volume data was recorded at two minute intervals using ISCO sensors. The nutrient mass released from the SSB, VIB and VTA was calculated using nutrient concentration and the flow volume associated with each sample.

In 2006, the SSBs releases onto a VIB/VTA were unrestricted. After a rainfall event feedlot runoff collected in the SSB was released to the VIB/VTA through a pipe sized to provide outlet control. Using this approach, when the SSB effluent was discharged onto a VIB/VTA which was already saturated from the rainfall, it resulted in a VTA release. To provide for infiltration in the VIB/VTA under saturated conditions, it was decided to control the SSB release by valving the outlet pipes, such that release could be scheduled when the VIB/VTA were not saturated. In 2007, valves were installed at the SSB outlet pipes at Central IA 1 and 2 and NW IA 1, so that the producers could manage the systems more efficiently. The NW IA 2 producer was reluctant to valve the SSB because the feedlot runoff collected in basin would back up into the feedlot as the SSB is a part of the feedlot and did not do so during this monitoring period.

In 2006, one sample was collected and sent for analysis for each release event. If the release continued for more than one day, one sample was collected for each additional day. In 2007, the producers started controlling SSB releases and releasing small amounts on subsequent days of the rainfall event, therefore a SSB release could not be associated with a rainfall event. Collecting one sample per day of the SSB release proved to be expensive. A new sampling protocol was established for collecting SSB samples under which one sample from the first day of SSB release was collected and sent for analysis. One sample per day was collected for the following day releases and these samples were archived in a freezer. When the data was analyzed, a few archived samples were selected (if required) to be sent for analysis. The rule for selecting archived samples was that if the SSB effluent from a rainfall event was released for more than three days and a sample was collected on the first day, then an archived sample was selected for the day that was 48 hours after the first sample.

In this case, mass of nutrients being released from the SSB was calculated as explained with an example in Table 9. After it rained on 8/21, 8/22 and 8/23, the producer released on 8/26 and 8/27 and one sample was collected and sent for analysis on 8/27. Therefore, in this case 8/21 to 8/27 is termed as one event and 203.8 m^3 is the representative volume for 8/27 sample.

Table 9: Example showing calculation of nutrient mass for SSB archived samples

Date	Rainfall (in)	SSB Release (m3)			
8/21/2007	0.5	0.0			
8/22/2007	1.77	0.0			
8/23/2007	0.65	0.0			
8/26/2007		15.6			
8/27/2007		188.2	sample sent for anaylsis		
8/28/2007	2.41	0.0			
9/2/2007		60.1			
9/3/2007		66.1	sample sent for anaylsis		
9/4/2007		153.9	archived sample		
9/6/2007		87.9	selected archived sample		
9/8/2007		311.5	archived sample		
9/9/2007		381.8	selected archived sample		
9/24/2007	0.6	81.3			
9/25/2007	0.41	0.0			
9/30/2007	0.33	0.0			
10/2/2007	0.51	0.0			
10/4/2007		245.7	sample sent for anaylsis		
10/5/2007	0.06	123.9	archived sample		
10/6/2007		73.7	selected archived sample		

The 8/28 to 9/9 period is considered as one event because it rained on 8/28 and the producer kept on releasing 11 days after the rainfall. A sample was sent for analysis on 9/3 and it represents a volume of 126.2 m^3 (60.1 + 66.1 m^3). Archived samples from 9/6 and 9/9 were selected based on the 48 hour criteria and sent for analysis. The 9/6 sample represents a volume of 241.8 m^3 (153.9 +87.9 m^3) and the 9/9 sample represents a volume of 693.3 m^3 (311.5 +381.8 m^3). The period from 9/24 to 10/6 is considered as the next event.

It was observed in the two years of study that the VIB tile drains flow all year around. Therefore it was difficult to associate a specific volume representing a VIB sample resulting from a rainfall event. The VIB sampling protocol was as follows: The Central IA 2 VIB was programmed to take a sample every 30 m^3 of tile flow and NW IA 2 was programmed for 120 m^3. Higher runoff volume was expected from NW IA 2 VIB because it has a 2.8 ha (7 acre) concrete feedlot as compared to a 1 ha (2.6 acre) earthen feedlot at Central IA 2. One VIB sample was collected after every rainfall event and sent for analysis. Any additional samples collected after the first sample prior to next rainfall were archived and selected to be sent for analysis if needed. The volume of water flowing out of the VIB was measured using a turbine meter. Therefore, volumes were cumulatively tracked, but because there is no time component, actual flow rates were not measured. The volumes were recorded during each site visit. The mass of nutrients discharged from the VIB was calculated using the concentration of the collected sample and the volume recorded between the pervious turbine meter recording and the reading obtained on the day of sample collection.

For VTA release events, one sample was collected per day of release. If the release continued for more than one day, one sample was collected for additional days and sent for analysis. For instance, if the flume at the VTA outlet was flowing for three days, a sample would be collected for each day and the volume for each day of release is used as representative volume for calculating nutrient mass. The VTA samples were not archived.

For SSB and VTA release events, if a release continued for more than one day and multiple samples are analyzed for that event, the total mass of nutrients released from that multiple day event was calculated by adding masses released for the individual days.

3.7 The VTS and ELG Models

3.7.1 The VTS Models

Two computer models were developed at Iowa State University (ISU) to predict the performance of vegetative treatment systems (VTSs). The Iowa State University models for VTSs are called as VIB-VTA model version 1.004 and VTA model version 1.004 (Wulf and

Lorimor, 2005). The VIB-VTA model is designed to predict the performance of a VIB-VTA system and the VTA Model is designed for a stand alone VTA system. These models predict runoff volume and nutrient mass leaving the system. These models are developed by using the pilot scale data and literature values. The user guidelines and model descriptions can be found in Wulf and Lorimor (2005).

The models are event or routine based and simulate the performance of both VTA and VTA-VIB systems. Both models require numerous inputs such as site specific weather information, soil properties, feedlot, settling basin, VIB and VTA design characteristics. The model outputs include released volume and mass of nutrients released from each component of the system.

*VTA model***:** The VTA model calculates daily runoff from a feedlot based on the inputted weather data and accumulates the runoff in the SSB and then releases it to the VTA. In the model, the length of the VTA is divided into 100 equal lengthwise sections and the model tracks the volume of effluent and concentration of nutrients from the SSB through these 100 VTA sections. The model also accounts for infiltration into the VTA and direct precipitation onto the VTS.

VIB-VTA Model: The VIB-VTA model calculates daily runoff from the feedlot, accumulates it in the SSB, and then releases it to the VIB with subsequent discharge to the VTA. The model tracks the wetting front of the settling basin effluent down the VIB soil profile as the liquid moves through the tiles. Tile flow from the VIB is routed to the VTA and the model simulates this as inflow to the VTA. The model accounts for infiltration, evaporation and direct precipitation onto the system. The runoff front in the VTA moves to the next section until water removal exceeds input and the wetted front stops moving.

The VIB-VTA and VTA models also contain certain events, which contain a code for executing that event. There are 10 events in these models: user input, soil properties calculation, snow events, five day rainfall, hyetograph, hydrograph, settling basin, VTA/VIB soil moisture, VTA/VIB infiltration and VTA/VIB redistribution. Most of the calculations are performed with daily execution of these events to generate final output. The soil properties event calculates porosity, field capacity and wetting front for four layers of the soil in the VIB and VTA. The snow melt event calculates the snow melt from a feedlot and adds it to the total volume released from a SSB. The five-day rainfall event in the model determines the antecedent moisture content of the feedlot surface. The hyetograph event generates a rainfall hyetograph from the precipitation input in the weather file. The feedlot runoff hydrograph is generated using the Soil Conservation Service (SCS) unit hydrograph method in the hydrograph event. The settling basin event tracks settling basin inputs, calculates release volume and nutrient concentrations, and routes the flow to the VIB/VTA. The model sets the nutrient concentrations entering the system based on settling basin capacity and type of feedlot surface. Mass of nutrients leaving the settling basin is calculated as the product of outflow volume and outflow nutrient concentration. The VIB/VTA soil moisture event determines evapotranspiration of the system and plant uptake of nitrogen and phosphorus. The VTA/VIB infiltration event estimates infiltration of runoff and precipitation into the sections of the VIB/VTA. The VTA redistribution event tracks moisture in soil profile of the VIB/VTA. The detailed description of the events is given in Wulf and Lorimor, 2005. The VTS models assume nutrient concentrations leaving the SSB based on feedlot surface and capacity of the basin (table 10). These numbers are based on literature values.

Table 10: Nutrient concentration assumed by the models based on feedlot surface and capacity of the basin

	Earthen Feedlots		**Concrete Feedlots**	
Basin Capacity	**Capacity ≥ 5 in.**	**Capacity < 5 in.**	**Capacity ≥ 5 in.**	**Capacity < 5 in.**
Nutrient/Pollutant	**mg/l**	**mg/l**	**mg/l**	**mg/l**
Total Nitrogen	67	135	135	200
Ammonia	50	100	100	150
Total Phosphorous	20	60	60	90
Total Solids	2000	4000	4000	6000
COD	2650	5300	5300	7950

3.7.2 The ELG Model

The Effluent Limitation Guidelines (ELG) model was developed at Iowa State University to predict the performance of traditional containment systems. The ELG model was modified from the runoff control model designed for containment systems in Kansas by

Koelliker et al. (1975). The user guidelines and model descriptions of the ELG model can be found in Wulf and Lorimor (2005).

This model uses weather data and feedlot design characteristic as inputs to predict daily feedlot runoff volume and runoff storage in a containment basin. The model predicts the volume of water to be pumped from the basin for land application. The model accounts for direct precipitation and evaporation from the storage facility. The model predicts the percentage of the runoff that may be released to the environment due to climatic conditions beyond the control of the operator. According to the model, water is pumped from the basin if: the current day precipitation and the preceding three days precipitation is less than 0.12 cm (0.05 inches), current day's temperature is above 0^{o}C (32^{o}F), ground must not be frozen, and ground must be free of snow. It is assumed by the model that adequate area is available for land application of pumped out volume.

The ELG model contains six events for running the model: weather input, five day rainfall, feedlot runoff, containment basin, dry consecutive days and totals. The five day rainfall event determines whether the feedlot surface condition is wet or normal. The feedlot runoff event calculates runoff volume due to rainfall/snowfall events. The containment basin event calculates daily basin volume and nutrient mass in the basin. The dry consecutive days event calculates the conditions suitable to pump from the basin. The totals event tabulates the overall system performance and nutrients released. The nutrients concentrations released from a containment system assumed by the ELG model in case of a basin overflow for a earthen feedlot are: TKN – 65 mg/l, NH_4-N- 50 mg/l, total P – 20 mg/l, total solids – 2000 mg/l and COD – 2650 mg/l; nutrient concentrations assumed for a concrete feedlot are: TKN – 98 mg/l, NH_4-N- 75 mg/l, total P – 30 mg/l, total solids – 3000 mg/l and COD – 3975 mg/l. The model assumes that nutrient concentrations coming in and leaving the containment system do not change with detention time.

4: Results and Discussion

4.1 Performance Evaluation of the Vegetative Treatment Systems

The performance evaluation of the VTS includes analyzing the effects of VTS on groundwater, deep soil, surface soil, surface water; analyzing the effectiveness of the VTS to control feedlot runoff and nutrients; and comparing VTS performance with containment systems performance predicted by the ELG model.

1. Surface water data analysis: As per each site's NPDES permit requirements, surface water samples were collected from the creek nearest to the site at the start of the each monitoring period. The NPDES permit required that two surface water samples should be collected from the creek at an upstream point and a downstream point with respect to the feedlot. The third sample was collected where the main tile line joined the creek. Two sets of surface water samples have been collected for each site for the two year monitoring. It was not possible to reach any conclusion concerning the impact of the systems on local surface water quality due to the limited data collection.

2. Groundwater data analysis*:* In accordance with each site's NPDES permit requirements, a set of three groundwater samples was collected at the beginning of each month during the monitoring period. Another set of three groundwater samples were also collected as a background sample in 2006 before any effluent was applied to the VTS. The three groundwater samples were collected from three groundwater wells that were installed up gradient, in the system and down gradient of the VTS. The placement of these wells was done by an IDNR hydro-geologist to represent up gradient, in the system and down gradient groundwater flow patterns. These samples were analyzed for NH_4-N, Cl, NO_3-N and fecal coliform. Groundwater data analysis for Central IA 1 & 2 and NW IA 1 & 2 is discussed in sections 4.1.1, 4.1.2, 4.1.3 and 4.1.4 respectively.

3. Deep soil data analysis: Deep soil samples were collected biennially with a soil sampling probe (Giddings Machine Company, CO) according to each site's NPDES permit requirements. Samples were collected 4.2 m (48 inches) deep and cut into 0-0.15 m (0-6 inches), 0.15-0.3 m (6-12 inches), 0.3-0.6 m (12-24 inches), 0.6-0.9 m (24-36 inches) and 0.9-1.2 m (36-48 inches) pieces. These pieces were put in soil sampling bags and sent for analysis to Soil and Plant Analysis Lab in the Department of Agronomy, Iowa State University. Deep soil samples were collected at the VTA inlet and outlet and VIB inlet. Since only one sample (which is the background sample) has been collected for each site at this time, it is not possible to conclude any impacts of nutrient loading in the soil with the limited data.

4. Surface soil data analysis: Six inch deep surface soil samples were collected annually with a hand held soil probe according to each site's NPDES permit requirements. The first set of surface soil samples was collected in 2006 as a background sample at the initiation of the monitoring at each site. The second and third sets of samples were collected at the end of the 2006 and 2007 monitoring periods respectively. The surface soil samples were collected near the VIB inlet and VTA inlet and outlet. If the VTA was longer than 122 m (400 feet), additional samples were collected every 61m (200 feet) along the VTA length. These samples were analyzed for P, K NH_4-N, NO_3-N and pH. Analysis of surface soil data for Central IA 1 & 2 and NW IA 1 & 2 is discussed in sections 4.1.1, 4.1.2, 4.1.3 and 4.1.4 respectively.

5. Overall VTS performance: In the 2006 and 2007 monitoring periods, flow based samples were collected for the SSB, VIB and VTA release events. The nutrient mass released from each release event was calculated using the flow volume. The overall VTS performance including individual VIB and VTA performance is evaluated per site based on the flow volume and nutrient mass data. The overall VTS performance evaluation for Central IA 1 & 2 and NW IA 1 & 2 is discussed in sections 4.1.1, 4.1.2, 4.1.3 and 4.1.4 respectively. However, performance evaluation of the SSBs for the four sites is better understood by combined analysis.

SSB performance: The SSB is an important component of the VTS. It settles solids from the feedlot runoff and also reduces the feedlot runoff velocity thereby attenuating the runoff hydrograph. The performance of the SSBs for the four sites was evaluated by comparing the monitored nutrient concentrations released from the SSB to the nutrient concentrations released from the SSB assumed by the VTS models. The nutrient concentrations assumed by the VTS models are for a SSB that is designed to less than 12.7

cm (5 inch) storms. The comparison of average nutrient concentrations released from the SSBs for the four sites in 2006 and 2007 is shown in Tables 11 and 12.

Table 11: Comparison of average monitored and modeled nutrient concentrations released from the SSB in 2006

Nutrient concentration released from SSB as assumed by VTS models (mg/L)			Average measured nutrient concentration released from SSB in 2006 (mg/L)			
Nutrients	Earthen feedlot	Concrete feedlot	central IA 1 (earthen)	central IA 2 (earthen)	NW IA 1 (earthen)	NW IA 2 (concrete)
TKN	135	200	429 (258)	141 (160)	1024 (1254)	1145 (777)
Ammonia - N	100	150	128 (87)	43 (62)	239 (357)	325 (178)
Total Phosphorous	60	90	88 (38)	30 (25)	137 (152)	152 (87)
Total Solids	4000	6000	9539 (3978)	4120 (3312)	22897 (19596)	17294 (12158)
COD	5300	7950	7903 (3951)	2371 (2366)	24378 (40483)	16895 (10939)

Standard deviations are provided in parenthsis

Table 12: Comparison of average monitored and modeled nutrient concentrations released from the SSB in 2007

Nutrient concentration released from SSB as assumed by VTS models (mg/L)			Average measured nutrient concentration released from SSB in 2007 (mg/L)			
Nutrients	Earthen feedlot	Concrete feedlot	central IA 1 (earthen)	central IA 2 (earthen)	NW IA 1 (earthen)	NW IA 2 (concrete)
TKN	135	200	349 (188)	780 (587)	308 (214)	1539 (208)
Ammonia - N	100	150	205 (107)	265 (211)	129 (81)	425 (952)
Total Phosphorous	60	90	102 (34)	215 (139)	49 (23)	263 (170)
Total Solids	4000	6000	5983 (2266)	15890 (8564)	7964 (3732)	43169 (33899)
COD	5300	7950	5872 (3189)	14076 (8274)	4977 (2515)	41931 (38619)

Standard deviations are provided in parenthsis

In 2006, the average monitored nutrient concentrations released from the SSB were higher than the VTS models assumptions for all the sites except for Central IA 2. The nutrient concentrations coming out of the Central IA 2 SSB were similar to the VTS model assumptions. This was likely due to the placement of round bales around the Central IA 2 SSB outlet by the producer to slow down the flow and reduce the solids leaving the basin.

The SSB outlets at Central IA 1 and NW IA 1 were valved in the beginning of the 2007 monitoring period and Central IA 2 SSB outlet was valved in June, 2007 to control the SSB releases depending upon the VIB/VTA saturation conditions. Due to this management change, water in the SSB was held for a much longer time as compared to 2006. The results of this change can be seen in the nutrient concentrations for the 2007 SSB releases. The average nutrient concentrations released from the Central IA 1 and NW IA 1 SSBs are comparable to the VTS model assumptions. The average total solids, TP and COD concentrations for Central IA 1 and NW IA 1 are the lowest compared to the other sites. The standard deviations for average total solids (TS) concentrations for Central IA 1 and NW IA 1 decreased compared to 2006. It signifies that installation of the gate valve also reduced the variation in TS concentrations leaving the basin. Since the Central IA 2 producer did not release from the SSB after it was valved, the average nutrient concentrations shown in Table 12 represent SSB releases prior to installation of the gate valve. Therefore, the effects installation of a valve at Central IA 2 cannot be evaluated.

The average nutrient concentrations released from the Central IA 2 and NW IA 2 SSBs were higher in 2007 compared to 2006. The NW IA 2 SSB had the worst performance in reducing all five nutrient concentrations as compared to the other sites. The NW IA 2 SSB did not provide enough settling and as a result SSB effluent had extremely high TS concentration (seven times higher than the model assumptions) coming out of the basin.

Figures 19 and 20 show the comparison of NH_4-N and TS released from the SSBs at the four sites in 2006 and 2007.

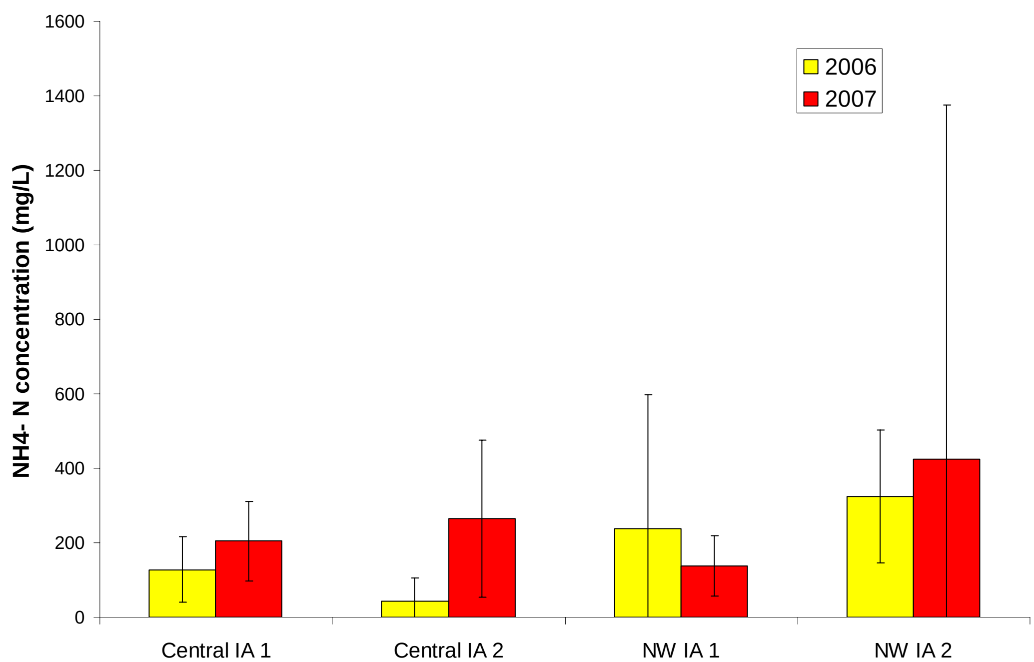

Figure 19: Comparison of average NH_4 – N concentrations released from the SSB in 2006 and 2007

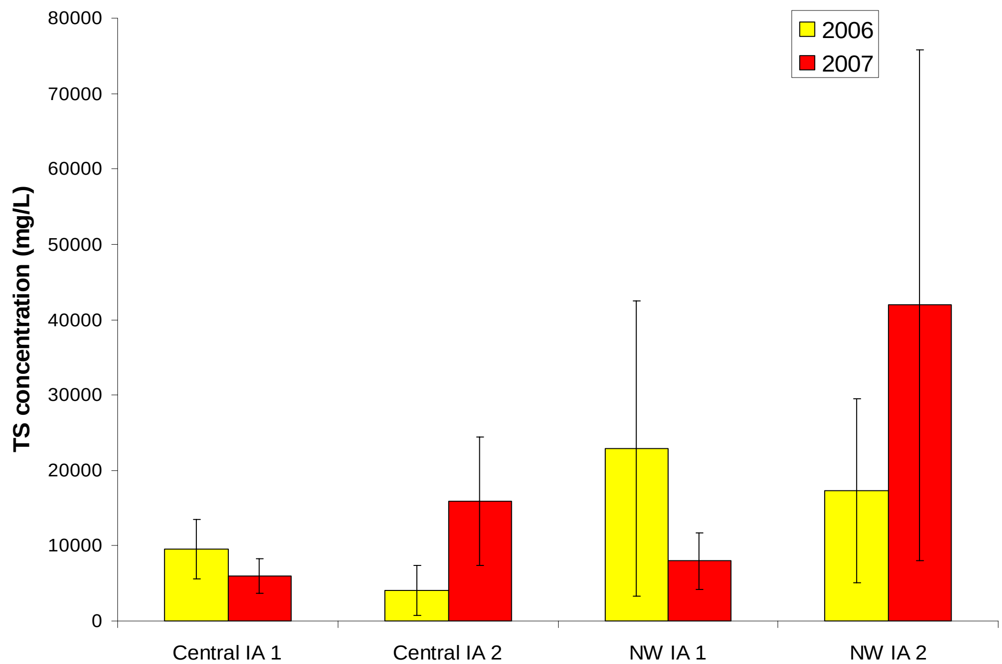

Figure 20: Comparison of average total solids concentrations released from the SSB in 2006 and 2007

The average TS concentrations released from the Central IA 1 and NW IA 1 SSBs in 2007 decreased by 37 % and 65 % compared to 2006. The average TS concentrations released from the Central IA 2 and NW IA 2 SSBs in 2007 increased by 74 % and 60 % compared to 2006. The average ammonia- N levels reduced in 2007 for NW IA 1 but not for Central IA 1 because the water was held in the Central IA 1 basin for a longer time than NW IA 1. Hence, installation of the gate valves at Central IA 1 and NW IA 1 improved SSB performance.

6. Performance comparison of VTS and traditional containment systems:

According to NPDES permit requirements, the VTSs should perform equal or better than the containment systems. The performance comparison is required to be in terms of nutrient mass released from the system. The Effluent Limitation Guidelines (ELG) model (refer section 3.7) was developed to predict the performance of containment systems and to make performance comparison with the VTS for the four sites. A weather file for each site was constructed containing 2006 and 2007 weather data that was recorded during monitoring periods (refer section 3.4). The ELG model was run with the site-specific data and using the weather file to predict the performance of a containment system in 2006 and 2007. The comparison of the measured VTS and modeled containment system performance for Central IA 1 & 2 and NW IA 1 & 2 is discussed in sections 4.1.1, 4.1.2, 4.1.3 and 4.1.4 respectively.

4.1.1 Performance Evaluation of the Central IA 1 VTS

The performance evaluation of the VTS at Central IA 1 includes analysis of groundwater and surface soil sample data, analyzing overall VTS performance and comparing the measured VTS and modeled containment system performance.

2006 and 2007 monitoring periods

2006 monitoring period: The monitoring for Central IA 1 was initiated in June 2006. The VTA vegetation was fully established in the beginning of the monitoring period and had a tall stand of vegetation by the end of the 2006 monitoring period (October, 2006) as shown in figure 22. During the 2006 monitoring period, Central IA 1 had 33.7 cm (13.3 inches) of rainfall. The largest storm was measured as 4 cm (1.6 inches). There were 14 SSB releases out of which two release events samples were not collected due to ISCO sampler malfunction. The two un-sampled events represent 28 % of the total volume released from the SSB during 2006 monitoring period. During the 2006 monitoring period, two VTA releases were recorded releasing 25 m^3 (883 ft^3) and 40 m^3 1412 (ft^3) of water out of the monitoring VTAs. Samples were not collected for the first VTA release event that represents 38 % of total volume released from the VTA. The two VTA releases resulted due to large volumes (> 400 m^3) being discharged from the SSB along with the rainfall onto a saturated VTA (due to rainfall). The un-sampled SSB and VTA release events were substituted with average nutrient concentrations to estimate nutrient mass released.

2007 monitoring period: A gate valve was installed at the Central IA 1 SSB in the beginning of the monitoring period (April, 2007) as shown in figure 21. As a result, the producer controlled SSB releases during the 2007 monitoring period. At the beginning of the 2007 monitoring period, the SSB was full due to snow melt. To accommodate for some large rainfall events in April 2007, the producer was forced to release from the basin onto a saturated VTA which resulted in VTA releases in April and May. The highest number of the

VTA releases occurred in the months of August thru October 2007 due to successive rainfall events. Central IA 1 had 124.5 cm (49.05) inches of rain during the 2007 monitoring period including a storm of 13.2 cm or 5.2 inches (greater than 25 year -24 hour storm) in August 2007. During the monitoring period, 26 VTA releases were recorded, releasing an estimated 11,755 m^3 (415,124 ft^3) of water out of the monitoring VTAs. In August 2007, Central IA 1 had 50.8 cm (20 inches) of rain which resulted in VTA release of over 4,700 m^3 (165,979 ft^3). Ten out of 26 VTA release events were a result of discharge from the SSB and the rest were a combination of rain and SSB discharge. Samples were not collected for 10 out of 26 VTA releases due to equipment malfunction. The 10 un-sampled events represent only 2 % of the total volume released from the VTA. The un-sampled VTA release events were substituted with average nutrient concentrations to estimate nutrient mass released. The flow volume was not measured for one of the VTA releases because water was backed up in the flume due to the flooding in the adjoining creek after successive rainfall events. The mass of nutrients released from this VTA release event was not estimated.

Figure 21: Picket fence at the SSB outlet in 2006 replaced with a gate valve in 2007 at Central IA 1

A good stand of vegetation was maintained in the VTA during the 2007 monitoring period (figure 22). It was observed that the east sides of both the VTAs were ponded for most of months during the monitoring period. Channeling was observed in both the VTAs occurring mostly on the east sides (figure 23). In June 2007, the producer cut about 0.15 m (6 inch) deep trenches perpendicular to the length of the VTA which reduced channeling. The VTAs had a good stand of vegetation throughout the year except for some bare patches due to constant ponding conditions on the east side as shown in figure 24 . The VTA vegetation was harvested once in July and the solids in the SSB were cleaned in June.

Figure 22: Good stand of vegetation at the Central IA 1 VTA in October, 2006 and October, 2007

Figure 23: Channeling occurring on the east side of the VTA at Central IA 1

Figure 24: Ponding occurring mostly on east side of both the VTAs at Central IA 1

The SSB and VTA release events at Central IA 1 for the 2006 and 2007 monitoring periods are listed in Tables 13 and 14. The nutrient mass released for each event is listed along with fecal coliform concentrations and pH values. The fecal coliform concentrations and pH values are averaged for multiple day events. The SSB release events in 2007 are classified according to the method described in section 3.6.

Table 13: SSB release event summary and released pollutant mass from the SSB for 2006 and 2007 monitoring periods at Central IA 1

Central IA 1 - SSB			Released mass of pollutants											
Event Date	**Rainfall**	**Volume**	**NH_4-N**	**TKN**	**NO_3- N**	**Total -P**	**ortho-P**	**TDS**	**TSS**	**BOD**	**COD**	**Cl**	**pH**	**Fecal coliforms**
	inches	**m^3**	**Kg**	**Kg**	**Kg**	**Kg**	**Kg**	**Kg**	**Kg**	**Kg**	**Kg**	**Kg**	**pH units**	**CFU/100ml**
7/3/2006	0.3	6	1	x	<0.01	1	0.3	50	22	22	60	3	6.7	2.1E+08
7/13/2006	0.39	1	0.2	1	<0.001	0.1	0.001	12	3	4	12	1	7.2	3.3E+06
7/26/2006	0.56	15	4	12	<0.01	2	0.8	209	91	70	269	8	6.6	3.2E+06
8/1/2006	0.43	0	0.1	0.3	<0.0002	0.04	0.0	3	1	2	4	0.2	6.5	5.7E+08
8/2/2006	0.4	12	2	8	<0.01	1	0.9	72	12	39	109	5	6.6	1.3E+08
8/6/2006	0.35	3	0.2	1	<0.003	0.2	0.1	19	3	2	13	1	7.1	4.1E+07
8/10/2006	1.53	139	16	60	<0.1	13	5.6	862	286	222	1016	70	7.0	8.8E+08
8/18/2006	0.73	84	5	20	<0.1	5	2.6	431	120	85	409	36	6.8	1.9E+07
8/28/2006	1.23	161	14	57	<0.2	11	4.8	967	247	306	1054	87	6.9	1.1E+09
9/3/2006#	0.59	49	6	21	<0.05	4	2	348	124	109	391	24	6.9	3.6E+08
9/10 - 9/11/2006	1.60	276	28	107	<0.2	26	12.2	1764	1095	496	1954	142	7.0	5.2E+07
9/16/2006	0.5	68	7	18	<0.07	5	3.4	424	53	115	483	36	6.7	4.2E+07
9/16 - 9/17//2006#	1.37	427	55	183	<0.4	38	18	3003	1072	940	3376	207	6.9	3.6E+08
9/21 - 9/22/2006	0.76	469	40	228	<0.5	49	23.1	3190	2871	713	4198	183	6.7	1.4E+07
4/1- 4/9/2007	0.18*	224	67	131	<0.2	17	13	1232	341	735	1727	96	7.2	3.1E+03
4/10-4/21/2007#	0.58	364	75	127	<0.4	37	25	1493	684	747	2137	86	7.1	5.2E+08
4/22-4/23/2007	1.09	318	113	128	<0.3	23	13	1541	597	718	2447	102	7.1	9.3E+07
4/24 - 4/29/2007	4.51	755	93	212	<0.8	52	30	3435	2095	752	4632	167	7.0	6.7E+07
5/6 - 5/13/2007	2.81	354	25	103	<0.4	17	9	1363	574	309	1374	67	7.1	1.2E+08
5/14 - 5/16/2007	0.41	102	14	24	<0.1	8	7	363	51	177	572	21	6.9	6.2E+05
5/23-5/31/2007	2.32	200	42	89	<0.2	17	14	960	304	548	1405	62	7.1	1.6E+08
7/3 - 7/6/2007	1.53	332	40	94	<0.8	36	30	1281	442	576	1654	73	6.4	9.9E+08
7/9 - 7/10/2007	0.60	67	31	62	<0.1	12	9	607	293	458	1029	30	6.8	2.9E+08
7/18 - 7/24/2007	2.75	556	104	206	<0.5	56	42	2175	1000	1310	3375	122	6.9	1.3E+09
7/26 - 7/28/2007	0.60	29	11	16	<0.03	4	3	190	23	146	279	11	7.0	5.1E+09
8/4 - 8/12/2007	7.18	478	108	191	<0.5	66	35	1929	1460	1441	3570	93	6.9	5.4E+08
8/14 - 8/20/2007	3.12	195	52	90	<0.2	24	23	917	435	687	1645	55	7.1	1.5E+07
8/21 - 8/27/2007	6.80	53	13	29	<0.05	8	7	248	148	168	452	13	7.0	1.4E+06
8/28 - 9/9/2007	3.00	1212	300	417	<0.1	155	68	4076	3213	2472	7444	223	7.4	5.5E+05
9/10 - 9/17/2007	1.50	422	108	146	<0.4	44	18	1245	1292	443	1574	85	7.5	5.5E+05
9/18 - 9/23/2007	1.33	251	53	78	<0.3	20	8	552	594	211	853	5	7.8	1.0E+05
9/24 - 10/6/2007	2.57	525	103	157	<0.5	51	35	1436	737	458	1597	120	7.5	2.8E+06
10/7 - 10/12/2007	2.8	328	33	66	<2.3	24	16	931	348	137	799	56	7.5	3.1E+07
10/13 - 10/31/2007	2.4	681	70	142	<0.7	50	32	1757	616	278	1782	127	7.7	5.5E+08

* settling basin was full due to snow melt
x TKN was not analyzed
Average concentrations were used to calculate released nutrient mass
pH and Fecal coliforms concentrations are averaged for multiple day events

Table 14: VTA release event summary and released pollutant mass from the VTA for 2006 and 2007 monitoring periods at Central IA 1

Central IA 1 - VTA			Released mass of pollutants											
Event Date	Rainfall	Volume	NH_4-N	TKN	NO_3- N	Total -P	ortho-P	TDS	TSS	BOD	COD	Cl	pH	Fecal coliforms
	inches	m^3	Kg	Kg	Kg	Kg	Kg	Kg	Kg	Kg	Kg	Kg	pH units	CFU/100ml
9/16 - 9/17//2006#	1.37	25	2	9	<0.03	2	1	149	78	40	160	9	6.8	6.5E+06
9/21 - 9/22/2006	0.76	40	3	15	<0.04	3	2	235	122	63	252	15	6.8	6.5E+06
4/15/2007#	D	30	2	4	<0.1	1	1	58	11	16	55	4	7.4	1.1E+08
4/22 -4/27/2007	2.6	4578	338	581	<4.6	159	105	11672	2391	3119	10818	608	7.3	3.6E+07
5/6 -5/82007	2.8	746	37	86	<4.7	20	8	1269	314	308	1178	63	7.3	1.7E+08
8/4 - 8/5/2007	5.5	1344	92	290	<1.3	72	51	3830	1290	1398	4166	149	7.0	3.4E+08
8/6 - 8/7/2007	1.5	369	34	91	<0.9	26	21	1089	1	558	1433	54	7.0	7.1E+06
8/8 -8/9/2007#	0.17	10	1	1	<0.02	0.4	0.3	19	4	5	18	1	7.4	1.1E+08
8/11/2007#	D	8	0.4	1	<0.02	0.4	0.3	15	3	4	14	1	7.4	1.1E+08
8/12/2007#	D	1	6.E-08	1.E-07	2.E-09	5.E-08	4.E-08	2.E-06	4.E-07	5.E-07	2.E-06	1.E-07	7.4	1.1E+08
8/18/2007#	0.6	28	2	3	<0.1	1	1	54	10	15	51	4	7.4	1.1E+08
8/20 - 8/21/2007	3.14	1241	89	139	<1.4	59	58	1999	202	810	2323	165	7.6	7.0E+06
8/22 - 8/24/2007	5.0		Water was backed up in the flume so volume not measured accurately											
8/28 - 8/29/2007	3.0	1714	23	58	<1.7	19	18	857	199	166	691	59	7.2	2.3E+05
9/4/2007	D	14	2	4	<0.01	1	1	59	19	26	65	3	7.4	1.3E+06
9/10/2007#	1.5	75	4	9	<0.2	3	3	148	29	40	139	10	7.4	1.1E+08
9/18/2007#	1.33	35	2	4	<0.1	2	1	69	13	19	65	5	7.4	1.1E+08
9/25/2007#	1.5	39	2	5	<0.1	2	1	77	15	21	72	5	7.4	1.1E+08
10/6/2007#	D	9	1	1	<0.02	0.4	0.3	17	3	5	16	1	7.4	1.1E+08
10/7-10/8/2007	2.8	556	14	17	2.8	14	13	337	16	16	152	37	7.4	4.0E+04
10/11/2007	D	25	1	3	0.0	2	1	52	5	6	43	4	7.6	3.1E+08
10/12/2007	D	102	8	17	<0.1	7	5	220	44	40	218	18	7.6	3.0E+07
10/13/2007#	0.1	4	0.3	1	<0.01	0.2	0.2	9	2	2	8	1	7.4	1.1E+08
10/14-10/15/2007	1.62	605	32	72	<0.8	34	23	1083	126	148	854	93	7.6	5.2E+08
10/18/2007	0.68	131	2	3	0.6	3	3	97	1	1	29	12	7.7	2.0E+05
10/19/2007	D	63	2	5	<0.1	3	3	105	16	13	78	8	7.5	9.0E+07
10/25/2007	D	16	1	3	0.04	1	1	45	5	6	32	3	7.7	2.3E+07
10/30/2007	D	12	1	1	0.01	1	1	26	4	4	20	2	7.7	6.1E+06
D - Discharge from the SSB resulted in VTA release														
# Average concentrations were used to calculate released nutrient mass														
pH and Fecal coliforms concentrations are averaged for multiple day events														

Surface soil data analysis

Thirteen surface soils samples were collected from the two monitoring VTAs at Central IA 1 (refer figure 3). The results for 13 surface soils sample points for both VTAs at Central IA 1 are shown in Table15.

Table 15: Surface soil sample concentrations for East and West VTA at Central IA 1

Central IA 1		P	K	NH4-N	NO3-N
West VTA		ppm	ppm	ppm	ppm
Inlet	Background	475	727	3	4
	2006	577	1323	4	27
	2007	716	1605	6	105
200 ft	Background	224	332	2	2
	2006	219	648	1	19
	2007	366	1055	4	130
400 ft	Background	141	201	2	1
	2006	106	168	1	1
	2007	160	270	3	9
600 ft	Background	303	365	2	2
	2006	333	456	1	6
	2007	350	627	4	50
800 ft	Background	209	335	2	3
	2006	307	565	2	11
	2007	264	487	3	28
Outlet	Background	186	417	2	4
	2006	206	805	2	10
	2007	145	495	4	28

Central IA 1		P	K	NH4-N	NO3-N
Eest VTA		ppm	ppm	ppm	ppm
Inlet	Background	408	579	5	33
	2006	555	1091	9	24
	2007	600	1656	6	134
200 ft	Background	117	374	2	18
	2006	214	663	1	12
	2007	548	1208	5	184
400 ft	Background	331	539	2	14
	2006	403	682	2	14
	2007	493	1434	6	143
600 ft	Background	298	409	2	4
	2006	392	618	2	15
	2007	411	665	5	88
800 ft	Background	241	355	2	10
	2006	317	453	3	7
	2007	355	1233	7	148
1000 ft	Background	351	423	2	2
	2006	324	629	4	12
	2007	302	480	6	28
Outlet	Background	444	609	2	9
	2006	287	714	4	4
	2007	311	675	4	30

East VTA: Seven soil samples were collected from the east VTA. The background phosphorus, potassium, NH_4-N and NO_3-N concentrations for the seven sample points in the east VTA (refer figure 11) ranged from 117 to 444 ppm, 355 to 609 ppm, 2 to 5 ppm and 2 to 33 ppm respectively. The background P and K concentrations in the east VTA were highest at the ends of the VTA and lower towards the center of the VTA. The P and K background concentrations at the east VTA inlet and outlet were similar.

The phosphorus, potassium, NH_4-N and NO_3-N concentrations for the seven sample points in the east VTA at the end of 2006 monitoring period ranged from 287 to 555 ppm, 453 to 1091 ppm, 1 to 9 ppm and 4 to 24 ppm respectively. The P, K, NH_4-N and NO_3-N concentrations at the end of 2006 were highest at the VTA inlet points. The average increase in P, K, NH_4-N and NO_3-N concentrations for the seven sample points after 5 months of monitoring were 11%, 31%, 11% and -8% (decrease). The increase in concentrations was higher for sample points closer to the VTA inlet as compared to sample points near the VTA outlet. This can be explained by the fact that in 2006, only two VTA releases were recorded indicating that most of the water was retained by the upper part of the east VTA.

The P, K NH_4-N and NO_3-N concentrations for the seven sample points in the east VTA at the end of the 2007 monitoring period ranged from 302 to 600 ppm, 480 to 1656 ppm, 4 to 7 ppm and 28 to 184 ppm respectively. The P and K concentrations at the end of 2007 were highest at the VTA inlet points. The average increase in P, K, NH_4-N and NO_3-N concentrations for the seven sample points, after one year of monitoring (end of 2007) were 15%, 24%, 38% and 84%. The average increase in P, K, NH_4-N and NO_3-N concentrations for the seven sample points, at the end of the two monitoring periods (i.e. 2007 results compared to background results) were 21%, 47%, 56% and 87%. The percent increase in NO_3-N concentrations at the end of 2007 (compared to background results) for the seven sample points were more than 90, indicating that most of the NH_4-N got converted to NO_3-N.

West VTA: The background phosphorus, potassium, NH_4-N and NO_3-N concentrations for the six sample points in the west VTA (refer figure 11) ranged from 141 to 475 ppm, 201 to 727 ppm, 2 to 3 ppm and 1 to 4 ppm respectively. The P and K background concentrations in the west VTA inlet were almost twice the outlet concentrations.

The P, K, NH_4-N and NO_3-N concentrations for the six sample points in the east VTA at the end of 2006 ranged from 106 to 577 ppm, 168 to 1323 ppm, 1 to 4 ppm and 1 to 27 ppm respectively. The average increase in P, K, NH_4-N and NO_3-N concentrations for the six sample points after 5 months of monitoring were 4%, 35%, -48% (decrease) and 68%.

The P, K NH_4-N and NO_3-N concentrations for the six sample points in the west VTA at the end of 2007 monitoring period ranged from 145 to 716 ppm, 270 to 1606 ppm, 3 to 6 ppm and 9 to 130 ppm respectively. The P and K concentrations at the end of 2007 were highest at the VTA inlet points. The average increase in P, K, NH_4-N and NO_3-N concentrations for the six sample points, after one year of monitoring (end of 2007) were 7%, 7%, 60% and 77%. The average increase in P, K, NH_4-N and NO_3-N concentrations for the six sample points, at the end of the two monitoring periods (i.e. 2007 results compared to background results) were 15%, 40%, 47% and 93%.

At the end of two monitoring periods, K, NH_4-N and NO_3-N concentrations increased for the 13 sample points in both VTAs. The P concentrations increased for 10 out of 13 sample points in both VTAs at the end of two monitoring periods.

Groundwater data analysis

Monthly groundwater samples were collected at Central IA 1 from the up gradient, in the system and down gradient wells (refer figure 11). The background and monitoring concentrations for the three wells are given in Table 16.

The NH_4- N concentrations were consistent at 0.2 mg/l during the monitoring periods in 2006 and 2007. The average monitored chloride concentrations in the up gradient, in the system and down gradient well are 233, 213 and 67 mg/l respectively. Presence of lower chloride concentration in the down gradient well compared to the up gradient well. The background chloride concentrations in the up gradient, in the system and down gradient wells are 194, 76 and 56 mg/l. The average monitored chloride concentrations for the three wells are higher than the respective background concentrations indicating that VTS might be contributing chloride to the ground water.

The average monitored NO_3-N concentrations in the up gradient, in the system and down gradient well are 144, 53 and 64 mg/l respectively. The up gradient well has the highest NO_3-N concentrations followed by the down gradient well and in the system well. The EPA nitrate –N concentration limit in drinking water is 10mg/L. The average monitored NO_3-N concentrations in three groundwater wells at Central IA 1 were higher than the EPA limit. The background NO_3-N concentrations in the up gradient, in the system and down gradient wells are 166, 216 and 74 mg/l, which are higher than the EPA limit indicating that NO_3-N concentrations were already higher before the VTS was operational. A potential reason for high nutrient concentrations in the up gradient well can be its close proximity to the earthen feedlot which has been operational for more than four decades. The monitored NO_3-N concentrations are lower than the respective background concentrations for the three wells for most of the months indicating that use of VTS did not increase the NO_3-N levels in the groundwater. The average monitored NO_3-N concentrations in the down gradient well are lower than the up gradient well, suggesting the same impact.

Table 16: Groundwater concentrations for up gradient, in the VTA and down gradient wells for Central IA 1

Up gradient well

Sample Date	NH_4-N mg/L	Cl mg/L	NO_3- N mg/L	Fecal coliforms CFU/100ml
5/31/2006	<0.2	194	166	<10
System operational				
8/9/2006	<0.2	11300	86	160
3/28/2007	<0.2	231	96	<1.0
4/9/2007	<0.2	218	99	<10
5/13/2007	<0.2	222	139	<20
6/8/2007	<0.2	230	174	<20
7/11/2007	<0.2	224	105	<100
8/7/2007	<0.2	243	104	300
9/7/2007	0.3	260	123	<10
10/11/2007	<0.2	235	100	<10

First sample is the background sample

In the system

Sample Date	NH_4-N mg/L	Cl mg/L	NO_3- N mg/L	Fecal coliforms CFU/100ml
5/31/2006	<0.2	76	216	<10
System operational				
8/9/2006	<0.2	4240	189	11000
3/28/2007	<0.2	119	136	<100
4/9/2007	<0.2	196	56	<10
5/13/2007	<0.2	227	37	420
6/8/2007	<0.2	228	12	240
7/11/2007	<0.2	216	28	92000
8/7/2007	<0.2	241	19	2900
9/7/2007	<0.2	243	4	400
10/11/2007	<0.2	237	0.3	180

First sample is the background sample

Down gradient well

Sample Date	NH_4-N mg/L	Cl mg/L	NO_3- N mg/L	Fecal coliforms CFU/100ml
6/1/2006	0.2	56	74	<10
System operational				
8/9/2006	<0.2	2620	51	200
3/28/2007	<0.2	64	108	<100
4/9/2007	<0.2	65	68	<10
5/13/2007	<0.2	60	62	<10.0
6/8/2007	<0.2	60	61	<10.0
7/11/2007	<0.2	65	73	20
8/7/2007	<0.2	81	73	40
9/7/2007	<0.2	75	20	10
10/11/2007	<0.2	70	63	<10

First sample is the background sample

A gradual decrease (from 216 mg/l to zero mg/l) in the NO_3-N concentrations in two years for in the system well can not be explained with the limited amount of data. However, the groundwater nutrient concentration data collected once in a month may not be frequent enough to capture the short term temporal changes in the pollutant concentrations. Therefore, data collected once a month may not be sufficient to indicate an impact of VTS on groundwater quality.

Overall VTS performance

The percent runoff control at Central IA 1 for 2006 and 2007 was 99% and 55% respectively. The percent runoff control is calculated as ((SSB release + rainfall) – VTA release)/ (SSB release + rainfall). The VTS runoff control performance decreased in 2007 as compared to 2006. The most important factor for the poor runoff control is that in 2007 Central IA 1 had 124.5 cm (49 inches) of rainfall in April thru October, which is much higher than average annual rainfall in Iowa of 88.9 cm (35 inches). The months from August thru October had about 78.5 cm (31 inches) of rainfall resulting in 23 out of the 26 VTA releases in 2007.

The pollutant mass retained in the VTS depends upon the volume of water retained by the VTA. Table 17 shows the percent pollutant mass retained in the VTS at Central IA 1 for the 2006 and 2007 monitoring periods. In 2006, Central IA 1 VTS had almost total retention of pollutants in the system. Central IA 1 had a lower percentage of pollutant control in 2007 as compared to 2006 because of low runoff control percentage during the year.

Table 17 Percent pollutant mass retained in the VTS for 2006 and 2007 at Central IA 1

	NH_4-N	TKN	Total -P	ortho-P	BOD	COD	Cl	Total Solids
2006	97	97	97	96	97	97	97	97
2007	53	44	41	28	47	44	19	35

The VTS runoff control performance for 2007 at Central IA 1 was impacted by an unusually wet year according to Iowa rainfall averages. However, the Central IA 1 VTS did show removal of nutrients for both 2006 and 2007. Table 18 lists average nutrient concentrations released out the SSB and the VTA for Central IA 1. In 2006 and 2007, the average nutrient concentrations released out of the VTA were lower than the SSB effluent concentrations indicating reduction of nutrients by the VTA.

Table 18 Average nutrient concentrations (with standard deviations) released from SSB and VTA for 2006 and 2007 at Central IA 1

Site	NH_4-N		TKN		Total P		Total Solids		COD	
	Mean	St Dev	Mean	St Dev	Mean	St Dev	Mean	St Dev	Mean	St Dev
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
2006										
Central IA 1 SSB	128	87	429	238	88	38	9539	3978	7903	3931
Central IA 1 VTA*	73		366		82		8970		6330	
2007										
Central IA 1 SSB	205	107	349	188	102	34	5983	2266	5872	3189
Central IA 1 VTA	59	34	124	80	46	21	2342	1405	1848	1326
* single sample concentration										

In 2007, controlled SSB releases resulted in some VTA releases only due to SSB discharge and others due to a combination of SSB release and rain on the VTA. A comparison of average nutrient concentrations of VTA releases occurring due to SSB release and SSB release + rain is given in Table 19. The VTA release nutrient concentrations due to a combination of SSB release and rain were lower due to dilution from the rainfall. Reduction in the phosphorus concentrations was higher than other nutrient concentrations and the BOD concentrations were least affected. There were no VTA releases that resulted only due to rain onto the VTA because the producer had to release from the SSB each time it rained to accommodate large rainfall storms.

Table 19 Comparison of average nutrient concentrations of VTA releases due to SSB release and SSB release and rain for Central IA 1 (2007)

VTA Release	NH_4-N	TKN	ortho-P	Total -P	TSS	TDS	BOD	COD	Cl
due to	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
SSB release	69	158	51	68	468	2470	548	2192	172
SSB release + rain	55	113	29	39	349	1783	525	1727	117
% difference	21	29	44	43	25	28	4	21	32

One of the important methods for estimating nutrient removal in the system is the calculating uptake of nutrients by the VTA vegetation. The VTA vegetation at Central IA 1 consisted mostly of perennial reed canary grass. A sample was collected from the reed canary grass harvested from the VTA in 2007 and sent for analysis of N and P to the Department of Agronomy Laboratory, Iowa State University. But results for the analysis were not received from the laboratory at the time of writing of the thesis. Hence, analysis of uptake of nutrients by the VTA vegetation is not included in this document.

An analysis of the annual nutrient loading rates will help in estimating the nutrient loading in Central IA 1 VTA. In 2006, the annual N and P loading rates for Central IA 1 VTA were 573 kg/ha (512 lb/acre) and 124 kg/ha (111 lb/acre). Hall (1993) suggests that about 45 kg/ha (40 lb/acre) of N and 17 kg/ha (15 lb/acre) of P should be applied for one ton yield of reed canary grass. Since the VTA was not harvested in 2006, N and P requirement for the reed canary grass based on yield cannot be calculated. In 2007, the producer harvested the VTA once and yielded 6,350 kg (14,000 lbs) of forage (from a 3.75 acre VTA) and the N and P requirement for the reed canary grass based on yield is calculated as 76 kg/ha (68 lb/ acre) and 28 kg/ha (25 lb/acre) respectively. The 2007 annual N and P loading rates for central IA 1 VTA were 2,008 kg/ha (1,793 lb/acre) and 579 kg/ha (517 lb/acre) respectively. Therefore, in 2007 the VTA received 26 times more nitrogen and 20 times more phosphorous than reed canary's requirement.

The Central IA 1 VTA was loaded with 5 tons/acre and 11 tons/acre of total solids in 2006 and 2007 respectively. Since monitoring period durations were different for 2006 and 2007, normalized annual loading rates over number of monitoring days in each year were calculated. The normalized annual loading rates for 2006 and 2007 were 75 kg/ ha –day (67 lb/acre-day) and 132 kg/ha-day (118 lb/acre-day) respectively. The mass of total solids released from the SSB into the VTA increased in 2007. Even though the total solids concentrations released from the SSB decreased in 2007 due to controlled SSB releases (refer figure 20), a higher mass of total solids was released onto the VTA due to high amount of rainfall received during the year.

Comparison of VTS and traditional systems performance

Central IA 1 VTS had two VTA release events in 2006. The ELG model did not predict releases from the containment system in 2006 for Central IA 1. But the ELG model predicted releases from the containment basin in 2007 for Central IA 1. In 2007, Central IA 1 had 26 VTA release events and the ELG model predicted seven containment basin release events/overflows. The VTS and ELG releases that continued for more than one day and were grouped as one release event for this comparison.

The 26 VTS events released 23, 827 m^3 (841,442 ft^3) of water out of the Central IA 1 VTAs and the ELG model predicted 8,061 m^3 (284,671 ft^3) of overflow from seven containment system releases. The nutrient mass released from the Central IA 1 VTS and the containment system during 2006 and 2007 is compared in Table 20. Since the mass of nutrients released from the Central IA 1 VTS is higher for both 2006 and 2007, the VTS did not perform equal or better than the modeled containment system performance. The mass of nutrients released from the VTS was higher because the ELG model predicted less or zero volume than the measured VTS volume and the nutrient concentrations coming out of the VTS were not low enough to perform equal or better than the modeled containment system performance.

Table 20 Comparison of nutrient mass released from Central IA 1 VTS and containment basin for 2006 and 2007

Mass released (Kg)	2006*	2007**
VTS TKN	15	1,397
ELG TKN	0	528
VTS NH_4-N	3	687
ELG NH_4-N	0	394
VTS Total P	3	429
ELG Total P	0	158
VTS Total soilds	357	27,830
ELG Total soilds	0	15,770
VTS COD	252	22,498
ELG COD	0	20,896
* Nutrient mass not calculated for 1 VTS event		
**Nutrient mass not calculated for 1 VTS event		
because volume could not be measured		

4.1.2 Performance Evaluation of the Central IA 2 VTS

The performance evaluation of the VIB-VTA system at Central IA 2 includes analysis of groundwater and surface soil sample data, analysis of overall VTS performance and comparison of VTS and modeled containment system performance.

2006 and 2007 Monitoring Periods

2006 Monitoring Period: The monitoring for Central IA 2 began in May 2006. Central IA 2 received 50.5 cm (19.92 inches) of rainfall during the 2006 monitoring period. In the beginning of the monitoring period, the VIB was partially vegetated and the VTA was fully vegetated (figure 25). By the end of the monitoring period (October, 2007), the VTA maintained a good stand of vegetation but the VIB still had a lot of bare spots. There were 22 SSB releases of which samples for three release events were not collected for during the

2006 monitoring period. The 3 un-sampled events represented 3 % of the total volume released from the SSB. Six release events were recorded from the VTA in 2006. The total volume of water released out of the system was 1,119 m^3 (39,517 ft^3). Most of the VTA releases resulted from rainfall events greater than 2.5 cm (1 inch). One of the six VTA release events was not sampled because the sample was discarded by mistake. The un-sampled VTA event represented 5 % of the total volume released out of the VTA. The un-sampled SSB and VTA release events were substituted with average nutrient concentrations to estimate nutrient mass released. There were eight VIB release events in the 2006 monitoring period. During the 9/10-9/12/06 VTA release event which resulted from a 7.6 cm (3 inch) rainfall, the flume was flowing for more than two days and it was observed that water on the VTA was flowing as sheet flow because the VTA was saturated after few hours of rainfall.

Figure 25: Vegetation in the VIB and VTA at Central IA 2 in May, 2006

2007 Monitoring Period: During the 2006-07 non-monitoring period, the VIB pump was shut off and the winter runoff was collected in the VIB. As a result, a layer of solids was accumulated on the VIB surface by the beginning of the 2007 monitoring period (April, 2007). The accumulation of solids decreased the infiltration rates, and as a result the VIB had standing water (up to 0.3 m or 1 foot) for first three months of the monitoring period shown in Figure 26. A gate valve was installed at the SSB outlet around mid June (figure 27). As a result, the producer started collecting feedlot runoff in the SSB that allowed the VIB to dry. In August, when the VIB was dry enough, solids accumulated in the VIB were removed along with thin layer of top soil and it was reseeded with reed canary grass. The VIB was partially vegetated at the end of the monitoring period (October, 2007) as shown in Figure30.

After the gate valve was installed at the SSB on 6/22/07, the producer did not release SSB effluent into the VIB. The feedlot runoff collected in the SSB was pumped out and land applied till the end of the monitoring period. Therefore, no SSB release events were recorded after 6/22/07. Based on the SSB dimensions and measured rainfall events, it was estimated that the producer pumped out approximately 2,680 m^3 (94,643 ft^3) of runoff collected in the SSB in four months. Eight SSB releases recorded before 6/22/07 were unrestricted basin releases. The volume was not measured for two out of eight SSB releases because debris (mostly consisting of solids in the VIB) was accumulated in front of the ISCO flow sensor. One out of 8 SSB releases was not sampled due to ISCO sampler malfunction. The un-sampled event represented 1.5% of total SSB volume released. The un-sampled SSB release events were substituted with average nutrient concentrations to estimate nutrient mass released.

Figure 26: Ponding in the Central IA 2 VIB due to accumulation of solids in 2007

Figure 27: Gate valve installed the Central IA 2 SSB outlet in 2007

The tile lines in the VIB flow throughout the year and 16 VIB release events represent the outflow from the VIB in 2007. In April 2007, the producer pumped the VIB effluent onto another area of his property instead of the VTA. As a result, the volume released from the VIB was not measured for the first three events. Central IA 2 had 94 cm (37 inches) of rainfall in the 2007 monitoring period. The flow sensor at the VTA outlet recorded 15 VTA release events in 2007. Nine out of the 15 VTA releases occurred after 6/22/07 which resulted from direct rainfall on the VIB and the VTA. Samples were not collected for 4 out of 15 VTA releases due to equipment malfunction. The 4 un-sampled events represent 9 % of the total volume released from the VTA. The un-sampled VTA release events were substituted with average nutrient concentrations to estimate nutrient mass released. Volume could not be measured for two out of the 15 VTA events because the water was backed up in the flume (figure 29). The flume releases water into a roadside ditch that was flooded during these two events. The VTA had a good stand of vegetation throughout the year as shown in figure 30 and was harvested in July. The top half of the VTA had standing water for most of the year (figure 28).

Figure 28: Ponding present at to top half of the Central IA 2 VTA

Figure 29: Water backed up in the Central IA 2 VTA flume due to flooding of the roadside ditch

Figure 30: Partially vegetated VIB and fully vegetated Central IA 2 VTA at the end of 2007 monitoring period

The SSB, VIB and VTA release events in the 2006 and 2007 monitoring periods are listed in Tables 21, 22 and 23. The nutrient mass released for each event is listed along with fecal coliform concentrations and pH values. The fecal coliform concentrations and pH values are averaged for multiple day events.

Table 21: SSB release event summary and released pollutant mass from the SSB for 2006 and 2007 monitoring periods at Central IA 2

Central IA 2 - SSB			Released mass of pollutants											
Event Date	Rainfall	Volume	NH_4-N	TKN	NO_3- N	Total -P	ortho-P	TDS	TSS	BOD	COD	Cl	pH	Fecal coliforms
	inches	m^3	Kg	Kg	Kg	Kg	Kg	Kg	Kg	Kg	Kg	Kg	pH units	CFU/100ml
7/1 - 7/2/2006	0.23	7	0.3	*	<0.01	0.2	0.1	22	4	4	21	2	7.3	1.7E+07
7/2/2006	0.1	5	0.2	*	<0.005	0.2	0.1	14	2	5	14	1	7.2	2.2E+07
7/11/2006	0.12	63	2.6	7	<0.03	2.4	1.7	254	12	17	104	12	7.1	1.4E+08
7/11/2006	0.03	8	0.5	1	<0.01	0.3	0.2	33	2	5	23	3	7.2	7.4E+07
7/13/2006	0.95	113	2.7	12	<0.1	3.0	2.0	267	56	18	156	19	7.6	1.4E+07
7/26/2006	0.24	3	0.1	0	<0.003	0.1	0.0	5	6	1	4	0	7.6	1.4E+06
8/6/2006	0.31	7	0.2	1	<0.01	0.2	0.1	29	4	2	16	1	7.4	6.3E+07
8/9/2006	2.22	244	2.7	14	0.1	1.9	1.0	515	85	37	182	38	9.4	4.1E+07
8/10/2006	0.92	120	1.3	6	<0.1	1.5	1.0	197	18	7	90	23	7.9	2.8E+08
8/13/2006	0.28	12	0.03	0	<0.01	0.1	0.1	13	1	0	4	1	7.3	3.0E+05
8/17/2006	0.43	23	0.1	1	<0.02	0.2	0.1	28	5	2	14	2	7.6	8.0E+05
8/28/2006	1.68	194	9.7	30	<0.2	4.5	0.5	756	56	11	469	34	8.6	5.2E+08
8/29/2006	0.16	3	0.1	0	<0.003	0.1	0.0	8	3	3	6	1	8.1	3.0E+09
9/2/2006	0.65	50	0.4	3	<0.1	0.5	0.1	92	28	7	48	5	7.6	3.6E+09
9/3/2006	0.37	29	1.5	5	<0.03	1.1	0.2	97	47	23	81	4	7.6	8.5E+09
9/10 - 9/11//2006	3.02	600	78.7	316	<0.6	62.8	12.4	4814	3856	1015	4974	340	7.8	7.8E+06
9/17/2006	1.00	91	2.9	12	<0.1	2.6	1.0	274	415	53	198	16	7.6	3.4E+07
9/22/2006#	0.38	8	0.3	1.1	<0.01	0.2	0.1	24.8	7.9	3.8	18.8	1.8	7.7	5.1E+08
10/16/2006	0.35	14	4.6	11	0.03	0.9	0.1	106	54	32	147	10	7.9	4.1E+07
10/18/2006	0.3	26	7.1	19	<0.03	3.4	0.5	191	246	79	293	15	7.7	2.0E+07
10/21/2006#	0.26	8	0.3	1.1	<0.01	0.2	0.1	24.0	7.6	3.7	18.2	1.7	7.7	5.1E+08
10/26/2006#	0.48	27	1	4	<0.03	0.8	0.4	83	26	13	63	6	7.7	5.1E+08
3/31/2007	0.7	33	9	37	<0.02	10	0.2	446	572	173	632	19	7.6	4.9E+07
4/3/2007#	0.2	10	3	8	<0.01	2	0.5	89	67	39	139	6	7.7	7.2E+07
4/11/2007	0.35		Volume was not measured because debris was struck in front of the sensor.											
4/22/2007	0.8	35	9	24	<0.04	6	1	333	158	130	415	23	7.5	1.2E+08
4/24 - 4/25/2007	4.5	331	66	161	<0.3	56	17	2391	1229	594	3247	136	7.7	9.1E+07
5/6 - 5/7/2007	1.5		Volume was not measured because debris was struck in front of the sensor.											
5/23 - 5/24//2007	2.7	142	20	68	0.1	21	8	1366	394	297	1774	64	7.7	7.3E+07
5/30/2007	1.3	83	19	67	<0.2	22	1	662	766	503	1622	64	7.4	3.6E+07
6/22/2007	2.3	45	2	10	<0.05	3	2	248	117	70	170	14	7.9	not available

* TKN was not analyzed

Producer did not release from the SSB after 6/22/2007

Average concentrations were used to calculate released nutrient mass

pH and Fecal coliforms concentrations are averaged for multiple day events

Table 22: VIB release event summary and released pollutant mass from the VIB for 2006 and 2007 monitoring periods at Central IA 2

Central IA 2 - VIB			Released mass of pollutants											
Event Date	Rainfall	Volume	NH_4-N	TKN	NO_3- N	Total -P	ortho-P	TDS	TSS	BOD	COD	Cl	pH	Fecal coliforms
	inches	m^3	Kg	Kg	Kg	Kg	Kg	Kg	Kg	Kg	Kg	Kg	pH units	CFU/100ml
8/9/2006	2.22		Volume was not measured											
8/10/2006	0.92	117	0.1	2	3	1	0.4	145	4	3	34	17	7.2	2.3E+08
8/28/2006	1.62	258	1	112	2	2	0.3	542	72	62	250	43	7.0	2.3E+09
9/2 - 9/4//2006	1.02	159	2	12	<0.1	2	1	380	51	44	178	27	7.2	1.0E+09
9/10 - 9/12//2006	3.02	766	20	91	<0.7	22	7	2634	587	338	1599	136	7.5	2.7E+07
9/17/2006	1.00	71	1	3	<0.07	1	0.2	117	6	10	46	12	7.1	2.9E+07
9/22/2006	0.38	43	1	2	<0.04	0	0.1	77	7	14	42	9	7.1	3.4E+06
10/19/2006	0.30	49	1	5	<0.05	1	0.1	147	32	27	97	15	7.5	1.2E+07
3/31- 4/2/2007	0.9		Volume not measured because the producer disconnected hose from the turbinemeter.											
4/24 - 4/27/2007	4.5		Volume not measured because the producer pumped VIB tile flow to another area of his property.											
5/5 - 5/11/2007	1.5		Volume not measured because the producer pumped VIB tile flow to another area of his property.											
5/23 - 5/30/2007	4.60	66	3	7	0.2	2	1	110	24	29	96	16	7	2.1E+06
5/31 - 6/6/2007	0.90	84	10	18	<0.04	4	3	328	28	98	227	26	7	5.8E+04
6/7 - 6/14/2007	No rain	72	7	12	<0.2	3	16	238	27	57	169	25	7	7.2E+03
6/15 - 6/21/2007	0.50	31	2	3	<0.03	1	0.2	81	11	11	40	9	7	1.8E+04
6/22 - 6/28/2007	2.30	53	3	5	<0.1	2	1	127	9	26	68	14	7	7.5E+05
6/29 - 7/6/2007	No rain	35	6	1	<0.03	5	4	187	31	111	203	8	6	5.1E+08
7/9 - 7/16/2007	0.60	37	1	2	<0.04	0.4	0	82	5	4	26	10	7	5.0E+05
7/19 - 7/24/2007	1.70	44	4	5	<0.01	1	1	149	8	6	44	8	7	1.9E+07
7/25 - 8/20/2007	6.35	110	2	4	1	1	0	189	29	6	43	28	7	6.0E+05
8/21 - 9/5/2007	2.95	216	<0.1	1	<0.2	1	1	207	11	<2.6	21	31	8	2.6E+04
9/6 - 10/1/2007	1.49	132	1	2	<0.1	0	0.1	242	19	<1.6	19	32	2	<100
10/2 - 10/10/2007	2.12	31	0	0	0.1	0	<0.003	47	2	0	4	8	7	3.7E+04
10/11 - 10/31/2007	4.61	210	1	2	0.2	0	<0.42	314	7	3	15	50	7	2.7E+03
pH and Fecal coliforms concentrations are averaged for multiple day events														

Table 23: VTA release event summary and released pollutant mass from the VTA for 2006 and 2007 monitoring periods at Central IA 2

Central IA 2 - VTA			Released mass of pollutants											
Event Date	Rainfall	Volume	NH_4-N	TKN	NO_3- N	Total -P	ortho-P	TDS	TSS	BOD	COD	Cl	pH	Fecal coliforms
	inches	m^3	Kg	Kg	Kg	Kg	Kg	Kg	Kg	Kg	Kg	Kg	pH units	CFU/100ml
8/9/2006	2.22	0.5	0.0005	0.002	<0.0005	0.0003	0.0001	0.1	0.02	0.01	0.03	<0.0024	6.8	8.3E+03
8/10/2006	0.92	72	0.04	1	2	0.3	0.2	80	<1.0	2	14	8	7.8	1.9E+05
8/28/2006	1.62	102	0.3	4	1	1	0.3	190	31	13	72	14	7.5	3.9E+08
9/3 - 9/4//2006	1.02	41	0.3	2	<0.04	0.4	0.1	89	10	9	42	7	7.5	8.3E+09
9/10 - 9/12//2006	3.02	851	19	89	<0.9	22	8	3317	451	281	1650	139	7.6	6.0E+07
9/17/2006#	1.00	54	0.4	2	<0.4	0.5	0.2	87	11	7	37	6	7.5	8.3E+08
3/25 - 3/29/2007	*		Water was backed up in the flume so volume not measured accurately											
3/31/2007#	0.7	14	0.2	0.5	<0.02	0.1	0.1	16	2	2	7	2	7.8	1.3E+07
4/24 - 4/26/2007	4.5		Water was backed up in the flume so volume not measured accurately											
5/23 -5/24/2007	2.7	52	2	3.1	<0.1	0.9	0.5	105	9.8	8	54	6	7.6	9.0E+07
5/30 - 5/31/2007	1.3	32	1	1.3	<0.03	0.3	0.2	29	2.2	4	15	3	7.5	1.4E+05
6/1/2007#	0.5	4	0.1	0.2	<0.01	0.03	0.02	5	1	1	2	1	7.8	1.3E+07
6/22/2007	2.3	115	1	2.7	0.4	0.9	1	97	8.4	27	35	12	7.7	1.0E+05
6/29/2007#	No Rain	29	0.4	1	<0.03	0.2	0.1	32	4	4	15	4	7.8	1.3E+07
8/19 - 8/20/2007	3.3	681	2	9.5	<0.9	6.1	4	300	130.7	37	195	27	7.1	5.6E+07
8/20 - 8/21/2007#	0.92	55	1	2	<0.1	0.4	0.3	62	7	8	28	7	7.8	1.3E+07
8/22 - 8/24/2007	1.77	59	<0.03	<0.4	<0.06	0.2	0.2	67	0.5	<0.71	7	11	8.1	3.2E+04
8/28 -8/29/2007	1.2	25	<0.01	0.1	<0.03	0.1	0.1	24	1.3	<0.30	2	4	8.4	2.6E+04
9/6 - 9/7/2007	0.65	13	<0.01	0.1	<0.01	0.05	0.04	14	0.1	0.1	2	2	7.9	2.6E+04
10/8/2007	0.98	14	<0.01	0.06	<0.01	0.05	0.05	8	0.09	0.2	1	2	8.1	1.0E+04
10/14-10/16/2007	3.72		Water was backed up in the flume so volume not measured accurately											
10/17-10/19/2007	0.88	14	<0.01	0.04	<0.01	0.04	0.04	11	0.1	<0.04	0.5	2	8.2	<100000

* Flow due to snow melt

Average concentrations were used to calculate released nutrient mass

pH and Fecal coliforms concentrations are averaged for multiple day events

Surface soil data analysis

Surface soil samples from the VIB inlet, VTA inlet and VTA outlet sample points (refer figure 12) were collected annually at Central IA 2. One set of background surface soil samples were collected in November 2005 and another two sets of samples were collected at the end of the 2006 and 2007 monitoring periods. The P, K, NH_4-N and NO_3-N concentrations for the three sets of soil samples for Central IA 2 are given in table 24.

Table 24: Surface soil sample concentrations for VIB and VTA sample points for Central IA 2

Central IA 2		P	K	NH4-N	NO3-N
		ppm	ppm	ppm	ppm
VTA inlet	Background	93	320	4	4
	2006	171	448	9	10
	2007	151	439	3	31
VTA outlet	Background	98	382	3	3
	2006	179	523	3	7
	2007	196	566	3	15
VIB inlet	Background	109	276	8	7
	2006	249	725	4	23
	2007	1124	230	6	230

VIB inlet: The background P, K, NH_4-N and NO_3-N concentrations at the VIB inlet were 109, 276, 8 and 7 ppm respectively. After the end of 2006 monitoring period, P, K and NO_3-N concentration increased to 249, 725 and 23 ppm but the NH_4-N concentration decreased to 4 ppm. At the end of the 2007 monitoring period, the P, K, NH_4-N and NO_3-N concentrations were 1124, 230, 6 and 230 ppm.

The P and NO_3-N concentrations at the VIB inlet increased in 2006 and 2007, but the K and NH_4-N concentrations decreased at the end of 2007 compared to the background results. The nutrient concentrations in the top soil at the VIB inlet which is a point of entry for SSB effluent are expected to increase with time.

VTA points: The background P, K, NH_4-N and NO_3-N concentrations at the VTA inlet were 93, 320, 4 and 4 ppm and at VTA outlet were 98, 382, 3 and 3 ppm respectively. At the end of 2006 monitoring period, the P, K and NO_3-N concentrations at VTA inlet were 171, 448, 9 and 10 ppm and at the VTA outlet were 179, 523, 3 and 7 ppm. At the end of the

2007 monitoring period, the P, K and NO_3-N concentrations at VTA inlet were 151, 439, 3 and 31 ppm and at the VTA outlet were 196, 566, 3 and 15 ppm. At the end of the two monitoring periods, the P, K and NO_3-N concentrations increased (compared to background results) and NH_4-N concentrations decreased for both VTA inlet and outlet.

Groundwater data analysis

Monthly groundwater samples were collected at Central IA 2 from the up gradient, in the system and down gradient wells (refer figure 12). The background and monitoring concentrations for the three wells are given in Table 25. The average monitored NH_4- N concentrations for the three wells were 3, 0.2 and 2 mg/l and are equal or less than the respective background concentrations. The monitored NH_4- N concentrations were highest for the up gradient well followed by the down gradient well and in the system well.

The average monitored chloride concentrations for the up gradient, in the system and down gradient wells were 24, 36 and 14 mg/l. The chloride concentrations were higher in the up gradient well compared to down gradient which is also shown by the average monitored concentrations. The background chloride concentrations for the up gradient, in the system and down gradient wells were 26, 40 and 11 mg/l. The average monitored concentrations for the up gradient and in the system wells were lower than their respective background concentrations, but vice versa for the down gradient well.

The average monitored NO_3-N concentrations in the up gradient, in the system and down gradient wells at Central IA 2 were 4, 0.5 and 3 mg/l which are below the EPA drinking water NO_3-N limit of 10 mg/l. The NO_3-N concentrations were higher in the up gradient well compared to the down gradient well which is also shown by average monitored concentrations. The background NO_3-N concentrations for the up gradient, in the system and down gradient wells were 10, 3 and 4 mg/l. The average monitored NO_3-N concentrations for the three wells are lower than their respective background concentrations indicating that operation of VTS did not increase the groundwater concentrations below the system.

The NO_3-N concentrations in the down gradient well were lower than 1 mg/L for 7 out of 12 months but they increased to 7, 4 and 15 mg/l for three months. The down gradient well is adjoined by corn field and NO_3-N leaching from the field during high rainfall events can be a potential reason for the variability in the data.

Table 25: Groundwater concentrations for up gradient, in the system and down gradient wells for Central IA 2

Up gradient Well				
Sample Date	**NH_4-N**	**Cl**	**NO_3- N**	**Fecal coliforms**
	mg/L	**mg/L**	**mg/L**	**CFU/100ml**
5/16/2006	3	26	10	<10
System operational				
9/14/2006	5	22	1	30
10/12/2006	4	27	6	<10
3/12/2007	4	26	10	<10.0
4/12/2007	2	13	3	<20
5/14/2007	4	26	4	<10
6/13/2007	3	24	3	<10.0
7/13/2007	0.1	27	2	<10
8/13/2007	3	23	2	<10
9/12/2007	4	26	3	<10
10/15/2007	3	25	2	<10
First sample is the background sample				
In the system well				
Sample Date	**NH_4-N**	**Cl**	**NO_3- N**	**Fecal coliforms**
	mg/L	**mg/L**	**mg/L**	**CFU/100ml**
5/22/2006	0.4	40	3	<10.0
System operational				
7/18/2006	0.3	34	0.2	<10.0
8/13/2006	0.2	37	1.0	<10.00
9/14/2006	0.5	36	0.6	10
10/12/2006	0.3	37	0.4	10
3/12/2007	<0.2	29	0.3	<10.0
4/12/2007	<0.2	39	0.5	<20
5/14/2007	<0.2	43	0.5	<10
6/13/2007	<0.2	37	0.4	<10
7/13/2007	<0.2	46	0.6	<10
8/13/2007	<0.2	42	0.4	<10
9/12/2007	<0.2	47	0.5	<10
10/15/2007	<0.2	5	0.5	<10
First sample is the background sample				
Down gradient well				
Sample Date	**NH_4-N**	**Cl**	**NO_3- N**	**Fecal coliforms**
	mg/L	**mg/L**	**mg/L**	**CFU/100ml**
5/16/2006	2	11	4	<10.0
System operational				
7/18/2006	2	10	3	<10.0
8/13/2006	2	9	1	<10.00
9/14/2006	2	8	0.2	<10.0
10/12/2006	1	13	0.7	<100
3/12/2007	2	8	0.9	<10.0
4/12/2007	4	29	7	<20
5/14/2007	2	11	0.6	<20
6/13/2007	1	15	4	<100
7/13/2007	2	12	0.8	<10
8/13/2007	1	10	0.9	<100
9/12/2007	2	13	0.2	123000
10/15/2007	2	30	15	1700
First sample is the background sample				

The down gradient NH_4- N, Cl and NO_3-N concentrations are not higher than the up gradient concentrations, suggesting that VTS may not be contributing source of nutrients to groundwater. However, the groundwater nutrient concentration data collected once in a month may not be frequent enough to capture the short term temporal changes in the pollutant concentrations. Therefore, data collected once a month may not be sufficient to indicate an impact of VTS on groundwater quality.

Overall VTS performance

The percent runoff control for 2006 and 2007 was 74% and 80% respectively. The percent runoff control is calculated as ((SSB release + rainfall) – VTA release)/ (SSB release + rainfall). The VTS runoff control of 80 % in 2007 may not represent a true number as effluent from the SSB was not released during the last four months of monitoring. The runoff control in 2007 might have been lower if the producer had released from the SSB during the last four months of monitoring.

The pollutant mass retained in the VTS is proportional to the volume of water retained in the VTA. Table 26 shows the percent pollutant mass retained in the VTS at Central IA 2 for 2006 and 2007 monitoring periods. The percentages in 2007 are higher as compared to 2006. The percentages for 2007 do not represent a true picture of pollutant mass retained in the system as the SSB effluent was not released onto the VIB for last four months of the monitoring period.

Table 26: Percent pollutant mass retained in the VTS for 2006 and 2007 at Central IA 2

	NH_4-N	TKN	Total -P	ortho-P	BOD	COD	Cl	Total Solids
2006	83	78	72	60	77	74	68	67
2007	94	95	92	79	95	95	75	89

The average nutrient concentration released from the SSB, VIB and VTA for 2006 and 2007 is shown in Table 27. The concentrations coming out of the VIB and VTA are lower than the SSB concentration showing that the VIB and the VTA removed pollutants/nutrients for both the years. However, in 2007 nine out of 15 VTA release events consisted mostly of rainfall falling directly on the VIB and VTA (as SSB effluent was not released onto the VIB for last four months of monitoring period), therefore low nutrient concentrations entered the VTA from the VIB that resulted in even lower final concentrations released from the VTA. The concentrations released from the VTA in 2007 might have been higher if the SSB effluent was released onto the system.

Table 27: Average nutrient concentrations (with standard deviations) released from the SSB, VIB and VTA for 2006 and 2007 at Central IA 2

Site	NH_4-N		TKN		Total P		Total Solids		COD	
	Mean	St Dev	Mean	St Dev	Mean	St Dev	Mean	St Dev	Mean	St Dev
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
2006										
Central IA 2 SSB	43	62	2371	2357	30	25	141	160	4120	3312
Central IA 2 VIB	12	10	1177	739	13	9	100	107	2680	1324
Central IA 2 VTA	8	12	688	715	10	9	37	40	1829	1331
2007										
Central IA 2 SSB	265	211	14076	8274	215	139	780	587	15890	8564
Central IA 2 VIB	71	59	2161	2417	38	42	119	127	3631	2754
Central IA 2 VTA	15	30	506	884	7	6	35	62	1240	1158

The producer did not release from the SSB after June, 2007 and as a result nine VTA releases that occurred after June consisted of rainfall falling onto the VIB and VTA. The VTA releases before June were a combination of SSB releases and rainfall directly onto the system. A comparison of average nutrient concentrations of VTA releases occurring due to rain and SSB release + rain is given in Table 28. The VTA release nutrient concentrations due to rain were lower than the combination of SSB release + rain except for TSS and chloride. The TDS, othro-P, and TP concentrations were least affected in this comparison.

Table 28 Comparison of average nutrient concentrations of VTA releases due to rain and SSB release and rain for Central IA 2 (2007)

VTA Release	NH_4-N	TKN	ortho-P	Total -P	TSS	TDS	BOD	COD	Cl
due to	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
SSB Release + rain	16	27	6	9	69	910	117	394	66
Rain	2	11	5	7	112	832	33	217	131
% difference	89	59	19	22	-61	9	72	45	-98

The analysis of uptake of nutrients by the VTA vegetation is not included in the thesis. The results for the analysis of nutrient uptake by reed canary grass harvested from the Central IA 2 VTA were not received from the laboratory at the time of writing of the thesis.

In 2006, the annual N and P loading rates for Central IA 2 VIB were 1,610 kg/ha (1,438 lb/acre) and 267 kg/ha (238 lb/acre). The annual N and P loading rates for Central IA 2 VTA were 1,485 kg/ha (1,326 lb/ acre) and 187 kg/ha (167 lb/acre). Since the VIB and VTA were not harvested in 2006, N and P requirement for the reed canary grass based on yield cannot be calculated.

The 2007 annual N and P loading rates for Central IA 2 VIB were 1,360 kg/ha (1,215 lb/acre) and 436 kg/ha (389 lb/acre) and for Central IA 2 VTA were 410 kg/ha (366 lb/acre) and 135 kg/ha (121 lb/acre). The producer harvested the VTA once and yielded 1,474 kg (3,250 lbs) of forage (from a 0.5 acre VTA) and the N and P requirement for the VTA reed canary grass based on yield is calculated as 143 kg/ha (128 lb/ acre) and 54 kg/ha (48 lb/acre) respectively. The VIB ponded for most 2007 and vegetation started growing in the VIB only after August. The VIB was not harvested in 2007, but assuming a 4.9 ton/ha (2 ton/acre) yield the N and P requirement for the VIB reed canary grass based on yield is calculated as 90 kg/ha (80 lb/ acre) and 34 kg/ha (30 lb/acre) respectively. The reed canary N and P requirement were calculated based on Hall (1993) suggestion that 45 kg/ha (40 lb/acre) of N and 17 kg/ha (15 lb/acre) should be applied for one ton yield of reed canary grass. Therefore, in 2007 the VTA received three times more nitrogen and phosphorous than reed canary's requirement. The VIB received 15 times more nitrogen and 13 times more phosphorus than the reed canary's requirement based on assumed yield. The Central IA 2 VTA was not as heavily loaded as compared to the VIB because the influent coming onto the VTA for 4 months consisted mostly of rain water.

The Central IA 2 VIB was loaded with 37 tons/ha (15 tons/acre) and 27 tons/ha (11 tons/acre) of total solids in 2006 and 2007 respectively and the VTA was loaded with 25 tons/ ha (10 tons/acre) and 12 tons/ ha (5 tons/acre) of total solids in 2006 and 2007. Since monitoring period durations were different for 2006 and 2007, normalized annual loading rates over number of monitoring days in each year were calculated. The normalized annual loading rates for the VIB in 2006 and 2007 were 207 kg/ha-day (185 lb/acre-day) and 123 kg/ha-day (110 lb/acre-day) respectively. The normalized VTA loading rates in 2006 and 2007 were 140 kg/ha-day (125 lb/acre-day) and 63 kg/ha-day (56 lb/acre-day). The normalized loading rate for the VIB was lower in 2007 because the VIB was loaded with solids from the SSB only for 3 months in the year. The normalized VTA loading rate was lower in 2007 as well because the SSB effluent was not released into the VIB/VTA after 6/22/07.

Comparison of VTS and traditional systems performance

The ELG model did not predict releases from the containment basin in 2006 for Central IA 2. But the Central IA 2 VTS measured six VTA releases in 2006. During the 2007 monitoring period, 15 VTA release events were recorded at Central IA 2 while the ELG model predicted two containment basin release events/overflows.

The 15 VTS release events released 1,109 m^3 (39,164 ft^3) of water out of the Central IA 2 VTA and the ELG model predicted 183 m^3 (6,463 ft^3) of overflow from two containment basin releases. The nutrient mass released from the Central IA 2 and the containment basin during 2006 and 2007 has been compared in Table 29. Since the mass of three out of five nutrients released from the Central IA 2 VTS is higher for both 2006 and 2007, the VTS did not perform equal or better than the traditional containment system performance predicted by the ELG models. However, the mass of nutrients released from the VTS was higher because of two reasons: the ELG model predicted less volume than the measured VTS volume for most of the releases and the nutrient concentrations coming out of the VTS were not low enough to perform equal or better than modeled containment system performance.

Table 29 Comparison of nutrient mass released from Central IA 2 VTS and containment basin for 2006 and 2007

Mass released (Kg)	2006	2007*
VTS TKN	98	21
ELG TKN	0	11
VTS NH_4-N	20	7
ELG NH_4-N	0	8
VTS Total P	25	9
ELG Total P	0	3
VTS Total soilds	4,266	934
ELG Total soilds	0	329
VTS COD	1,815	364
ELG COD	0	436

*Nutrient mass not calculated for 3 VTS events because volume could not be measured

4.1.3 Performance Evaluation of the Northwest IA 1 VTS

The performance evaluation of the VTS at NW IA 1 includes analysis of groundwater and surface soil sample data, analysis of overall VTS performance and comparison of measured VTS and modeled containment system performance.

2006 and 2007 Monitoring Periods

2006 monitoring period: The monitoring for NW IA 1 initiated in August 2006. The VTA had a tall stand of vegetation by the end of the monitoring period (October, 2006) which consisted mostly of reed canary grass (figure 31). In 2006 monitoring period, NW IA 1 had 22 cm (8.7 inches) of rainfall in the 2006 monitoring period. Five SSB releases were recorded in 2006 and one event was not sampled due to ISCO sampler malfunction. The un-sampled event represented 8 % of total volume released from the SSB. There were two VTA releases in the 2006 monitoring period in the month of September. The total volume released from these events was 334 m^3 (11,795 ft^3). Both releases resulted from rainfall greater than 3.8 cm (1.5 inches). The un-sampled SSB and VTA release events were substituted with average nutrient concentrations to estimate nutrient mass released.

Figure 31: Good stand of VTA vegetation at NW IA 1 at the end of 2006 monitoring period

2007 monitoring period: A valve was installed in the SSB outlet pipe in the beginning of the monitoring period (April, 2007) so the producer controlled SSB releases depending upon the VTA saturation conditions. The SSB was full due to snow melt at the beginning of the monitoring period. To accommodate for runoff from rainfalls in April, the producer had to release from the SSB which resulted in VTA releases in April. In the 2007 monitoring period, NW IA 1 received 75.3 cm (29.64 inches) of rain. There were 20 releases from the

SSB in 2007. The volume released from the basin could not be measured for two out of 20 SSB release events due to ISCO malfunction. The producer removed the ISCO sensor to change the SSB outlet pipe size from 0.2 to 0.15 m (8 to 6 inches) and as a result the SSB release volume was not measured from 4/10 – 4/21/07.

There were13 releases recorded at the VTA flume releasing an estimated 2,900 m^3 (102,412 ft^3) of water out of the monitoring VTA. Seven out of 13 VTA releases resulted from release from the SSB and the rest were a combination of rain and SSB release. Samples were not collected for three out of 13 VTA releases due to equipment malfunction. The un-sampled events represent 4 % of the total volume released from the VTA. The un-sampled VTA release events were substituted with average nutrient concentrations to estimate nutrient mass released. The VTA had good stand of vegetation for the whole year. The VTA was harvested twice in 2007 in the months of June and September. It was observed that channeling occurred in the VTA on sides of the VTA (Figure 32).

Figure 32: Channeling on one of the sides of the NW IA 1 VTA in 2007

The SSB and VTA release events for the 2006 and 2007 monitoring periods are listed in Tables 30 and 31. The nutrient mass released for each event is listed along with fecal coliform concentrations and pH values. The fecal coliform concentrations and pH values are averaged for multiple day events.

Table 30: SSB release event summary and released pollutant mass from the SSB for 2006 and 2007 monitoring periods at Northwest IA 1

Northwest IA 1 - SSB			Released mass of pollutants											
Event Date	Rainfall	Volume	NH_4-N	TKN	NO_3- N	Total -P	ortho-P	TDS	TSS	BOD	COD	Cl	pH	Fecal coliforms
	inches	m^3	Kg	Kg	Kg	Kg	Kg	Kg	Kg	Kg	Kg	Kg	pH units	CFU/100ml
8/18/2006[#]	0.63	255	61	261	<0.3	35	7	2345	3499	1341	6222	208	7.1	2.1E+07
9/10/2006	1.2	611	47	153	<0.6	25	7	3756	1557	339	2321	477	7.6	4.5E+07
9/15 - 9/16/2006	1.72	1504	61	1255	<1.5	168	38	7974	27381	1399	6108	867	7.1	2.6E+07
9/21 - 9/22/2006	1.58	1389	89	222	<1.4	52	25	9028	3444	1004	6319	1146	7.4	4.1E+05
9/23/2006	0.06	21	16	58	<0.02	7	1	386	648	386	1746	22	6.3	1.3E+07
3/31 - 4/2/2007	2.18	375	82	217	<0.2	4	4	3482	1985	1039	3309	205	7.1	5.1E+07
4/10 - 4/21/07	0.80		Sensor was removed to change the SSB outlet pipe - volume not recorded											
4/22 - 4/29/2007	1.49	448	78	122	<0.4	15	6	2578	627	976	2461	284	7.2	5.7E+07
5/1/2007	0.12		Flow volume not recorded due to ISCO malfunction											
5/4 - 5/8/2007	2.14	190	29	215	<0.2	10	4	1263	342	243	1012	126	7.2	1.4E+08
5/23 - 5/24/2007	1.12	226	22	46	<0.2	6	3	1087	163	214	1078	98	7.1	1.0E+09
5/29 - 5/30/2007	0.5	17	2	5	<0.02	1	0	92	5	22	80	11	7.6	5.7E+06
6/13- 6/15/2007	1.2	813	142	246	<0.8	49	37	4988	1056	1546	4905	555	6.8	1.3E+09
6/16 - 6/18/2007[#]	0.37	226	29	69	<0.3	11	6	1313	485	334	1124	148	7	3.4E+08
6/21 - 6/22/2007	1.17	497	62	182	<0.5	24	12	3775	1356	1008	2329	441	7	4.5E+07
8/4 -8/9/2007	2.06	880	60	175	<0.9	43	25	3915	1390	702	2340	345	7.4	5.1E+08
8/18/2007	0.71		Flow volume not recorded due to ISCO malfunction											
8/20-8/27/2007	3.31	1418	138	465	<4.7	128	74	11117	7653	1998	10457	1138	7.4	2.3E+09
8/28 - 8/30/2007	0.78	261	30	80	<0.3	15	9	1826	438	347	1315	263	7.3	5.1E+07
9/6-9/8/2007	1.9	616	71	190	<1.5	35	22	4314	1035	820	3106	622	7.4	2.5E+08
9/9 - 9/13/2007	0.33	255	16	38	<0.4	11	8	844	182	163	597	99	7.5	1.2E+08
9/18-9/20/2007	0.61	236	19	41	<0.6	11	7	1654	430	180	1108	212	7.5	8.1E+07
9/24-10/5/2007	2.51	773	45	115	<0.8	33	19	2859	716	607	1909	464	7.4	5.8E+06
10/6-10/12/2007	1.87	1148	68	217	<1.1	47	26	4662	3607	558	2919	654	7.5	1.5E+08
10/13-10/23/2007	2.77	1560	170	465	<1.6	132	46	7787	9583	1679	9007	1048	7.6	1.8E+05

Average concentrations were used to calculate released nutrient mass

pH and Fecal coliforms concentrations are averaged for multiple day events

Table 31: VTA release event summary and released pollutant mass from the SSB for 2006 and 2007 monitoring periods at Northwest IA 1

Northwest IA 1 - VTA			Released mass of pollutants											
Event Date	Rainfall	Volume	NH_4-N	TKN	NO_3- N	Total -P	ortho-P	TDS	TSS	BOD	COD	Cl	pH	Fecal coliforms
	inches	m^3	Kg	Kg	Kg	Kg	Kg	Kg	Kg	Kg	Kg	Kg	pH units	CFU/100ml
9/16/2006	1.72	30	1	5	<0.03	1	1	154	14	14	73	13	7.2	2.5E+07
9/21/2006	1.58	303	16	61	<0.3	12	5	1183	300	153	704	112	7.4	1.4E+07
3/31-4/1/07	2.38	193	0.1	1	0.1	2	0.3	39	4	2	15	<1.0	7.2	2.1E+02
4/1 - 4/2/2007	D	368	72	159	<0.4	20	5	2836	1178	950	2696	191	7.2	2.1E+07
4/10 -4/11/2007#	0.8	15	1	3	<0.02	1	0.3	60	15	12	45	7	7.5	9.4E+07
4/15/2007	D	15	4	6	<0.02	1	0.2	93	23	31	88	10	7.5	6.0E+05
4/24/ - 4/29/2007	0.97	26	2	4	<0.03	1	1	103	7	25	65	12	7.6	1.5E+07
5/6 - 5/9//2007	1.55	128	11	41	<0.1	5	2	645	96	72	470	79	7.6	3.0E+07
9/8/2007	D	21	1	2	<0.1	1	1	60	6	4	28	8	7.3	5.5E+06
10/7 - 10/8/2007	1.8	94	<0.05	1	0.2	1	1	57	1	2	15	8	7.6	1.8E+05
10/11/2007	D	76	3	9	<0.1	3	2	314	38	37	183	43	7.6	1.4E+09
10/12/2007#	D	108	9	20	<0.1	4	2	420	105	83	316	49	7.5	9.4E+07
10/14-10/19/2007	2.65	1818	99	243	<1.9	92	41	5284	2032	863	4325	634	7.6	8.5E+06
10/20/2007	D	66	8	17	<0.1	4	2	421	131	73	333	46	7.6	5.3E+05
10/21/2007#	D	8	0.6	1	<0.01	0.3	0.2	30	8	6	23	4	8	9.4E+07

D - Discharge from SSB resulted in VTA release

Average concentrations were used to calculate released nutrient mass

pH and Fecal coliforms concentrations are averaged for multiple day events

Surface soil data analysis

Eight surface soils samples were collected from the monitoring VTA at NW IA 1 from the surface soil points located in figure 14. The P, K, NH4-N and NO_3-N concentrations for the eight sample points for NW IA 1 VTA are listed in Table 32.

Table 32: Surface soil sample concentration for eight VTA sample points at NW IA 1

NW IA 1		P	K	NH4-N	NO3-N
VTA		ppm	ppm	ppm	ppm
Inlet	Background	176	972	6	25
	2006	321	1556	2	21
	2007	489	2925	8	150
200 ft	Background	71	1833	22	2
	2006	439	1524	1	17
	2007	509	1725	4	67
400 ft	Background	265	975	3	28
	2006	374	1175	2	7
	2007	355	1616	3	71
600 ft	Background	199	522	4	21
	2006	382	984	1	18
	2007	416	1394	3	33
800 ft	Background	220	456	3	26
	2006	315	757	2	3
	2007	437	1392	2	27
1000 ft	Background	191	576	4	29
	2006	395	947	1	16
	2007	441	1593	3	45
1200 ft	Background	243	537	3	18
	2006	366	884	2	21
	2007	484	2060	3	65
Outlet	Background	157	430	4	15
	2006	252	635	1	3
	2007	410	1600	3	51

The background phosphorus, potassium, NH_4-N and NO_3-N concentrations in the VTA ranged from 71 to 265 ppm, 430 to 1833 ppm, 3 to 22 ppm and 2 to 29 ppm respectively. The background P concentrations were higher for sampling points towards the middle of the VTA as compared to end sampling points. The background K concentrations were higher for points closer to VTA inlet compared to the VTA outlet points.

A second set of surface soil samples were collected at the end of the 2006 monitoring period. The P, K, NH4-N and NO_3-N concentrations at the end of 2006 ranged from 252 to 439 ppm, 635 to 1556 ppm, 1 to 2 ppm and 3 to 21 ppm respectively. At the end of 2006, the NH_4-N concentration decreased for all the eight sample points and NO_3-N concentrations decreased for most of the points. The average increase in P and K concentrations for the seven sample points after 5 months of monitoring were 45% and 29 %.

At the end of 2007 monitoring period, a third set of surface soil samples were collected. The P, K, NH_4-N and NO_3-N concentrations ranged from 355 to 509 ppm, 1392 to 2925 ppm, 2 to 8 ppm and 27 to 150 ppm respectively. The 2007 concentrations compared to 2006 increased for all the eight points of the VTA. The P, K and NO_3-N concentrations in 2007 compared to the background concentrations increased for the eight points of the VTA and the NH_4 - N concentrations decreased for five out of eight VTA sample points. The average increase in 2007 P and K concentrations compared to the background results for the seven sample points were 56% and 55 %.

Groundwater data analysis

The groundwater samples were collected monthly at NW IA 1 from the up gradient, in the system -1 and in the system -2 wells (refer figure 14). The in the system -1 well was up gradient to the in the system-2 well. The down gradient well to NW IA 1 VTS was not installed by the IDNR. The background and monitoring concentrations for the three wells are given in Table 33.

The NH_4- N concentrations were consistent around 0.2 mg/l for the three wells for most of the months during the monitoring periods in 2006 and 2007. The average monitored chloride concentrations for up gradient, in the system-1, and in the system -2 wells were 48, 37 and 144 mg/l. Chloride was present in higher concentrations for in the system -2 well compared to the up gradient well. The background chloride concentrations in the up gradient, in the system-1, and in the system -2 wells were 54, 87, and 19 mg/l. The average monitored concentration for the three wells were higher than their respective background concentrations.

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Table 33 Groundwater concentrations for up gradient, in the system -1 and in the system - 2 wells at NW IA 1

Up gradient well				
Sample Date	**NH_4-N**	**Cl**	**NO_3- N**	**Fecal coliforms**
	mg/L	**mg/L**	**mg/L**	**CFU/100ml**
7/10/2006	0.2	54	18	<10
System operational				
3/13/2007	0.211	50	8	120
3/27/2007	<0.2	43	27	<10.0
4/8/2007	<0.2	57	28	<10
5/13/2007	<0.2	48	20	<100
6/7/2007	<0.2	40	19	<100
7/11/2007	<0.2	29	15	<100
8/7/2007	<0.2	60	24	<100
9/7/2007	<0.2	59	22	30
10/11/2007	<0.2	47	19	110
First sample is the background sample				
In the system - 1 well				
Sample Date	**NH_4-N**	**Cl**	**NO_3- N**	**Fecal coliforms**
	mg/L	**mg/L**	**mg/L**	**CFU/100ml**
7/10/2006	0.4	87	39	<10.0
System operational				
9/15/2006	1.52	40	2	550
10/15/2006	0.351	10	1	180
3/13/2007	0.277	19	4	100
3/27/2007	<0.2	27	6	<20
4/8/2007	<0.2	87	47	<10.0
5/13/2007	<0.2	72	37	<100
6/7/2007	<0.2	38	19	20
7/11/2007	<0.2	49	25	<100
8/7/2007	0.208	46	26	<10
9/7/2007	<0.2	15	1	100
10/11/2007	<0.2	7	1	<10
First sample is the background sample				
In the system - 2 well				
Sample Date	**NH_4-N**	**Cl**	**NO_3- N**	**Fecal coliforms**
	mg/L	**mg/L**	**mg/L**	**CFU/100ml**
7/10/2006	0.9	19	8	<10
System operational				
9/15/2006	<1.50	112	24.5	1400
10/15/2006	<0.2	119	43	190
3/13/2007	<0.2	120	34	20
3/27/2007	<0.2	124	27	50
4/8/2007	<0.2	135	36	<10.0
5/13/2007	<0.2	130	34	200
6/7/2007	<0.2	127	29	<10.0
7/11/2007	<0.2	131	36	<100
8/7/2007	<0.2	174	29	<100
9/7/2007	<0.2	200	30	10
10/11/2007	<0.2	225	34	<10
First sample is the background sample				

The average monitored NO_3-N concentrations for up gradient, in the system-1, and in the system -2 wells were 20, 15 and 32 mg/l which are higher than the EPA nitrate –N concentration limit in drinking water of 10mg/L. The NO_3-N concentrations for in the system – 2 well are higher than the up gradient well indicating that the VTS might be contributing NO_3-N to the groundwater beneath the system. The background NO_3-N concentrations for up gradient, in the system-1, and in the system -2 wells were 18, 39 and 8 mg/l. The average monitored NO_3-N concentrations for the three wells are higher than their respective background concentrations indicating an increase in NO_3-N concentrations over time.

The NO_3-N concentrations for in the system – 1 well, range from 1 mg/l (during beginning and ending of the monitoring period) to 47 mg/l (during the middle of the monitoring period). The variability in the data cannot be explained with limited amount of available data. Groundwater data collected once a month may not be sufficient to represent short term changes occurring in pollutant concentrations in the groundwater. Therefore, due to limited data collection, it is not possible to conclude an impact of the VTS on groundwater quality.

Overall VTS Performance

The percent runoff control at NW IA 1 for 2006 and 2007 was 96% and 85% respectively. The percent runoff control is calculated as ((SSB release + rainfall) – VTA release)/ (SSB release + rainfall). The VTS runoff control performance was lower in 2007 as compared to 2006. In 2006, there were two VTA releases (333 m^3 or 11,760 ft^3) as compared to 13 VTA releases in 2007 releasing approximately 3,000 m^3 (105944 ft^3) of water out of the monitoring VTA.

Table 34 shows the percent pollutant mass retained in the VTS at NW IA 1 for 2006 and 2007 monitoring periods. In 2006, NW IA 1 VTS had almost total retention of pollutants in the system. But in 2007, lower runoff percent control resulted in lower percentages of pollutant control compared to 2006.

Table 34: Percent pollutant mass retained in the VTS for 2006 and 2007 at NW IA 1

	NH_4-N	TKN	Total -P	ortho-P	BOD	COD	Cl	Total Solids
2006	94	97	96	93	96	97	95	97
2007	80	82	76	81	83	82	84	84

A comparison of average nutrient/pollutant concentrations released out of the SSB and VTA is listed in Table 35. The average concentrations released out of the VTA are lower than the SSB effluent concentrations for both 2006 and 2007 indicating removal of nutrients by the VTA.

Table 35: Average nutrient concentrations (with standard deviations) released from SSB and VTA for 2006 and 2007 at NW IA 1

Site	NH_4-N		TKN		Total P		Total Solids		COD	
	Mean	St Dev	Mean	St Dev	Mean	St Dev	Mean	St Dev	Mean	St Dev
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
2006										
NW IA 1 SSB	239	357	24378	40483	137	152	1024	1254	22895	18596
NW IA 2 VTA	41	11	2427	105	37	2	171	26	5049	467
2007										
NW IA 1 SSB	132	83	5070	2581	48	23	317	220	7865	3843
NW IA 2 VTA	83	70	2924	2151	40	24	185	126	4860	3255

In 2007, controlled SSB releases resulted in some VTA releases only due to SSB release or due to a combination of SSB release and rain on the VTA. A comparison of average nutrient concentrations of VTA releases occurring due to SSB releases and SSB release + rain is given in Table 36. The VTA release nutrient concentrations due to a combination of SSB release and rain were lower for ortho-P, TDS, total P and chloride. But the VTA release nutrient concentrations due to a combination of SSB release and rain were higher for NH_4-N, TKN, TSS, BOD and COD. Typically lower VTA release concentrations are expected from a combination of rain and SSB release due to dilution. But a mixed trend is observed at NW IA 1. There were no VTA releases that resulted only due to rain onto the VTA.

Table 36: Comparison of average nutrient concentrations of VTA releases due to SSB release and SSB release and rain for NW IA 1 (2007)

VTA Release	NH_4-N	TKN	ortho-P	Total -P	TSS	TDS	BOD	COD	Cl
due to	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
SSB release + rain	94	208	21	41	1064	4051	875	3159	434
SSB release	69	156	28	44	923	4467	586	2933	543
% difference	-37	-33	27	6	-15	9	-49	-8	20

The sample results for the analysis of reed canary grass harvested from the VTA in 2007 were not received from the laboratory at the time of this writing of the thesis. Therefore, analysis of uptake of nutrients by the VTA vegetation is not included in this document.

The VTA vegetation at NW IA 1 consisted mostly of perennial reed canary grass. In 2006, the annual N and P loading rates for NW IA 1 VTA were 1,411 kg/ha (1,260 lb/acre) and 208 kg/ha (186 lb/acre). Since the VTA was not harvested in 2006, N and P requirements for the reed canary grass based on yield cannot be calculated.

In 2007, the producer harvested the VTA twice and yielded a total of 15,422 kg (34,000 lbs) of forage from 4.14 acre VTA. The N and P requirement for the reed canary grass based on yield is calculated as 167 kg/ha (149 lb/ acre) and 63 kg/ha (56 lb/acre) respectively (based on 45 kg/ha (40 lb/acre) of N and 17 kg/ha (15 lb/acre)of P required for one ton yield of reed canary grass). The 2007 annual N and P loading rates for NW IA 1 VTA were 2,091 kg/ha (1,867 lb/acre) and 417 kg/ha (372 lb/acre) respectively. Therefore, in 2007 the VTA received with 13 times more nitrogen and 7 times more phosphorous than reed canary's requirement.

The NW 1 VTA was loaded with 35 tons/ha (14 tons/acre) and 52 tons/ ha (21 tons/acre) of total solids in 2006 and 2007 respectively. Since monitoring period durations were different for 2006 and 2007, normalized annual loading rates over number of monitoring days in each year were calculated. The normalized annual loading rates for 2006 and 2007 were 291 kg/ha-day (260 lb/acre-day) and 246 kg/ha-day (220 lb/acre-day) respectively. The mass of total solids released from the SSB into the VTA decreased in 2007. The total solids concentrations released from the SSB decreased in 2007 due to controlled SSB releases (refer figure 20), hence decreasing the total solids normalized loading rate.

Comparison of VTS and traditional systems performance

The ELG model did not predict releases from the containment systems in 2006 and 2007 for NW IA 1. But the VTS at NW IA 1 had six VTA release events in 2006 and 13 VTA release events in 2007. The two VTS releases in 2006 released 334 m^3 (11,795 ft^3) and the 13 VTA releases in 2007 released 2,937 m^3 (103,719 ft^3) of water out of the NW IA 1 VTA. The nutrient mass released from the NW IA 1 and the containment basin during 2006 and 2007 has been compared in Table 37. Since the mass of nutrients released from the NW IA 1 VTS is higher for both 2006 and 2007, the VTS did not perform equal or better than the modeled traditional containment system performance.

Table 37: Comparison of nutrient mass released from NW IA 1 VTS and containment basin for 2006 and 2007

Mass released (Kg)	2006	2007
VTS TKN	66	506
ELG TKN	0	0
VTS NH_4-N	17	212
ELG NH_4-N	0	0
VTS Total P	13	135
ELG Total P	0	0
VTS Total soilds	1,615	14,007
ELG Total soilds	0	0
VTS COD	777	8,602
ELG COD	0	0

4.1.4 Performance Evaluation of the Northwest IA 2 VTS

The performance evaluation of the VTS at NW IA 2 includes analysis of groundwater and surface soil sample data, analysis of overall VTS performance and comparison of VTS, and modeled containment system performance.

2006 and 2007 monitoring periods

2006 monitoring period: The monitoring for Northwest IA 2 initiated in August 2006. The VTA vegetation was fully established in the beginning of the monitoring period (figure 33) but one half of the VIB had standing water for most of the monitoring period. In the 2006 monitoring period, NW IA 2 received 27.7 cm (10.91 inches) of rainfall. There were six SSB release events out of which one event was not sampled due to equipment malfunction. The un-sampled event represented 8% of total volume released from the SSB. There were five VIB release events in 2006 releasing 2,900 m^3 (102,412 ft^3) into the VTA. Four VTA release events were recorded during 2006. The volume for one out of four VTA release events was not measured. In 2006, approximately 160 m^3 (5650 ft^3) of VTA effluent was released into the VIB. The un-sampled SSB and VTA release events were substituted with average nutrient concentrations to estimate nutrient mass released.

Figure 33: Good stand of the VTA vegetation in 2006 at NW IA 2

2007 monitoring period: The producer used the VIB to collect the winter runoff (from November 2006 to March 2007). As a result, in the beginning of 2007 monitoring period one half of the VIB was covered of solids and the other half had standing water in it (figure 34). The VIB remained in the same condition for the most of the year with sparse vegetation growing on a small area in the middle of the VIB. The SSB at NW IA 2 did not provide enough settling and semi-solid slurry like effluent was observed to be flowing out of the SSB flume (figure 35). As a result, the VIB surface was covered with solids during the 2007 monitoring period. Solids were accumulated in the flume at the SSB outlet which created a hindrance in the accurate volume measurement with the ISCO 720 submerged probe.

During the 2007 monitoring period, NW IA 2 received 65 cm (25.6 inches) of rainfall. There were 26 release events recorded at the SSB of which 13 events were not sampled due to solids accumulation in the flume. The 13 un-sampled events represented 50% of total volume released from the SSB. The un-sampled SSB release events were substituted with average nutrient concentrations to estimate nutrient mass released. There were 14 release events recorded at the VIB outlet. One VTA release event was recorded in 2007 for NW IA 2. The VTA had a good stand of vegetation (mostly reed canary grass) during the monitoring period (figure 36). The VIB and VTA were harvested once in July. The VTA flow was observed to be evenly spread along the width indicating maximum utilization of the VTA area.

Figure 34: (L to R) Solids accumulation in one half of the VIB towards the inlet and standing water in the other half towards the outlet in 2007 at NW IA 2

Figure 35: Semi solid slurry released from the SSB outlet flume into the VIB at NW IA 2

Figure 36: Good stand of VTA vegetation at NW IA 2 in 2007

The SSB, VIB and VTA release events for the 2006 and 2007 monitoring periods are listed in Tables 38, 39 and 40. The nutrient mass released for each event is listed along with fecal coliform concentrations and pH values. The fecal coliform concentrations and pH values are averaged for multiple day events. The VTA outlet pipe releases VTA effluent into the VIB, therefore the VTA releases were recycled back to the VIB. The VTA release events shown in Table 40 were recycled back to the VIB.

Table 38: SSB release event summary and released pollutant mass from the SSB for 2006 and 2007 monitoring periods at Northwest IA 2

Northwest IA 2 - SSB			Released mass of pollutants											
Event Date	Rainfall	Volume	NH_4-N	TKN	NO_3- N	Total -P	ortho-P	TDS	TSS	BOD	COD	Cl	pH	Fecal coliforms
	inches	m^3	Kg	Kg	Kg	Kg	Kg	Kg	Kg	Kg	Kg	Kg	pH units	CFU/100ml
8/1 - 8/2/2006	1.72	914	207	788	<0.5	111	32	4518	5842	1817	10278	378	7.0	3.4E+07
8/5/2006	0.74	341	230	706	<0.3	76	28	5051	3754	3754	12115	240	6.6	4.0E+06
8/18/2006	1.7	951	311	772	<0.8	125	25	9592	4508	3727	14096	623	6.9	3.3E+06
9/10-9/11/2006#	0.8	403	131	462	<0.4	61	21	3832	3139	1690	6811	257	6.7	4.7E+07
9/15 - 9/17/2006	2.54	1716	607	2059	<1.7	328	187	19045	16643	11736	34315	1289	6.6	2.9E+06
9/21 - 9/22/2006	1.36	710	43	225	<0.5	41	9	3577	3329	671	754	389	7.3	2.1E+06
3/29 - 4/2/2007#	2.8	1944	826	2991	<3	511	214	33272	50649	19742	81513	2143	6.9	1.6E+08
4/10 - 4/11/2007#	0.48	141	60	218	<0.2	37	16	2420	3684	1436	5929	156	6.9	1.6E+08
4/27/2006	No rain	15	5	11	<0.02	2	1	153	71	89	246	11	7.0	6.0E+07
5/4/2007#	0.64	124	53	190	<0.2	33	14	2118	3223	1256	5188	136	6.9	1.6E+08
5/5/2007#	0.45	150	64	232	<0.2	40	17	2576	3921	1528	6310	166	6.9	1.6E+08
5/6/2007#	0.6	194	82	298	<0.3	51	21	3313	5043	1966	8116	213	6.9	1.6E+08
5/8/2007	No rain	4	1	4	<0.004	1	0.5	57	50	32	100	3	6.3	1.1E+08
5/23/2007#	0.42	7	3	11	<0.01	2	1	125	191	74	307	8	6.9	1.6E+08
6/13/2007#	0.6	46	20	71	<0.1	12	5	791	1204	469	1937	51	6.9	1.6E+08
6/14/2007	0.6	447	228	1045	<1.1	179	97	12956	40208	7014	51377	469	6.6	2.2E+08
6/22/2007	0.8	203	59	237	<0.2	35	21	2657	730	1677	3833	213	7.0	8.0E+07
8/1- 8/2/2007#	0.8	320	136	493	<0.5	84	35	5478	8339	3251	13421	353	6.9	1.6E+08
8/4/2007	1.23	1521	686	5796	<1.5	774	221	35293	103444	23883	149385	1704	6.7	3.6E+08
8/15/2007	0.37	26	11	38	<0.1	5	1	625	287	191	579	45	7.2	2.4E+08
8/18/2007	0.8	261	53	171	<0.7	22	11	1878	1591	981	2922	172	7.6	1.0E+07
8/20/2007	1.8	960	249	868	<2.4	155	82	8544	10272	4762	19488	607	7.3	3.0E+07
8/23/2007#	1.35	138	59	213	<0.2	36	15	2366	3601	1404	5795	152	6.9	1.6E+08
8/29/2007	0.35	44	24	71	<0.1	9	6	663	933	562	1317	68	7.0	3.0E+07
9/2 - 9/3/2007	0.63	240	82	155	<0.2	41	15	3095	2207	1706	4006	357	6.9	1.2E+07
9/9/2007#	0.55	43	18	66	<0.1	11	5	730	1112	433	1789	47	6.9	1.6E+08
9/24/2007#	0.45	69	29	105	<0.1	18	8	1172	1785	696	2872	76	6.9	1.6E+08
9/29/2007#	0.6	184	78	283	<0.3	48	20	3147	4790	1867	7709	203	6.9	1.6E+08
10/1/2007	0.3	8	5	16	0.003	3	2	140	277	143	291	13	6.6	4.8E+08
10/8/2007	2.16	755	235	660	<0.8	148	81	7093	12978	5999	15016	522	6.8	3.3E+08
10/13-10/15/2007#	2.27	1446	615	2226	<2	380	159	24757	37686	14690	60652	1595	6.9	1.6E+08
10/16-10/17/2007	0.86	240	229	651	<0.2	157	26	8644	11526	3770	26893	303	6.4	6.7E+07
# Average concentrations were used to calculate released nutrient mass														
pH and Fecal coliforms concentrations are averaged for multiple day events														

Table 39: VIB release event summary and released pollutant mass from the VIB for 2006 and 2007 monitoring periods at Northwest IA 2

Northwest IA 2 - VIB			Released mass of pollutants											
Event Date	Rainfall	Volume	NH_4-N	TKN	NO_3- N	Total -P	ortho-P	TDS	TSS	BOD	COD	Cl	pH	Fecal coliforms
	inches	m^3	Kg	Kg	Kg	Kg	Kg	Kg	Kg	Kg	Kg	Kg	pH units	CFU/100ml
8/1 - 8/2/2006	1.72	139	36	268	<0.1	17	3	1452	781	797	1564	96	6.9	1.3E+08
8/5 - 8/6/2006	0.74	179	41	134	<0.3	16	5	1799	308	897	2142	103	7.0	4.7E+05
8/18/2006	1.7	374	8	23	<0.7	5	1	954	164	164	863	46	7.2	6.2E+05
9/15 - 9/17/2006	2.54	1393	79	337	<1.4	59	15	6965	2396	2661	8664	439	7.0	1.0E+06
9/21 - 9/22/2006	1.36	818	142	369	0.9	57	9	4663	2020	3485	8834	307	6.8	6.0E+05
4/1 - 4/18/2007	No rain	373	16	53	3.3	6	0.4	1179	138	267	1000	115	7.1	2.7E+04
4/19 - 4/21/2007	No rain	374	40	61	<0.4	9	1.1	1309	232	329	1297	135	7.1	5.0E+03
4/22 - 4/28/2007	No rain	194	9	19	<0.1	3	0.0	466	69	100	463	53	7.2	8.0E+04
4/29 - 5/8/2007	No rain	237	8	20	<0.2	2	0.5	663	73	61	348	59	7.1	1.6E+05
6/7 - 6/22/2007	0.8	159	14	98	<0.2	9	2.4	1113	255	756	1438	96	6.8	2.2E+07
7/28/ - 8/4/2007	1.19	79	8	41	<0.1	4	1.0	665	103	225	957	55	7.0	2.3E+08
8/5 - 8/9/2007	0.01	70	12	35	<0.2	6	1.5	554	89	215	693	65	7.3	7.0E+05
8/16 - 8/20/2007	1.8	105	4	18	6.5	3	1.0	429	212	128	490	39	7.0	2.9E+07
8/21 - 8/22/2007	No rain	142	4	17	<0.4	2	0.4	470	64	75	313	52	7.2	4.8E+06
8/24 - 9/7//2007	0.35	541	50	113	<0.5	20	0.9	2434	254	698	2110	236	6.9	6.0E+04
10/1 - 10/8/2007	2.01	78	2	13	0.3	2	0.0	235	94	57	199	32	7.3	6.9E+06
10/9 - 10/11/2007	No rain	210	1	32	<0.2	5	0.2	610	153	120	580	87	7.1	1.5E+08
10/12 - 10/16/2007	0.15	62	5	18	<0.1	6	1.4	188	368	90	570	23	7.1	1.5E+06
10/17 - 10/22/2007	0.01	65	13	17	<0.06	4	1.7	350	320	165	451	33	7.0	<100000
pH and Fecal coliforms concentrations are averaged for multiple day events														

Table 40: VTA release event summary and released pollutant mass from the VTA for 2006 and 2007 monitoring periods at Northwest IA 2

Northwest IA 2 - VTA			Released mass of pollutants											
Event Date	Rainfall	Volume	NH_4-N	TKN	NO_3- N	Total -P	ortho-P	TDS	TSS	BOD	COD	Cl	pH	Fecal coliforms
	inches	m^3	Kg	Kg	Kg	Kg	Kg	Kg	Kg	Kg	Kg	Kg	pH units	CFU/100ml
8/5/2006	0.74	53	14	42	<0.05	5	1.5	468	122	284	366	22	6.9	2.0E+05
8/18/2006	1.7	50	0.2	1	0.47	0.3	0.2	23	33	3	17	1	6.8	2.0E+04
9/16/2006	2.54	57	1	4	<0.06	1	0.2	116	22	20	102	8	7.3	1.0E+05
9/21/2006	1.36		Flow volume was not measured											
4/1 - 4/2/2007	1.97	22	2	9	<0.01	1	0.4	128	68	55	179	10	7.2	2.7E+07

Surface soil data analysis

At NW IA 2, one surface soil samples was collected at the inlet and outlet of east and west VTAs (refer figure 9) and one sample was collected at the VIB inlet. The surface soil sample locations are shown in figure 13 (refer section 3.4). The results of three sets of surface soil samples collected at the sampling points in shown in table 41.

Table 41: Surface soil sample results for the five sample points at NW IA 2

NW IA 2		P	K	NH4-N	NO3-N
		ppm	ppm	ppm	ppm
W VTA inlet	Background	84	327	5	9
	2006	129	588	18	60
	2007	418.5	683	5	225
W VTA outlet	Background	258	599	5	6
	2006	222	588	3	29
	2007	302	1011	4	356
E VTA inlet	Background	98	336	4	7
	2006	194	587	4	24
	2007	338	872	5	306
E VTA outlet	Background	251	548	6	9
	2006	274	752	3	32
	2007	239	678.5	4	139
VIB inlet	Background	283	1520	6	13
	2006	59	516	12	7
	2007	417	1491	6	329

The background phosphorus, potassium, NH_4-N and NO_3-N concentrations for the VIB inlet were 283, 1520, 6 and 13 ppm. The P, K, NH_4-N and NO_3-N concentrations at VIB inlet collected at the end of 2006 decreased to 59, 516, 12 and 7 ppm. The P, K, NH_4-N and NO_3-N concentrations at the end of 2007 monitoring period increased to 417, 1491, 6 and 329 ppm. The increase in the concentration at the VIB inlet at the end of 2007 is likely due to poor SSB performance.

The background P, K, NH_4-N and NO_3-N concentrations of both VTA inlets ranged from 84 to 98 ppm , 327 to 336 ppm, 4 to 5 ppm, and 7 to 9 ppm respectively. The background P, K, NH_4-N and NO_3-N concentrations of both VTA outlets ranged from 251 to 258 ppm, 599 to 548 ppm, 5 to 6 ppm, and 6 to 9 ppm respectively. The nutrient concentrations at VTA inlet were lower than VTA outlet points.

The P, K, NH_4-N and NO_3-N concentrations at the end of the 2006 monitoring period of both VTA inlets ranged from 129 to 194 ppm , 587 to 588, 4 to 18 ppm, and 24 to 60 ppm respectively. The P, K, NH_4-N and NO_3-N concentrations at the end of the 2006 monitoring period of both VTA outlets ranged from 222 to 274 ppm, 588 to 752 ppm, 3 to 3.2 ppm, and 29 to 32 ppm respectively. The P and K concentrations increased by about 40 % and NH_4-N and NO_3-N concentrations increased by about 75% for the both VTA inlet points at the end of 2006. A mixed trend was seen in change of concentrations at the both VTA outlet points as concentrations for west VTA decreased and east VTA increased at the end of the 2006 monitoring period.

At the end of the 2007 monitoring period, P, K, NH_4-N and NO_3-N concentrations at both VTA inlets ranged from 338 to 419 ppm , 638 to 872, 4.7 to 4.8 ppm, and 225 to 306 ppm respectively. The P, K, NH_4-N and NO_3-N concentrations at the end of 2007 monitoring period of both VTA outlets ranged from 239 to 302 ppm, 679 to 1011 ppm, 4 to 5 ppm, and 140 to 356 ppm respectively. At the end of 2007, the P and K concentrations at the both VTA inlets increased, but a mixed trend was observed for both VTA outlets.

The 2007 P, K, NO_3-N and concentrations compared to the background concentrations, increased or were similar for both VTA and VIB sample points. The NH_4-N concentrations decreased for most of the VTA points and increased for the VIB inlet.

Groundwater data analysis

The groundwater samples were collected monthly at NW IA 2 from the up gradient and down gradient wells (refer figure 13). The background and monitored concentrations for the two wells are given in Table 42. The up gradient well remained dry most of the times; therefore samples were not collected from this well.

The NH_4- N concentrations were consistent at 0.2 mg/l during the monitoring periods in 2006 and 2007. The average monitored chloride concentrations in the up gradient and down gradient wells are 52 and 87 mg/l. The chloride levels increased in the down gradient well as compared to its background concentrations (75 mg/l) over the two year monitoring period.

Table 42 Groundwater concentrations for the up gradient and down gradient wells for Central IA 1

Up gradient well				
Sample Date	**NH_4-N**	**Cl**	**NO_3- N**	**Fecal coliforms**
	mg/L	**mg/L**	**mg/L**	**CFU/100ml**
No samples available in 2006 due to dry well				
3/13/2007	<0.2	48.8	41	10
Sample for May 2007 not available due to dry well				
6/7/2007	<0.200	59.8	43	<10.0
Sample for July 2007 not available due to dry well				
Sample for August 2007 not available due to dry well				
Sample for September 2007 not available due to dry well				
10/11/2007	<0.2	47	39.6	<10
Background sample not available				

Down gradient well				
Sample Date	**NH_4-N**	**Cl**	**NO_3- N**	**Fecal coliforms**
	mg/L	**mg/L**	**mg/L**	**CFU/100ml**
8/9/2006	0.293	74.5	176	N/A
System operational				
3/13/2007	<0.2	77.2	120	<10.0
3/27/2007	<0.2	77.3	134	<100
4/8/2007	<0.2	73.4	101	<10.0
5/13/2007	<0.2	73.5	112	<10
6/7/2007	<0.2	86	109	<100
7/11/2007	<0.2	92.9	109	<100
Sample for August 2007 not available due to dry well				
9/7/2007	<0.2	108	93.7	<10
10/11/2007	<0.2	107	92.6	2000
First sample is the background sample				

The background NO_3-N concentration in the down gradient well is 176 mg/l which is higher than the EPA nitrate –N concentration limit in drinking water of 10mg/L indicating presence of high NO_3-N concentrations before the construction of the VTS. The average NO_3-N concentrations in the up gradient and down gradient wells were 41 and 109 mg/l. The average monitored NO_3-N concentrations in the down gradient well are higher than the up gradient well. A potential reason for high NO_3-N concentrations in the down gradient well can be its location. The well is located close to the VIB, an area which was used as a disposal site for feedlot runoff released from the site for over four decades before the VTS construction. Another reason for high NO_3-N concentrations could be proximity of the well to a drainage tile line that runs close to location of the well.

Groundwater data collected once a month may not be sufficient to represent short term changes occurring in pollutant concentrations in the groundwater. Therefore, due to limited data collection, it is not possible to conclude an impact of the VTS on groundwater quality.

Overall VTS performance

The percent runoff control at NW IA 2 for 2006 and 2007 was 98% and 99% respectively. The VTS runoff control performance in 2007 was almost 100% because of one VTA release measuring 22 m^3 (777 ft^3) was recorded compared to approximately 9500 m^3 released from the SSB.

Table 43 shows the percent pollutant mass retained in the VTS at NW IA 2 for 2006 and 2007 monitoring periods. In 2006 and 2007, the NW IA 2 VTS retained 99% of all pollutants/nutrients in the system because of 99 % runoff control in 2007.

Table 43: Percent pollutant mass retained in the VTS for 2006 and 2007 at NW IA 2

	NH_4-N	TKN	Total -P	ortho-P	BOD	COD	Cl	Total Solids
2006	99	99	99	99	99	99	99	99
2007	99	99	99	99	99	99	99	99

The average nutrient concentrations released out of the SSB, VIB and the VTA are compared in Table 44. In 2006, the average NH_4-N and TKN concentrations coming out of the VTA were higher compared to the VIB concentrations. For the 2007 data, only one VTA release occurred therefore the mean concentrations are concentrations from one release sample. The nutrient/ pollutant concentrations released from the VTA in 2007 are higher than mean concentrations released from the VIB. It might be due to comparison with a single sample concentration available for 2007. In 2006 and 2007, the average VIB release concentrations are lower than the SSB indicating removal of nutrients in the VIB.

Table 44: Average nutrient concentrations (with standard deviations) released from SSB and VTA for 2006 and 2007 at NW IA 2

Site	NH_4-N		TKN		Total P		Total Solids		COD	
	Mean	St Dev	Mean	St Dev	Mean	St Dev	Mean	St Dev	Mean	St Dev
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
2006										
NW IA 2 SSB	325	177	16895	10939	152	87	1145	777	17294	12158
NW IA 2 VIB	132	105	7023	4352	60	47	697	949	8248	5348
NW IA 2 VTA	166	106	7509	4383	60	34	541	345	7697	4029
2007										
NW IA 2 SSB	425	200	41931	38679	263	170	1539	950	43169	33899
NW IA 2 VIB	66	44	5111	3611	37	27	250	179	5596	2606
NW IA 2 VTA*	96		8220		60		432		9030	

*single sample concentration

The analysis of uptake of nutrients by the VTA vegetation is not included in this thesis because reed canary grass samples collected from the VTA in 2007 were not back from the lab at time of writing of the thesis.

In 2006, the annual N and P loading rates for NW IA 2 VIB were 6,531 kg/ha (5,831 lb/acre) and 966 kg/ha (862 lb/acre). The annual N and P loading rates for the VTA in 2006 were 2,281 kg/ha (2,037 lb/acre) and 310 kg/ha (277 lb/acre). Since the VIB and the VTA were not harvested in 2006, N and P requirement for the reed canary grass based on yield cannot be calculated.

In 2007, the producer harvested the VIB and the VTA in July and yielded 907 kg (2,000 lbs) and 2,721 kg (6,000 lbs) of forage from the VIB (2.3 acre) and VTA (1.5 acre) respectively. The 2007 annual N and P loading rates for the VIB were 22,112 kg/ha (19,743 lb/acre) and 3,608 kg/ha (3,222 lb/acre) and the VTA N and P loading rates were 1,123 kg/ha (1,003 lb/acre) and 164 kg/ha (146 lb/acre). The ratios of N and P applied to the crop requirement were calculated based on reed canary grass N and P requirement. In 2007, the VIB received 1,262 times more nitrogen and 549 times more phosphorous than reed canary's requirement. The VTA received 14 times more nitrogen and five times more phosphorous.

The NW IA 2 VIB was loaded with 89 tons/ha (36 tons/acre) and 505 tons/ha (204 tons/acre) of total solids in 2006 and 2007 respectively. The VTA was loaded with 35 tons/ha (14 ton/acre) and 22 tons/ha (9 ton/acre) total solids in 2006 and 2007. The normalized annual VIB loading rates for 2006 and 2007 were 67 kg/ha-day (60 lb/acre-day) and 6,647 kg/ha-day (5,935 lb/acre-day) respectively. The normalized annual VTA loading rates were 290 kg/ha –day (259 lb/acre-day) and 184 kg/ha –day (164 lb/acre-day) in 2006 and 2007. The mass of total solids released from the SSB into the VTA increased in 2007. The inability of the NW IA 2 SSB to settle solids resulted in high total solids concentrations being released into the VIB.

Comparison of VTS and traditional systems performance

The ELG model did not predict releases from the containment basin in 2006 and 2007 for NW IA 2. But the VTS at NW IA 2 had four VTA releases in 2006 and one VTA release event in 2007. The four VTS releases in 2006 released 160 m^3 (5650 ft^3) and one VTA releases in 2007 released 22 m^3 (777 ft^3) of water out of the NW IA 2 VTA. The nutrient mass released from the NW IA 2 and the containment basin during 2006 and 2007 has been compared in Table 45. Since the mass of nutrients released from the NW IA 2 VTS is higher for both 2006 and 2007, the VTS did not perform equal or better than the traditional containment system performance predicted by the ELG model.

Table 45: Comparison of nutrient mass released from NW IA 2 VTS and containment basin for 2006 and 2007

Mass released (Kg)	2006	2007
VTS TKN	47	9
ELG TKN	0	0
VTS NH_4-N	14	2
ELG NH_4-N	0	0
VTS Total P	6	1
ELG Total P	0	0
VTS Total soilds	783	196
ELG Total soilds	0	0
VTS COD	485	179
ELG COD	0	0

4.2 Comparison of Measured and Modeled VTS Performance

The measured system performance in 2006 for the four sites is compared with the modeled VTS performance (predicted by the VTS models) to determine the accuracy of the VTS models. In 2007, the SSB releases were controlled depending upon the saturation conditions of the VIB/VTA. This operational change in the management of the VTSs is not incorporated in the VTS models. As a result, the VTS models cannot predict the 2007 VTS performance. Therefore, measured and modeled system performance is compared for 2006 data.

The comparison of the modeled and measured results was done in two parts: comparison of the effluent volume released from each component of the VTS and comparison of the mass of nutrients released from the VTS.

Comparison of release volume: Initial comparisons included plotting of modeled and measured releases for the SSB, VIB and VTA per day for the 2006 monitoring period.

SSB performance: The daily modeled and measured SSB release volume was compared for each site. Figure 37 shows an example of such a plot for NW IA 2. The VIB-VTA and VTA models predicted flow from the SSB on the same dates that the measured releases occurred at all sites. During the 2006 monitoring period, the model for Central IA 1 predicted more than the measured discharge from the SSB for 18 out of 20 release events. The VIB-VTA model for Central IA 2 also predicted more SSB discharge than measured for 35 out of 38 events during the six month monitoring period. In the case of NW IA 1, the modeled SSB release was more than the measured for seven out of 12 release events. The modeled SSB release for Northwest IA 2 was similar to the monitored release for all the runoff events.

VIB performance: The measured and modeled VIB release volume was plotted versus the monitored time period for the two sites with a VIB-VTA system. The modeled VIB release for Central IA 2 was less than the measured release for 14 out of 16 tile flow events. Of these 14 events, the VIB-VTA model predicted no release for 11 events. The VIB-VTA model predicted more than the measured release for four out of seven events at NW IA 2.

VTA performance: The VTAs at all four sites had well established vegetation by the end of 2006 monitoring period. The VTAs at all four sites recorded releases during the 2006 monitoring period. But the VIB-VTA and VTA models did not predict any release from the VTA for the four sites during this period. Central IA 1 and 2 recorded two and six VTA release events, respectively. NW IA 1 and 2 recorded two and four VTA release events, respectively.

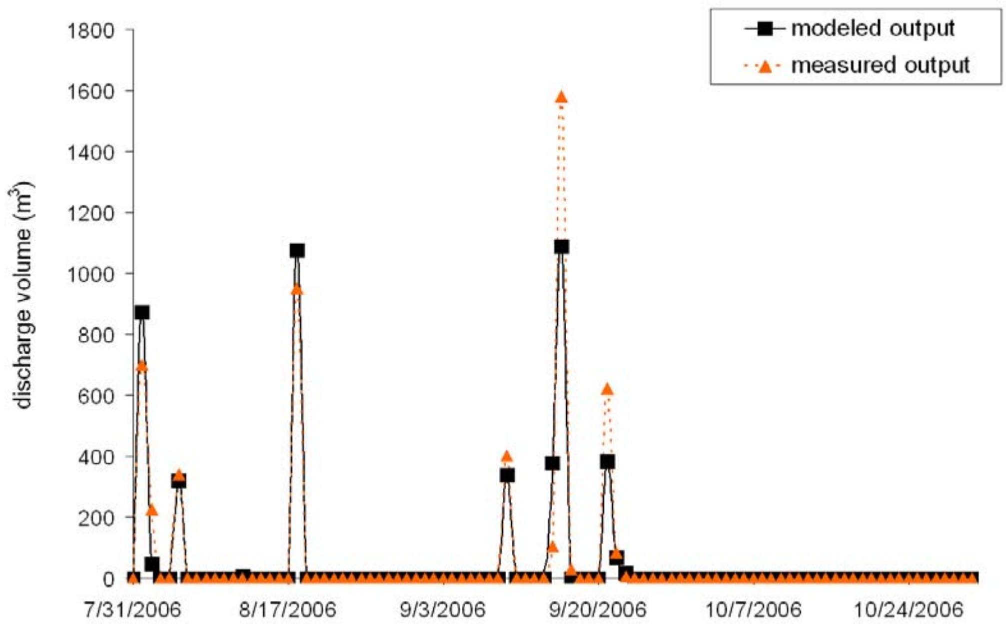

Figure 37: Daily SSB discharge for the monitoring period at Northwest IA 2

Next, the measured and modeled release volumes were compared. The daily release volume data was summed per event and days with no release were omitted from the data set. The difference between modeled and measured release from the SSB, VIB and VTA were calculated for each release event. Table 46 shows the average difference between modeled and measured values per site for each component of the system over the monitoring period.

Table 46: Average difference between modeled and measured releases for each site (2006)

Site	Average difference between modeled and measured release (m^3)	Monitoring period (days)	Modeled component performance
Solid settling basin			
Central IA 1	4.4	153	Modeled flow > Measured flow
Central IA 2	24.7	184	Modeled flow > Measured flow
Northwest IA 1	-153.41	123	Measured flow > Modeled flow
Northwest IA 2	-57.17	123	Measured flow > Modeled flow
Vegetated infiltration basin			
Central IA 2	-38.46	184	Measured flow > Modeled flow
Northwest IA 2	-21.37	123	Measured flow > Modeled flow
Vegetated treatment area			
Central IA 1	-187.06	153	Measured flow > Modeled flow
Central IA 2	-32.57	184	Measured flow > Modeled flow
Northwest IA 1	-166.77	123	Measured flow > Modeled flow
Northwest IA 2	-48.47	123	Measured flow > Modeled flow

During the 2006 monitoring period, rainfall resulted in VTA releases at all four sites. Neither the VIB-VTA or VTA model predicted release from the VTAs; hence, the models overestimated the VTA performance at all four sites. However, on average, the VIB-VTA model better predicted release from the VIB than the VTA during the monitoring periods for Central and NW IA 2 .The VTS models have shown a mixed trend in modeling SSB performance. The VTS models under predicted the SSB performance for Central IA 1 and 2 and over predicted the SSB performance for NW IA 1 and 2.

The measured releases from the SSB, VIB and VTA were compared to the predicted model releases for the four sites. In figure 38, the points lying above the 1:1 line (theoretically where modeled equals measured) show that the model is predicting more release than the monitored results from the SSB. Points below the 1:1 line show that model under estimated the SSB release volume.

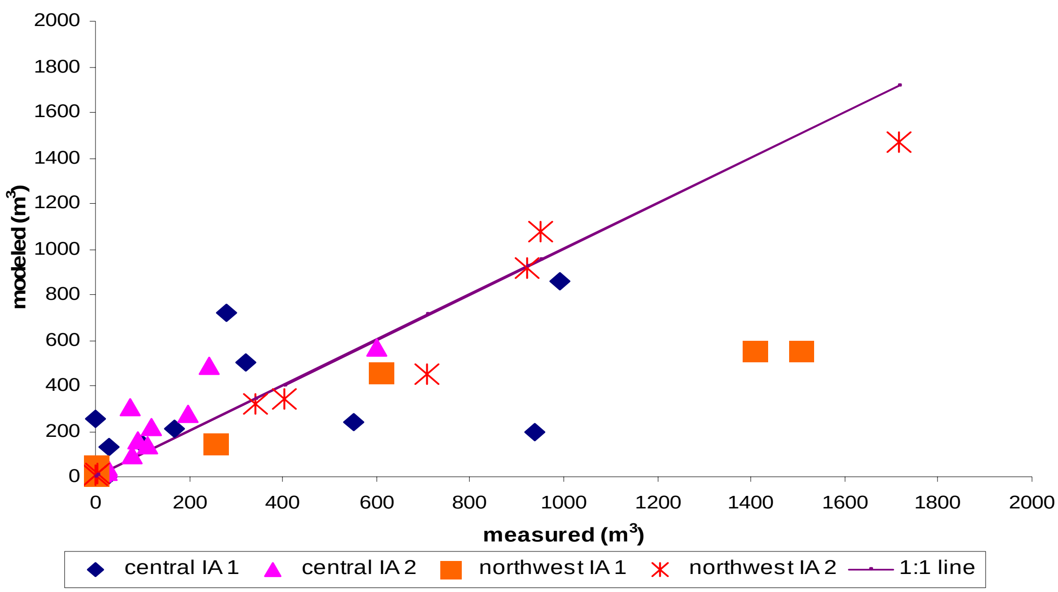

Figure 38: Measured versus modeled SSB releases

Figure 39 shows the measured and modeled releases from the VIB for the two sites. The model over estimated the VIB performance for central IA 2 for 14 of the 16 events and 3 of the 7 events for Northwest IA 2. As seen in the graph, the magnitude of the over/under prediction varies by event.

Figure 40 show over estimation of the VTA's performance for the four sites. The VTA models predicted no release from the VTA at the four sites but the VTAs at all four sites released at least twice during the monitoring periods. The number of release events at the VTA recorded at each site is as follows: Central IA 1 – two events, Central IA 2 – six events, Northwest IA 1 – two events and Northwest IA 2 – four events.

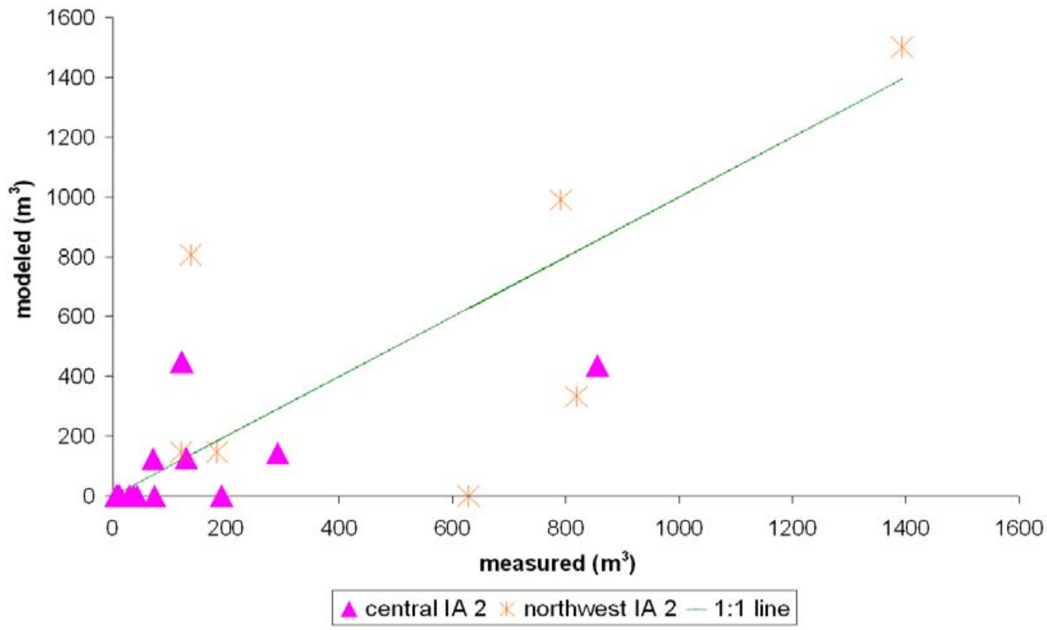

Figure 39: Measured versus modeled VIB releases

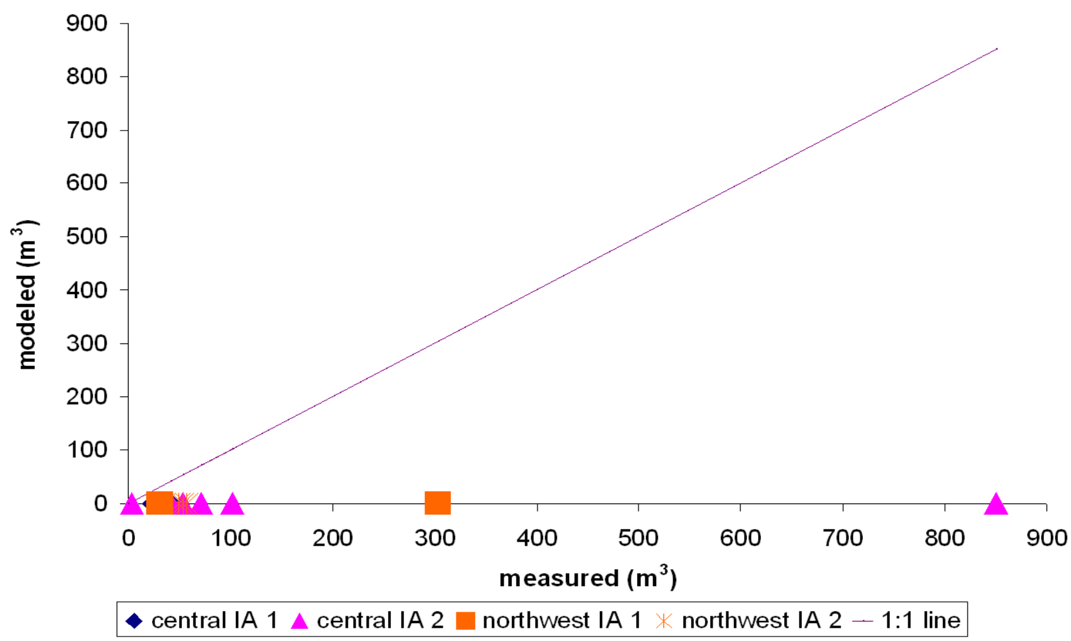

Figure 40: Measured versus modeled VTA releases

The performance of the VTS models was tested using linear regression. Linear models were fit for the SSB and VIB modeled versus measured releases as shown in Figures

41 and 42. The coefficient of determination R^2 for each linear fit line was calculated using MS Excel and the slope of the linear fit line was tested to be significantly different from one at the 0.05 significance level using t-test. The model is considered to be an accurate prediction of the system if the R^2 value is high and the slope of the linear fit is close to one (the 1:1 theoretical line where the modeled value equals the measured value).

The R^2 values calculated by fitting linear models to the SSB performance were: Central IA 1 – 0.93, Central IA 2- 0.83, Northwest IA 1 – 0.92 and Northwest IA 2 – 0.95. The slope of the linear fit line was not significantly different from one for three of the four sites. At Northwest IA 1, while the R^2 value was high, the slope of the line was determined to be significantly different from one, signifying that the model is consistently predicting less than the measured values. Analysis of SSB flow data from Central IA 1, Central IA 2 and Northwest IA 2 have high R^2 values and slopes of the regression lines that are not significantly different from one, implying that the modeled and measure discharge volumes compare reasonably.

Figure 42 shows the accuracy of the VIB-VTA model to predict VIB performance at two sites. The R^2 value for Central IA 2 is 0.51 and the slope is significantly different from one at the 0.05 significance level; this indicates that modeled and measured values are not comparable and the model is predicting less than the measured for most of the events. In the case of Northwest IA 2, the slope of the regression line is not significantly different from one, but the R^2 is only 0.42 implying inconsistent performance of the model compared to the measured values. Initial lack of well established vegetation on the VIBs may be a factor in the model's overestimation of the VIB performance.

There is no relationship between the measured and modeled VTA releases because the model did not predict release events for the four sites during the monitoring period.

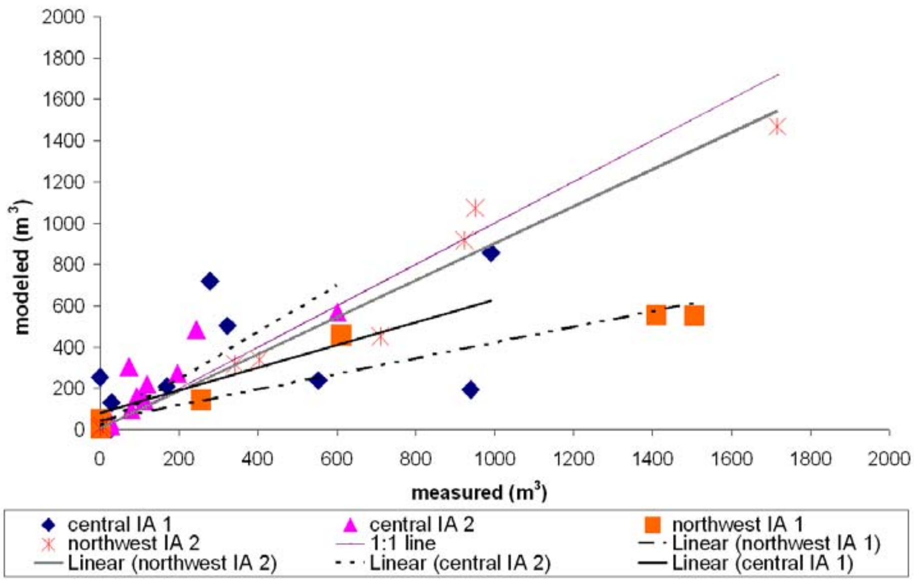

Figure 41: Linear models fit to modeled versus measured SSB releases per site

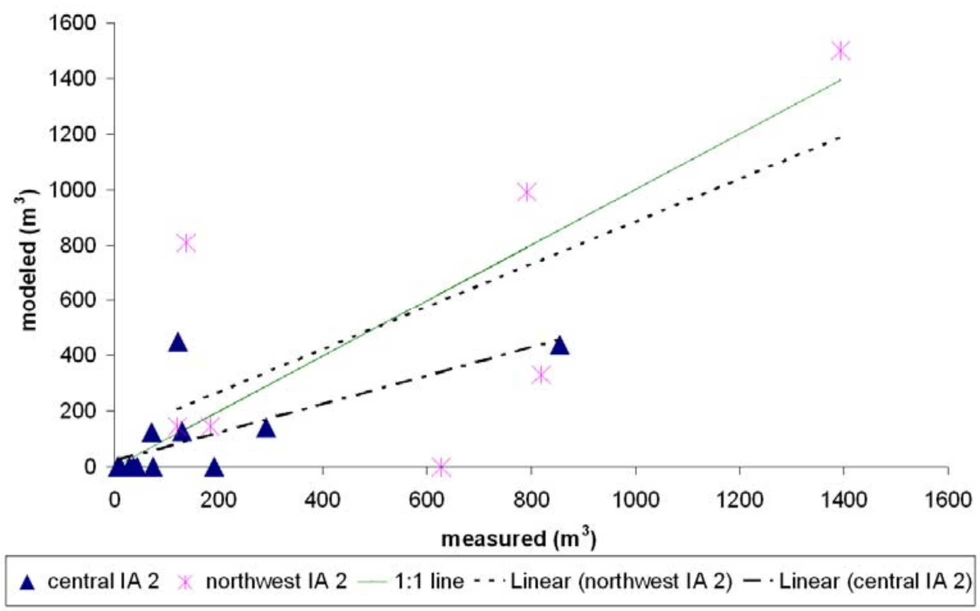

Figure 42: Linear models fit to modeled versus measured VIB releases

Comparison of mass of nutrients: The VTS models determine the concentration of nutrients leaving the SSB depending upon the settling basin capacity and type of feedlot surface. See Table 11 for comparison of the nutrient concentration assumed by the VTS models to the average measured SSB nutrient concentration in 2006. Central IA 2 SSB concentrations were similar to the VTS model concentrations and all the other sites measured higher SSB concentrations compared to VTS model assumptions.

The total nutrient mass released from the VTA at each site during the monitoring period is compared against the nutrient mass release predicted by the VTS models (figure 43). The VTS models predicted no release of nutrients from the VTS because the model did not predict any VTA release events during the monitoring period. The total mass of nutrients released from the VTS at Central IA 2 is higher compared to the other sites because more release events occurred at this site. The release of nutrients from the system is dependent on the release event from the VTS.

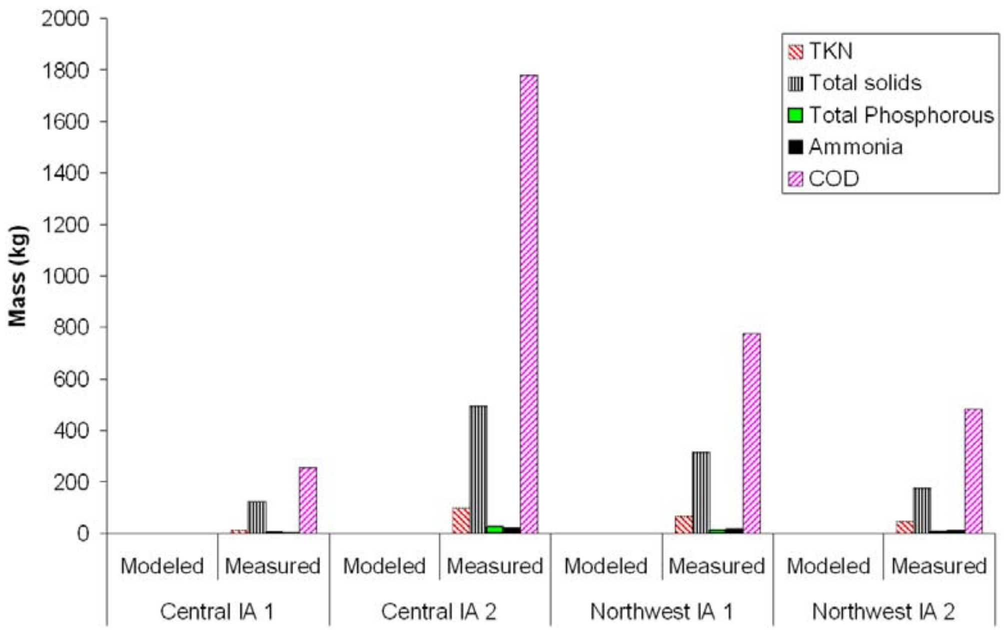

Figure 43: Comparison of measured and modeled pollutant mass released from the system for each site

The measured pollutant concentrations leaving the SSB are greater than predicted by the model. This has resulted in higher pollutant concentrations in the subsequent components of the system. The increased mass released from the VTA could be a result of either high nutrient concentration in the release or high flows exiting the VTA. The potential sources for the difference between the measured and modeled flow volumes from the VTA at each site are: SSB performance for each site (either low attenuation of flow or low solids retention), poor infiltration within the VTA during both dry and saturated conditions (creating higher than predicted flows off the VTA system), channeled flow in the VTAs, inability of the model to simulate flow under saturated conditions due to a large rainfall event or successive small rainfall events, and sensitivity of the VTS models to the soil hydraulic properties. In other words, the difference in the modeled and measured results can be due to the inability of the VTS models to simulate the flow in the system at the four sites or due to physical components in the systems that control the runoff.

4.3 System Cost

The construction cost of the VTSs is an important criteria for evaluating overall feasibility of these systems. Cost surveys were prepared and sent to the four producers for obtaining total cost of the VTSs. The cost survey that was sent to the producers and detailed survey results obtained from the Central IA 1 & 2 and NW IA 1 & 2 producers are included in tables 1A, 2A, 3A, 4A and 5A respectively. The total cost of the system included the construction cost and cost charged by the engineering consulting companies hired to design these systems. The cost of construction included cost for earthwork, concrete materials cost, labor cost, construction materials cost, etc. The construction cost for the VTS does not include feedlot construction cost. The summarized results of the cost surveys are shown in Table 43. The average cost per head for construction of the VTS (included in this study) is $90. The average per head cost was elevated due to high construction cost for NW IA 1 as compared to other sites, which was due to high earthwork costs. The average cost per head for construction of the study VTS (excluding NW IA 1) is $65.

Table 47 Construction and engineering costs, total cost and per head cost for the VTSs at the four sites.

Cost (US dollars)	Central IA 1	Central IA 2	NW IA 1	NW IA 2
Construction cost	56,358	152,547	193,072	237,525
Engineering consultant cost	22,522	21,822	39,379	23,511
Total Cost	78,880	174,369	232,451	261,036
Cattle head	1,400	2,400	1,400	4000
Cost per head	56	73	166	65

Traditional containment systems used for feedlot runoff control usually involves the use of a settling basin to remove solids and releasing the settled runoff to a detention basin/containment basin. The total cost of construction (including engineering, construction and irrigation system cost) of a containment basin system for an open earthen feedlot with windbreak and open earthen feedlot with shed is $215,000 for 1500 head which equals $143 per head. The total cost of construction (including engineering, construction and irrigation system) of a containment basin system for a concrete feedlot with shed is $170,000 for 1500 head which equals $113 per head (Lawrence et.al., 2006)

A complete confinement building with solid floor and a complete confinement building with slatted floor are also used for housing cattle. The complete confinement building with solid floor uses bedding for the concrete floor and manure is removed weekly from the areas along the feed bunks. The complete confinement building with slatted floor has slatted floor with concrete slats over a 2.4 m (8 foot) deep pit for collection and removal of manure. The pit is designed to be pumped twice per year. These confinement buildings are designed for minimizing feedlot runoff and do not require a runoff control environmental structure. The construction cost (or initial investment) for complete confinement building with solid floor is $613 per head and for complete confinement building with slatted floor is $705. These costs are calculated for 1500 head confinement buildings (Lawrence et.al, 2006).

Another upcoming technology for minimizing feedlot runoff is hoop barns for beef cattle. The hoop barns house beef cattle instead of raising cattle in open feedlots. These are open ended hoop barns made by a white polyvinyl tarp stretched over curved trusses that are attached to fixed side walls. Bedding is used on the floor and scarped regularly for cleaning the manure. The use of hoop barns also eliminates the need for runoff control technologies. The estimated construction cost for hoop barns is $300 per animal space (Miller, 2005).

The average construction cost for the VTS is lowest compared to cost for constructing other runoff control environmental structures. The construction costs for alternatives designed for eliminating the need for runoff control technologies are also higher than the VTS construction cost.

5: Summary and Conclusions

Vegetative treatment systems (VTS) are an alternative technology to control runoff from open beef feedlots. These systems consist of a solids settling basin (SSB) followed by a vegetative treatment area (VTA) or a combination of a vegetated infiltration basin (VIB) and a VTA. A study was conducted to analyze the performance of these systems in the state of Iowa. The VTSs constructed on four CAFO feedlots were monitored by Iowa State University according to the each site's NPDES permit requirements. The objectives of this two year study included evaluation of the performance of these systems by analysis of the measured data collected during the two year monitoring period; performance comparison of the VTSs and traditional containment systems and; comparison of the modeled and measured system performance for the first year of the study.

The four sites were monitored for the following durations: Central IA 1 – May thru October 2006 and April thru October 2007; Central IA 2 – June thru October 2006 and April thru October 2007; Northwest IA 1 and Northwest IA 2 – August thru October 2006 and April thru October 2007. The volume and mass of nutrient released from the SSB, VIB and VTA were measured during the monitoring periods. Monthly groundwater, annual surface water, annual surface soil and biennial deep soil samples were collected to analyze the effects of the VTS on soil and water.

The surface water samples were collected at the beginning of the each site's monitoring period. The deep soil samples were collected before the initiation of monitoring at each site. Since only two sets of surface water samples and one set of deep soil samples were collected for each site, it is not possible to conclude any impacts of the VTSs on surface water quality and nutrient loading in the deep soil at the time of this writing.

Surface soil data: Six inch deep surface soil samples were collected before the initiation of the monitoring period, at the end of the 2006 monitoring period and at the end of the 2007 monitoring period.

At the end of the 2006 monitoring period, the P and K concentrations increased for most of the VTA sampling points at the four sites. The P and K concentration at the end of 2006 monitoring period increased for Central IA 2 VIB but decreased for NW IA 2 VIB. For the end of 2006 data, no pattern was observed in the changes of NH_4 -N and NO_3-N concentrations for VIBs and VTAs at the four sites.

At the end of the 2007 monitoring period, the P, K, NH_4 -N and NO_3-N concentrations increased for most of the VTA sampling points at Central IA 1 and NW IA 1. For the central IA 2 VIB, all the concentrations increased in 2007 except K and for NW IA 2 VIB, all the concentrations increased except for NH_4 –N. At the end of 2007 monitoring period, P, K, NH_4 -N and NO_3-N concentrations increased for most of the VTA points at NW IA 2, but showed an opposite trend for Central IA 2.

After two years of monitoring, the average percent increase in P, K, NH_4 -N and NO_3-N concentrations for Central IA 1 VTA points was 18, 44, 52 and 90 respectively and for NW IA 1 VTA points 56, 55, -12 (decrease) and 58 respectively. At the end of 2007 monitoring period, the K concentrations for both Central IA 2 and NW IA 2 VIBs decreased and P and NH_4-N concentrations increased. For Central IA 2 and NW IA 2 VTAs, the P, K and NO_3-N concentrations increased and NH_4 –N concentrations decreased after two years of monitoring. Since NH_4 –N in the soil gets converted to NO_3-N over time and therefore it results in increased NO_3-N concentrations and decrease in NH_4 –N concentrations.

Sawyer et. al. (2002) lists P and K application rates for perennial grasses or pastures based on P and K concentrations found in Iowa soils. The background P and K concentrations found at the four sites fall under the “very high” category which means that these soils do not require additional P and K application. The four sites, prior to construction of the VTS were heavily loaded with P and K.

Three years of surface soil data does not provide a trend in P, K, NH_4 -N and NO_3-N concentration changes and therefore it is not possible to conclude an impact of the VTS on nutrient loading in the top soil.

Groundwater data: The groundwater concentration data was collected monthly from three wells (up gradient, down gradient and in the system) during the monitoring periods. The background NO_3-N concentration in all the three wells at Central IA 1, NW IA 1 and 2 was higher than 10 mg/l (which is the EPA’s NO_3-N limit in drinking water) indicating that NO_3-N levels were higher before the construction of the VTS. Average monitored NO_3-N concentrations for three wells at Central IA 1, NW IA 1 & 2 were greater than 10 mg/l indicating presence of high nitrate- N in the groundwater. Harter et al. (2002) measured average shallow groundwater NO_3-N concentrations at five dairies in California over a four year period as 64 mg/L, also indicating the presence of high levels of nitrate-N in the groundwater at AFO sites.

The average monitored NO_3-N concentrations for three wells were lower than the background concentrations for Central IA 1and 2 and NW IA 2. The average up gradient NO_3-N concentration was higher than average down gradient concentration for Central IA 1& 2 and NW IA 2 indicating that VTS might not have affected the groundwater quality below these systems. This is likely due to the fact that SSB effluent applied to the VTAs is low (less than 1 kg for most of the events) in NO_3-N mass. But an opposite trend was seen for NW IA 1; as the average up gradient NO_3-N concentration was lower than the average down gradient concentration.

The ammonia-N levels in the groundwater wells at all the locations were consistent around 0.2 mg/l over the two year monitoring period. Chloride which moves with the groundwater and is an indicator of presence of manure has a secondary maximum containment level (SMCL) of 250 mg/l in drinking water (according to the US EPA). The chloride levels in the three wells at the four locations were below the specified limit. The average chloride levels in the down gradient well is lower than the up gradient well for Central IA 1 & 2, and it is vice versa for NW IA 1& 2.

A lack of trend is observed in the average up gradient and down gradient nutrient concentrations comparisons for the four sites. Moreover, the groundwater nitrate-N concentration data collected once in a month may not be frequent enough to capture the short term temporal changes in the pollutant concentration in the groundwater; therefore monthly collected data may not be sufficient to indicate an impact of the VTS on groundwater quality.

SSB performance: The performance of the SSBs was evaluated by comparing the monitored nutrient concentrations released from the SSB to the nutrient concentrations released from the SSB assumed by the VTS models. In 2006, the nutrient concentrations coming of the SSB were higher than the model assumptions for all sites except for Central IA 2. Placement of round bales around the SSB outlet can be a potential reason for better SSB performance at Central IA 2. In 2007, gate valves were installed at the SSB outlets for Central IA 1 & 2 and NW IA 1. As a result, the nutrient concentrations coming out of the Central IA 1 and NW IA 1 SSB were lower than 2006 and were comparable to the VTS model assumptions. The NW IA 2 SSB showed the worst solid settling performance in 2007 compared to other sites.

VIB performance: The performance of the VIBs at Central IA 2 and NW IA 2 was affected in 2007 due to the accumulation of solids. Both the sites used the VIBs to control the winter runoff (during the non-monitoring period) which resulted in accumulation of large amount on solids on the VIB surface. Poor settling performance of the NW IA 2 SSB was another reason for accumulation of solids in the NW IA 2 VIB. The accumulation of solids in the VIB decreased the infiltration and drainage rates and as a result the SSB effluent flowing into the VIB was ponded for most of the 2007 monitoring period. The VIBs were not fully vegetated in 2007 due to the standing water conditions and as result nutrient removal by the vegetation was affected. In 2006, the VIBs were partially vegetated at both sites and had better stand vegetation as compared to 2007.

VTA Performance: A healthy stand of vegetation is required for nutrient removal by the vegetation. The VTAs at the four sites had a good stand of vegetation during both 2006 and 2007 monitoring periods. The VTA performance was affected by channeling and constant ponded conditions. According to Dickey and Vanderholm (1981), channeling in the vegetative filter system affects the degree of pollutant removal as compared to overland flow. Channeling was observed in the VTAs and may be a potential reason for low runoff control performance. At Central IA 1, channeling was observed towards the east side of both the VTAs. Channeling was also observed in the NW IA 1 VTA. The flow in the Central IA 2 and NW IA 2 VTA was observed to be evenly distributed along the width of the VTA and very few instances of channeling were recorded. However, the Central IA 2 VTA was ponded toward the VTA inlet for most of 2007 monitoring period affecting the infiltration rates.

VTS performance: The VIB and VTA performance are linked to the overall system performance. The percent runoff control in 2006 and 2007 for each site is given in Tables 48 and 49. In 2006, the Central IA 2 VTS and in 2007, the Central IA 1 VTS had lowest percent runoff control compared to other sites. The NW IA 2 VTS had almost total runoff control for both the years. The percent runoff control for the four sites in 2006 and 2007 was affected by various factors including amount and intensity of rainfall, VIB/VTA area, VIB/VTA infiltrations rates, SSB storage capacity and management techniques.

Table 48: Percent runoff control for the four sites in 2006

Site	Monitoring rainfall	# of SSB releases	Annual SSB volume released	# of VTA releases	Annual VTA volume released	Volume on VTS due to rainfall	% runoff control (SSB+rainfall-VTA) / SSB+rainfall
	inches		cubic meter		cubic meter	cubic meter	
Central IA 1	13	14	1713	2	65	5134	99
Central IA 2	20	22	1653	6	1119*	2638	74
NW IA 1	9	5	3780	2	333	3707	96
NW IA 2	11	6	5034	4	160**	4275	98

* volume not measured for one out six releases
** volume not measured for one out four releases

Table 49: Percent runoff control for the four sites in 2007

Site	Monitoring rainfall	# of SSB releases	Annual SSB volume released	# of VTA releases	Annual VTA volume released	Volume on VTS due to rainfall	% runoff control (SSB+rainfall-VTA) / SSB+rainfall
	inches		cubic meter		cubic meter	cubic meter	
Central IA 1	49	20	7,445	26	11,756[d]	18,890	55
Central IA 2	37	9[a]	680[b]	15	1,109[c]	4,871	80
NW IA 1	25	20	9,701[e f]	13	2,937	10,506	85
NW IA 2	26	26	9,529	1	22	10,031	99

a- Producer did not release from the SSB after 6/22/07
b - volume discharged for 2 out of 9 events was not measured
c - volume discharged for 3 out of 15 events was not measured accurately because water was backed up in the flume
d - Volume released for one event was not measured accurately because water was backed up in the flume
e -SSB volume released was not measured from 4/8-4/12/07 because sensor was removed for changing SSB pipe
f - Volume was not measured for 2 events due to ISCO malfunction

The overall performance of the system can also be analyzed by the percent of pollutant mass retained in the system. Table 50 shows the percent pollutant mass retained in the system for the four sites in 2006 and 2007. The pollutant mass retained in directly proportional to the runoff controlled by the VTS and concentration of pollutants reduced by the VIB and VTA. Since Central IA 2 in 2006 and Central IA 1 had lower runoff control percentages in 2007, the pollutant mass retained in the system also show similar percentages. The percentages in 2006 are a result of half year of monitoring while the 2007 percentages are from a full year of monitoring and that might be a reason for higher percentages in 2006.

Table 50: Percent pollutant mass retained in the system for 2006 and 2007

	NH_4-N	TKN	Total -P	ortho-P	BOD	COD	Cl	Total Solids
2006								
Central IA 1	97	97	97	96	97	97	97	97
Central IA 2	83	78	72	60	77	74	68	67
NW IA 1	94	97	96	93	96	97	95	97
NW IA 2	99	99	99	99	99	99	99	99
2007								
Central IA 1	53	44	41	28	47	44	19	35
Central IA 2	94	95	92	79	95	95	75	89
NW IA 1	80	82	76	81	83	82	84	84
NW IA 2	99	99	99	99	99	99	99	99

Another aspect affecting the overall system performance is removal of nutrients by the VTS vegetation. The VIB/VTA vegetation at the four sites consisted mostly of reed canary grass. A core sample was collected from the reed canary grass harvested from the VTAs at the four sites in 2007 and sent for analysis of N and P to the Department of Agronomy Laboratory, Iowa State University. But results for the analysis were not received from the laboratory at the time of writing of the thesis. Hence, analysis of uptake of nutrients by the VTA vegetation is not included in the thesis.

The annual aerial nutrient loading rates were calculated for the VIB and VTA for the four sites. Since the 2006 and 2007 monitoring periods were of different durations, normalized loading rates were calculated for a better comparison better the two years. The normalized loading rates for the four sites for 2006 and 2007 are given in Table 51. The NW IA 2 VIB was heavily loaded with total solids in 2007 compared to the other sites. This was due to poor settling performance of the NW IA 2 SSB.

The nutrient requirements of reed canary grass were calculated for 2007 based on the annual yield. Since the VTAs were not harvested in 2006, the nutrient requirements could not be calculated. The ratio of nutrient applied to the crop requirement was calculated to estimate the nutrient loading of the VIBs and VTAs in 2007. The ratios are provided in Table 52. The Central IA 2 VIB ratio was calculated by assuming a 4.9 ton/ ha (2 ton/acre) annual yield. The Central IA 2 VTA was least overloaded with nutrients compared to other sites. The reed canary grass species are known to be tolerant to flooding conditions and high nutrient levels. The VTAs at the four sites maintained a good stand of vegetation (except for some bare patches) in 2007 under such nutrient loading rates. But the NW IA 2 VIB could not grow a healthy stand of vegetation due to such high nutrient loading rates.

Table 51: Normalized loading rates for the VIB and VTA for 2006 and 2007

	TKN	Total -P	Total Soilds
	lb/acre-day	lb/acre-day	lb/acre-day
2006			
Central IA 1 VTA	3	1	67
Central IA 2 VIB	8	2	185
Central IA 2 VTA	7	1	125
NW IA 1 VTA	10	2	260
NW IA 2 VIB	47	7	60
NW IA 2 VTA	17	2	259
2007			
Central IA 1 VTA	8	2	118
Central IA 2 VIB	6	2	110
Central IA 2 VTA	2	1	56
NW IA 1 VTA	9	2	220
NW IA 2 VIB	92	15	2101
NW IA 2 VTA	5	1	91

Table 52: Ratio of nutrient applied to crop requirement based for the four sites in 2007

Site	N	P
Central IA 2 VIB	15	13
Central IA 2 VTA	3	3
Central IA 1 VTA	26	20
NW IA 1 VTA	13	7
NW IA 2 VIB	1262	549
NW IA 2 VTA	14	5

The VTS performance was compared with the traditional containment system performance (predicted by the ELG models) as required by the each site's NPDES permit. The performance comparison was done in terms of nutrient mass released from the system in 2006 and 2007. Since the mass of nutrients released from the VTS at the four sites was higher than the ELG model predictions for both 2006 and 2007, the VTS did not perform equal or better than the modeled containment systems performance.

The potential reasons for differences between VTS performance and modeled ELG performance are: the ELG model may not provide accurate predictions for Iowa and the VTSs at the four sites did not provide required runoff control. Further research is needed is needed to calibrate the ELG for Iowa conditions.

The measured data collected from the 2006 monitoring period of the four sites was compared to the data predicted by the VTS models. The comparison was done in two parts: comparison of the release volume released from each component of the VTS and comparison of the mass of nutrients released from the VTS. The comparisons were done to evaluate the performance of the VTS models. The VTS models over estimated the performance of VTAs at all four sites. The VTS models also over estimated the VIB performance for both the sites. A mixed trend was observed in the model's performance for predicting flow from the SSB. The concentration of nutrients released from the SSB was much higher than the concentration predicted by the VTS models. The total mass of nutrients released from the system at the four sites could not be compared to the modeled values, as the model did not predict releases from the VTA for the four sites during the 2006 monitoring period.

The potential sources for the difference between the measured and modeled flow volumes from the VTA at each site are: SSB performance for each site (either low attenuation of flow or low solids retention), poor infiltration within the VTA during both dry and saturated conditions (resulting in higher than predicted flows off the VTA), inability of the model to simulate flow under saturated conditions due to a large rainfall event or successive small rainfall events, and sensitivity of the VTS models to the soil hydraulic properties. Further research is needed for improving the VTS models to better predict the measured VTS performance.

Conclusions: The performance of the VTS at the four monitored sites in 2006 and 2007 were affected by issues including inability of VTA to control releases, low reduction of nutrient concentrations in the SSB effluent, ponded conditions in the VIB. Potential reasons that affect the above stated problems include including high rainfall totals and intensity, VTA area, VIB/VTA soil type, SSB storage capacity, channeling in the VTAs, lower infiltrations rates in the VTA soil, solid accumulation in the VIB, and SSB management techniques. The factors affecting each site are discussed.

Central IA 1: The water table below the VTA was monitored for Central IA 1 for about two months during the 2007 monitoring period. Average depth of the Central IA 1 water table was found to be approximately 0.7 m (2.5 feet) deep indicating a high water table below the VTA. Proximity of the site to the creek negatively impacts the water table recession rate which was measured to be about 0.64 cm/day (0.25 inches/day). High water table combined with slow recession rate affected the VTA infiltration rates resulting in runoff from the VTA. The infiltration rate of the VTA soil was measured to less than 1.5 cm/h (0.6 inches/h). Channeling in the VTA resulted in under utilizing of the VTA area that contributed to higher chances of a VTA release.

It was observed that Central IA 1 SSB had a limited storage capacity which forced the producer to release from the SSB during saturated conditions. Figure 44 shows that water is backed up into the feedlot but still the SSB had several feet of available room that was not used. Central IA 1 had about 124.5 cm (49 inches) of rainfall in seven months including a 25 year – 24 hour storm. This unusually wet year also contributed to a high number of VTA releases from the system. Another reason affecting the VTS performance is the proximity of the site to the creek. Flooding in the creek during high rainfall conditions affected the performance of the system.

Figure 44: Water backed up in the feedlot while the SSB still has room available at the sides

Central IA 2: The water table below the VTA was monitored for Central IA 2 during the 2007 monitoring period. The Central IA 2 water table was measured to be about 0.9 m (3 feet) deep and it was estimated that approximately 3.8 cm (1.5 inches) of rainfall falling onto the VTA will result in runoff.

In 2007, it was observed that upper half of the VTA was ponded for most of the year indicating slow drainage of the VTA soil profile. The VTA is surrounded by the tile line for improving the drainage conditions in the VTA. The 1.2 m (4 feet) deep tile line drains slowly therefore affecting the VTA infiltration rates. A small sized VTA (VTA: feedlot ratio of 0.2) combined with slower drainage of VTA profile can be a potential reason for higher number of VTA releases. Also, the Central IA 2 SSB is not sized to hold a 25 year, 24 hour storm. The limited storage capacity forced the producer to release from the SSB during VTA saturated conditions, thereby increasing chances of a VTA release.

Northwest IA 1: The water table below the NW IA 1 VTA was monitored for three months during the 2007 monitoring period. It was found that NW IA 1 has a shallow water table depth of about 0.7 m (2.5 feet). Due to shallow water table, the soil profile fills up quickly after a rainfall event, thereby retarding infiltration rates in the VTA. This increases the chances of a VTA release. Channeling in the VTA resulted in under utilization of the VTA area that also contributed to higher chances of a VTA release. During heavy rainfall conditions, water in the SSB backs up into the feedlot even though several feet of SSB depth is unused. Figure 45 illustrates the situation. The under utilization of the SSB capacity forces the producer to release during saturated VTA conditions.

Figure 45: Water backed in the feedlot but the SSB still has several feet of available room

Northwest IA 2: The VIB performance at NW IA 2 was affected by poor settling performance of the SSB, which resulted in solids being discharged into the VIB thereby releasing high nutrient concentrations into the system. Due to accumulation of solids in the VIB, it remained ponded and slowed the infiltration rates. The lack of VIB vegetation also affected the nutrient removal by the vegetation. A potential reason for poor settling at the NW IA 2 SSB could be the liquid density of the feedlot runoff. The runoff flowing from a concrete feedlot does not have sufficient density to settle the solids, thereby releasing slurry like effluent from the SSB.

The NW IA 2 SSB has a limited storage capacity and cannot hold a 25 year 24 hour storm. The inability to hold large storms in the SSB forces the producer to releases into the VIB during saturated conditions, thereby affecting the VIB performance. The runoff control performance of the NW IA 2 VTS was better compared to the other sites. A potential reason for such a performance could be deeper water table below the VTA compared to other sites. The water table depth was not monitored at this site but the up gradient groundwater well remained dry for most of the monitoring period suggesting existence of a deeper water table.

Recommendations: The VTS at four sites were monitored and showed mixed results for two years of monitoring. The potential reasons affecting the performance of the VTSs were identified. Further research is needed to better understand the factors that will help in improving the performance of the four monitored VTSs in Iowa. When properly sited, these systems may provide a cost effective and viable option for controlling runoff from large and as well as small beef feedlots.

None of the four sites met all the IDNR siting criteria for constructing VTS. The observed seasonal high water table depths at Central IA 1 & 2 were zero foot and for NW IA 1 was 0.3 m (1 foot), which do not match the IDNR siting criteria of greater than 1.2 -1.5 m (4 to 5 feet). The infiltration rates for the VTA at Central IA 1 and 2 are less than 1.5 cm/h (0.6 in/h) and do not meet the IDNR siting criteria recommended rates of 1.5 – 5 cm/h (0.6 to 2 in/h). The Central IA 2 and NW IA 2 SSBs are not designed to store a 25 year 24 hour rainfall which is also recommended in the IDNR design criteria for the VTS.

Based on this study, following recommendations are suggested for a better overall performance of the VTSs:

- Location of the VTS site
    - The VTA infiltration rates were measured to be less than 1.5 cm/h (0.6 in/h) at two of the sites included in the study. The runoff control performance of these sites was affected by infiltration rates less than 0.6 in/h. The IDNR recommends the VIB and VTA infiltration rates of minimum 1.5 cm/h (0.6 in/h) to a maximum of 5 cm/h (2 in/h). Since no data is available from this study that proves that infiltration rates greater than 0.6 in/h will improve system performance but it is recommended that VTA infiltration rate should at least be greater than 0.6 in/h which is also in accordance with IDNR's minimum recommendations.

  - Based on the data available from this study, the runoff control performance of the sites was affected by a seasonal high water table depth of less than 0.3 m (1 foot). The seasonal high water table depth greater than 0.9 m (3 feet) is recommended for improved system performance. This is in agreement with the IDNR recommendations that suggest that a seasonal high water table be greater than 1.2 - 1.5 m (4 to 5 feet) with or without artificial tile drainage for construction of the VTS.
  - The IDNR does not recommend a groundwater recession rate in the VTS siting criteria but groundwater recession was recorded for one of the sites in this study. It was found that groundwater recession rate affects the infiltration rates and runoff control performance. The groundwater recession rate should be high enough to provide for infiltration in the soil during successive rainfall events.
- Two of the four sites cannot hold a 25 year -24 hour storm in their SSBs that affected the runoff control performance. The VIB performance for one the site's was affected by poor settling performance of the SSB. Based on this study, it is recommended that the SSB should be sized adequately to at least hold a 25 year -24 hour storm and should provide settling of solids.
- Based on the study, it was found that active management of the basins improved SSB performance as well as the overall system performance. It is recommended that the SSBs releases to the VIB/VTA should be actively managed to avoid releasing onto a saturated VIB/VTA.
- Channeling affected the VTA performance for three out of four sites in this study, so it is recommended that good stand of vegetation should be maintained and channeling should be minimized by management of the VTAs.

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Appendix

The beef site cost survey send to the producers for estimation of the total cost involved in the construction of the VTS is shown below.

Table 1 A: The cost survey sent to the producers

Beef site cost survey

Site Name:

Note: We are trying to obtain total system costs. Please add categories as necessary, but do not duplicate expenditures within the categories

Type of work	Cost (dollars)	Description
Electrical materials		
Electrical labor		
Earthwork		
Concrete materials		
Concrete labor		
Construction materials (PVC pipe, tile, gravel etc)		
Equipment rental		

Farm labor		
Hired labor		
Other labor		
Mileage cost		
Engineering consultant costs		
Other costs		
Total cost		

Notes:

Table 2 A: Cost survey results obtained from Central IA 1 Producer

Type of work	Cost (dollars)	Description
Earthwork	19,483.10	Preparing settling basins and VTAs
Concrete materials, labor and construction	21,316.83	Concrete and construction of twp concrete SSBs, walls, floors and three concrete spreaders
Construction materials (PVC pipe, tile, gravel etc)	2,691.69 and 597.24	For Steel reinforcing rods and PVC pipes
Equipment rental	3,387.50	Dirt scarper rental for 135.5 hrs
Farm labor	6,775.00	Our tractor-fuel and man hours to operate rented dirt scraper
Other labor		Many hours of ourselves and our farm employees. We never figured the hours or cost
Engineering consultant costs	22,522.00	Curry-Wille and associates engineering the AT project and blue prints
Other costs	812.00	Seeds to plant vegetation area. We used our own labor and equipment.
	1,295.00	Fabric and machine rent to install fabric in the VTAs
Total cost	**78,880.84**	

Table 3 A: Cost survey results obtained from Central IA 2 Producer

Type of work	Cost (dollars)	Description
Electrical labor	9,200.00	
Earthwork	32,000.00	Dirt work
Concrete materials	42,600.00	Settling basins
Concrete labor	30,000.00	
Construction materials (PVC pipe, tile, gravel etc)	19,720.10 and 6,627.03	Tile, manholes and PVC pipes
Farm labor	2,000.00	Seeding and general help 100 hours@20.00 per hour
Engineering consultant costs	21,822.48	CWE and Curry-wille & associates
Other costs	1,100.00	Seed cost
	4,200.00	Pipe under higway
	1,500.00	Manifold; pipe for VIB and VTA
	3,600.00	Pumps for manholes
Total Cost	**174,369.61**	

Table 4 A: Cost survey results obtained from NW IA 1 Producer

Type of work	Cost (dollars)	Description
Earthwork	111,421.50	Grading, berms, basins and installing drain pipes
Concrete materials and labor	61,782.54	
Construction materials (PVC pipe, tile, gravel etc)	9,273.92	Geo textile fabric, PVC pipe, valves, fill sand
Equipment rental	3,600.00	Pay loader, tractor and skid laoder
Farm labor	2,800.00	Seeding, building blocks for spreaders and hauling sand
Engineering consultant costs	39,379.00	
Other costs	4,194.40	Seeding
Total cost	**232,451.36**	

Table 5 A: Cost survey results obtained from NW IA 2 Producer

Type of work	Cost (dollars)	Description
Electrical materials and labor	3,139.05 390.00	Electrical work Utility poles
Earthwork	35,422.50	
Concrete materials	99.62 1,441.64 841.90 97,879.93	Rebar chairs Rebar and forms Curbs for manhole Concrete
Concrete labor	14,328.50 4,786.41	Concrete labor Concrete pumping
Construction materials (PVC pipe, tile, gravel etc)	1,537.49 405.20 1,837.50 2,784.30	PVC pipe Tile Re-route pipe Gravel
Equipment rental	1540.95	Skid loader, trencher and tractor rental
Farm labor	7,287.50	
Hired labor	4,678.50	
Mileage cost	30.00	
Engineering consultant costs	23,511.00 5,900.00	Curry-wille engineering Eisenbrawn engineering
Other costs	7,153.30	Soil boring
	6,575.33	Clean water diversion road crossing/ hookups
	4,222.54	Pumps
	35,243.00	Tilling, digging, PVC pipes, etc.
Total cost	**261,036.16**	

Table 6 A: Analytical methods and instruments used for analysis of groundwater samples

Parameter	Method	Analytical Instrument
Nitrate-N	EPA 353.2	Automated Cadmium Reduction
Fecal coliforms	SM 9222 D	NA
Chloride	SM 4500-Cl E	Ion Chromotagraphy
Ammonia-N	EPA 350.1	Block Digester – Foss Automated Titrator

Table 7 A: Analytical methods and instruments used for analysis of deep and surface soil samples

Parameter	Method	Analytical Instrument
Nitrate-N	2M KCl	Lachat QC 8000 FIA
Ammonium-N	2M KCl	Lachat QC 8000 FIA
Phosphorus	Bray 1:10	Hach DR 4000 Spectrophotometer
Potassium	Neutral Ammonium Acetate	Perkin Elmer AAnalyst 100
pH	pH 1:1	Beckman 32 pH Meter

Table 8 A: Analytical methods and instruments used for analysis of surface water and VTS effluent samples

Parameter	Method	Analytical Instrument
TKN	EPA 351.2	Block Digester/Lachat Autoanalyzer
Nitrate-N	EPA 353.3	Manual Cadmium Reduction
Ortho-phosphate	EPA 365.1	Continuous flow analyzer-colormetric
Total phosphorus	EPA 365.1	Continuous flow analyzer-colormetric
COD	SM 5220 D	Block Digester - Spectrophotometer
BOD	SM 5210 B	NA
Fecal coliforms	SM 9222 D	NA
Chloride	SM 4500-Cl E	Continuous flow analyzer-colormetric
Ammonia-N	SM 4500-NH3 B,E	Macro Digestion - Titration
TSS	USGSI-3765-85	Gravimetric
TDS	SM 2540 C	Gravimetric
pH	EPA 150.1	Potentiometric meter

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