6-2009

Performance of Six Vegetative Treatment Systems for Controlling Runoff from Open Beef Feedlots in Iowa

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Abstract

Beef feedlots of all sizes are looking for more cost-effective solutions for managing feedlot runoff. Vegetative treatment systems (VTSs) are one potential option that has been proposed. Iowa State University (ISU) has monitored the performance of six VTSs on open beef feedlots throughout Iowa since 2006. These feedlots have interim, National Pollution Discharge Elimination System (NPDES) permits that allow the use of VTSs to control and treat feedlot runoff. As part of the permit requirements for these feedlots the effluent volumes, nutrient concentrations, and nutrient masses exiting each component of the VTS were monitored. This paper describes the VTSs and monitoring methods used in this study and evaluates the effectiveness, in terms of both effluent concentration and nutrient mass transport reductions, of each system. During the three-year monitoring period, results have shown that VTSs are capable of reducing the nutrient mass exiting the VTSs by 65 – 99% as compared to a settling basin only system, with performance varying by both site and year. In addition to overall mass transport reductions, nutrient concentrations were also reduced, typically reduced by 50-90%, during treatment. Furthermore, monitoring results have shown a consistent improvement in system performance during the three years of the study. Much of this improvement can be attributed to improved management techniques and system modifications that addressed key performance issues.

Keywords

Vegetative treatment areas, vegetative treatment systems, feedlot runoff control

Disciplines

Agriculture | Bioresource and Agricultural Engineering

Comments

This is an ASABE Meeting Presentation, Paper No. 097054.

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An ASABE Meeting Presentation

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Written for presentation at the
2009 ASABE Annual International Meeting
Sponsored by ASABE
Grand Sierra Resort and Casino
Reno, Nevada
June 21 – June 24, 2009

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Introduction

Runoff from open lot animal feeding operations has long been recognized as a potential pollutant to receiving surface waters. This effluent is known to contain nutrients such as nitrogen and phosphorus, as well as other potential pollutants such as organic matter, solids, and pathogens. As a result, the Environmental Protection Agency (EPA) developed a set of Effluent Limitation Guidelines (ELGs) which described the design and operating criteria for feedlot runoff control systems for concentrated animal feeding operations (CAFOs) (Anschutz, 1979). These ELGs historically required collection, storage, and land application of the feedlot runoff. Recent modification to the ELGs allows the use of alternative treatment systems when the performance, based on the mass of nutrients released, of the alternative systems is equivalent to or exceeds that of a traditional containment system (Federal Register, 2003). As a result, open feedlots are looking for new cost effective methods of handling feedlot runoff. Vegetative treatment systems (VTSs) are one option that has shown promise.

A vegetative treatment system (VTS) is a wastewater treatment system that uses at least one form of vegetative treatment, i.e. a vegetative treatment area (VTA) or a vegetative infiltration basin (VIB), with other pretreatment components to control and treat feedlot runoff. A VTA is an area that is level in one dimension (width) and has a slight slope (less than 5%) in the other (length) that is planted and managed to maintain dense, permanent vegetation (Moody et al., 2006). Operation of the VTA involves applying effluent evenly across the top width of the VTA. The effluent then flows down the length of the VTA where it is treated via sedimentation and infiltration. A VIB is a relatively flat area surround by berms to prevent surface outflow of effluent. VIBs have drainage tiles installed approximately 1.2 m below the soil surface to maximize the infiltration of effluent into the soil (Moody et al., 2006). Effluent draining through the soil profile is collected in the tile lines and pumped onto a VTA for further treatment.

Woodbury et al. (2003) studied the effectiveness of a VTS that used a solid settling basin (SSB) and vegetative treatment area (VTA) to control runoff on a small feedlot near Clay Center, Neb. This was a 600-head facility with approximately 2.16 ha of feedlot area. Runoff from the feedlot drained to a flat-bottom debris basin that provided between five and eight minutes of retention time for solid settling. Effluent was released from the basin via thirteen discharge pipes onto a VTA. In this study no effluent was ever released from the VTA. Monitoring of the effluent volume and nitrogen content of effluent released from the debris basin showed that more nitrogen was removed with the vegetation harvested from the VTA than was applied in the feedlot runoff. As a result of this study, Woodbury et al. (2003) concluded that vegetative treatment systems could provide effective treatment of feedlot runoff.

In a literature review, Koelsch et al. (2006) reported on approximately 40 field and plot studies related to VTS performance. In this review, they (Koelsch et al., 2006) reported that VTAs commonly reduced total solids by 70-90%. Additionally total nitrogen (TN), total Kjeldahl nitrogen (TKN), and ammonia/ammonium nitrogen (NH_3/NH_4-N) were reduced by approximately 70% in properly designed and managed VTAs (Ikenberry and Mankin, 2000). Phosphorus (P) removal rates had more variability than nitrogen, with typical removal rates ranging from 7 to 100% (Koelsch et al., 2006).

Several investigators have also studied the effectiveness of VIBs. In lab-scale tests with swine manure, Prantner et al. (2001) reported that 93% reduction in NH_4-N and an 89% reduction in P occurred during filtration through the soil column. Additionally, Lorimor et al. (2003), Yang and Lorimor (2000), and Edwards et al. (1986) all report the use of VIBs to treat runoff from open feedlots. In these studies, they found high reductions (78 – 87%) in suspended solids, TKN, NH_4-N, and P; however, a significant increase in nitrate concentrations was seen as a result of treatment in the VIB. These lab and plot scale studies have shown that VTSs have the potential to successfully treat lot runoff; however, testing of VTSs on commercial feedlots is required to determine how performance varies for different management techniques, system designs, siting criteria, and environmental conditions.

The objective of this study was to evaluate the effectiveness of six VTSs installed to provide runoff control on CAFO sized open beef feedlots in Iowa. This evaluation was made based on nutrient concentration and mass reductions occurring during the treatment process. To achieve these objectives, the flow volumes and nutrient concentrations at the outlet of each treatment component in the VTS were monitored. Thus, specific objectives were to evaluate the nutrient masses and concentrations exiting solid settling basins (SSBs), vegetative infiltration basins (VIBs), and the vegetative treatment areas (VTAs) at these facilities.

Materials and Methods

The performance of six vegetative treatment systems was monitored as part of this study. These treatment systems were located on CAFO sized open beef feedlots throughout the state of Iowa. A map showing the locations of these facilities is shown in Figure 1. Data summarizing the characteristics of these feedlots and the VTSs installed at each location are provided in Table 1. At many of the locations more than one VTS was installed, at these sites one system was selected as the pilot system (monitored by Iowa State University). The producer was required to monitor the other VTSs. Table 2 provides information about the sizes of the different components used in the pilot VTSs, including the size of the drainage area (feedlot and additional contributing area), the volume of the settling basin, the area of the VIB, and the area of the VTA. Summaries of the design and operation of each of the six pilot VTSs are provided in the following sections. Changes in both system component design and management techniques occurred during the study and must be considered when interpreting the results.

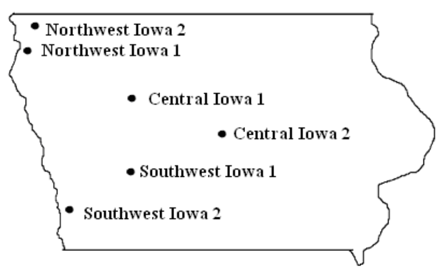


Figure 1. Map showing the locations of the six VTS monitored for this study.

Table 1. Summary of number of cattle and the VTS configurations for the pilot and total site.

Site	Number of Cattle		VTS Components	
	On Farm	Pilot System	On Farm	Pilot System
Central Iowa 1	1,500	1,000	2 SSB[1] - 3 VTA[2]	1 SSB - 2 VTA
Central Iowa 2	2,400	650	3 SSB - 5 VIB[3] - 2 VTA	1 SSB - 1 VIB - 1 VTA
Northwest Iowa 1	3,400	1,400	3 SSB - 5 VTA	1 SSB - 1 VTA
Northwest Iowa 2	4,000	4,000	1 SSB - 1 VIB - 1 VTA	1 SSB - 1 VIB - 1 VTA
Southwest Iowa 1	2,300	2,300	1 SSB - 10 VTA	1 SSB - 10 VTA
Southwest Iowa 2	5,500	1,200	12 SSB – 7 VTA	1 SSB - 1 VTA

[1] SSB – Solid Settling Basin
[2] VTA – Vegetative Infiltration Area
[3] VIB – Vegetative Infiltration Basin

Table 2. Summary of component sizes for the pilot VTSs.

Site	Drainage Area (ha)	SSB (m^3)	VIB (ha)	VTA (ha)
Central Iowa 1	3.09	4,289	--	1.52
Central Iowa 2	1.07	51	0.32	0.20
Northwest Iowa 1	2.91	3,710	--	1.68
Northwest Iowa 2	2.96	110	1.01	0.28
Southwest Iowa 1	7.49	11,550	--	4.05
Southwest Iowa 2	3.72	6,275	--	3.44

Site Descriptions

Central Iowa 1 (CN IA 1)

Central Iowa 1 was 4.2-ha earthen open beef feedlot with a permitted capacity of 1,500 cattle located in central Iowa. The VTS at this site consisted of two solid settling basins, a vegetative treatment area (VTA) divided into three channels, a containment berm located at the southeast corner of the VTA, and a vegetated waterway (located on the eastern edge of the VTA). The VTS was divided into two portions, the pilot and the non-pilot system. The western lot (labeled Feedlot Area 1 in Figure 2) was the pilot portion of the feedlot. This was a 3.09-ha earthen feedlot area permitted for 1,000 head of cattle. Runoff effluent drained into a solid settling basin (labeled SSB 1) designed to hold 4,289 m^3 of effluent. Effluent captured in the settling basin was then released onto the two western channels of the VTA (labeled VTA 1 and VTA 2). These two VTAs were operated in parallel, i.e., effluent was released onto both VTAs (VTA 1 and VTA 2) at the same time; both channels received similar effluent loadings. Each of these VTAs was 24 m wide with an average length of 311 m, giving a VTA to feedlot area ratio of 0.5:1. During the winter of 2007 and the spring of 2008, the producer converted a portion, 1.01-ha, of the pilot system open feedlot area into a confinement building (hoop structure) to house cattle. This reduced the remaining pen area which contributed feedlot runoff to the pilot system, from 3.08-ha to 2.06-ha and resulted in an increased VTA to feedlot area ratio of 0.7:1. Also, during 2008 three earthen berms were constructed within each of the VTAs. These berms helped slow the flow of water through the VTAs, redistribute effluent over the width of the VTAs, and provide some effluent storage within the VTAs. A final berm, prior to the outlet from the pilot VTA, was added in mid-June 2008.

Initial treatment of feedlot runoff occurred in solid settling basins. The downstream end of the settling basin was surrounded by concrete walls, while earthen berms were used for the settling basin sidewalls. The settling basin has a maximum depth of 1.2 m with 223 m^2 of concreted area. The remainder of the SSB bottom was constructed with a compacted earth bottom. The settling basin was designed with a porous dam outlet; the outlet was constructed on the downstream end of the settling basin out of vertical pieces of 2” x 4” lumber spaced 1.9 cm apart. After flowing through the porous dam outlets the effluent entered two 20-cm diameter pipe outlets which directed flow to VTA 1 and VTA 2. During the summer of 2007, a V-notch weir and knife-gate were added behind the porous dam outlet of the pilot system settling basin in an attempt to improve solids retention in the SSB. The knife-gate provided the producer with more control over when, how much, and at what rate effluent was released from the settling basin onto the VTA. In addition to the porous dam outlets, each settling basin was constructed with an emergency overflow weir on the downstream wall of the settling basin. The overflow weir was rectangular in shape, 46 cm long, and 15 cm below the top of the downstream end wall.

The effluent in the settling basin was released onto concrete pads which direct the effluent into a concrete level spreader at the upper end of each VTA. The level spreaders were the width of the VTA, 3 m long, and 0.15 m deep. The spreaders encourage uniform application of the settling basin effluent over the width of the VTA. The three VTA channels were constructed parallel to each other and “stair step” down in elevation with VTA 1 being the highest and VTA 3 the lowest. This design minimized the amount of cut-and-fill required during construction of the VTAs. The VTAs were designed to have a 0.5% slope along the length and to be level across its width. Geotextile flow spreaders were located at 61 m intervals down the length of each VTA channel to help maintain uniform flow distribution. These geotextile spreaders constantly required maintenance, i.e., the spreader needed to be restrung to maintain tension. As mentioned, during the summer of 2008 the producer added three earthen flow spreaders to each VTA. These earthen spreaders were installed to increase effluent retention time in the VTA and to improve flow distribution over the VTA. After installation of the earthen spreaders geotextile spreader were no longer maintained.

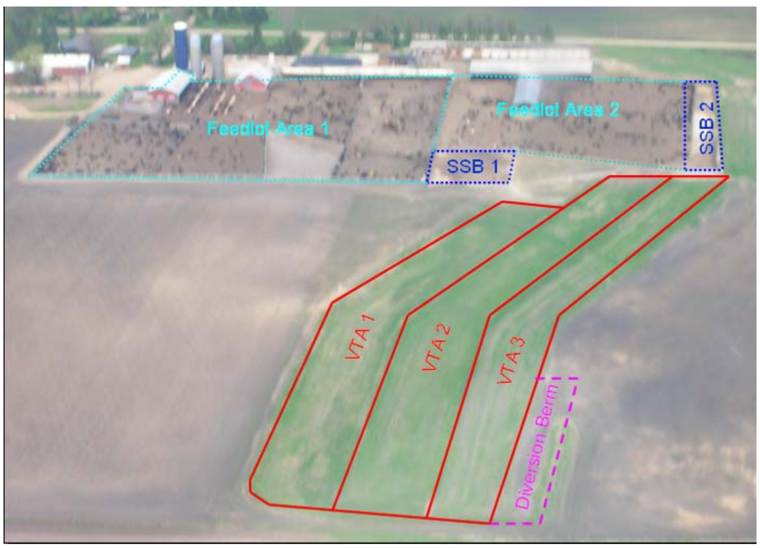


Figure 2. Layout of Central Iowa 1 and the VTS used to control and treat runoff generated by the facility.

Central Iowa 2 (CN IA 2)

Central Iowa 2 had three VTSs for handling runoff from the 3.24-ha earthen/concrete feedlot and was permitted for 2,500 head of cattle. A map showing the feedlot and the different system treatment components is shown in Figure 3. This location used three VTSs to treat feedlot runoff. These are referred to as the South, Middle, and North systems. The Middle system was the pilot VTS at this location, and consisted of a SSB, the Middle VIB, and the Middle VTA. The North VTS consisted of a long, narrow SSB, three VIBs (VIB 1, VIB 2, and VIB 3), and the North VTA. The South system consisted of two SSBs (South SSB 1 and South SSB 2), the South VIB, and crop land across the road which served as a land application area for any effluent released from the South VIB.

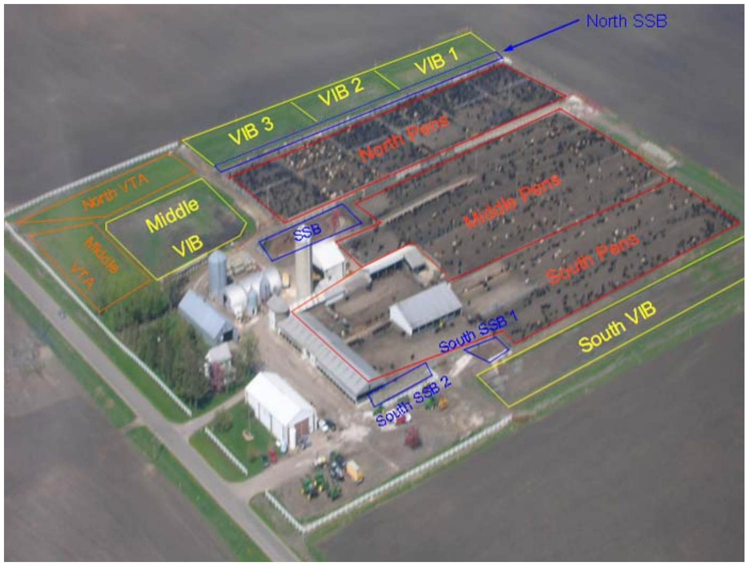


Figure 3. Diagram of the VTS's for Central Iowa 2.

The pilot system controlled runoff from 1.07-ha of feedlot. This portion of the feedlot consisted of three pens, two of which were earthen and a third which was approximately half earthen and half concrete. The feedlot runoff drained into a 61 cm deep concrete SSB with a volume of 51 m^3. The outlet from the settling basin was a 30.5 cm PVC pipe that releases effluent into the VIB. Prior to reaching the outlet pipe the effluent flowed through a porous dam which slowed the flow. In 2006, to reduce the amount of solids leaving the basin, the producer placed a “fence” of round bales in the settling basin to further slow and to filter the flow. During 2007, the round bale filter was not used, but a gate valve was installed at the settling basin outlet to provide the operator with more control over when, how much, and at what rate effluent was released to the VIB. Due to poorer solid-liquid separation during 2007, the producer decided to use the round bale filter along with the gate valve in 2008.

Wet conditions in the VIB made it difficult to establish and maintain vegetation in this treatment component. This 0.32 ha VIB was designed with 1.2 m berms surrounding it. The VIB provided storage for the 25-year, 24-hour storm within the VTS. The VIB had 10 cm (4 inch) diameter perforated tiles installed approximately 1.2 m below the soil surface. These tiles were spaced 6 m apart. A perimeter tile was installed around the VIB to intercept outside groundwater flow and prevent it from entering the VIB system. Flow from the VIB tile lines is collected in a concrete sump and is then pumped onto a 0.2 ha VTA. A gated pipe is used to spread VIB effluent evenly across the top width of the VTA. Flow then proceeded down the length of the VTA via gravity drainage. Both the VIB and VTA are planted with reed canary grass and brome grass.

Northwest Iowa 1 (NW IA 1)

Northwest Iowa 1 had three stand alone VTA systems receiving runoff from a feedlot area of 6.88 ha. The feedlot runoff control system for this 3,400 head open beef cattle feedlot consisted of three solids settling basins, five vegetative treatment areas, and one outlet channel. The five VTAs ran parallel to each other and were “stair stepped” down a hill, with the first VTA constructed at the highest elevation. All the VTAs were surrounded by 0.9 m high berms to prevent transfer of effluent from one VTA to another, were level along their width, and were sloped (5%) along their length.

Figure 4. Diagram of the VTS's located on Northwest Iowa 1.

The pilot system portion of the feedlot (feedlot D) was approximately 2.91-ha of earthen feedlot that contained up to 1,400 head of cattle. Feedlot runoff was collected in a 1.2 m deep SSB having a volume of 3,710 m^3. The SSB was designed to store runoff from a 25-year, 24-hour storm. A 15 cm SSB outlet pipe discharged water onto a 1.4 m wide concrete level spreader which was level across the top width of the VTA. A ball valve was added in the spring of 2007 to control the release of effluent from the SSB to the VTA. This effluent was released onto a VTA that was 479 m long by 35 m wide, giving a VTA to feedlot area ratio of 0.57 to 1. Again any effluent released from this VTA received further treatment as it flowed through the outlet channel. The VTA was initially planted with brome and reed canary grasses. Over the monitoring period, the brome grass took over becoming the dominate species.

Northwest Iowa 2 (NW IA 2)

Northwest IA 2 had a VIB-VTA system designed to control runoff from a 2.96-ha concrete feedlot; a picture of this facility is shown in Figure 5. A concrete settling basin of 101 m^3 capacity collected the runoff from the feedlot. The SSB was 0.6 m deep and has a V-notch weir at the outlet. The effluent flowing through the V-notch weir then flowed into a concrete channel and through an H-flume for measurement. In 2008, a series of stop-blocks was added to control when an SSB release would occur. The stop-blocks were constructed from 5 cm diameter PVC pipe and stacked at the SSB outlet. The stop-blocks were then removed, from the top down, to dewater the SSB from the top down.

Effluent from the settling basin was released into a 1.01-ha VIB. The VIB had 15 cm diameter perforated tiles installed 1.2 m deep and spaced 4.6 m apart. The VIB was built 0.9 m deep in the ground, and allowed storage of the 25-year, 24-hour storm runoff with an additional 0.3 m of freeboard before a VIB overflow would occur. Wet conditions in the VIB again made it difficult to maintain vegetation. Flow from the tile lines was collected in a sump and pumped onto each of the VTAs. A gated pipe was used to spread flow evenly cross the top width of the VTA. The 0.28 ha VTA was divided into two, 27 m wide channels. At a given time, effluent was pumped onto only one of the VTA channels. The channel receiving effluent was switched manually by the producer by switching a set valves. Topographically, the VTA was at higher elevation than the VIB, as a result any effluent reaching the bottom of the VTA was routed back into the VIB. A surface inlet was used to capture this effluent at the bottom of the VTA. It was then routed through a 15 cm pipe that flowed via gravity back into the VIB. Thus, any release from the VTA was recycled back into the VIB, and not released from the overall VTS.

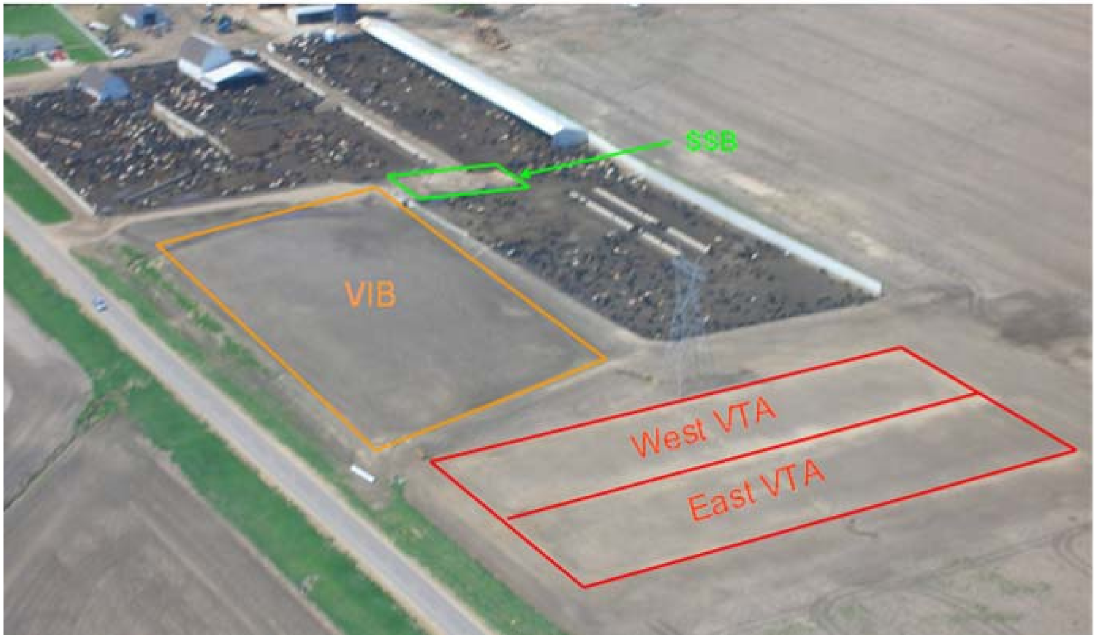


Figure 5. Diagram of the VTA system at Northwest Iowa 2.

Southwest Iowa 1 (SW IA 1)

Southwest Iowa 1 was a 7.49-ha earthen feedlot. At this location all the runoff effluent was handled by one VTS; a diagram of the system and feedlot is shown in Figure 6. Feedlot runoff at this site drains to two vegetative channels located on each side of the feedlot. These channels direct feedlot runoff into the solid settling basin. The solid settling basin was completely earthen, approximately 2.1 m deep, and designed to contain all runoff from a 25-year, 24-hour storm. The outlet of this settling basin was a perforated PVC riser pipe surrounded by a porous dam. The outlet pipe ran from the settling basin to a gated pipe at the top of the VTA. A gate valve was installed in this line to control effluent release onto the VTA. The VTA was 4.05-ha in area and divided into ten channels, each approximately 0.4 ha in size. The channels ran parallel to one another and transported runoff from the top of the VTA down to a berm at the bottom end. Effluent reaching the bottom of the VTA was then directed to the western most of the channels. The outlet from this the VTA was located 0.6 m above the bottom of the westernmost channel. This provided storage of effluent in the VTA before a release could occur. Tile lines surrounded each of the VTAs. These lines run along the edges of the VTAs to a main running along the bottom of the VTAs. An access point was installed in early 2008 so that the amount and quality of flow in the tile lines could be monitored. This access point was on the southwest edge of the VTS. These tile lines were installed to control the water table depth below the system and to enhance the infiltration of effluent into the soil. In this paper effluent monitored from the tile lines at this access point was considered a release from the VTS system. Also, concentration and mass transport data from the tile lines surrounding the VTAs was included in the VIB data analysis.

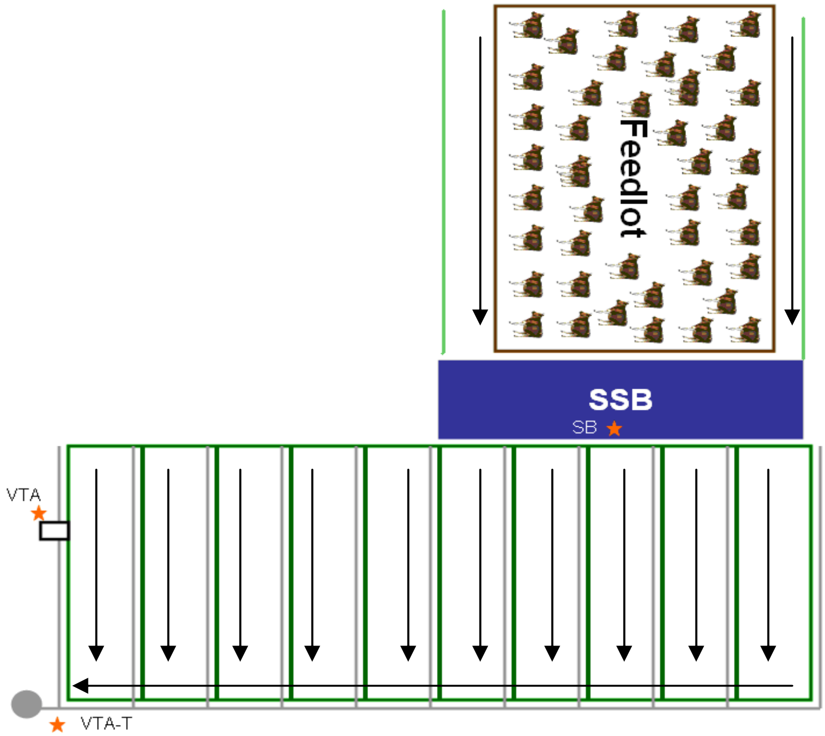


Figure 6. Diagram of the feedlot and VTS. Runoff from the feedlot drains into two channels that direct flow into the solid settling basin. Effluent is then released via gated pipe onto the VTA where it flows down the VTA and then over to the westernmost VTA. Additionally, the VTA's are underlain with tile lines (shown in grey) that connect to a main at the bottom of the VTA's.

Southwest Iowa 2 (SW IA 2)

Southwest Iowa 2 was a 20.2-ha earthen feedlot that used seven VTSs to control feedlot runoff. Each VTS consisted of an SSB and a VTA. A diagram of the VTSs at this site is shown in Figure 7. The pilot system at this location was feedlot C, SSB C, and VTA C. The feedlot area for the pilot system is 3.08 ha. Runoff from this area drained into a solid settling basin designed to hold the 25-year, 24-hour storm. The outlet of this settling basin was a perforated PVC pipe surrounded by a porous dam. The pipe ran from the settling basin to a gated pipe at the top of the VTA. A gate valve was installed in the PVC pipe to provide the producer with control of when effluent would be applied onto the VTA. The pilot VTA had an area of 3.5-ha, giving a VTA to feedlot area ratio of 1.1. This VTA was constructed with small ridges along the length of the VTAs. These ridges slowed the flow of effluent through the system and provided more time for infiltration to occur. A pipe outlet was located at the bottom of the VTA. A gate valve was installed at this outlet. This gate valve was closed between November 1st and April 1st to prevent outflow from snowmelt; between April 1st and November 1st the gate valve was left open so that outflow from the VTA could be monitored.

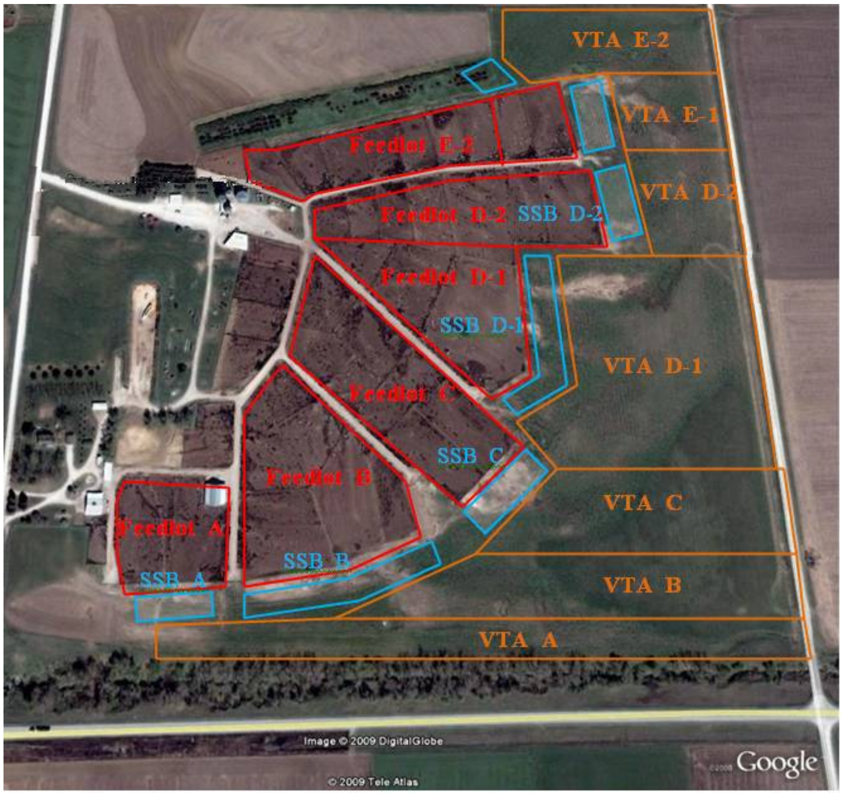


Figure 7. Diagram of the VTA system at Southwest Iowa 2.

Description of the Monitoring Equipment

The primary objective of monitoring the VTS was to quantify the nutrient mass released for each release event from the SSB, VIB, and the VTA at each site. This was done by monitoring flow volumes and effluent concentrations at the SSB outlet, the VIB outlet (where applicable), and the VTA outlet. ISCO samplers (Teledyne ISCO, Lincoln, NE) were used to collect flow paced samples during the release events. The rainfall depth and intensity and daily minimum and maximum temperatures at each site were also monitored. Methods used to make these measurements are discussed in the following sections.

Rainfall and Temperature Measurement

Precipitation depth and intensity were measured using and 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 cold weather conditions. Temperature was measured at the sites hourly using Hobo temperature loggers (Onset, Bourne, MA). The ISCO rain gauge and the Onset temperature logger are shown in Figure 8.

Figure 8. ISCO 674 tipping bucket rain gauge (Teledyne ISCO, Lincoln, NE) (left) and Hobo temperature logger (Onset, Bourne, MA) (right).

Pipe Outlet Volume Measurement and Sampling

Pipe outlets were used at the SSBs at Central Iowa 1, Central Iowa 2, Northwest Iowa 1, Southwest Iowa 1, and Southwest Iowa 2. Additionally, pipe outlets were used in the tile line at Southwest Iowa 1, and the VTA outlets at Southwest Iowa 2 and Northwest Iowa 2. At these locations an ISCO 750 low profile area-velocity sensor (Teledyne ISCO, Lincoln, NE), shown in Figure 9, was used to measure flow. The ISCO 750 low profile area velocity sensor used Doppler technology to measure the average velocity in a full or partially flowing pipe. An integral pressure transducer measured the depth of water flow in the pipe. The depth, along with the diameter of the pipe, allowed calculation of the flow area. Flow rate was calculated by the ISCO 6712 sampler as the product of velocity and flow area by the ISCO 6712 sampler. The ISCO 6712 sampler also maintained a cumulative flow volume and collected samples based on the measured volume.

The ISCO 6712 automated sampler was a portable sampler used to collect flow or time based samples. It was powered with a twelve-volt deep cycle marine battery recharged with a solar panel. The sampler had the versatility to integrate a large range of modular sensors with various flow measurement devices. The sampler was programmed with four different programs at one time. A specific program was then selected based on current site and predicted weather conditions to collect samples according to the required situation.

Figure9. ISCO 750 low profile area velocity sensor and module (left) and ISCO 6712 portable sampler (right)

Flume Volume Measurement and Sampling

At locations where a pipe outlet was not installed as part of the system design, a 0.46 m (1.5 foot) H-flume in conjunction with an ISCO 720 submerged probe (Teledyne ISCO, Lincoln, NE) was used to monitor flow. These locations included the VTA outlets at Central Iowa 1, Central Iowa 2, Northwest Iowa 1, Southwest Iowa 1, and the solid settling basin outlet at Northwest Iowa 2. A picture showing an outlet flume is provided in Figure 10. The ISCO 720 probe, also shown in Figure 10, used a differential pressure transducer to measure the level of water above the sensor. The ISCO 720 probe was placed in the stilling well of the H-flume. Flow rate was then calculated by the ISCO 6712 using a stage-flow relationship for the H-flume.

Figure 10. 0.46m outlet flume from a VTA (left) and the 720 submerged probe and module.

Vegetative Infiltration Basin Release Volume Measurement and Sampling

Effluent from the VIB was collected in a sump and then pumped onto the VTA. The pumped volume was measured continuously using a Neptune 5 cm (2-inch) turbine flow meter (Neptune, Tallassee, AL). Flow based samples were again collected using the ISCO 6712 automated sampler. 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 had the capacity to interpret analog data from flow meters that output a 4-20 milliamp signal. The 780 Module allowed the flow signal to pace the sampler. The Neptune turbine flow meter, shown in Figure 11, was designed for full pipe flow and was capable of measuring a flow rate up to 756 liters per minute. The Tricon/E3 encoder (Neptune, Tallassee, AL) was attached to a register that will output an analog 4-20 milliamp signal. This signal was sent to the ISCO 780 4-20 milliamp module. Photos of the turbine meter and encoder are shown in Figure 11.

Figure 11. Neptune flow meter with Tricon/E3 encoder (left) and Neptune flow meter as installed to measure flow from the VIB into the VTA.

Data Collection and Analysis

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 at Central Iowa 1, Central Iowa 2, Northwest Iowa 1, Southwest Iowa 1, and Southwest Iowa 2 started controlling SSB releases. Northwest Iowa 2 began controlling SSB releases in 2008. When the SSB outlet was controlled producers released small amount of effluent on consecutive days. Collecting one sample per day of SSB release proved to be expensive due to sample analysis costs. To help reduce sampling cost, a new sampling protocol was developed. The new protocol was to collect a SSB sample from the first SSB release after a rainfall event. One sample per day was collected for each of the following two days' releases; these samples were archived in a freezer. When the flow data was analyzed, a few archived samples were selected 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 54 hours after the first sample. The same procedure was used in the analysis of VIB data.

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 each additional day and sent for analysis. The sample concentration was then used to represent the concentration of the effluent released on that specific day when calculating the nutrient mass release. Flow data was recorded every two minutes by the ISCO samplers. The flow data was retrieved from the samplers and processed in Flowlink software (Teledyne ISCO, Lincoln Nebraska). Data from Flowlink was transported in to Microsoft Excel for further analysis.

The ISCO samplers were programmed with site and sampling location specific programs which were different for the SSB, VIB, and the VTA. The samplers were programmed so that most of the samples would be collected close to the hydrograph peak. The sample believed to be closest to the peak of the hydrograph was selected for analysis. The SSB, VIB, and VTA samples were analyzed for ammonia-nitrogen (NH_3-N), five-day biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), chloride (Cl), pH, total phosphorus (TP), total dissolved solids (TDS), total Kjeldahl nitrogen (TKN), total suspended solids (TSS), nitrate-nitrogen (NO_3-N), ortho-phosphorus (OP), and Fecal Coliforms (FC).

For complete sample analysis of the twelve parameters, the commercial laboratory required sample volumes of two liters with no treatment, one liter treated with H_2SO_4, and 100 ml in sterile bottle. After collection, the samples were placed on ice and shipped to a certified laboratory for analysis. A chain of custody protocol was followed during sample shipment. Samples were shipped within 24 hours of collection and packed with enough ice to maintain a temperature below 4°C during the shipping process.

Results and Discussion

Concentration Data

Effluent concentrations were monitored at the outlet of each treatment component in the VTS. Table 3 shows the average concentration and standard deviations of effluent released from the settling basin at each of the six sites. In examining concentrations exiting the solid settling basin it is quickly seen that almost all parameters are substantially higher for Northwest Iowa 2. This is the only entirely concrete feedlot used in the study and the results seem to indicate that either this settling basin isn't functioning as well as the SSBs at the other locations, or that solids in the runoff at this site are harder to settle. Along with the high concentration of suspended solids, the concentration of dissolved solids are also more than double those seen at the other sites. Currently we are investigating what characteristics of the waste at this site make it more difficult to settle solids.

Table 3. Averages and standard deviations of concentrations in effluent released from the SSB at each of the six locations.

						SSB						
Site	**NH_3-N†**	**BOD_5†**	**COD†**	**Cl†**	**pH**	**TP†**	**TKN†**	**TSS†**	**NO_3-N†**	**OP†**	**TDS†**	**FC‡***
CN IA 1	142	1721	5602	305	7.1	83	326	1640	1.37	53	4754	1.73E+08
	(57)	(706)	(2447)	(157)	(0.2)	(23)	(117)	(1012)	(0.50)	(15)	(2029)	(4.84E+00)
CN IA 2	120	1771	6466	366	7.6	109	361	2972	1.90	43	5430	1.33E+08
	(126)	(1945)	(6597)	(183)	(0.2)	(95)	(363)	(3339)	(1.29)	(27)	(3183)	(3.19E+00)
NW IA 1	187	2763	11379	718	7.3	86	561	5595	2.24	37	7370	5.87E+07
	(55)	(2156)	(11257)	(83)	(0.1)	(46)	(401)	(7052)	(1.80)	(17)	(1701)	(4.61E+00)
NW IA 2	492	8274	34933	931	6.8	222	1635	17016	2.58	101	15265	9.44E+07
	(209)	(3539)	(15751)	(255)	(0.1)	(61)	(545)	(9135)	(2.28)	(46)	(5092)	(1.88E+00)
SW IA 1	68	424	1609	207	7.5	53	126	1052	2.05	36	2997	1.27E+07
	(20)	(89)	(119)	(81)	(0)	(8)	(34)	(271)	(1)	(5)	(1141)	(3.83E+00)
SW IA 2	99	952	4539	1051	7.6	83	288	4647	2.66	28	8153	1.04E+08
	(54)	(517)	(1511)	(770)	(0)	(12)	(144)	(709)	(1)	(24)	(3985)	(6.58E+00)

* Geometric mean and standard deviation.

† Concentration in mg/L

‡ Concentration in CFU per 100 mL

Table 4 shows the average concentrations of flow through tile drainage for three locations. Concentrations shown for Central Iowa 2 and Northwest Iowa 2 are for the VIBs at these locations, and the concentration for Southwest Iowa 1 is from the continuously monitored tile lines surrounding the VTA. Because there are tiles under every berm on the Southwest Iowa 1 VTA, this sample location was also included in the VIB concentrations data analysis. One aberration with the Southwest Iowa 1 concentration data is higher than expected total suspended solids. At this site sediment builds-up in the tile line and it frequently builds-up around the monitoring equipment. As a result, collected samples have high concentrations of sediment in them.

Concentrations at Northwest Iowa 2 were generally higher than from the other two locations. There are several possible explanations for this. It could be due to the high concentrations entering this component from the solid settling basin. Alternatively, a surface drain was installed in this VIB. The surface drain is usually closed, unless standing water persists for more than three or four days on this VIB surface. Then, to prevent standing water, the surface drain is opened and material flows directly to the sump without percolation through the soil profile, reducing the level of treatment.

Table 4. Averages and standard deviations of concentrations in effluent released from the VIB at each of the three locations.

						VIB						
Site	NH_3-N†	BOD_5†	COD†	Cl†	pH	TP†	TKN†	TSS†	NO_3-N†	OP†	TDS†	FC‡*
CN IA 2	27	283	1084	204	7.0	16	80	343	4.29	11	2191	4.48E+06
	(32)	(279)	(885)	(53)	(0.3)	(14)	(59)	(241)	(5.17)	(16)	(764)	(1.41E+2)
NW IA 2	166	2624	7291	477	7.1	58	511	1884	4.19	25	6216	1.33E+07
	(112)	(967)	(2196)	(124)	(0.1)	(18)	(234)	(312)	(2.67)	(25)	(1892)	(4.52E+0)
SW IA 1	9	142	732	141	7.1	17	54	4433	12.51	6	1492	1.06E+07
	---	---	---	---	---	---	---	---	---	---	---	---

* Geometric mean and standard deviation.
† Concentration in mg/L
‡ Concentration in CFU per 100 mL

The concentrations of nutrients released from the VTA at Northwest Iowa 2 were again substantially higher than at the other locations; where as concentrations at Central Iowa 2 were lower for most nutrients than at other locations. These two sites both utilize a VIB as a pretreatment component prior to release of effluent into the VTA, while the remaining four sites all release effluent directly from an SSB into the VTA. This may in part be explained by the fact that Central Iowa 2 had a high level of treatment in the VIB which reduced the amount of these nutrients applied to the VTA, whereas Northwest Iowa 2 had a much lower performance level in the VIB. Northwest Iowa 1 and Central Iowa 1 nutrient concentrations in the VTA release was very similar. Likewise concentrations in the releases from Southwest Iowa 1 and Southwest Iowa 2 were similar in concentration to each other.

Table 5. Averages and standard deviations of concentrations in effluent released from the VTA at each of the six locations.

						VTA						
Site	NH_3-N†	BOD_5†	COD†	Cl†	pH	TP†	TKN†	TSS†	NO_3-N†	OP†	TDS†	FC‡*
CN IA 1	52	786	2984	193	7.2	51	181	1209	2.23	33	3006	1.24E+07
	(26)	(712)	(2947)	(154)	(0.3)	(29)	(164)	(1615)	(1.18)	(9)	(2539)	(7.11E+0)
CN IA 2	8	94	441	114	7.8	7	26	144	3.42	4	1192	6.02E+06
	(6)	(72)	(286)	(12)	(0.2)	(3)	(16)	(62)	(3.50)	(1)	(391)	(1.91E+2)
NW IA 1	63	569	2415	398	7.4	41	167	642	1.09	25	3962	2.45E+07
	(21)	(171)	(515)	(37)	(0.1)	(4)	(20)	(334)	(0.09)	(9)	(406)	(3.55E+0)
NW IA 2	152	2716	7352	405	7.2	101	456	1968	2.31	22	5612	1.98E+06
	(51)	(889)	(956)	(84)	(0.3)	(70)	(75)	(1039)	(2.09)	(7)	(634)	(1.23E+1)
SW IA 1	14	132	625	97	7.6	17	40	471	2.21	11	1913	2.42E+05
	(19)	(169)	(785)	(67)	(0.1)	(20)	(52)	(157)	(0.96)	(14)	(1716)	(2.56E+2)
SW IA 2	23	120	1036	170	7.4	29	66	492	1.39	18	1831	1.36E+07
	(10)	(76)	(814)	(73)	(0.0)	(13)	(39)	(508)	(0.55)	(2)	(909)	(2.56E+2)

* Geometric mean and standard deviation.
† Concentration in mg/L
‡ Concentration in CFU per 100 mL

Table 6 shows the percent concentration reduction occurring during treatment in the VTS. All parameters experienced concentration reductions expect for nitrate-nitrogen, which increased in concentration at three sites. Although nitrate-nitrogen increased at these locations, actual concentrations still averaged below 5 mg/L at all locations. For all other parameters concentration reductions ranged from 25 to 98%, with most parameters typically seeing concentration reductions raging from 50-80%.

Table 6. Concentration reductions occurring in the vegetative treatment system.

	Percent Reduction in Effluent Concentrations in VTS											
Site	**NH_3-N**	**BOD_5**	**COD**	**Cl**	**pH**	**TP**	**TKN**	**TSS**	**NO_3-N**	**OP**	**TDS**	**FC***
CN IA 1	64	54	47	37	-1	38	44	26	-62	38	37	93
CN IA 2	93	95	93	69	-2	94	93	95	-80	92	78	95
NW IA 1	66	79	79	45	-2	53	70	89	51	33	46	58
NW IA 2	69	67	79	56	-6	55	72	88	10	78	63	98
SW IA 1†	80	69	61	53	-1	69	69	55	-8	70	36	98
SW IA 2	77	87	77	84	3	65	77	89	48	35	78	87

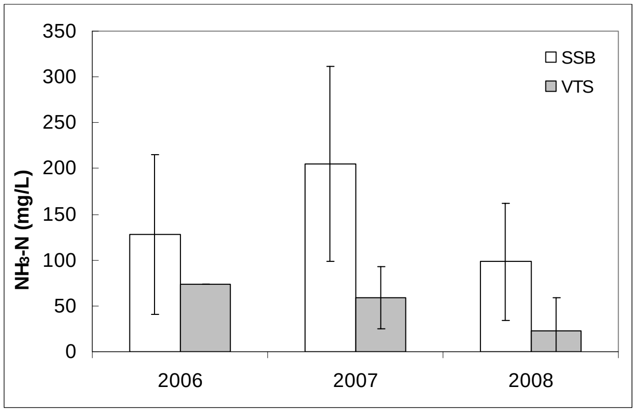
* Geometric mean and standard deviation.

† Percent concentration reduction calculated based on VTA surface releases.

Along with the overall average concentration over the course of monitoring it is also important to consider how performance has been changing over the three years of monitoring. To do this we will look at how average concentrations of select parameters at each site have changed with time. At each site concentration graphs are shown for four parameters, these being ammonia-nitrogen, chemical oxygen demand, chloride, and total solids. These parameters were selected to represent an array of the types of contaminants found in feedlot runoff. Ammonia-nitrogen and chloride are both found in the soluble form; however, ammonia-nitrogen has a strong affinity to bind to soil whereas chloride does not. Total solids (sum of total dissolved solids and total suspended solids) was selected to show how effectively solids were being removed, and chemical oxygen demand was selected to show how effectively organic waste strength was being reduced.

Central Iowa 1

As a general trend it appears that concentrations in the effluent released from both the SSB and VTA tended to decrease with time. The one exception to this trend was an increase in ammonia-nitrogen concentrations in the settling basin effluent when comparing averages from 2006 and 2007. Part of the concentration decreases in the effluent released from the SSB can be explained by improved management of the system as the producer gained experience. Specifically, adding a valve to the settling basin allowed the producer to control the retention time in the SSB and appears to have improved settling. This lead to longer settling times and improved solid-liquid separation, but it likely enhanced the conversion of some organic nitrogen into ammonia-nitrogen. Likewise, the concentrations in the effluent released from the VTA have continued to decrease. There are several possible reasons for this. First, as mentioned the producer installed a valve on the settling basin outlet and controlled effluent application to the VTA. This has allowed the producer to minimize release of feedlot runoff from the VTA. With the valve, the majority of VTA releases are a result of runoff from direct rainfall onto the VTA. Moreover, it appears that as the vegetation matures and develops it may be providing increased filtration of the effluent.



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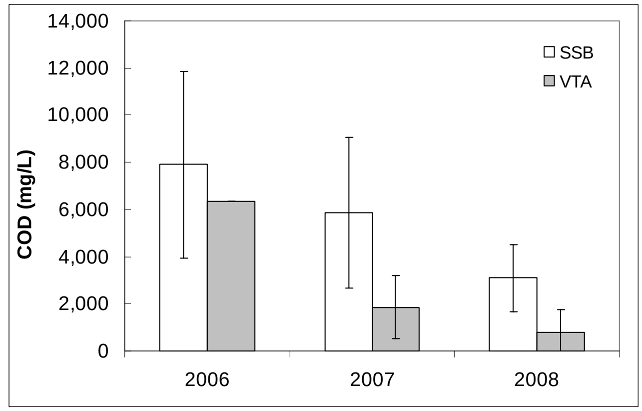

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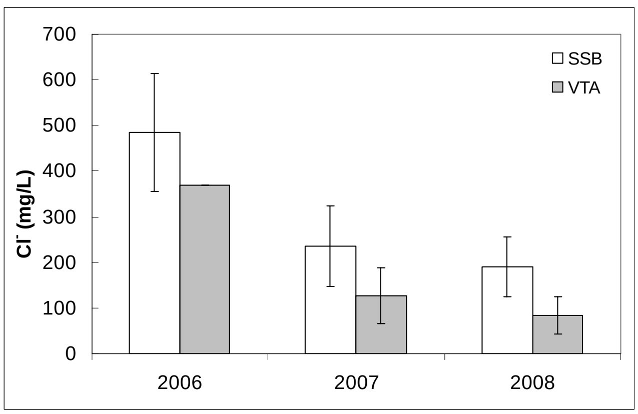

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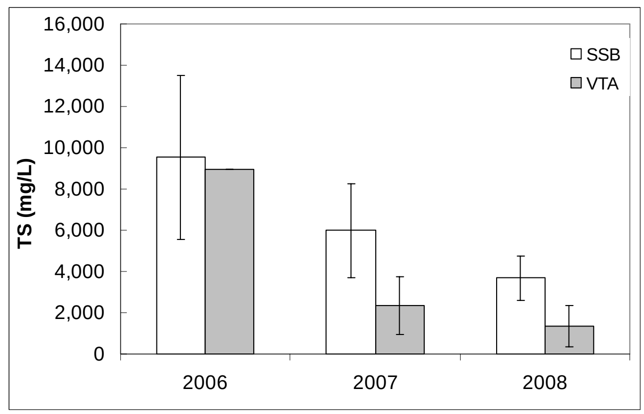

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Figure 12. Graphs of average concentrations released from the SSB and VTA for Central Iowa 1 during 2006, 2007, and 2008; graphs shown are (a) NH_3-N, (b) COD, (c) Cl, and (d) TS. Error bars on these graphs represent one standard deviation about the mean.

Central Iowa 2

In examining the average concentrations for Central Iowa 2, the most evident item is the elevated concentration of all components, but particularly those of the settling basin, in 2007. As mentioned in the site description this site used a bio-filter in 2006 and 2008 to help filter solids from the effluent prior to release from the settling basin. In 2007, this bio-filter was not used and the results show that average concentrations in the effluent released from the SSB were substantially higher. Also, concentrations in the VIB and the VTA effluent were also higher in 2007. This was most likely due to the higher concentrations entering each of these components. This data seems to indicate that the performance of the settling basin is key to the success of the vegetative components.

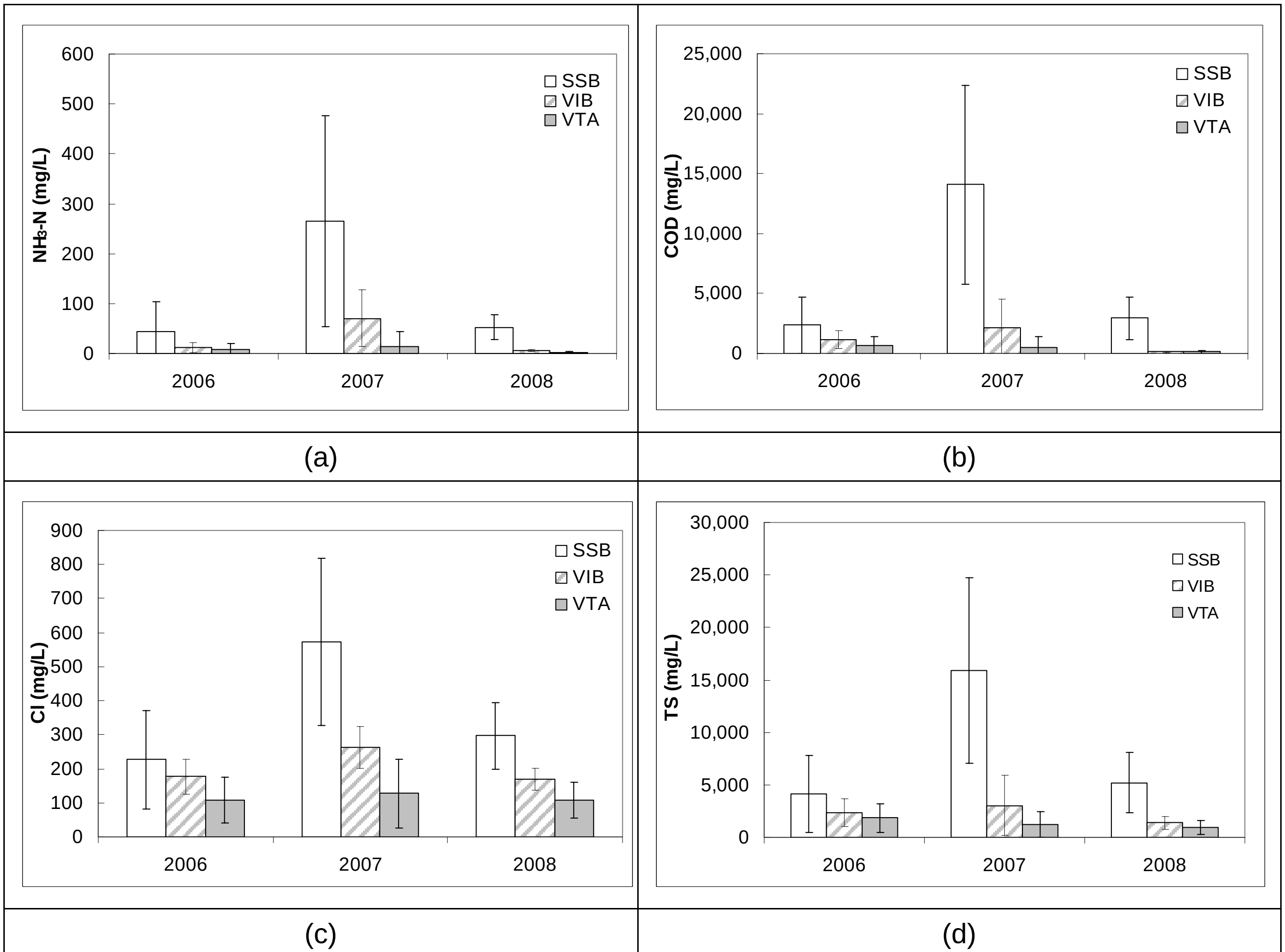
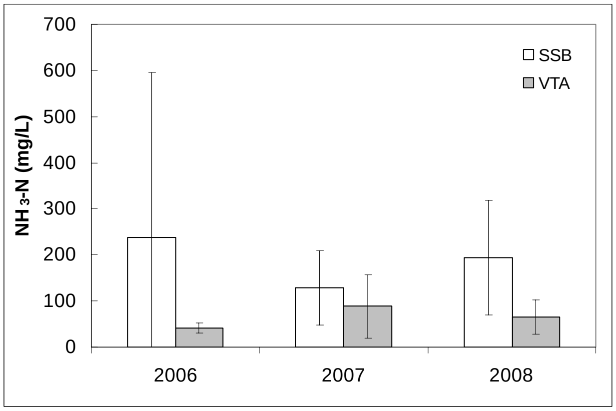


Figure 13. Graphs of average concentrations released from the SSB, VIB, and VTA for Central Iowa 2 during 2006, 2007, and 2008; graphs shown are (a) NH_3-N, (b) COD, (c) Cl, and (d) TS. Error bars on these graphs represent one standard deviation about the mean.

Northwest Iowa 1

The average concentrations of effluent released from the solid settling basin tells a similar story to what we saw at the previous sites. Concentrations of COD and TS were substantially higher in 2006 than in 2007 and 2008 after a valve was installed at the settling basin outlet. This again seems to indicate that increasing the retention time in the settling basin increases the separation of solids and organic material. At this site, the longer retention time had little effect on ammonia-nitrogen and chloride concentrations. At this location, effluent concentrations released from the VTA have been relatively stable for all four parameters.



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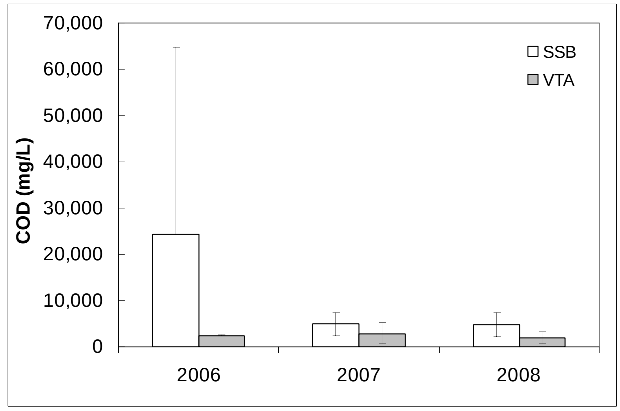

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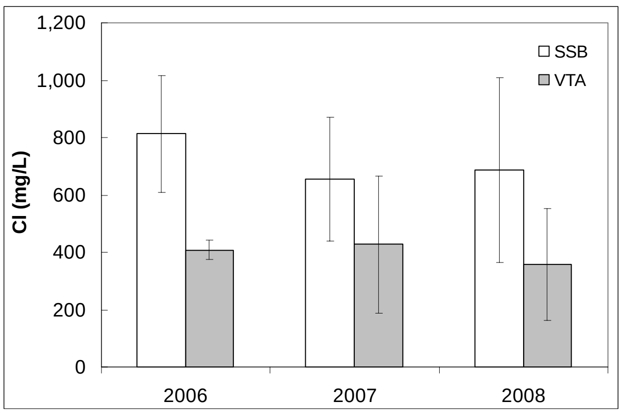

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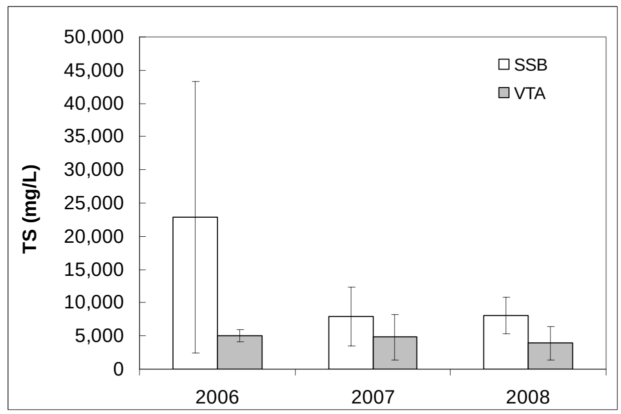
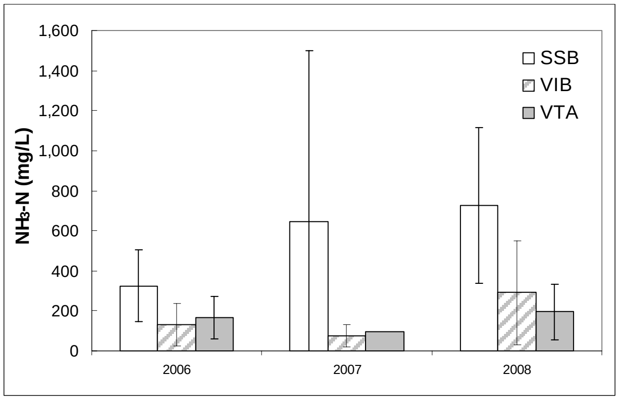


(d)

Figure 14. Graphs of average concentrations released from the SSB and VTA for Northwest Iowa 1 during 2006, 2007, and 2008; graphs shown are (a) NH_3-N, (b) COD, (c) Cl, and (d) TS. Error bars on these graphs represent one standard deviation about the mean.

Northwest Iowa 2

At Northwest Iowa 2, average concentrations at all three locations have been relatively consistent from year to year. One noticeable difference was higher concentrations in the VIB effluent in 2008 than in previous years. The surface inlet in the VIB was used more frequently than in previous years, which may have contributed to this increased concentration. Also of note is that in 2006 and 2007 concentrations in the VTA effluent were approximately the same ad in the VIB, i.e., it appears that little to no concentration reductions occurred during treatment in the VTA. During these two years there were very few VTA release events and this may have been at least in part due to the number of samples available. Moreover, when VTA release events did occur they were often caused by application of VIB effluent that was higher than average in concentrations.



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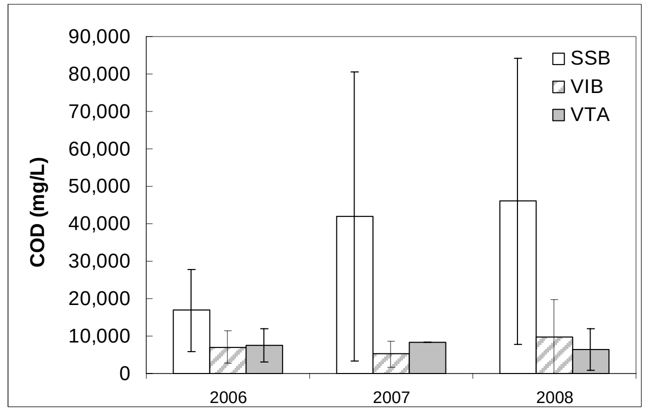

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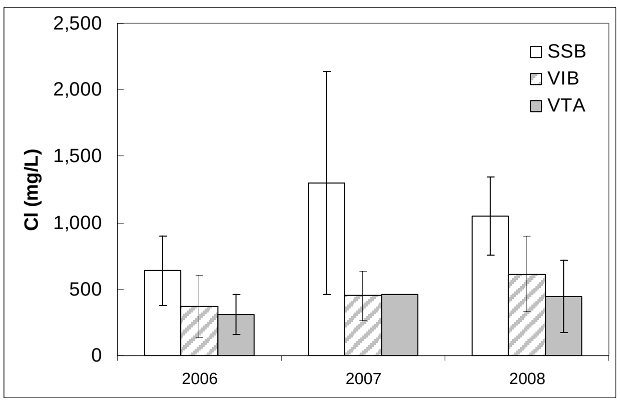

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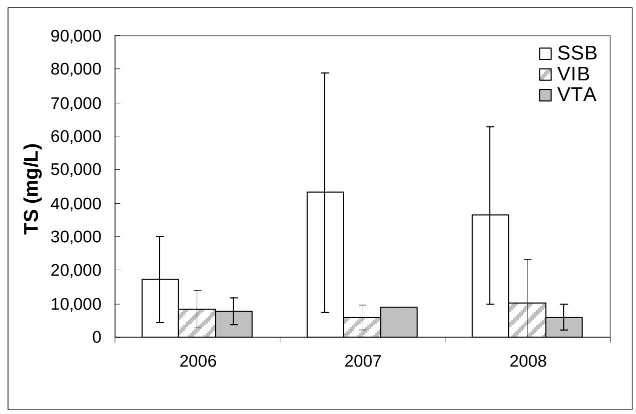
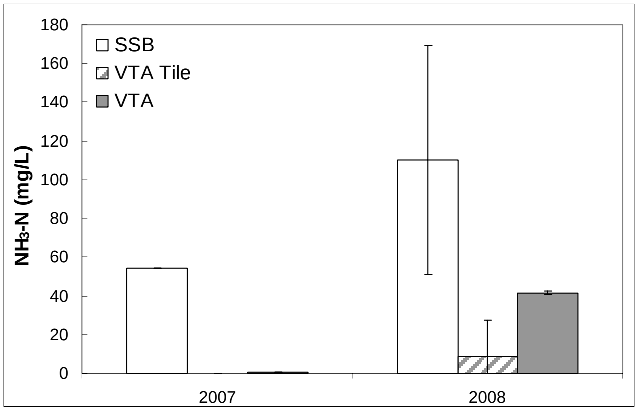


(d)

Figure 15. Graphs of average concentrations released from the SSB, VIB, and VTA for Northwest Iowa 2 during 2006, 2007, and 2008; graphs shown are (a) NH_3-N, (b) COD, (c) Cl, and (d) TS. Error bars on these graphs represent one standard deviation about the mean.

Southwest Iowa 1

For Southwest Iowa 1 the results from 2007 only represent one month of monitoring data; the first real chance to examine how this system was performing was in 2008. To date, concentration reductions have been lower than at other sites. Only half of the VTAs had vegetation established going into the 2008 monitoring year and this may have contributed to the lower nutrient removal efficiencies. Also of note is the high variability in the tile line concentrations, especially as compared to the other sampling locations. This variability would seem to indicate that the concentration spiked after effluent was applied to the VTA but would then return to pre-application levels.



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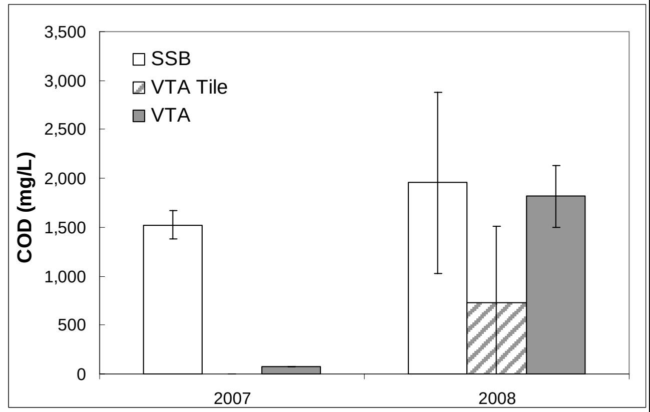

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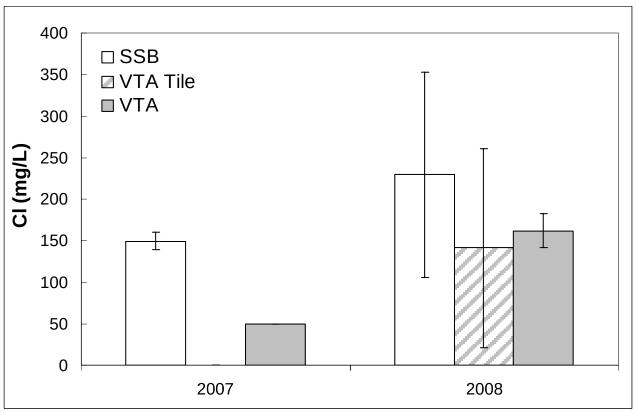

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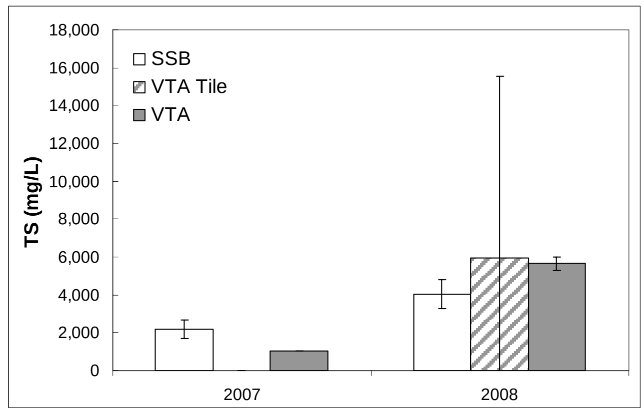

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Figure 14. Graphs of average concentrations released from the SSB, VTA, and VTA tile lines for Southwest Iowa 1 during 2006, 2007, and 2008; graphs shown are (a) NH_3-N, (b) COD, (c) Cl, and (d) TS. Error bars on these graphs represent one standard deviation about the mean.

Southwest Iowa 2

For Southwest Iowa 2, the average concentrations leaving the settling basin have increased from 2007 to 2008. At this location, the producer was not able to get the basin cleaned out between 2007 and 2008; this may have provided an ammonia source to the feedlot runoff and contributed to the higher ammonia-nitrogen concentrations in 2008. Also, reduced capacity in the basin may have contributed to poor settling and led to slightly higher concentrations of COD and Total Solids. Concentrations in the VTA effluent still decreased in 2008 as compared to 2007. The release events from this in 2008 were caused by large rainfall events during the spring and early summer. Again, many of the releases were rainfall runoff from the VTA and not feedlot runoff. In 2007, this was not always the case; during the first half of the year, the basin was not actively managed and feedlot runoff was applied right after rainfall events.

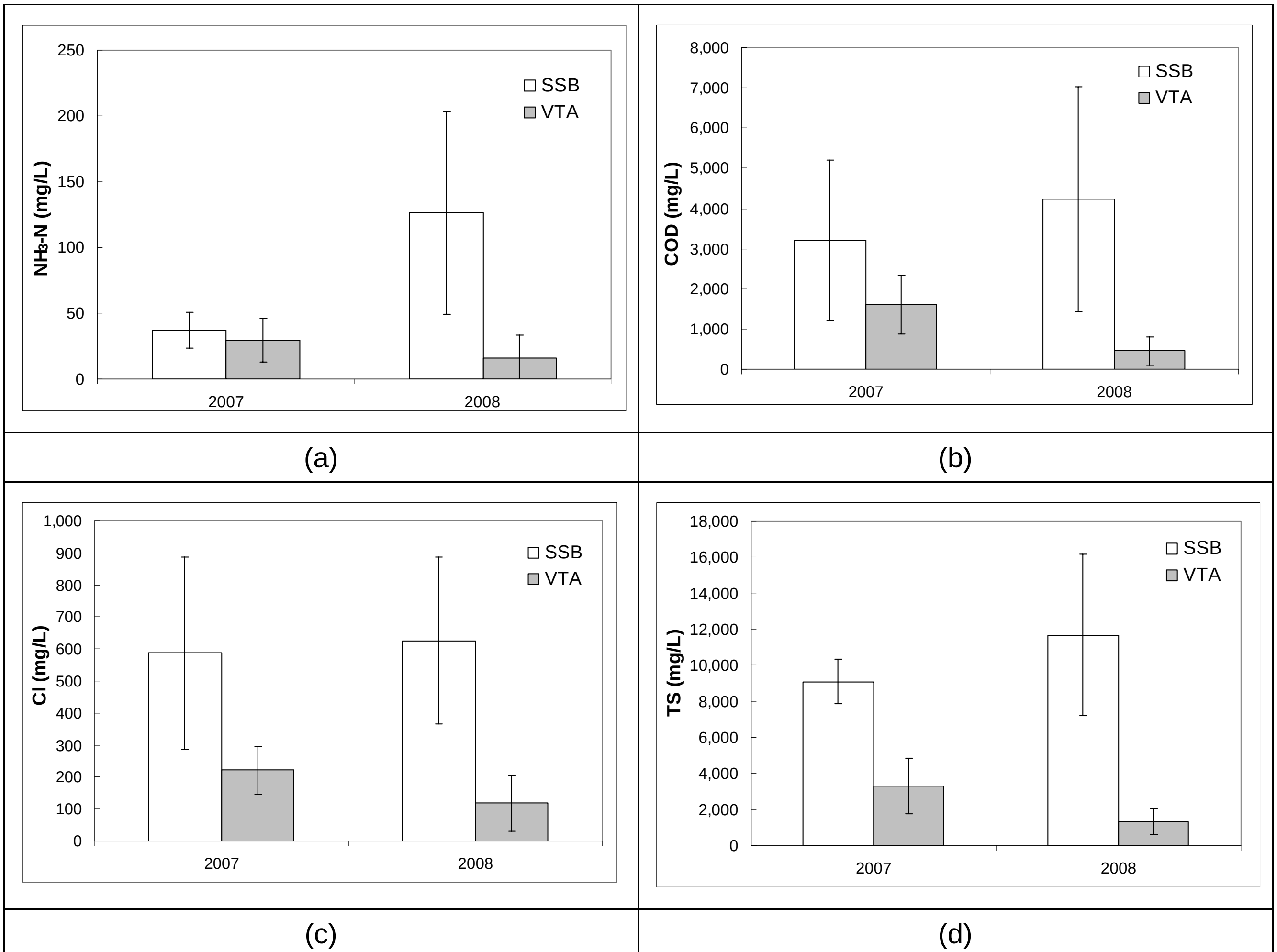


Figure 14. Graphs of average concentrations released from the SSB and VTA for Southwest Iowa 2 during 2006, 2007, and 2008; graphs shown are (a) NH_3-N, (b) COD, (c) Cl, and (d) TS. Error bars on these graphs represent one standard deviation about the mean.

Mass Transport Data

The overall mass of nutrients transported through the system is important. Tables 7, 8, and 9 show the mass of nutrients released from the SSB, the VIB, and the VTA. The results in these three tables have been normalized by dividing by the total depth of rainfall and the permitted number of cattle on the pilot VTS feedlot. This normalization makes it possible to compare results from location to location. Table 6 shows the comparison for effluent volume and contaminant masses released from the settling basin at each location. As can be seen, the runoff volume per cm of rainfall per 100 cows ranged from a low of 2.4 m^3 at Central Iowa 2 to a high of 20.9 m^3 at Southwest Iowa 2. Central Iowa 2 and Northwest Iowa 2, both at the low end of this spectrum had higher stocking densities than the other locations, thus they had smaller contributing drainage areas per cow than the other locations. The locations with the highest runoff volumes, Northwest Iowa 1 and Southwest Iowa 2, were the lots with the steepest slope, which may have contributed to a greater percentage of rainfall being converted to runoff. The mass of nutrients are shown in kg per 100 head of permitted cattle and per cm of precipitation. Ammonia-nitrogen transport was similar for Central Iowa 1, Northwest Iowa 1, and Southwest

Iowa 2. All three of these systems are similar in design and producer management. The similarity in transport among these three systems continues for most of the parameters with the exception of Cl, TSS, and TS which are substantially greater for Northwest Iowa 1. Also of note is that even though Northwest Iowa 2 had less runoff per cm of precipitation per 100 head of cattle, the mass of each of the contaminants released from the settling basin was similar to, or higher than, other locations due to the much higher nutrient concentrations.

Table 7. Mass of nutrients released from SSB per 100 head of cattle per cm of precipitation.

					SSB							
	Volume†	**NH_3-N‡**	**BOD_5‡**	**COD‡**	**Cl‡**	**Total P‡**	**TKN‡**	**TSS‡**	**NO_3-N‡**	**ortho-P‡**	**TDS‡**	**TS‡**
Central Iowa 1	6.8	0.89	8.8	29.5	1.52	0.51	1.79	9.3	0.00	0.43	24.5	34
Central Iowa 2	2.4	0.18	2.4	10.6	0.75	0.20	0.58	5.2	0.01	0.10	11.3	17
Northwest Iowa 1	14.5	1.99	17.9	68.8	9.25	1.00	4.85	40.5	0.01	0.63	92.3	133
Northwest Iowa 2	3.6	1.73	30.4	146.8	3.35	0.89	6.30	70.9	0.01	0.42	55.4	126
Southwest Iowa 1	9.4	0.68	4.8	13.4	1.72	0.41	1.04	15.2	0.00	0.33	39.7	55
Southwest Iowa 2	20.9	1.88	17.4	71.3	10.54	1.57	4.48	65.8	0.06	0.89	114.8	181

† Units of m^3 per 100 head of cattle and cm of precipitation

‡ Units of kg per 100 head of cattle and cm of precipitation

Table 8 shows the mass transport after treatment in the VIB. Again the tile lines surrounding the VTA at Southwest Iowa 1 are included in this analysis. As can be seen, transport of most of the parameters was similar at all three sites; however, there are a few exceptions such as the high transport of solids at Southwest Iowa 1. Again this is most likely an aberration caused by the sediment build–up around the sampler. Also of note is that the oxygen demand, both biochemical and chemical, were higher for Northwest Iowa 2. Again given the similar volume of effluent per cm of rainfall and per 100 head leaving this component this high mass transport is again due to high concentrations in the effluent. Possible reasons for these higher concentrations were discussed in the concentration section of this paper.

Table 8. Mass of nutrients released from VIB per 100 head of cattle and per cm of precipitation

					VIB							
	Volume†	**NH_3-N‡**	**BOD_5‡**	**COD‡**	**Cl‡**	**Total P‡**	**TKN‡**	**TSS‡**	**NO_3-N‡**	**ortho-P‡**	**TDS‡**	**TS‡**
Central Iowa 2	3.2	0.04	0.4	1.8	0.47	0.03	0.16	0.6	0.01	0.02	5.0	6
Northwest Iowa 2	2.6	0.44	5.5	15.6	1.22	0.14	0.99	2.6	0.00	0.07	16.7	19
Southwest Iowa 1	2.5	0.06	0.6	3.8	0.71	0.13	0.32	10.7	0.14	0.08	14.8	26

† Units of m^3 per 100 head of cattle and cm of precipitation

‡ Units of kg per 100 head of cattle and cm of precipitation

At four locations (Central Iowa 1, Central Iowa 2, Southwest Iowa 1, and Southwest Iowa 2) the average release volume was around five to six m^3 per 100 head (based on permitted number) per cm of rainfall. For the northwest Iowa sites this volume was substantially less, between one and two cubic meter per 100 head (based on permitted number) per cm of rainfall. Overall, nutrient mass releases were similar from all sites after normalizing based by cm of precipitation and the permitted number of head at each location. Items of note are that even though Central Iowa 2 had a larger volume of release, the mass of nutrients released was still low due to the extremely low concentrations in the release.

Table 9. Mass of nutrients released from VTA per 100 head of cattle and per cm of precipitation

	Volume†	NH_3-N‡	BOD_5‡	COD‡	VTA Cl‡	Total P‡	TKN‡	TSS‡	NO_3-N‡	ortho-P‡	TDS‡	TS‡
Central Iowa 1	5.7	0.24	2.4	8.5	0.55	0.17	0.51	1.8	0.01	0.13	9.6	11
Central Iowa 2	6.8	0.02	0.2	1.3	0.27	0.02	0.07	0.4	0.01	0.01	3.5	4
Northwest Iowa 1	2.0	0.14	1.3	5.3	0.72	0.09	0.34	2.1	0.00	0.04	7.1	9
Northwest Iowa 2	1.1	0.31	4.1	10.8	0.54	0.06	0.68	2.0	0.00	0.04	7.1	9
Southwest Iowa 1	5.2	0.21	1.8	8.2	0.85	0.26	0.63	4.5	0.01	0.18	23.6	28
Southwest Iowa 2	5.7	0.10	0.6	3.8	0.69	0.14	0.26	1.8	0.00	0.09	7.9	10

† Units of m^3 per 100 head of cattle and cm of precipitation

‡ Units of kg per 100 head of cattle and cm of precipitation

Table 10 shows the overall concentration reductions occurring at each of the sites. Overall decreases in the release volumes ranged from an increase of 180% at Central Iowa 2 to decreases of 90% at Northwest Iowa 1. Overall, nutrient mass transport reductions were similar for most sites with the exception of Southwest Iowa 1 and Central Iowa 1. At the remaining four locations, concentration reductions generally ranged from 80 to 99%. The majority of the release volume at Central Iowa 1 occurred in 2007. This was a very wet year, with this site experiencing 140 cm (55 inches) as opposed to the average rainfall of 85 cm (33 inches). This extremely wet year kept the VTA in saturated conditions for extended periods. Southwest Iowa 1 also had poor performance in comparison to the other location. This site has only been monitored for one complete year (2008) as opposed to the other sites. This site experienced several large rainfall events which resulted in substantial portions of the overall system release volumes due to breaches in the settling basin berms as well as the berms surrounding the VTA. During these breach events flow was estimated from either the stage-storage relationship of the basin or from measurement of the depth and duration of the outflow event. Depth and duration measurements were used in a rectangular weir equation to estimate release volumes. Grab samples from these events were used in calculating mass releases.

Table 10. Percent reduction in nutrient transport from the VTS as compared to a settling basin only system.

	% Reduction in Mass Transport											
	Volume	NH_3-N	BOD_5	COD	Cl	Total P	TKN	TSS	NO_3-N	ortho-P	TDS	TS
Central Iowa 1	16%	72%	72%	71%	64%	66%	71%	81%	-107%	69%	61%	66%
Central Iowa 2	-184%	87%	91%	88%	65%	88%	88%	92%	43%	88%	69%	76%
Northwest Iowa 1	86%	93%	93%	92%	92%	91%	93%	95%	94%	93%	92%	93%
Northwest Iowa 2	69%	82%	87%	93%	84%	93%	89%	97%	71%	91%	87%	93%
Southwest Iowa 1	17%	60%	52%	11%	9%	4%	8%	0%	-9702%	21%	3%	2%
Southwest Iowa 2	73%	95%	97%	95%	93%	91%	94%	97%	93%	89%	93%	95%

Along with the overall average mass transport over the course of monitoring it is also important to consider how performance has been changing over the three years of monitoring. To do this we will look at how the normalized mass transport varied by year. At each site transport graphs are shown for the same four parameters as was shown in the concentration analysis.

Central Iowa 1

As a general trend it appears that transport of contaminants through the settling basin is increasing each year, this is surprising since nutrient concentrations in the effluent released from the settling basin have continued to decrease. This increase has been mostly due to an increase in release volume of feedlot runoff per cm of rainfall per 100 head. Mass transport of the contaminants from the VTA was substantially reduced in each of the three years with the worst system performance seen in 2007. This was by far the wettest year at this site and the wet, rainy conditions made it difficult for the producer to effectively manage his settling basin outlet.

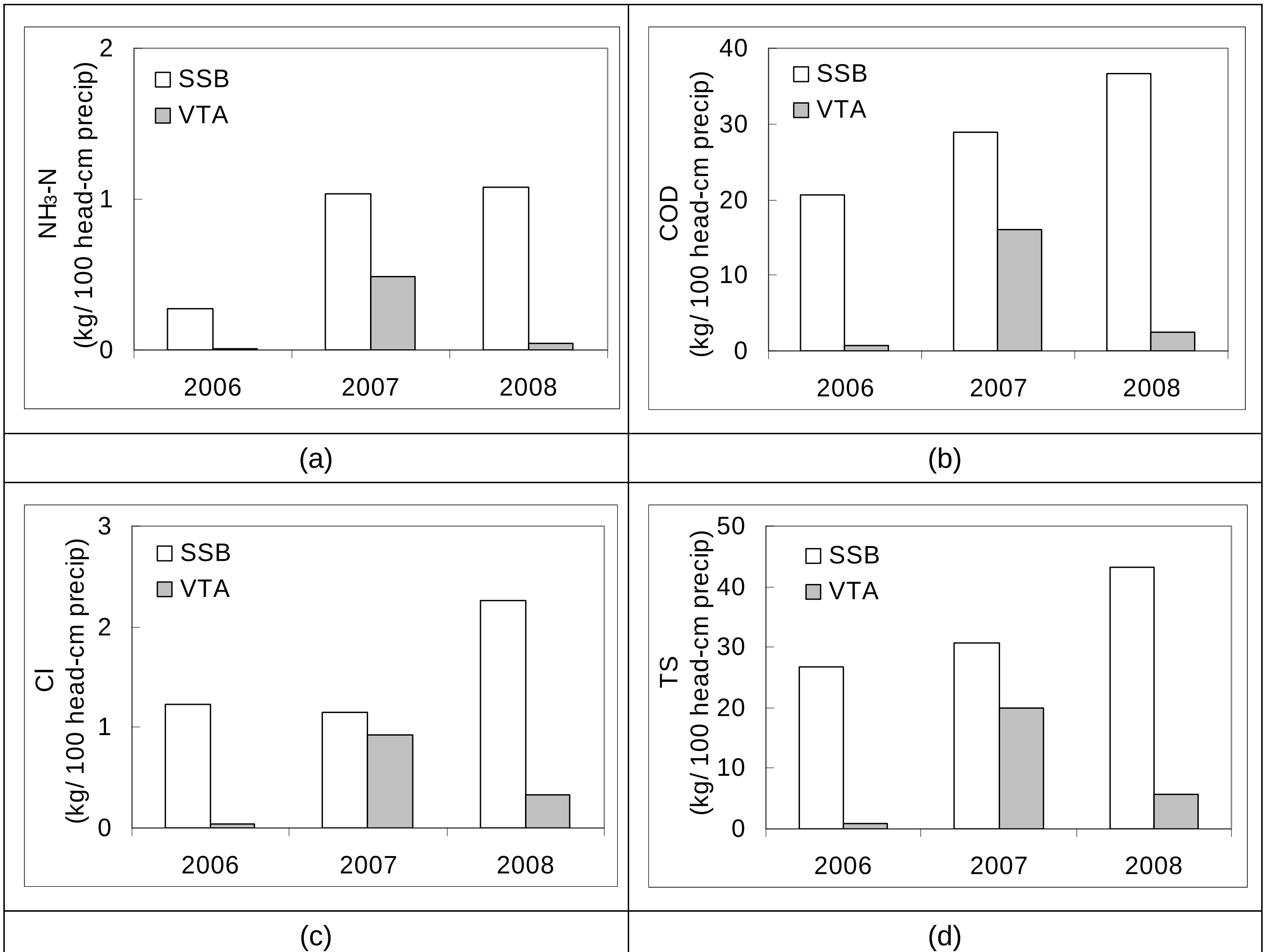
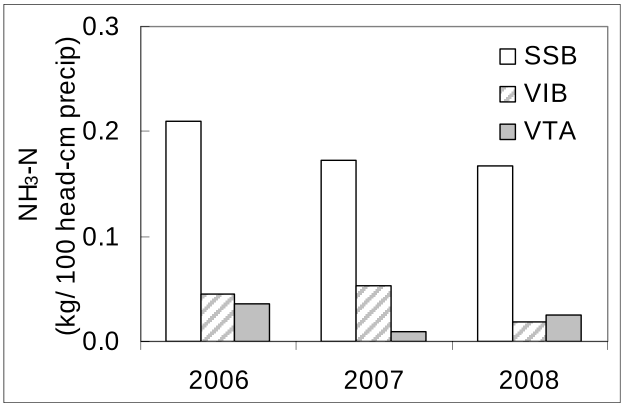
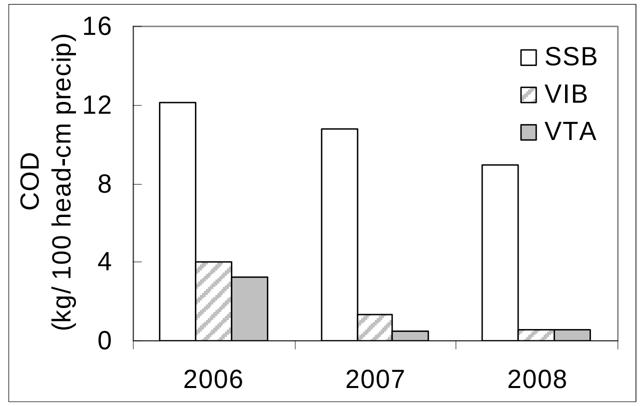


Figure 15. Graphs of yearly normalized mass transport from the SSB and VTA for Central Iowa 1 during 2006, 2007, and 2008; graphs shown are (a) NH_3-N, (b) COD, (c) Cl, and (d) TS.

Central Iowa 2

Overall mass transport of the four parameters (NH_3-N, COD, Cl, and TS) have remained relatively steady for the SSB outlet with a slight downward trend in both NH_3-N, and COD transport. Again transport of these parameters was substantially reduced during treatment in the VIB and VTA. In this case it appears there is a more evident trend that COD transport is decreasing with time, while HN_3-N, Cl, and TS transport have remained relatively consistent over the three years.





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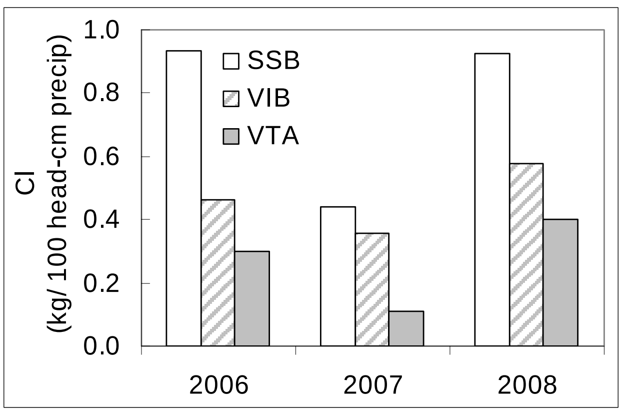
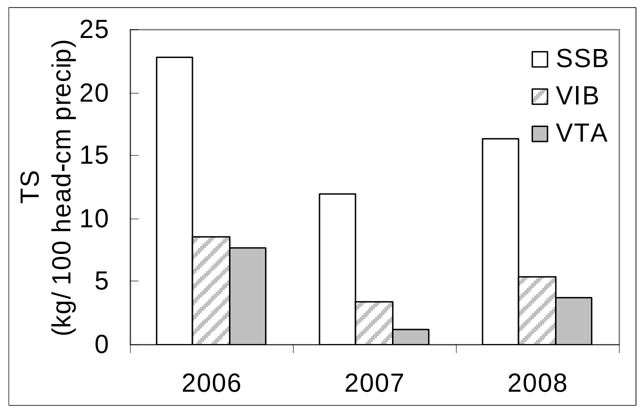




(c) (d)

Figure 16. Graphs of yearly normalized mass transport from the SSB, VIB, and VTA for Central Iowa 2 during 2006, 2007, and 2008; graphs shown are (a) NH_3-N, (b) COD, (c) Cl, and (d) TS.

Northwest Iowa 1

At Northwest Iowa 1 the transport of these four parameters out of the VTA has been consistently lower than that out of the solid settling basin. In this case the lower transport of most parameters out of the SSB in 2007 can be attributed to the fact that we were unable to monitor the outlet of the SSB outlet for approximately one month as the producer made modifications. It is anticipated that if these results were included the settling basin transport numbers would be similar for all three years. Also it appears that transport out of the VTA was lower in 2008 than in the previous years. This most likely can be attributed to improved management of the system. During 2008 the producer consistently monitored conditions within the VTA and made sure that effluent released from the SSB did not reach the VTA outlet.

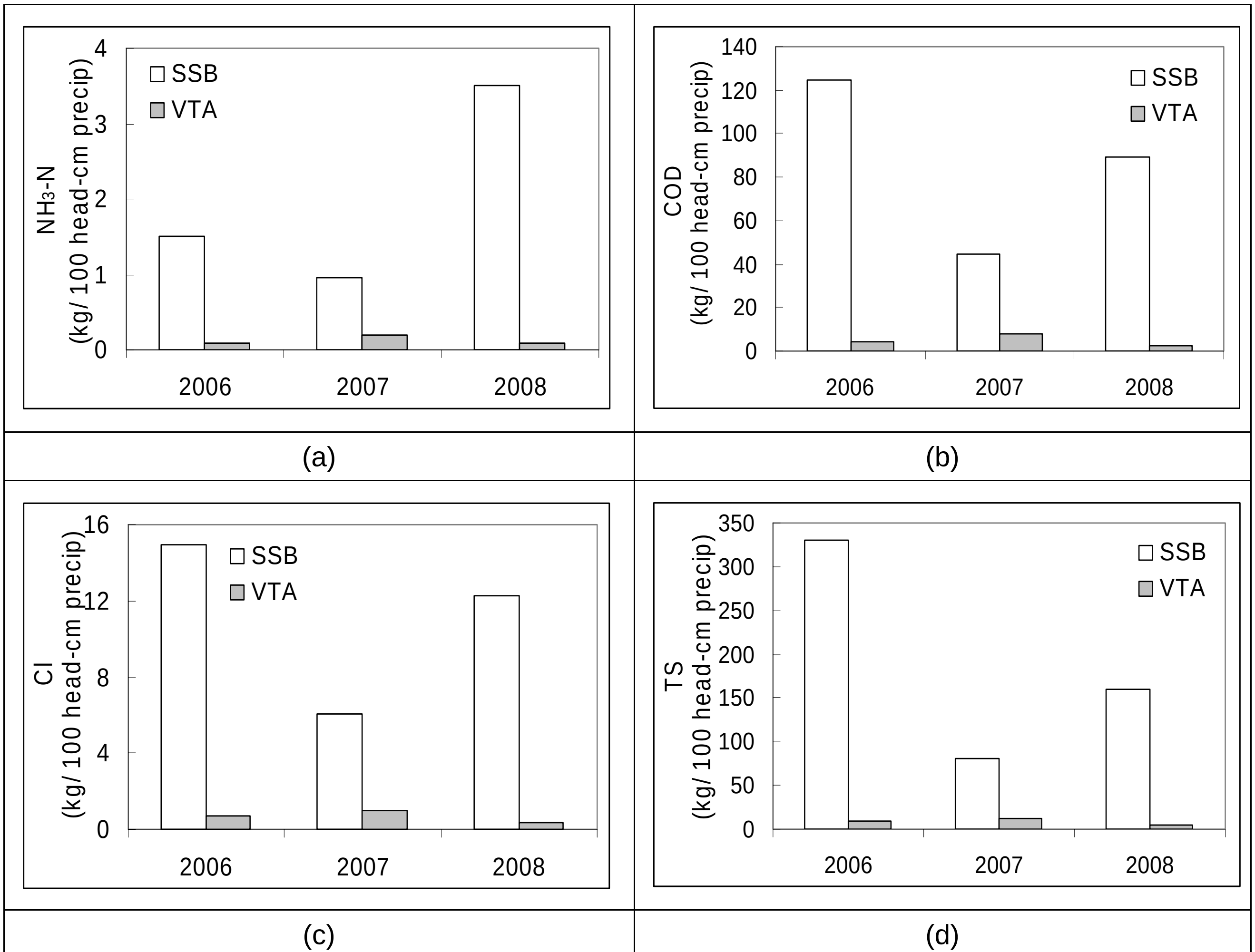
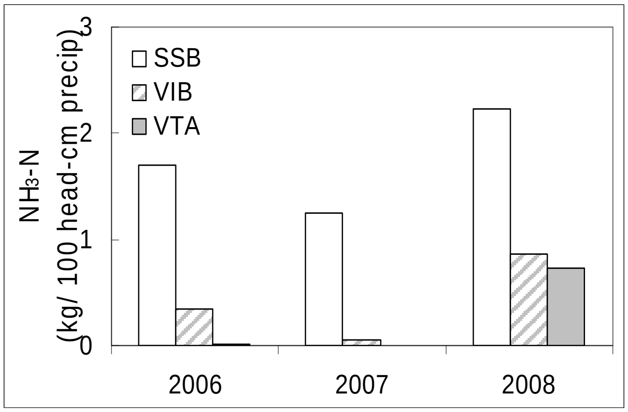


Figure 17. Graphs of yearly normalized mass transport from the SSB and VTA for Northwest Iowa 1 during 2006, 2007, and 2008; graphs shown are (a) NH_3-N, (b) COD, (c) Cl, and (d) TS.

Northwest Iowa 2

Performance of the VTS at Northwest Iowa 2 has been relatively consistent over the three years with little to no release from the VTA during the first two years of monitoring. In 2008 the producer applied effluent to the VTA at a faster rate than in previous years. This resulted in effluent release from the VTA which was recycled back into the VIB. During this time period the producer had the outlet from his VIB opened. It is believed that this effluent was then pumped out to the top of the VTA and applied again where a large percentage of it again reached the outlet of the VTA. This recycling of effluent in the system causes the mass transport number for the VTA and VIB to be larger in 2008 than the otherwise would have been. Also, it appears the transport of total solids from the SSB was reduced in 2008. This in part can be attributed to the producer installing stop-blocks at the SSB outlet to improve settling and solids retention within the basin; however, this concentration reduction appears to have had no effect on the transport of ammonia, chemical oxygen demand, or chloride.



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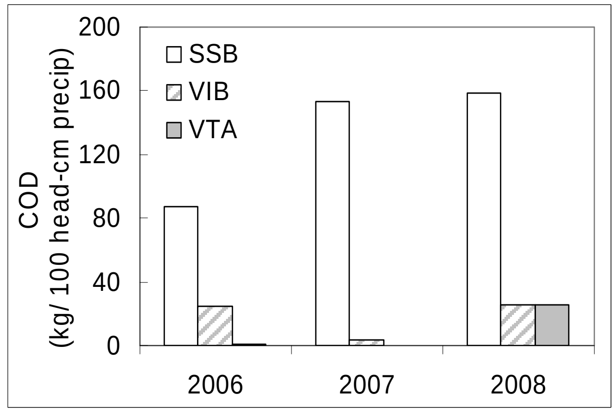
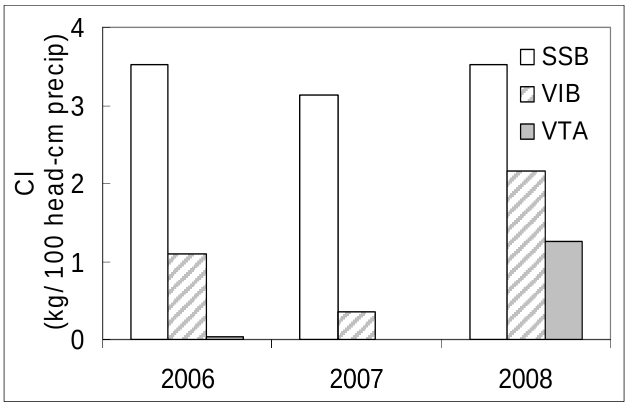
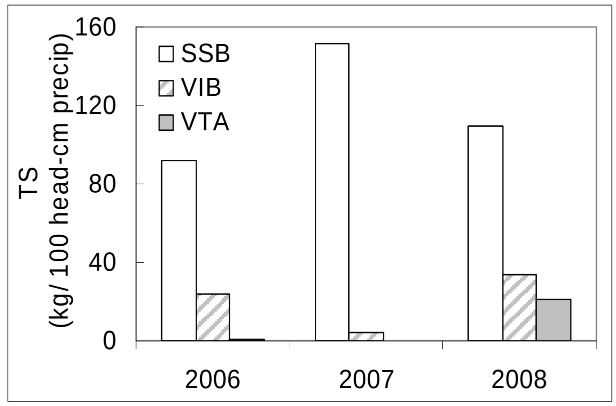


(b)



(c)

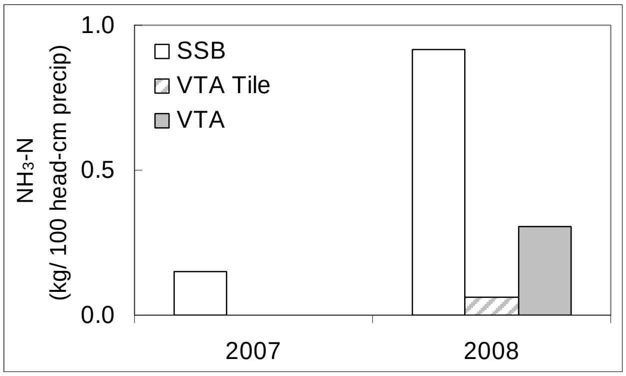


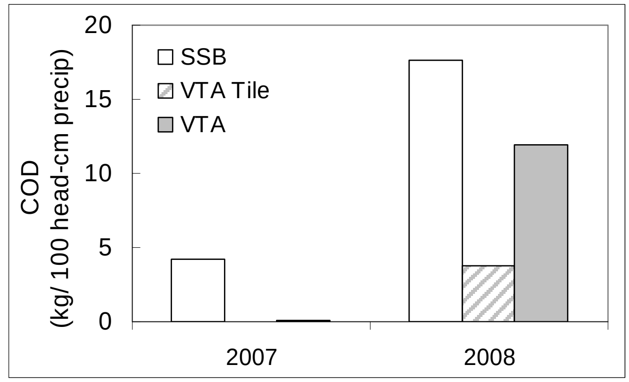
(d)

Figure 18. Graphs of yearly normalized mass transport from the SSB, VIB, and VTA for Northwest Iowa 2 during 2006, 2007, and 2008; graphs shown are (a) NH_3-N, (b) COD, (c) Cl, and (d) TS.

Southwest Iowa 1

Southwest Iowa 1 was only monitored for from September through December in 2007, so it is hard to make year-to-year comparison with so little data in 2007. In 2008 this site experienced some setbacks in operation of the system; specifically breaches in both the berms surround the settling basin and the VTA. Transport from these events was estimated as described above. These events caused a substantial volume of the overall system release. One other item of note is that mass transport in the tile lines account for about ¼ of the total transport of these contaminants from the system. Although not shown, approximately 80% of all nitrate lost from this system was in the tile lines.





(a)

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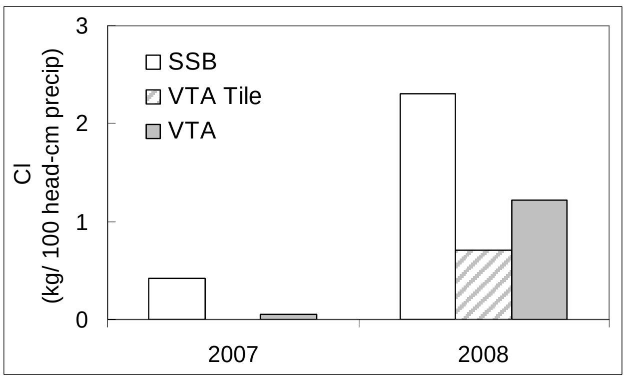
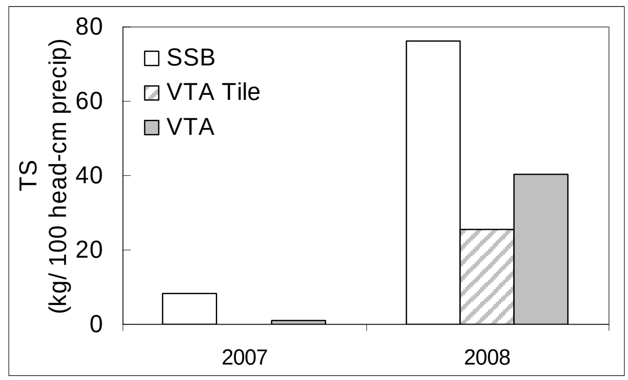




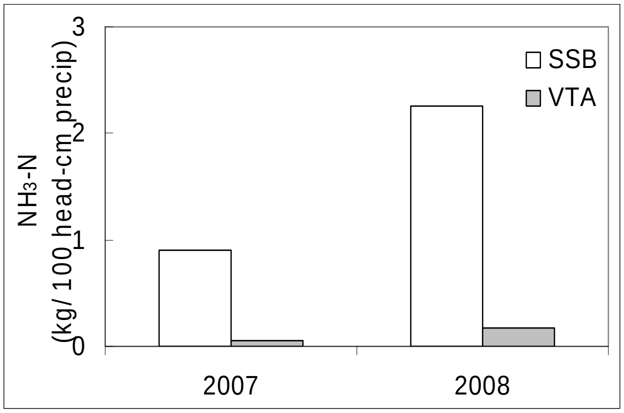
(c)

(d)

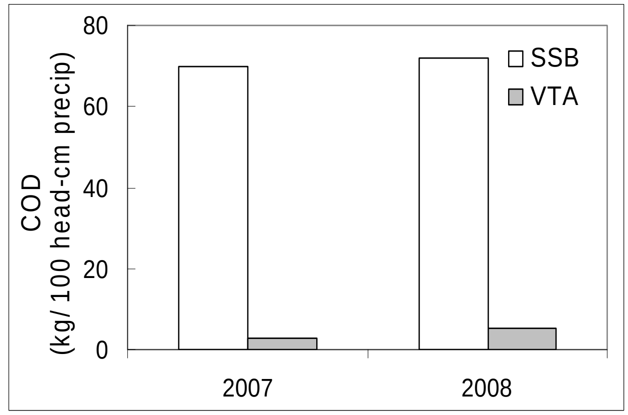
Figure 19. Graphs of yearly normalized mass transport from the SSB, VTA, and VTA Tile for SW IA 1 during 2006, 2007, and 2008; graphs shown are (a) NH_3-N, (b) COD, (c) Cl, and (d) TS.

Southwest Iowa 2

At Southwest Iowa 2 the transport of COD, Cl, and TS from both the SSB and VTA have been consistent over the last two years of monitoring. Ammonia-nitrogen release from the VTA was also consistent over the two years of monitoring; however, the transport of ammonia-nitrogen from the settling basin almost doubled. This large increase can be attributed to the fact that concentrations of ammonia in the settling basin outlet also more than doubled in 2008 as compared to 2007. This large increase in ammonia concentrations may have been caused by the fact that all the solids captured by the SSB in 2007 were not removed. The organic nitrogen attached to these solids accumulating in the SSB have had time to undergo ammonification and may now be acting as an ammonia source to the feedlot runoff effluent. This data would seem to indicate that solids that have accumulated within the basin may be acting as an ammonia source to the feedlot runoff.



(a)



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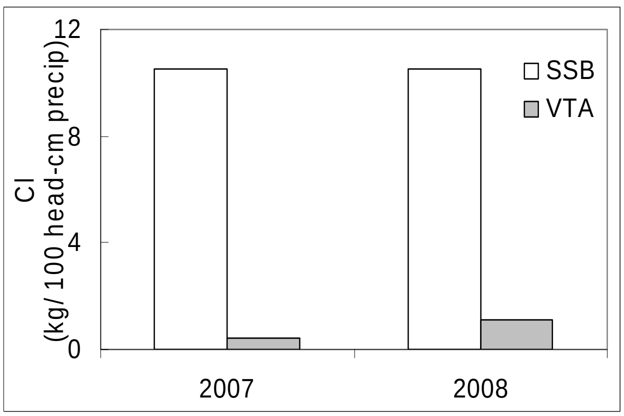

(c)

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Figure 20. Graphs of yearly normalized mass transport from the SSB and VTA for Southwest Iowa 2 during 2006, 2007, and 2008; graphs shown are (a) NH_3-N, (b) COD, (c) Cl, and (d) TS.

Conclusions

The performances of the six vegetative treatment systems monitored in this study varied based on weather, location, and management factors. Overall system performance was mixed with nutrient transport reductions ranging from 65-99% for most locations; however, performance was lower at specific locations. The VTSs also provided concentration reductions ranging 60 to 90% for most contaminants. These results show that system management is one of the keys to maximizing system performance. Moreover, monitoring of these sites indicates that as producers have gained experience in managing the systems performance has improved.

During the course of this study modification have been made to the system components in an attempt to improve performance. Modifications have included the addition of valves on the outlet of the settling basins and the addition of earthen flow spreaders in the VTAs. The addition of gate valves on the settling basin outlets improved solids retention in the basin and decreased nutrient concentration in the outflow. Additionally, the concentration of effluent released from the VTA has continuously decreased as vegetation within the VTAs has matured. The concentration reductions in the VTA outflow are also in part due to improved management that has ensured that the majority of VTA releases are due to rainfall from the VTA surface rather than actual runoff from the feedlot.

Also the normalized mass transport of various parameters was compared. Based on this data is appears that improved management has had a positive impact on the mass of parameters released from the VTAs. In general these VTS system have shown the ability to reduce mass transport by 70-95% as compared to a settling basin alone. Thus although these VTSs are not yet preventing release of all feedlot runoff nutrients they are providing a high level of nutrient control in most cases. Moreover, system performance has continued to improve as the system have matured, been modified, and as management techniques have been refined. It is believed that with several more minor modifications and with continued refinement and development of management techniques it is possible to provide high levels of runoff control with VTSs.

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