Multi-State Vegetative Treatment System Technology: Implementation and Performance - Final Report

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This is the final report for the Multi-state vegetative treatment systems: implementation and performance project. The report provides a concise description of the project, monitoring results, and conclusions obtained. The first section contains a summary of the data collected and our recommendations, based on the monitoring results and experiences with these systems, on how to site, design, and manage successful vegetative treatment systems. A brief summary and overview of the design, operation, and performance of each of the ten vegetative treatment systems monitored is provided. These summaries focus on the specifics of each specific system. The appendix contains a list of manuscripts written in support of this project. These manuscripts are included along with this report.

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Study Conclusions and Recommendations

Table 1 summarizes the monitored results of this study by showing the total reductions in effluent release volumes and nutrient transport, i.e. percent reduction by mass, achieved in the vegetative components of the treatment system. In general, most systems were able to achieve a high level of treatment; retaining more than 85% of solids and nutrients released from the settling basin. At many sites this occurred despite relatively low levels of hydraulic performance. These sites were still able to achieve high levels of treatment as much of the release volume was a result of rainfall runoff.

Table 1. Percent reductions in effluent volumes and nutrient transport as a result of treatment in the vegetative treatment systems (calculated as the difference between solid settling basin and vegetative treatment area release/recycle divided by solid settling basin release).

	Percent Reductions in Effluent Volume and Nutrient Transport					
Site	Effluent Volume	TS	TP	TKN	NH_3-N	COD
Central Iowa 1	41	77	75	78	77	79
Central Iowa 2	23	81	91	90	91	90
Northwest Iowa 1	88	93	89	93	93	93
Northwest Iowa 2†	100 (65)	100 (93)	100 (93)	100 (90)	100 (83)	100 (94)
Southwest Iowa 1	40	50	59	64	74	57
Southwest Iowa 2	69	92	88	92	92	92
Nebraska 1†	100 (81)	100 (85)	100 (84)	100 (86)	100 (90)	100 (86)
Nebraska 2*	---	---	---	---	---	---
Minnesota 1	100	100	100	100	100	100
South Dakota 1	100	100	100	100	100	100

† Site utilized effluent recycle; no effluent was released from the runoff control system, only recycled within the system. Values in parenthesis give percent of effluent and nutrients/contaminants treated the first time through the system.

* Settling bench flow data is unavailable at this site due to monitoring difficulties.

Given the right set of weather conditions, vegetative treatment system effluent releases will occur; when they do it is important to manage the system such that the release is a result of the rainfall onto the VTA rather than the runoff collected from the feedlot surface. VTS system performance is greatly enhanced when the operator has the ability to actively manage when the feedlot runoff is distributed to the VTA. Additionally, the use of properly designed physical flow barriers such, as berms, or the use of effluent recycling systems can limit or eliminate releases as a result of chronic wet periods. With these ideas in mind we think there are three major considerations for optimizing vegetative treatment system performance; these are siting, design, and management. The impact of each of these three factors is discussed below.

Siting

Siting is of premier importance for achieving successful runoff control. Specifically, hydraulic conductivity and depth to water table play large roles in the system's hydraulic performance. In this study we had several sites (mostly in Iowa) that dealt with shallow water tables and others (Minnesota, and Nebraska) that had substantially deeper water tables. Sites with a shallow water table were more hydraulically challenged as there is less pore-space available in the soil profile to infiltrate and store additional water. This made the sites more susceptible to vegetative treatment system releases via saturation excess flow, i.e., saturation of the soil profile from the bottom up. At locations with deeper water tables this phenomenon was less likely to occur. At these locations the primary mechanism of vegetative treatment area release was as Hortonian flow, i.e., the application rate exceeded the infiltration rate of the soil.

Of the two limiting conditions, hydraulic conductivity limitations are easier to accommodate by adjusting the vegetative treatment area size and the effluent application rate. Water table limitations are affected by these variables, but to a lesser extent as weather conditions that completely saturate the soil profile leave the system vulnerable to release. Andersen et al. (2010) and Faulkner et al. (2010) discuss modeling the phenomena of saturation excess flow in vegetative treatment areas and offer the possibility of providing fundamental guidance on required water table depths to control all runoff from a 25-year, 24-hour storm or from continuous precipitation records under various climatic conditions.

Along with hydraulic properties, siting has a direct impact on the soil chemical properties, including the phosphorus sorption capacity and the initial soil phosphorus content. Locations with a high phosphorus sorption and low initial phosphorus content should be sought as this increases the phosphorus sink potential of the VTA soil as soil sorption is the dominant mechanism of phosphorus retention in vegetative treatment systems. Additional work on the effect of siting on nitrogen fate and transport is required to finalize any recommendations; however, ground water quality monitoring results from the Iowa sites tended to indicate nitrate concentrations decreased after installation of vegetative treatment systems. From the authors experience with these and other VTS systems, especially for ones located in proximity to perched and static groundwater, a sound geological investigation of a potential site is strongly advised for siting VTS.

Design

Designing VTS systems for ease of management and operational flexibility is a key factor in vegetative treatment system performance. Based on our monitoring results and experiences with these systems we recommend that all solids settling basin outlets have a control structure that allows the producer to close off the basin outlet and temporarily detain runoff effluent. This is critical at sites with shallow water tables where soil saturation can occur; in areas with deeper water tables this management practice has been effective in reducing the risk of a vegetative treatment system release. In addition to providing a delay before effluent is applied to the vegetative treatment area, a control structure also improved both the performance and consistency of solids removal during treatment in the settling basin.

The solid settling basin needs to be constructed to facilitate period solids removal. To facilitate cleaning the design the basin should be designed to accommodate the available equipment. Additionally, the designer needs to consider the climatic conditions of the region. In Iowa, the producer found it challenging to get the basins cleaned out, often times there was only a short window available in the summer in which the basin was dry enough to drive equipment into. In drier climates this has seemed to be less of an issue. If the VTS is located in a region where clean-out could prove difficult it may be advantageous to line portions of the basin with concrete so that producer can clean out solids during wetter periods.

Designs which take into consideration even distribution of the feedlot runoff onto the vegetative treatment area perform better. Several methods have been suggested, including gated pipe, level-lipped spreaders, and sprinkler irrigation. Sprinklers have the advantage of providing uniform distribution over the entire vegetative treatment area, but have additional costs associated with their use (i.e., pumps, application equipment, piping). Gated pipes and level-lipped spreaders are often used on sloped vegetative treatment areas where gravity flow can distribute the effluent down the length of the vegetative treatment area. Gravity distribution has the disadvantage of accumulation of nutrients at the upper end of the VTA. This occurs because small storm events do not generate sufficient runoff and flow rates to move the feedlot runoff through the entire length of the treatment area. To some extent this can be alleviated by temporally detaining runoff within the settling basin and then surging the stored effluent onto the VTA, but even with this technique the application depth will still be deeper at the entrance to the treatment area. VTA's with gravity flow distribution require maintenance to ensure that uniform sheet flow occurs and to avoid flow channeling.

Perhaps the most important design variable is the vegetative treatment area size. There is no simple criteria that can be used to provide a single answer for ideal size as it is affected by climate, siting conditions, and the management of the system. However, based on our monitoring results and some simple water balance modeling we feel that a feedlot to vegetative treatment area ratio of one-to-one provides a good compromise between size and operational flexibility. Simulation results by Smith et al. (2007) have suggested that increasing VTA length is more effective than increasing VTA width at reducing solids and nutrient releases. This can't be confirmed from this study; however, work by Dillaha et al. (1988) suggests that additional VTA length can improve solids removal.

We also recommend that a small berm or end block (less than 2 feet in height) be constructed at the end of the vegetative treatment area for overland flow designs. The observation of the authors is that this added measure minimized release of effluent that could not be infiltrated by the treatment system during a distribution event. This berm should have an emergency overflow and a means in which the producer could dewater the ponded area to preserve vegetation. Varying soil conditions such as antecedent moisture conditions in the VTA and vegetation retardance vary daily, and make it difficult to know when to stop a release from a basin to a VTA. There is a delayed reaction between stopping a basin release and when a wetting front ceases its movement down the VTA. This berm or end block provides insurance for the producer that should they misjudge and apply a little too much effluent or apply it a little too quickly a release should not occur. This ponding is a feedback system, that is if there is a lot of water ponded at the end the producer knows that he released too much or for too long a period. They then mentally adjust for the right amount the next time. Eventually experience is gained and they (the system operator) are able to judge the correct volume to release from the basin. The purpose of this berm is not to catch all vegetative treatment area runoff and hold it for extended periods of time, but rather act as a safety measure to make system management easier. One critical design issue for this berm or end block is that during heavy rain storms rainwater runoff the VTA is collected. This runoff is substantially cleaner than runoff originating from the feedlot and future consideration should be given to whether this VTA only runoff needs to be recycled, infiltrated, or could be released from the systems.

Management

Based on our monitoring results it is clear that infiltration provided the majority of treatment in the vegetative treatment systems studied. Maximizing infiltration in VTA's are key to their success in minimizing releases of feedlot runoff effluent. This puts a premium importance on proper management of the system. Systems that provide the producer with control over when and at what rate effluent is applied to the vegetative treatment components offer the producer with the opportunity to maximize treatment. It has been our experience that learning the most effective management techniques can take several years, but certainly can have a positive impact on nutrient mass releases. Moreover, one management technique cannot be recommended for all systems; there will be a learning curve as producers experiment with their systems to see what works best for their operation, their management style, and the various weather conditions they encounter. However, there are several management recommendations that can be generalized to all sites.

- Producers must be vigilant in watching for signs of flow channelization and maintaining uniform sheet-flow over the vegetative treatment area. Gullies and rills must be repaired by filling and reseeding the areas.
- System components (level spreaders, settling basins, etc.) should be cleaned as often as weather permits.
- Good vegetation is critical to success. Vegetation stands can take several years to develop, but improve soil structure, increase infiltration, and provide increased resistance to flow as the stand improves.
- Settling basin effluent should be captured and held until after a storm event. Allowing for a day or two to pass until distribution to the VTA improves performance. This can be achieved with a valve on the settling basin outlet(s). This improves solids removal within the settling basin resulting in lower nutrient loadings and decreases the risk of a release. All effluent should be released to the VTA within 72-96 hours to accommodate the next event. While not a storage system, the researchers found this delay a very useful tool in improving the performance of VTS systems.
- Provide mechanisms for the producer to adapt and manage the VTS. Valves/flow metering devices were found to be an important management tool for owners and operators. Timers and surge valves can be utilized on pumped systems. Provide producers with the ability to adapt to weather conditions and adjust application rate to the current soil conditions.
- Allow for distribution of sediment basin effluent to cropland during the growing season and "save" the VTA for the rest of the year. This added flexibility reduces nutrient loading within the vegetative treatment system and allows the producer to utilize nutrients in the runoff as a fertilizer source.

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Central Iowa 1, Sac City, Iowa

Site Basics

Feedlot Size	3.09 hectares (7.64 acres)
Number of Cattle	1,000 head
VTS Configuration	Solid Settling Basin – Gravity Flow Vegetative Treatment Area
Solid Settling Basin Capacity	4,290 m^3 (1.13 million gallons)
Vegetative Treatment Area Size	1.49 hectares (3.68 acres)
Average Annual Precipitation	85.0 cm (33.5 inches)

Site Description

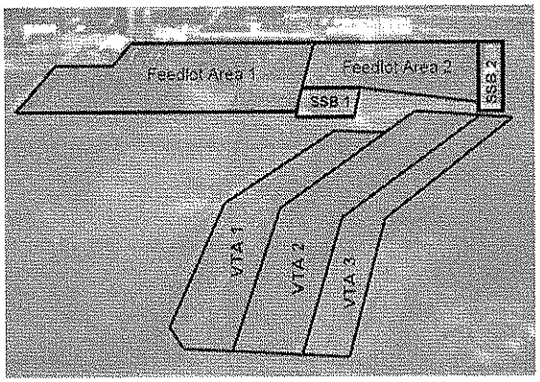

Figure 1. Feedlot and installed runoff control system.

The monitored portion of Central Iowa 1 was a 3.09-ha earthen feedlot (Figure 1, Feedlot Area 1) with a permitted capacity of 1,000 head of cattle. The vegetative treatment system consisted of a solid settling basin (SSB 1) and two vegetative treatment area channels (VTA 1 & VTA 2). Feedlot runoff first drained into the SSB, which was designed to hold 4,290 m^3 of effluent. The downstream end of the settling basin was a concrete wall; basin sidewalls were compacted earth. To facilitate solids removal the SSB bottom consisted of 223 m^2 of concreted area near the basin outlet; the remaining area was constructed of compacted earth. The porous dam settling basin outlet was located on the downstream end of the settling basin and was constructed of vertical pieces of 3.8 x 8.9 cm lumber spaced 2 cm apart. After flowing through the porous dam the effluent entered one of two 20-cm diameter pipe outlets, which directed flow to the VTA channels. In addition to the porous dam outlet, the settling basin also had an emergency overflow weir to prevent the basin from over-topping. The overflow weir was rectangular in shape, 46 cm long, and 15 cm below the top of the downstream end wall. Effluent from the settling basin was released onto concrete pads which directed the effluent into a concrete level spreader at the upper end of each VTA channel. The level spreaders were the width of the VTA (24 m), 3 m long, and 0.15 m deep. The spreaders encouraged uniform application of the settling basin effluent across the width of the VTA channels. The VTA channels were operated in parallel; i.e., effluent was released onto both channels at the same time, with both receiving similar amounts of settled effluent. Each channel was 24 m wide with an average length of 311 m; giving a VTA to feedlot area ratio of 0.5:1. The VTA channels were constructed parallel to each other and "stair-stepped" down in elevation. This design minimized the amount of cut-and-fill required during construction of the VTA. The VTA was designed with a 0.5% slope along the length and level across their width. Geotextile flow spreaders were located at 61 m intervals down the length of each VTA channel to help maintain uniform flow distribution. Initially the VTA was planted to a mixture of reed canary and brome grass; canary grass became the dominate species within two years of system operation.

During 2006 the SSB outlet was operated passively, i.e., flow was controlled by the hydraulic characteristics of the porous dam outlet. Feedlot runoff was allowed to drain freely from the SSB during and shortly after rainfall events. Beginning in 2007 the producer began to actively manage the SSB outlet, first by using stand-pipes to control when effluent was released and then through the use of a V-notch weir and knife-gate. 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. This allowed the producer to hold feedlot runoff within the basin until several days after precipitation events, allowing the VTA more time to dry and solids in the effluent to settle. During winter 2007 and spring 2008, the producer converted a portion, 1.01-ha, of the feedlot area into a confinement building (hoop structure) to house cattle. This reduced the remaining pen area exposed to rainfall from 3.08-ha to 2.06-ha and resulted in an increased VTA to feedlot area ratio of 0.7:1. This reduced hydraulic loading onto the vegetative treatment area. During spring 2008 three earthen flow-spreaders were constructed within each of the VTA channels. The flow-spreaders helped slow the flow of water through the VTA, redistribute effluent over the width of the VTAs, and provided some effluent storage within the VTAs. After constructing the earthen flow spreaders, the geotextile spreaders were no longer maintained. A final berm, prior to the VTA outlet, was added in mid-June 2008.

Monitoring Results

Average runoff volumes ranged from 7 to 11 m^3/100 head-cm precipitation during the four-years of monitoring. During this period, feedlot area was substantially reduced. Prior to the reduction in lot size, 30% and 23% of all precipitation was converted to feedlot runoff. After reducing lot size, 53% and 45% of rainfall was converted to runoff. The reduction in lot size resulted in an increased cattle stocking density (from 31 m^2/head to 21 m^2/head). Based on ASABE standard D384.2 this would increase the amount of water applied through cattle excrement by 12.7 cm/year. It appears that the higher stocking density may have lead to higher antecedent moisture conditions and a greater percentage of the precipitation being converted to feedlot runoff. Stocking density did not result in a clear pattern in VTA release volume; rather it appears that during wetter conditions a greater fraction of the applied water (effluent and rainfall) was released from the VTA. In general, the VTA infiltrated between 59 and 100% of all applied effluent.

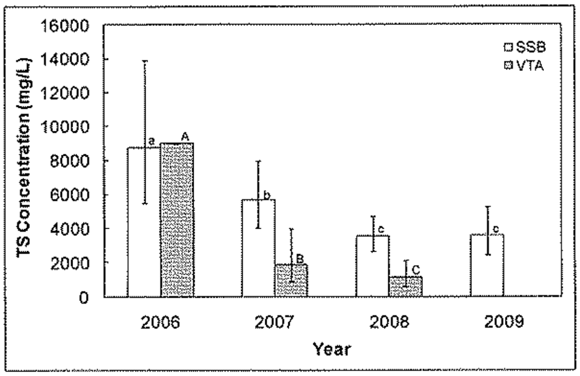

Figure 2. Average annual total solids concentrations for runoff control system components. Lower and upper case letters represent significant differences (α = 0.05) between years for solids settling basin and vegetative treatment area effluent concentrations respectively.

In general, the concentration of most monitored constituents closely followed that of total solids. Thus, a relatively complete evaluation of system performance can be obtained by understanding solids transport in and through the system. Analysis of total solids concentration data indicated significant decreases ($p < 0.0001$) in effluent concentration for both year and VTS component, indicating that the VTA was providing a significant reduction in effluent total solids concentrations in most years and that both the SSB and VTA effluent concentrations showed a decreasing trend with time in solids concentration as the producer learned to better manage the system. Several items stood out when examining the total solids concentrations, first modifying the SSB outlet had a positive impact, significantly reducing SSB effluent concentrations. Second, the variability of the SSB effluent was also reduced by the modification. This would seem to indicate that when operated passively the settling basin performance was quite variable, with performance possibly being impacted by the hydraulic characteristics of each runoff event. After switching to active SSB outlet control, the producer was able to achieve more consistent settling basin effluent quality. Similar, but more dramatic, trends in solids concentrations were seen in VTA effluent. This would seem to indicate that through active SSB outlet management the producer was able to match effluent application rates to those the VTA was capable of handling. This reduced or eliminated the portion of VTA release that was related to feedlot runoff, which resulted in reduced VTA effluent concentrations. When using active SSB management, the VTA release events tended to be due to direct rainfall runoff from the VTA and not SSB releases. In general, this system was able to achieve high levels of treatment averaging 89, 87, 84, 87, and 85% reductions in transport of ammoniacal nitrogen, chemical oxygen demand, total phosphorus, total Kjeldahl nitrogen, and total solids. These results are similar to those a containment basin runoff control system would have achieved under similar weather conditions.

Central Iowa 2, Nevada, Iowa

Site Basics

Feedlot Size	1.07 hectares (2.64 acres)
Number of Cattle	650 head
VTS Configuration	Solid Settling Basin – Vegetative Infiltration Basin – Pumped Vegetative Treatment Area
Solid Settling Basin Capacity	560 m^3 (150,000 gallons)
Vegetative Infiltration Basin Area	0.32 hectares (0.79 acres)
Vegetative Treatment Area Size	0.2 hectares (0.49 acres)
Average Annual Precipitation Depth	89.2 cm (35.1 inches)

Site Description

Figure 3. Feedlot and installed runoff control system.

The monitored portion of the Central Iowa 2 site was a 1.07-ha earthen feedlot (Middle Pens) permitted for 650 head of cattle. 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 (Figure 3, SSB) with a volume of 560 m^3. The outlet from the settling basin was a 30.5 cm PVC pipe that released effluent into the VIB (Middle VIB). Prior to reaching the outlet pipe, the effluent flowed through a porous dam which slowed the flow. The porous dam was constructed of 5-cm wide vertical plastic strips spaced 2 cm apart. During 2006 the producer placed a "fence" of soybean stubble/straw round bales in the settling basin to further slow and to filter the flow. In 2007 the porous dam and round bale filter were removed from the settling basin and not used. A gate valve was installed during the summer of 2007 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 and 2009. Effluent from the SSB was released via a 30.5-cm diameter PVC pipe to the vegetative infiltration basin (VIB).

Wet conditions in the VIB made it difficult to establish and maintain vegetation in this treatment component. Reed canary grass was reseeded in 2007 and 2008 to improve stand quality. The 0.32-ha VIB was surrounded by 1.2 m high berms and provided storage for the 25-year, 24-hour storm within the vegetative treatment system. The VIB had 10 cm (4 inch) diameter perforated tiles, spaced 6 m apart, installed approximately 1.2 m below the soil surface. A perimeter tile was installed around the VIB to intercept outside groundwater flow and prevent it from entering the VIB. Flow from the VIB tile lines was collected in a concrete sump and pumped onto a 0.2 ha VTA (Middle VTA). Gated pipe was 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 were planted with a mixture of reed canary and brome grass initially, with canary grass becoming the predominant species during the first two years of system operations.

Monitoring Results

Effluent volume released from the SSB ranged from 1.1 to 5.8 m^3/100 head-cm precipitation. Lower hydraulic transport coefficients in 2007 and 2008 were due to the producer pumping and land applying feedlot runoff on fields outside of the VTS. This was done to lessen the hydraulic loading of the secondary VTS treatment components. Unfortunately, this practice minimized the meaning of the SSB transport coefficients in 2007 and 2008 as accurate pump and haul volumes were not available. It is believed that the values recorded in 2006 and 2009 are much more representative of the runoff volumes anticipated from the feedlot. In 2006 and 2009, 35 and 23% of all precipitation was converted to feedlot runoff. In 2007 and 2008 (the years the producer pumped from the SSB), only 7 and 13% of all rainfall was monitored as settling basin outflow.

Vegetative infiltration basin hydraulic transport coefficients were similar in 2007, 2008, and 2009 despite the fact that the SSB transport coefficient was variable. The slightly higher hydraulic transport coefficient in 2006 appears to correspond to the increased transport from the SSB. Hydraulic transport coefficients from the VTA ranged from 1.1 to 3.4 m^3/100 head-cm precipitation. This implies that between 16 and 41% of all rainwater and applied VIB effluent was released from the VTA. Estimated evapotranspiration would more than account for the 59 to 84% reduction in hydraulic transport within the VTA.

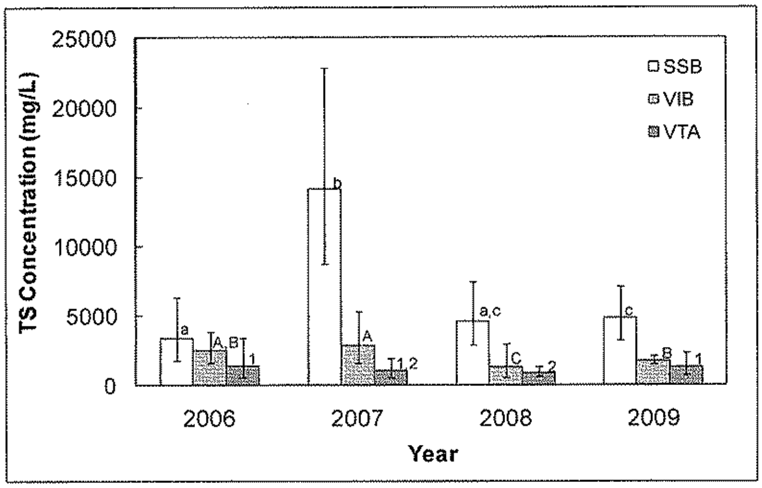

Figure 4. Average annual total solids concentrations for runoff control system components. Lower case letters, upper case letters, and numbers represent significant differences ($\alpha = 0.05$) between years for solids settling basin, vegetative infiltration basin, and vegetative treatment area effluent concentrations respectively.

In general, nutrient concentrations tended to trend with the total solids concentration of the effluent. Statistical analysis of total solids concentrations indicated that the year, component, and year x VTS component interaction were all significant ($p < 0.0001$). These results indicated that the VTS consistently achieved a significant reduction in total solids concentrations, but no trend in temporal variation of performance was evident. It can be noted though, that in 2007 (the year the biomass filter was not used in the settling basin) average solids concentrations from this component were very high; however, the VIB was still capable of achieving low solids concentrations in the draining effluent. This indicates the robustness in the system as the VIB was capable of compensating for the poor settling basin performance. The vegetative treatment area had low concentrations of all parameters throughout the four years, with the lowest concentrations occurring in 2008. This corresponds to the lowest effluent concentrations from the VIB. This follows the general trend in overall performance of this system; that the majority of the overall concentration reductions occurred in the VIB with the VTA providing some additional effluent polishing. In general, this site was capable of achieving high levels of treatment even with the limited hydraulic conditions. The site averaged 91, 89, 89, 90, and 80% reductions in ammoniacal nitrogen, chemical oxygen demand, total phosphorus, total Kjeldahl nitrogen, and total solids transport. These levels of treatment are comparable to what a containment basin system would have achieved under similar site and weather conditions.

Northwest Iowa 1, Hawarden, Iowa

Site Basics

Feedlot Size	2.91 hectares (7.19 acres)
Number of Cattle	1,400 head
VTS Configuration	Solid Settling Basin – Gravity Flow Vegetative Treatment Area
Solid Settling Basin Capacity	3,710 m^3 (980,000 gallons)
Vegetative Treatment Area Size	1.68 hectares (4.14 acres)
Average Annual Precipitation Depth	65.9 cm (26.0 inches)

Site Description

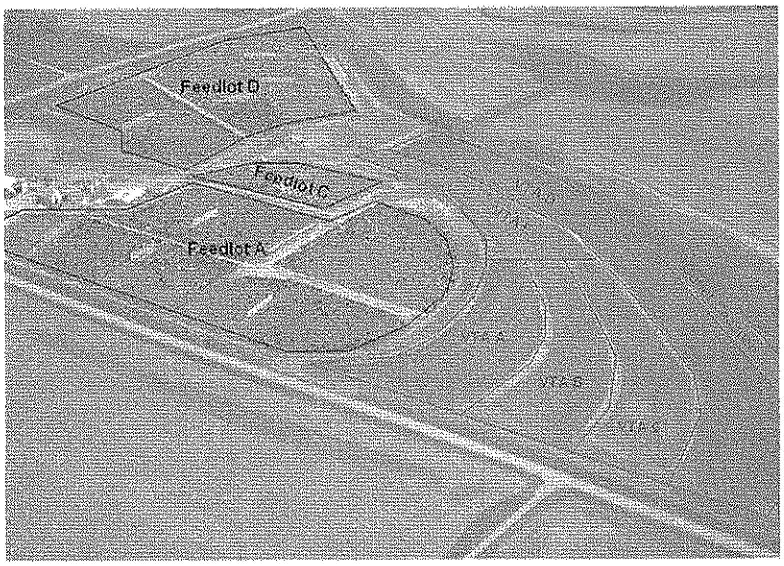

Figure 5. Feedlot and installed runoff control system.

The pilot portion of the site consisted of a 2.91-ha earthen feedlot (Figure 5, Feedlot D) that contained 1,400 head of cattle. Feedlot runoff drained into a 1.2 m deep SSB that held a volume of 3,710 m^3 (SSB D). An earthen berm surrounded the down-gradient portion of the settling basin to retain runoff. The basin floor was partially concrete and partially compacted earth. A concrete wall was built into the down-gradient earthen berm to house the porous dam outlet structure. The dam was constructed of vertical pieces of 3.8 x 8.9 cm lumber spaced 2 cm apart. A 15 cm SSB outlet pipe released water onto a 1.4 m wide concrete level spreader that distributed effluent along the top width of the VTA. A valve was added at the SSB outlet in the spring of 2007. This allowed the producer to control the hydraulic retention time rather than relying on the hydraulic characteristics of the outlet. This was done primarily to control release rate onto the VTA, but also to improve solids retention within the basin. Settled runoff effluent was released onto a 479 m long by 35 m wide VTA. In the spring of 2009 an earthen berm, with emergency spillway, was constructed at the end of the VTA. A valved pipe ran through the berm to allow the producer to manually release VTA effluent if needed. The VTA was initially planted with a mixture of brome and reed canary grass. Over the four years monitoring period, brome took over and became the dominate species.

Monitoring Results

Average runoff ranged from 10 to 18 m^3/100 head-cm precipitation during the four year monitoring period. At this location, feedlot runoff ranged from 50 to 85% of the annual precipitation volumes. These values were higher than those seen at other locations and would seem to suggest that less storage (both depression and infiltration) occurred on the feedlot. Previous research on earthen feedlots has suggested that between 36 and 86% of precipitation can result in runoff, so this site appears to be on the upper end of this range. At this site, the highest percentage conversion of rainfall to feedlot runoff occurred in 2008 as a result of a series of larger rainfall events in early June that left the feedlot with wet antecedent moisture conditions. Releases from the VTA ranged from 0.9 to 2.5

m^3/100 hd-cm of precipitation. The relatively consistent VTS hydraulic transport coefficients resulted from similar annual precipitation volumes and consistent system management.

In general the concentration of most monitored constituents closely followed that of total solids. The statistical analysis of total solids concentrations indicated that both component ($p < 0.0001$) and year ($p = 0.0411$) were significant; however, the year x VTS component interaction was not significant (0.8994). This implies that the VTA treated the effluent and resulted in a significant reduction in solids concentration during all four years. Year was significant due to the large difference in total solids concentration in the settling basin effluent in 2006 in comparison to the other three years. A valve was installed on the settling basin outlet in early 2007; active producer management increased the retention time in the basin, which encouraged good settling. Additionally, the variability in total solids concentrations at the SSB was greatly reduced. This indicates that switching to active basin outlet management and "batch" settling, as opposed to the "flow-through" process used in 2006, improved the consistency of the settling basin performance. Average solids concentrations from the VTA effluent remained consistent with time; however, the larger variability in VTA solids concentrations in 2007, 2008, and 2009 would seem to indicate two types of VTA release events were occurring – events resulting from rainfall runoff from the VTA and events where SSB effluent reached the end of the VTA. For instance in 2007 rainfall runoff events averaged 501 mg/L while SSB release mixed with rainfall averaged 5,857 mg/L. In 2008 and 2009 rainfall averages were 1,436 and 902 mg/L while SSB driven releases averaged 5,872 and 4,724 mg/L respectively. This would seem to imply that by managing his solid settling basin outlet the producer was able to eliminate the release of feedlot runoff in some, but not all, instances. The VTS provided a high level of treatment for the feedlot runoff effluent during all four years. VTA effluent concentrations were consistently significantly lower than at the SSB, including in 2006 when the SSB was passively managed. This provides a strong indication that the VTA was effective in treating the runoff effluent. In general, concentration reductions of 50-70% were seen for most parameters, including solids and nitrogen. Lower reductions (~40%) were seen for phosphorus. Large (> 90%) reductions in fecal coliform concentrations were seen after switching to active basin management.

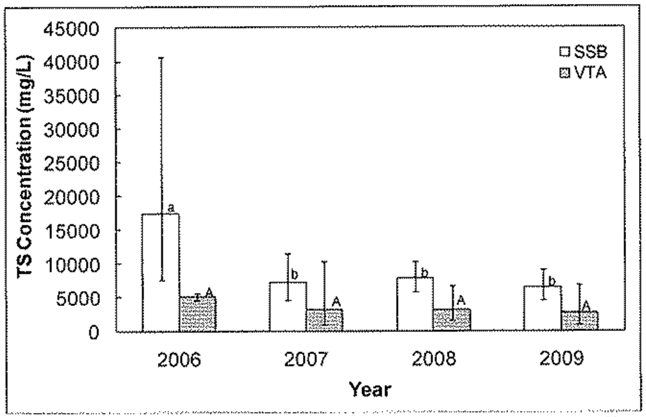

Figure 6. Average annual total solids concentrations for runoff control system components. Lower and upper case letters represent significant differences ($\alpha = 0.05$) between years for solids settling basin and vegetative treatment area effluent concentrations respectively.

Overall, the system failed to meet the zero-discharge standard set by the ISU-ELG model. The system did, however, achieve a high level of treatment averaging 92, 93, 89, 93, and 93% reductions in ammoniacal nitrogen, chemical oxygen demand, total phosphorus, total Kjeldahl nitrogen, and total solids transport. Thus even though this system did not meet the zero-discharge standard, it still achieved a high level of treatment.

Northwest Iowa 2, Inwood, Iowa

Site Basics

Feedlot Size	2.96 hectares (7.31 acres)
Number of Cattle	4,000 head
VTS Configuration	Solid Settling Basin – Vegetative Infiltration Basin – Pumped Vegetative Treatment Area with Effluent Recycle
Solid Settling Basin Capacity	1,120 m^3 (295,000 gallons)
Vegetative Infiltration Basin Area	1.01 hectares (2.50 acres)
Vegetative Treatment Area Size	0.90 hectares (2.22 acres)
Average Annual Precipitation Depth	65.9 cm (26.0 inches)

Site Description

Figure 7. Feedlot and installed runoff control system.

This site utilized a vegetative infiltration basin (VIB) and a vegetative treatment area (VTA) system to control runoff from a 2.96-ha concrete feedlot (Figure 7). A concrete settling basin of 1,120 m^3 capacity collected runoff from the feedlot. The SSB was 1.2 m deep and had a V-notch weir at the outlet. Effluent flowing through the V-notch weir entered a concrete channel and went through an H-flume for measurement. In 2008, a series of stop-blocks were added to the SSB outlet to control effluent release into the VIB. The stop-blocks were constructed from five cm diameter PVC pipe and stacked at the SSB outlet. The stop-blocks were then removed, from the top down, to dewater the SSB. Solids at this site proved difficult to settle, even after the addition of the stop block control. To improve solids removal from the SSB effluent, a biomass filter was constructed in the summer of 2009. The biomass filter was approximately 5 m wide and 3 m long. Corn stover and/or corn cobs were used as biomass material in the filter. The biomass was added to the filter as a loose material, and then compressed to a depth of 0.5 m by adding weight to the top of the material. SSB effluent flowed through this filter prior to release into the VIB. The PVC stop-block control system was used to meter the rate at which effluent was allowed to enter the filter.

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 provided storage for a 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 made it difficult to maintain vegetation. In 2008, a surface inlet with a control valve was added to drain effluent from the VIB during periods of prolonged ponding. Flow from the tile lines and surface drain was collected in a sump and pumped onto the VTA. The 0.60-ha VTA was divided into two, 27 m wide channels. At a given time, effluent was pumped onto only one of the channels. The channel receiving effluent was controlled by valves that were manually switched by the producer. A gated pipe was used to spread flow evenly across the top width of the VTA channel. Effluent reaching the bottom of the VTA channels was captured by a surface inlet and routed back to the VIB through a 15 cm PVC pipe. In 2009 a third 0.30-ha VTA was constructed. Use of the VTA began in the fall of 2009 after vegetation was established.

Monitoring Results

Hydraulic transport from the concrete feedlot remained consistent during the monitoring period ranging from 3 to 5 m^3/100 head-cm precipitation. The percentage of rainfall that was converted to feedlot runoff ranged from 34 to 66% of the annual precipitation, exhibiting similar variability to the earthen lots. In general, the same percentage of precipitation converted to runoff on the concrete lot was similar to that of the earthen lots; this was surprising as previous researchers have suggested higher curve numbers be used to predict runoff from concrete feedlots. VIB hydraulic transport coefficients were lower than the SSB, indicating that SSB effluent was being evaporated and transpired during treatment in the infiltration basin. The VIB showed a large variability in measured hydraulic transport coefficients. Three of the four years (2006, 2008, and 2009) were similar; however, a much lower value was found in 2007. Vegetative treatment area hydraulic transport coefficients broke into two categories, 2006 and 2007 which had very low VTA release volumes and 2008 and 2009 which had higher release volumes. In 2008 and 2009 a surface inlet was used to drain effluent from the VIB more frequently than in previous years. This increased the VIB effluent application rate onto the VTA. Moreover, this site had a steeply sloped VTA which made control of the application rate critical to preventing effluent recycle events. The more aggressive surface drainage of the VIB was performed to promote vegetation growth in the VIB; however, the faster application rate appears to have saturated the VTA and caused frequent recycle events.

Statistical analysis of total solids concentrations indicated that component, year, and the VTS component x year interaction were all significant ($p < 0.0001$, $p = 0.0259$, and $p = 0.0286$ respectively). No clear trend in overall VTS performance was seen; however, general trends in the performance of different components were present. Total solids concentrations at the SSB outlet were very high and extremely variable. Settling basin performance appeared to have been best in 2006; however, this was only a partial year of monitoring and only represented three release events, thus 2007 results better represents baseline settling basin performance at this site. The producer made several modifications to improve solids separation, first (in late spring of 2008) he installed stop-blocks to control effluent retention time in the settling basin and then added a biomass filter (summer of 2009). Both modifications led to improvements in solid separation. Total solids concentrations at the VIB and VTA outlet have remained relatively constant. Much of the concentration reduction achieved at this site occurred within the vegetative infiltration basin. Overall, the system averaged 91, 96, 95, 94, and 95% reduction in mass transport for ammoniacal nitrogen, chemical oxygen demand, total phosphorus, total Kjeldahl nitrogen, and total solids. Overall, no release event occurred from the VTS due to the recycling nature of this system. Thus overall this site/system combination proved to be extremely effective at treating feedlot runoff.

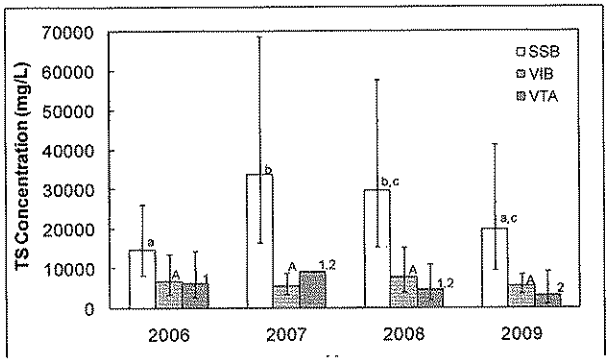

Figure 8. Average annual total solids concentrations for runoff control system components. Lower case letters, upper case letters, and numbers represent significant differences (α = 0.05) between years for solids settling basin, vegetative infiltration basin, and vegetative treatment area effluent concentrations respectively.

Southwest Iowa 1, Vallisca, Iowa

Site Basics

Feedlot Size	7.49 hectares (18.51 acres)
Number of Cattle	2,300 head
VTS Configuration	Solid Settling Basin – Gravity Flow Vegetative Treatment Area
Solid Settling Basin Capacity	11,550 m^3 (3.05 million gallons)
Vegetative Treatment Area Size	4.05 hectares (10.01 acres)
Average Annual Precipitation	92.0 cm (36.2 inches)

Site Description

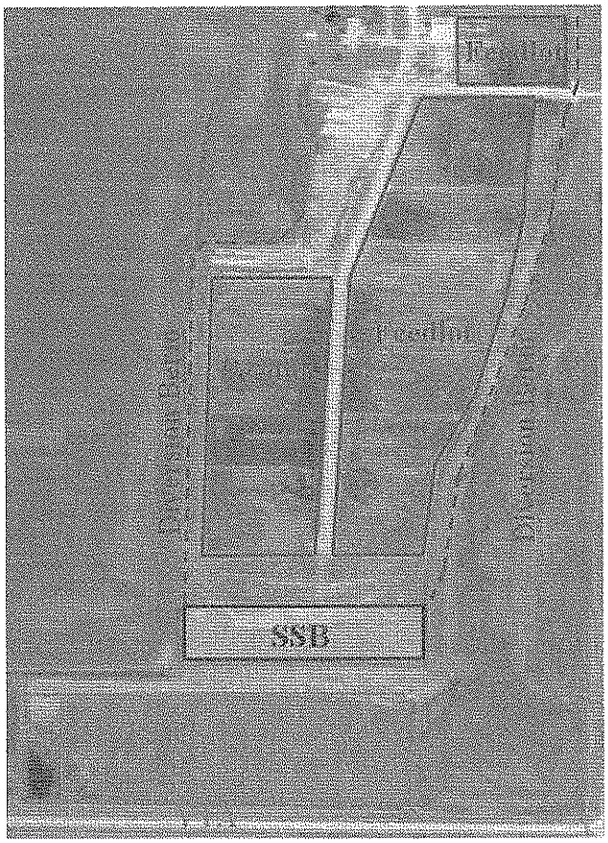

Figure 9. Feedlot and installed runoff control system.

Southwest Iowa 1 was a 7.49-ha earthen feedlot (Figure 9). At this location all the runoff effluent was handled by one VTS. Feedlot runoff at this site drained to channels located on both sides of the feedlot. These channels directed feedlot runoff into the solid settling basin and allowed sedimentation of course solids prior to reaching 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 located 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 VTA channel via gravity flow. The outlet from this VTA was located 0.6 m above the bottom of the westernmost channel. This provided storage of effluent in the VTA before a release would occur. Tile lines surrounded each of the VTAs and were installed to control the water table depth below the system and to enhance the infiltration of effluent into the soil. These were located 1 m below the soil surface, 15 cm (6") in diameter, and ran along the edges of the VTAs to a main running along the bottom of the VTAs. A tile line access point was installed in early 2008 at the southwest edge of the VTS so that the amount and quality of flow in the tile lines could be monitored. At this site both overland releases and releases in the tile line drainage system were monitored and are reported.

Monitoring Results

At SW IA 1 hydraulic transport coefficients for the feedlot were very consistent over the three years of monitoring ranging from 11 to 13 m^3/100 head-cm precipitation. This corresponded to between 34 and 45% of all precipitation being converted into feedlot runoff/SSB release. At this location the VTA had two means of hydraulic transport, surface overland flow and tile flow (monitoring of tile flow began in 2008). When the VTA was constructed, tiles were installed around each of the ten VTA channels. The sum of the VTA tile and VTA overland outflows for 2008 and 2009 was 7.2 m^3/100 head-cm precipitation both years.

Statistical analysis of total solids concentrations indicated that both year ($p = 0.0027$) and VTS component ($p < 0.0001$) were significant; the VTS component x year interaction ($p = 0.2249$) was not. This indicated that although significant differences in total solids concentrations occurred from year-to-year the VTA consistently reduced TS concentrations in all years. Sampling in 2007 only represented one month of data in which only two SSB and one VTA release event occurred. Monitoring of the VTA tile-lines began in 2008.

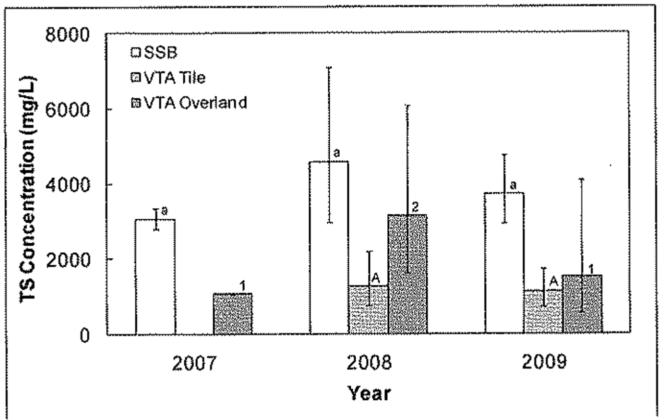

Figure 10. Average annual total solids concentrations for runoff control system components. Lower and upper case letters represent significant differences ($\alpha = 0.05$) between years for solids settling basin and vegetative treatment area effluent concentrations respectively.

This system was the last to be constructed and very few modifications were made after operation began. The system was constructed with a control valve on the settling basin outlet; good settling was achieved in all three years of monitoring and no differences in SSB effluent TS concentrations were seen. Although not significantly different, average SSB total solids concentration and variability was highest in 2008. Three SSB release events were caused by breaches in the SSB sidewalls; these releases had high suspended and dissolved solids concentrations in comparison to the other events and resulted in the increased average concentrations as well as the increase in concentration variability. The 2007 VTA release event was the result of VTA rainfall runoff; therefore, the resulting TS concentration was low. Only half of the VTAs had vegetation established going into the 2008 monitoring year. This may have contributed to lower nutrient removal efficiencies than seen in 2009. Much of the poor performance at this site was due to inadequate system management which resulted in high SSB stage and a need to dewater the basin in wet weather situations; improvements in systems performance occurred as the producer learned to better manage the system.

In general, this system was able to achieve moderate levels of treatment averaging 69, 55, 58, 61, and 55% reductions in transport of ammoniacal nitrogen, chemical oxygen demand, total phosphorus, total Kjeldahl nitrogen, and total solids. These results were slightly lower than those a containment basin runoff control system would have achieved under similar weather conditions; however, improvements in system management and operation could have significantly improved performance.

Southwest Iowa 2, Red Oak, Iowa

Site Basics

Feedlot Size	3.08 hectares (7.61 acres)
Number of Cattle	1,200 head
VTS Configuration	Solid Settling Basin – Gravity Flow Vegetative Treatment Area
Solid Settling Basin Capacity	6,275 m^3 (1.66 million gallons)
Vegetative Treatment Area Size	3.50 hectares (8.65 acres)
Average Annual Precipitation	92.0 cm (36.2 inches)

Site Description

Figure 11. Feedlot and installed runoff control system.

Southwest Iowa 2 had a 3.08-ha earthen feedlot (Figure 11, Feedlot C). Originally this site utilized a settling bench and vegetative treatment system to treat feedlot runoff; the settling bench was replaced with a settling basin in the summer of 2007 (SSB C). The outlet of the settling basin was a perforated PVC pipe surrounded by a porous dam. The pipe ran from the settling basin to a gated pipe located at the top of the VTA (VTA C). A gate valve was installed in the PVC pipe to provide the producer with control over 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 1.1:1. This VTA was constructed with small ridges perpendicular to 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.

Monitoring Results

The hydraulic transport coefficient from the feedlot ranged from 11 to 20 m^3/100 head-cm precipitation. This amounts to between 37 and 64% of the annual precipitation being converted to runoff. Interestingly, average total solids concentrations followed the same trend as the hydraulic transport coefficient, peaking in 2008 before decrease significantly in 2009. Investigation of the rainfall pattern at this location reveals that both 2007 and 2008 experienced several heavy rainfall events, which resulted in increased solids transport from the settling basin.

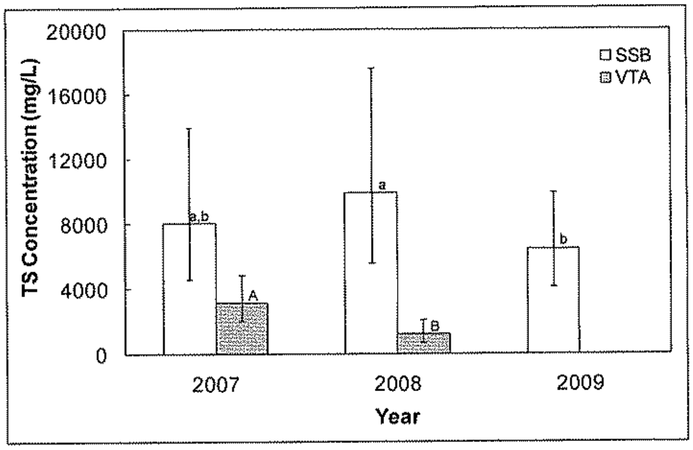

Figure 12. Average annual total solids concentrations for runoff control system components. Lower and upper case letters represent significant differences (α = 0.05) between years for solids settling basin and vegetative treatment area effluent concentrations respectively.

Statistical analysis of Southwest Iowa 2 effluent total solids concentrations suggested that VTS component ($p < 0.0001$), year ($p = 0.0286$), and the VTS component x year interaction ($p = 0.0017$) were all significant. In this case, the significant interaction indicated that VTA effluent quality improved while SSB effluent solids content remained constant. The results showed that in all years the effluent solids concentration was significantly reduced during treatment in the VTA. The average concentrations of solids in the SSB effluent increased from 2007 to 2008. The producer was not able to get the basin cleaned out between 2007 and 2008; this reduced the capacity of the settling basin and appeared to have provided a source of TS to the SSB effluent. These solids were mostly in the dissolved form, as TSS concentrations actually decreased slightly between 2007 and 2008. Cleaning solids from the basin resulted in reduced TS, TDS, and TSS concentrations in 2009. VTA release events in 2008 were caused by large rainfall events during the spring and early summer; the reduction in concentration indicated that 2008 releases were mostly a result of rainfall runoff. In 2007, this was not always the case; during the first half of the year, the settling basin outlet was passively managed. Feedlot runoff was applied during and immediately after rainfall events increasing the risk of a VTA feedlot runoff release.

As expected most parameters in the VTA effluent followed similar trends to TS; however, there were two exceptions, NO_3-N and ortho-phosphorus, both of which showed no significant decrease in concentration between the two years. The fact that ortho-phosphorus concentrations in the VTA effluent didn't decrease may indicate that the soil was nearly saturated with phosphorus, limiting the phosphorus sink potential of the VTA and allowing the soil to serve as a phosphorus source to any rainfall runoff. This site had high background soil phosphorus concentrations, i.e., before system use, which could shorten the VTA phosphorus life. Although average NO_3-N concentrations were similar, a much larger variability in sample concentration was seen in 2008. This may indicate that the high nitrogen application rate was leading to high nitrate concentrations in the upper portion of the soil profile. The increased variability would indicate that this was a very dynamic process and that the increased nitrate wasn't always present, possibly due to denitrification, vegetative uptake, or leaching.

In general, this system was able to achieve high levels of treatment averaging 94, 94, 91, 94, and 95% reductions in transport of ammoniacal nitrogen, chemical oxygen demand, total phosphorus, total Kjeldahl nitrogen, and total solids. These results are similar to those a containment basin runoff control system would have achieved under similar weather conditions.

Nebraska 1, Rockville, Nebraska

Site Basics

Feedlot Size	4.78 hectares (11.8 acres)
Number of Cattle	1,200 head
VTS Configuration	Solid Settling Basin – Pumped-Sloped Vegetative Treatment Area
Solid Settling Basin Capacity	4,367 m^3 (1.15 million gallons)
Vegetative Treatment Area Size	4.45 hectares (11 acres)
Average Annual Precipitation	66.4 cm (26.2 inches)

Site Description

This site consisted of 1,200 head of cattle on 11.8 acres of feedlot. Runoff was directed into four settling basins sized to hold 100% the runoff from a 25 year 24 hour storm (a 4.6" rain event or 3.6" of runoff) plus annual solids accumulations and freeboard (varied by basin, 0.6-1 ft). This storage allows the producer to delay distribution onto the VTA for 1-2 days, allowing the VTA soil profile time to dry after the rainfall event. The three upper basins drain through pipes to the far west (or lowest in elevation) basin, where effluent drained to a sump. It was then pumped by a 7.5 hp vertical turbine pump onto one of eight VTA distribution areas through underground pipe. Flow to the VTA was controlled via a pump timer and surge valves. Traditionally surge valves are used to increase distribution uniformity in irrigation of high intake family soils, however, in this VTS, it was used as a time management tool. The surge valve allowed for application to two distribution areas without producer intervention. That is runoff was applied to two distribution areas with one setting of the timer, greatly reducing the time needed by the producer to manage the VTA. The design application time was two hours. Each VTA distribution area was 244 meters by 20 meters for a total of 4.5 hectares, and land leveled to a 1% slope. Any runoff from the distribution areas was collected at a small bermed area (end-blocked) at the end of each distribution area (VTA). There were short pipes with valves in the berms to allow VTA runoff conveyance between the distribution areas and recycle pipeline which transported excess effluent back to the pump station.

The VTA was comprised of a Hord Silt Loam soil and defined as an irrigation design group 6, 1.0 in/hr by the NE NRCS irrigation handbook. However, the actual intake family was a design group 6 or 0.9 in/hr. The available water holding capacity defined by the soil survey was 12.2 in at an expected rooting depth of 5 feet. The VTA was planted to Meadow Brome, Tall Fescue, Orchard Grass, Smooth Brome, Intermediate Wheat, and Pubescent Wheat. The distribution areas had small gullies form just after construction due to some heavy rains, which were filled in during the fall of 2008 and spring 2010. With this maintenance, distribution improved these distribution areas.

Monitoring Results

Two ISCO 6712 samplers were used to monitor the VTS; one monitored pump on/off time and verified flow with an in-line flow meter, the other used an area-velocity sensor to measure return-flow (leaving VTA). Issues were experienced in 2008 with the return line and VTS establishment; however changes made to the monitoring system allowed for good quality data to be collected for 2009 and 2010. Samplers were generally deployed in March and removed in late October. Researchers were generally present during data collection, typically one to three days after a runoff event and operated the VTS system. When rain fell onto this VTA, nutrients and sediments were carried off the surface whether there was feedlot runoff recently applied or not. The ability of this system to hold feedlot runoff off the VTA during a storm event allowed the researchers to observe the nutrient contribution of the VTA surface: the "background" nutrient concentration. During fourteen large rainfall events, water ran off of the VTA when no SSB water had been pumped onto the VTA for at least two days, indicating that nutrients will still be lost from the VTA during intense rainfall events. The nutrient concentrations of runoff as a result of direct precipitation were less compared to when runoff was distributed to the VTA from the feedlot. Concentrations (in 2009) were 79% less for NH_4-N, 59% less for Total N, and 42% less for P compared to feedlot runoff concentrations. Additionally, they made up only 12% of NH_4-N, 9% of Total N, and 7% total P of the total mass of nutrients re-applied to the VTA. These values suggest that runoff from the VTA without application is a small percentage of the total nutrient mass leaving the system, but that VTA surface losses from previous applications continue to contribute to nutrient loading.

During 2008, much higher volumes of lot runoff were experienced than anticipated. During the first spring, feedlot runoff from the SSB was diverted from onto an adjacent alfalfa field to allow the grass time to establish. During the summer and fall of 2008, water infiltrated on the VTA more slowly than anticipated, causing liquid to reach the end of the VTA in as little as 15 minutes (design = 2 hrs). During 2009, with an established grass stand and higher infiltration rates, the VTS was operated such that different amounts of runoff from the VTA were recorded, from zero up to 100 m^3, allowing different management scenarios to be tested. Applications up to 40 min at 390 gpm resulted in no runoff. In 2009, researchers often "forced" varying amounts of runoff in order to obtain nutrient and mass reduction data. For 2009, an average 94% reduction in water volume was achieved. (Note that this system recycled the water back to the pumping station, therefore runoff from the VTA was not actually released from the system, i.e., 100% containment). Averaged over the year, the mass of nutrients were reduced 94% for Total Nitrogen and 94% for Phosphorous. June 2010 was a chronic wet period, with 60% of the monitored rainfall events occurring within a month. Pumping 38% of the runoff onto an adjacent field allowed the system to contain all of the flows during this period (100% containment).

Nebraska invested heavily in using Electro-Magnetic Induction (EMI) surveys to characterize the nutrient distribution across the VTA. An EMI survey is apparent conductivity of the soil, inferring where salts (runoff water) accumulate (specific salts are not distinguished) in the VTA. Differencing this conductivity with time provides information on the spatial distribution of the salts (feedlot runoff) accumulating in the soil. There were only small conductivity differences; demonstrating that runoff was evenly distributed across the VTA and that the plant uptake matched what was applied. The blue-green areas on the right (near the distribution pipes) did receive feedlot runoff and were dense with vegetation, and showed a negative conductivity due to either plant uptake and removal (most likely) or possibly deep percolation.

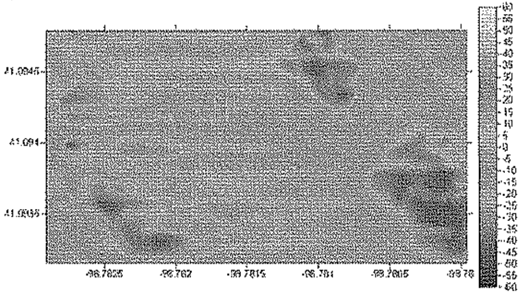

Figure 13. EMI conductivity difference map between 2007 and 2010. Flow across VTA is from right to left. Scale to right is in ±60 mS/m.

In general, the results suggest that the primary method of nutrient reduction is infiltration rather than the filtering effect of the vegetation. From a design perspective this finding puts importance on the need to ensure that liquid is captured by the soil rather than relying on residence times within the VTA for treatment.

Nebraska 2, Albion, Nebraska

Site Basics

Feedlot Size	4.78 hectares (11.8 acres)
Number of Cattle	1,700 head
VTS Configuration	Settling Bench – Sloped Vegetative Treatment Area
Settling Bench Length	15.2 m (50 ft)
Vegetative Treatment Area Size	3.82 hectares (9.45 acres)
Average Annual Precipitation	68.8 cm (27.1 inches)

Site Description

This site consists of a 5,000 head feedlot with several VTS systems. The VTS system chosen for monitoring consisted of 4.78 hectares of open lots housing 1,700 head of cattle. Lots were located on both sides of the rectangular VTA (along the length). Runoff from the feedlots flowed in from either side across a 15.2-meter wide settling bench down gradient of the pens. The VTA was comprised of a 3.82 hectares moderately sloping (west edge is 1.1% to the east, center is 0.18% to the south, east edge is 2.6% to the west) rectangular VTA with contributing feedlot pens bordering it on the east and west. Any runoff not infiltrated or treated by the VTA discharged through a single pipe outlet on the south end (all runoff eventually drained to this pipe). The soil types were Valentine-Dunday Loam fine sands, Thurman Loamy fine sand, and Valentine fine sand. The VTA was planted to smooth brome grass.

The settling bench was constructed to be level; however, the research noted some uneven distribution across the bench, especially on the east pens and on the south-west corner. This unevenness of the east pens led to overloading of the bench in the SW corner and the middle-east side, resulting in an uneven distribution of nutrients and runoff water entering the VTA at these points, which is evidenced by the EMI maps. Short circuiting also occurred from a large gully on the south end where feedlot water channelized and reached the VTA outlet with little opportunity to infiltrate, contributing significantly to the runoff leaving the VTS. The settling bench was cleaned one to two times per year, however, solids buildup on the bench still caused water to pond in the feedlot pens, often creating undesirable lot conditions.

Monitoring Results

Inflow to the VTA was sheet flow. A below ground sump pump with an event logger and an ISCO 6700 with a depth sensor were used to measure inflow to the VTA. Effluent entered the sump through a one foot wide flat steel intake. The runtime of the pump was then monitored to estimate release volume. Outflow from the VTA was monitored by an ISCO 6712 and area-velocity flow sensor. The site was monitored just after construction in 2008 through 2010. VTA inflow monitoring was unsuccessful during the study as sediment movement in the bench either prevented water from entering the sump, or overcame the sump with concentrated flow that gave incorrect volumes. Often solids collected during the runoff event would preclude liquid from entering the narrow sump inlet and thus neither concentration data nor flow data was collected.

During 2008 large amounts of VTA runoff were recorded due to several high intensity storm events and the lack of an established grass stand. Improved grass stand in 2009 significantly decreased the VTA release volume. The site was only monitored for the first six months of 2010, during which the site received more rainfall than the all of 2009, with over 70% of the precipitation for that time period falling during a one month period.

Based on the amount of nutrients in the runoff, and assuming a large percentage of the inflow was infiltrated into the VTA, it is clear that significantly more nutrients were entering the VTA, than were harvested in the grass. It is likely that the bench may not be providing enough solids settling to achieve the desired nutrient release reduction, particularly during large storm events. However, for small storm events, of less than approximately 0.5 inch, as a general rule, discharges did not occur.

During 2010, four inflow grab samples were collected from the bench. Nutrient concentrations were then compared to the outflow, showing 66% to 79% decreases in all analyzed components (Table 1). This is likely the best measure of performance for this system during the very high rainfall period in early 2010. Unlike the other NE VTA site, the concentration reductions are very substantial, suggesting that in the absence of a basin, large concentration reductions are performed in the VTA. However, without mass flow data, we are not able to say this with certainty.

Table 1. 2010 Average Inflow and Outflow Concentration Results for non-basin sloped VTS

	NH_4-N (mg N/L)	Total N (mg/L)	Total P (mg/L)	Electrical Conductivity (mmho/cm)	COD (mg/L)	Total Solids (mg/L)
Inflow (n=4)	181.9	434.8	174.3	2.81	4763	9688
Outflow (n=9)	61.2	134.6	54.9	1.07	1003	2369
% reduction	66%	69%	69%	62%	79%	76%

None of the rainfall during the monitoring period approached the level of the 25-yr, 24-hour storm, yet the system had several discharges. In 2008, vegetation was developing and many of the events would have occurred when almost no vegetation cover was present. In 2009, vegetation was better established and almost no discharges occurred, during what would be considered a "normal" year. During 2010, again none of the events exceeded the 25-yr storm; however, the amount of rainfall in June combined with few drying days between events, made for a chronic wet period, leading to over 98% of the runoff occurring in that one-month period. Simply characterized, 2008 a very wet year with nearly no vegetation established, resulted in large volumes of runoff and nutrients discharged, in 2009 a "normal" year resulted in fewer discharges from the system (6% of 2008), and 2010 was like 2009 until June, when a chronic wet period produced large discharge volumes.

Electro-Magnetic Induction (EMI) surveys were used to characterize the nutrient distribution across the VTA. An EMI survey is apparent conductivity of the soil, inferring where salts (runoff water) accumulated (specific salts are not distinguished) in the VTA. Differencing this conductivity with time provides information on the spatial distribution of the salts (feedlot runoff) accumulating in the soil. Surveys were performed in November 2007 and June 2010 and used to evaluate the distribution of feedlot runoff across the VTA. An uneven distribution of runoff across the east side of the VTA is clearly visible in Figure 14; runoff (and nutrients) from the feedlot collected and pooled in this area of the VTA. On the other (west) side there were three locations where runoff flow was more concentrated, but to a lesser extent than the eastern edge.

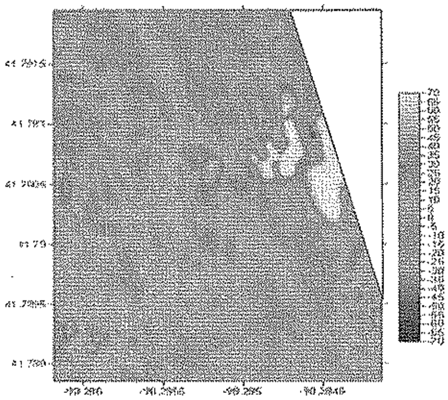

Figure 14. VTA EMI difference map between 2010 and 2007. Outlet at bottom center, inlet to VTA from lots, right and left side. Scale to right is in ±70 mS/m.

Overall, the results indicate that grass stands require several years to achieve designed yields for nutrient removal and are critical to VTS performance. The solids settling bench did not appear to provide adequate settling to achieve the desired nutrient concentration reduction, particularly during large storm events. Additionally, the bench did not evenly distribute runoff on lots that were not land leveled at the time of bench construction. When constructed properly runoff appeared to spread out more evenly, even if concentrated flow still existed next to the bench. Although the non-basin sloped VTS discharged during several storm events during the sampling period, it generally only discharged during the largest storm events and chronic wet periods.

Western Minnesota 1, Morris, Minnesota

Site Basics

Feedlot Size	3.52 hectares (8.71 acres)
Number of Cattle	2,250 head
VTS Configuration	Solid Settling Basin – Gravity Flow Vegetative Treatment Area
Solid Settling Basin Capacity	2,418 m^3 (0.69 million gallons)
Vegetative Treatment Area Size	3.52 hectares (8.71 acres)
Average Annual Precipitation	64.5 cm (25.4 inches)

Site Description

The research VTS consisted of a 3.58 hectares of earthen feedlot permitted for 2,250 head of beef cattle. Runoff from the feedlot's seven pens drained into three concrete settling basins located on the east side of the pens (Figure 15). The settling basins were designed to hold all runoff from the 25-year, 24-hour storm. The release structure at each basin consisted of a boarded gate operated manually by the producer. The boarded gate was used to release effluent into an H-flume where an automated sampler was used to collect samples and record flow leaving the basin. Effluent from the H-flume entered concrete spreaders extending the entire length of each basin. The spreaders evenly applied effluent across the top of a 3.52 hectare VTA. The bottom portion of the VTA was constructed and seeded in the fall of 2005 with the rest seeded in 2006.

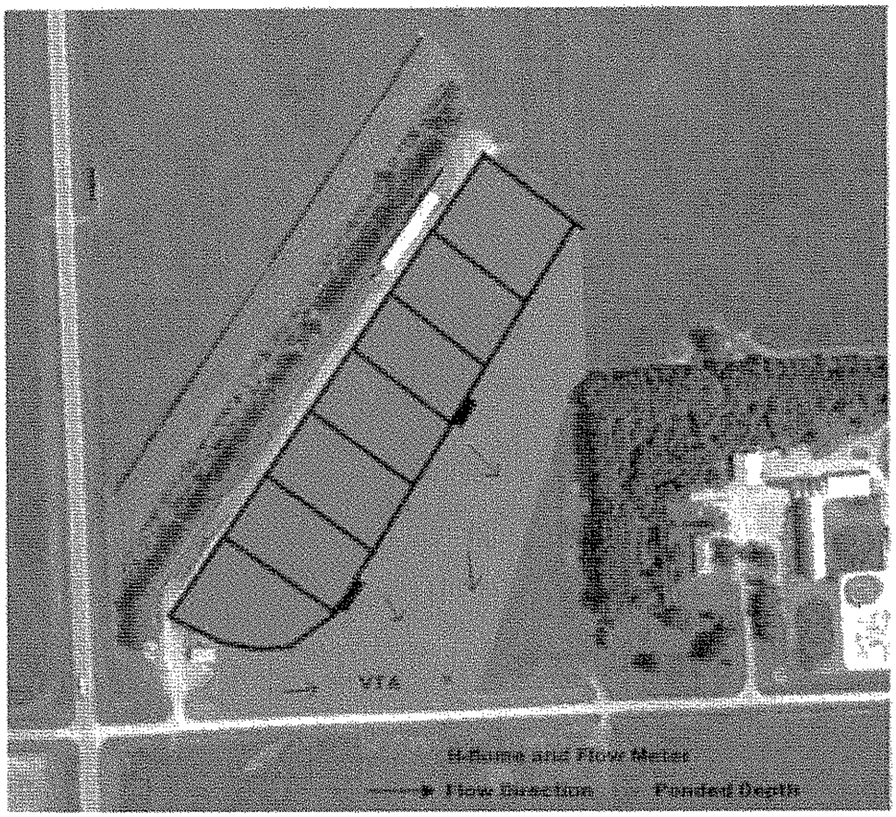

Figure 15. Feedlot and installed runoff control system.

The vegetation consisted of Kentucky bluegrass, perennial rye, and fine fescue. The end of the VTA consists of an earthen berm with a depth measurement instrument at the lowest point. In a ponding event at the end of the VTA, the depth of water can be measured and a volume of water can be calculated simulating a release. The VTA area was 3.52 hectares (8.71 acres).

Monitoring Results

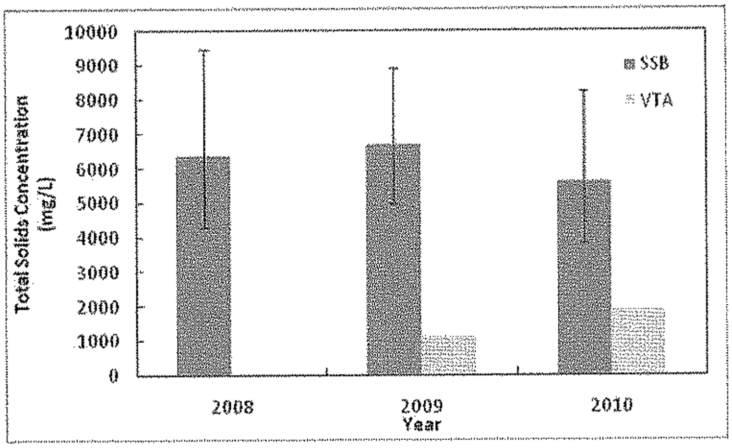

Figure 16. Average annual total solids concentrations for runoff control system components. Error bars represent one standard deviation about the average and are shown for sampling periods where multiple samples were available.

Site monitoring began in 2008 and continued through 2010. Average total solids concentrations for the solid settling basin and vegetative treatment area effluent is shown in Figure 16. Concentrations for the solid settling basin remained consistent over the three years of monitoring, as did the variability of the effluent quality (error bars represent +/- one standard deviation about the mean). This indicates that the producer was relatively constant in his management of the system. Only two VTA ponding events were reported; both occurred in the early spring as a result of snowmelt. Effluent concentrations were similar between the two events. Overall, solid settling basin concentrations averaged 121, 304, 75, 6311, and 6219 mg/L for NH_3-N, TKN, Total P, Chemical Oxygen Demand, and Total Solids concentrations. Concentrations for the VTA averaged 98, 173, 17, 3174, and 1510 mg/L for NH_3-N, TKN, Total P, Chemical Oxygen Demand, and Total Solids concentrations. Thus, this VTA achieved concentration reductions ranging from 19% for NH_3-N to 78% for Total P.

As discussed in the system description, this site utilized three settling basins to control runoff. The volume of effluent released from each of the settling basins was approximately equal, indicating that effluent was being equally split onto the VTA. Effluent concentrations at the second solid settling basin were higher (in general) than at the other two settling basins. This resulted in between 40-45% of the mass applied to the VTA coming from this settling basin.

Overall, this system proved very successful having no release from the vegetative treatment area. Over the three year monitoring period this site averaged 3.7 m^3 of effluent released from the settling basin per 100 head of cattle per cm of precipitation. Treatment in the VTA (counting ponding at the edge of the VTA as a release) was able to infiltrate over 81% of all the rainfall and feedlot runoff applied to the VTA. Moreover, treatment resulted in mass transport reductions (based on what ponded at the end of the VTA) of 37, 75, 46, and 72% for total Kjeldahl nitrogen, total phosphorus, chemical oxygen demand, and total solids On the other hand, a 17% increase in NH_3-N transport occurred despite reductions in NH_3-N concentration. With the incorporation of a berm at the end of the vegetative treatment area this site was able to eliminate releases from the runoff control system.

South Dakota 1, Brandon, South Dakota

Site Basics

Feedlot Size	5.91 hectares (14.6 acres)
Number of Cattle	2,000 head
VTS Configuration	Solid Settling Basin – Gravity Flow Vegetative Treatment Area
Solid Settling Basin Capacity	8,800 m^3 (2.33 million gallons)
Vegetative Treatment Area Size	5.34 hectares (13.2 acres)
Average Annual Precipitation	62.7 cm (24.7 inches)

Site Description

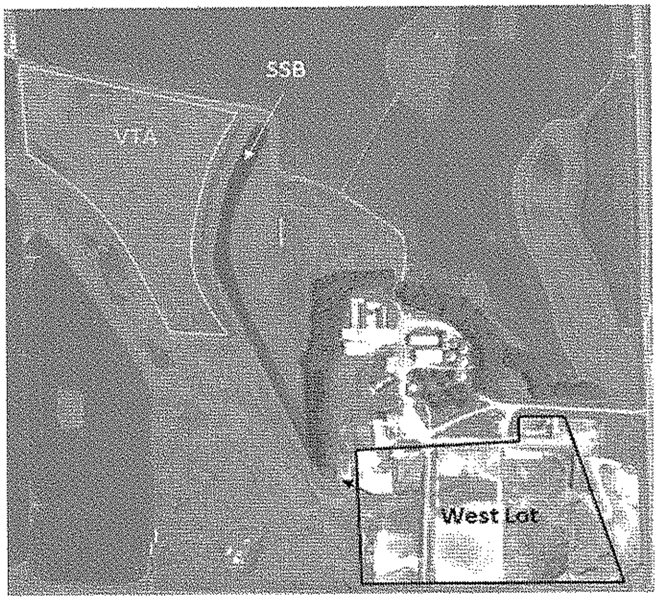

Figure 17. Feedlot and vegetative treatment system. The grid pattern evident in the VTA shows the berms surrounding each VTA cell.

This site consisted of an earthen lot designed and permitted for 2,000 head of cattle. This location utilized two VTs systems, east and west. The east system was monitored minimally to assure compliance with the permit and assist with management; east system data are not included in this report. The west system was monitored and fully supported by the CIG grant. The basic layout of the systems consists of a series of settling basins located on a sloped feedlot. The outlet of these basins consists of slotted gates (picket gates) made out of a 2"x 4" construction designed to retard the effluent flow leaving each basin. The effluent then empties into an earthen channel allowing for additional solid settling. This channel transports effluent to a basin structure located prior to the VTA. The slope of the channel is designed at a 0.5 % grade to allow more solids settling before entering the VTA. The channel and settling basin are operated as a single, continuous unit. When the basin is full, water will back up into the channel. Within this basin there are seven controlled outlet structures (pipes with concrete caps) that convey effluent into seven different VTA cells, which are separated longitudinally with berms. The effluent was spread across the top of the VTA with the use of gated pipe. The flow was measured in each outlet with a turbine flow meter. Samples were collected manually at the outlets of the gated pipe. Operational difficulties dictated the removal of an automated sampler that was used during the first few weeks of site monitoring. Earthen spreaders are located at 200 feet increments down the length of the VTA. The VTA vegetation was tall and intermediate wheat grass and smooth brome. Vegetation was established in 2009. The feedlot owners actively managed the settling basin outlets to uniformly distribute the water among the cells and retain the water as long as possible. Retention times (in the basin) were limited by (1) the 72-hour regulatory limit on water retention in the unlined basin and (2) the perceived probability of additional rainfall that might cause problematic increases in the basin-stored water volume.

Monitoring Results

This site was monitored for a partial year in 2010 so in comparison to the other sites data is somewhat limited. During this time five releases from the solid settling basin and one vegetative treatment ponding event occurred. Overall, solid settling basin concentrations averaged 45, 102, 31, 1923, 1734 mg/L of NH3-N, total Kjeldahl nitrogen, total phosphorus, chemical oxygen demand, and total solids. These release events basically broke into two groups, the April and May events had higher concentrations while the June release concentrations were substantially lower. Concentrations in the VTA ponding event, which occurred in April, where very low at 4, 17, 2, 224, and 310 mg/L of NH3-N, total Kjeldahl nitrogen, total phosphorus, chemical oxygen demand, and total solids. Overall this means the system achieved between 80 and 95% reductions in effluent concentrations.

At this site the feedlot averaged 26 m^3/100 head of cattle and cm of precipitation. This site infiltrated almost 98% of all applied rainfall and effluent. In addition, over 99% reductions in nutrient transport occurred for NH3-N, total Kjeldahl nitrogen, total phosphorus, chemical oxygen demand, and total solids. The berm at the end of the VTA was capable of handling and retaining the volumes of effluent transported through the VTA. Thus preliminary analysis has shown that this site has the capability to operate successfully.

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Andersen, D.S., R. Burns, L. Moody, I. Khanijo, C. Pederson, M. Helmers, and J. Lawrence. 2009. Performance of six vegetative treatment systems for controlling runoff from open beef feedlots in Iowa. Proceedings of the 2009 ASABE International Meeting. Paper Number: 097054

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Bond, B.J., R.T. Burns, T.P. Trooien, S.H. Pohl, C. Henry, L.B. Moody, M.J. Helmers, and J. Lawrence. 2011. Comparison of construction costs for vegetated treatment systems in the Midwestern United States. Applied Engineering in Agriculture (In Press).

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