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The Use of the Soil-Plant-Air-Water Model to Predict the Hydraulic Performance of Vegetative Treatment Areas for Controlling Open Feedlot Runoff

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Abstract

Several Iowa beef feedlots have interim, National Pollution Discharge Elimination System (NPDES) permits for vegetative treatment systems (VTS) to control and treat feedlot runoff. In Iowa, performance of these systems is predicted for permitting purposes using either the Iowa State University-Vegetated Treatment Area (ISU-VTA) Model or the Iowa State University -Vegetated Infiltration Basin/Vegetated Treatment Area (ISU-VIB/VTA) Model. For an Iowa NPDES permit, these systems must be shown through modeling to have equal or better performance than a conventional runoff containment basin on the basis of median nutrient mass released over 25 years. Modeling is also a useful design tool for both Concentrated Animal Feeding Operations (CAFOs) and non-CAFO sized operations wishing to utilize VTS systems. Field-scale VTS performance monitoring conducted over the past two years by ISU has shown that the current ISU models do not accurately predict actual hydraulic performance at the monitored VTSs. The ISU models are being revised to improve their performance. Along with improving the ISU-VTS model performance, other modeling alternatives are being investigated. The Soil-Plant-Air-Water (SPAW) model is one possible alternative for modeling the hydraulic performance of a VTA. For this paper, the SPAW predicted performance was compared to monitoring results at four VTAs located in Iowa. Two different methods were used to model the VTA performance, the first method utilized the field module of SPAW; this method was found to have Nash-Sutcliffe modeling efficiencies ranging from 0.16 to 0.57. At all locations, the SPAW model underestimated the amount of release that occurred from the VTAs. The second modeling method utilized the pond module of SPAW, for this method the Nash-Sutcliffe modeling efficiencies ranged from 0.26 to 0.83. Again, the SPAW model underestimated the cumulative volume of effluent released from the VTAs.

Keywords

runoff control, SPAW, vegetative treatment system, feedlots, vegetative treatment area

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Comments

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Keywords. runoff control, SPAW, vegetative treatment system, feedlots, vegetative treatment area

Introduction

Pollution associated with runoff from open beef cattle feedlots has been a concern for many years. The passage of the Federal Water Pollution Control Act Amendments in 1972 placed the Environmental Protection Agency (EPA) in charge of developing runoff control guidelines (Anschutz, 1979). As a result, the EPA released the Effluent Limitation Guidelines, which described the design and operating criteria of the waste treatment system for concentrated animal feeding operations (CAFO's) (Sweeten, 2003). These effluent limitation guidelines historically required collection, storage, and land application of the feedlot runoff; however, recent modifications allow the use of an alternative treatment system whose performance is equivalent to, or exceeds, that of a traditional containment system (Federal Register, 2003). As part of permitting alternative treatment technologies, a comparison of the median annual release volume over a 25-year period between a traditional containment system and the proposed alternative treatment system is required.

Vegetative treatment systems (VTS) are one possible alternative treatment technology that has been proposed. A VTS is a combination of treatment components, of which at least one component utilizes a form of vegetative treatment to manage runoff from open lots (Moody, 2006). Vegetative treatment areas (VTAs) and vegetative infiltration basins (VIBs) are two proposed vegetative treatment components for VTSs. A VTA is an area that is level in one dimension and has a slight slope along the other, planted and managed to maintain a dense stand of vegetation (Moody, 2006). Operation of a gravity flow VTA consists of applying feedlot effluent evenly across the top of the vegetated area and allowing the effluent to flow down the length of the treatment area (Moody, 2006). Gross and Henry proposed a modification to VTAs, called a "sprinkler VTA," which uses a sprinkler system to apply the effluent more evenly over the VTA (Gross, 2007). Ikenbery and Mankin identified several methods in which effluent was treated by VTAs, these included settling solids, infiltrating runoff, and filtering the effluent as it flowed through the vegetated area (Ikenberry, 2000). A VIB is a flat area surrounded by berms and planted to permanent vegetation (Moody, 2006). These areas have drainage tiles located approximately 1.2 meters (4 feet) below the soil surface to encourage infiltration of effluent through the soil profile. The tile lines collect the infiltrating effluent, which then receives secondary treatment, often from a VTA. Pollutant removal in the VIB relies on filtration of the effluent as it flows through the soil, uptake of nutrients by plants, and pollution degradation (Moody, 2006).

Currently, Iowa State University is monitoring the performance of six vegetative treatments systems located around the state of Iowa. At four of these locations, a complete year of monitoring data was collected in 2007. At these sites, the vegetative treatment system is divided into both pilot and non-pilot systems. The pilot systems are monitored by Iowa State University and will be the focus of this modeling study. Moody et. al. provide a description of the monitoring techniques Iowa State is using to determine system performance at these locations (Moody, 2006), The data being collected includes daily temperature and precipitation values, as well as the volume of effluent and mass of nutrients exiting each component of the treatment system. Table 1 shows the size of the feedlots and the vegetative treatment area of the pilot system at each of the four locations. In addition, the configuration of the VTS system is specified.

Table 1. Description of the four pilot systems monitored by ISU during 2007. Displayed in the table are the site name, the system configuration (solid settling basin (SSB), vegetative treatment area (VTA), and vegetative infiltration basin (VIB)) and the areas of the feedlot and the VTA.

Site Name	System Configuration	Feedlot Area (ha)	VTA Size (ha)
Central IA 1	1 SSB - 2 VTA	1.07	1.53
Central IA 2	1 SSB - 1 VIB - 1 VTA	3.08	0.24
Northwest IA 1	1 SSB - 1 VTA	2.92	1.68
Northwest IA 2	1 SSB - 1 VIB - 1 VTA	2.95	0.60

On these sites there are two different VTS configurations, a solid settling basin (SSB) followed by a stand-alone VTA, or a SSB followed by a VIB which is then followed by a VTA. Schematics of both types of systems are shown in Figure 1. The first system displayed is a stand-alone VTA system; in this system, runoff is generated from the beef feedlot and contained in a solid settling basin designed to provide sufficient detention time to settle solids from the effluent. The effluent from the solid settling basin is then released onto the VTA as permitted by soil and weather conditions. These VTAs utilize gravity flow to spread the effluent down the length of the VTA. The second system, which is the vegetated infiltration basin – vegetated treatment area system, also utilizes a solid settling basin, but in this case, the effluent is first released to a VIB. Tile lines collect the effluent draining from the VIB. This tile drainage is then pumped onto the VTA for further treatment.

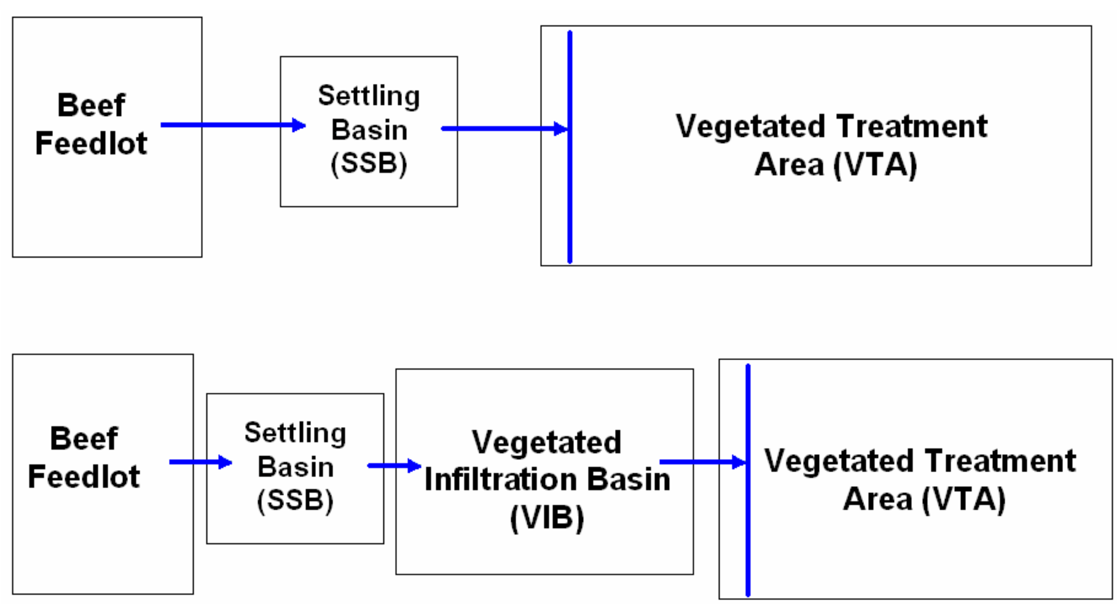

Figure 1. Schematic of the two types of VTSs monitored by ISU. The upper diagram displays the flow path of effluent through a stand-along VTA system and the lower diagram displays the flow path of effluent through a VIB-VTA system.

Data in the literature review performed by Koelsch suggest that VTSs may be effective in a variety of situations (Smith, 2007). Modeling the performance of these systems plays a key role in determining where these systems would perform as desired, as well in determining the optimum design of a VTS. There is a recent history of modeling VTS performance, for example, Tolle developed a series of models that have been used to simulate VTS performance throughout Kansas (Tolle, 2007); Wulf and Lormior developed a series of models for VTSs in Iowa (Wulf, 2005), referred to here as the ISU models. The ISU models have been studied to determine what variables have an important influence of VTS system performance (Smith, 2007), and have also been compared to monitoring data taken at four locations (Khanijo, 2007). In her study, Khanijo compared the ability of the ISU-VTA and ISU-VIB/VTA model to predict discharge volumes as well as nutrient mass released from four VTSs. Khanijo found that the ISU models over-predicted VTS performance on all sites, specifically over-predicting both VIB and VTA hydraulic performance; these models are currently undergoing revisions to improve the models predictive power. Along with improving the performance of these models, ISU is also looking at the use of other available models that could be utilized to aid in both the design of VTSs as well to quantify the expected system performance. One model that shows promise for predicting the hydraulic performance of VTAs is SPAW.

The SPAW model was developed to perform a one-dimensional water budget on agricultural fields using a daily time step. SPAW performs this water budget in the vertical dimension and focuses the simulation on major components in the water balance such as runoff, infiltration, evapotranspiration, percolation, and the water content of the soil profile. By assessing the available room for water storage in the soil profile, the VTA size required to infiltrate and hold the volume of effluent generated from the design storm size can be determined. Gross and Henry report the use of SPAW in design of their VTA systems on small feedlots in Nebraska (Gross, 2007); specifically they suggested that SPAW could be used to verify that all least half of the available water holding capacity of the root zone is available to infiltrate and retain effluent from the feedlot.

There are several reasons that make SPAW a logical choice for modeling the hydraulic performance of vegetative treatment areas. One of the key reasons is the popularity of the SPAW model. It is a publicly available model and has a history of being used to model the performance of wastewater storage systems (Moffitt, 2004;Moffitt, 2003). In these studies, Moffitt used SPAW to evaluate the temporary storage design proposed by the NRCS's Animal Waste Management software on a daily basin (Moffitt, 2003) and then showed that SPAW could be used to simulate the level in wastewater containment structures on dairy operations (Moffitt, 2004). In addition to Moffitt's use of SPAW to model effluent level in waste containment structures, Saxton has used SPAW to simulate soil moisture in a variety of situations (Saxton, 1983). In these simulations, Saxton showed that SPAW could be used to simulate the temporal soil moisture patterns as a function of soil texture, vegetation type, and hydrological inputs with reasonable accuracy (Saxton, 1983). Thus, SPAW could be used to quickly assess the expected hydrological response of a vegetative treatment area to the hydrological inputs it receives. Based on the modeled hydraulic response, the overall performance of the VTS can then be determined.

Objective

The objective of this investigation was to test the ability of the SPAW model, as well as the ISU-VTA Model, to simulate the hydrological performance of the vegetative treatment area (VTA) component of a vegetative treatment system (VTS). This study focused only on the hydrology of the VTA; nutrient transport into and through the system was not considered. The predicted VTA performance was compared to the monitored VTA performance at four sites throughout Iowa. Hydraulic performance of the VTA was modeled with three different methods. The first method utilized the field module of the SPAW model, the second method utilized the pond module of the SPAW model, and the third methods utilized the ISU-VTA model. The results of the three modeling options are compared to determine which option is most effective in predicting VTA hydraulic performance.

Methodology – SPAW Field Module

The field module of the SPAW model was used to perform a water balance on four Iowa VTAs. The hydraulic processes performed by the VTA are included in this water balance; these processes are infiltration, runoff, evapotranspiration, percolation, and storage of water in the soil profile. In this model, runoff is simulated with the NRCS/SCS curve number method. The amount of runoff predicted is sensitive to the curve number selected, thus accurate knowledge of the curve number is important in order to accurately predict the amount of runoff that is expected to occur. There is guidance available on predicting the proper curve number; for example, a soil survey map can be utilized to determine what hydraulic soil group a soil would fall in, and then land cover can be used to give a reasonable estimate of the curve number. The curve number method is a relatively simple method of predicting runoff volume and has several limitations; however, this method has been developed from years of empirical data and provides a quick method to determine runoff volumes. In SPAW, the curve number used to simulate runoff depth is adjusted based on soil moisture; if the soil profile reaches 90% of the saturated water content extra runoff is predicted from the event.

Another of the chief limitations of using the field module of the SPAW model is that application of the feedlot effluent onto the VTA must be assumed uniform over the entire VTA. For gravity flow systems, this often is not the case, as channeling may develop throughout the VTA. In addition, for smaller runoff events, the effluent may not cover the entire treatment area, but instead will all be infiltrated in the front sections of the VTA. For these simulations, the equivalent depth of effluent applied to the VTA was added to the precipitation depth on a daily basis. This was done because many of the events that occurred had small equivalent depths that were at or below the irrigation depths SPAW was capable of simulating. Adding the effluent application depth to the precipitation should provide similar results to modeling the process as irrigation, as both functions are handled similarly in the SPAW model.

Initial SPAW model runs utilizing the filed module were performed for each of the four sites, Northwest Iowa 1 and 2 and Central Iowa 1 and 2, based on initial assumptions about the water table depth and the appropriate curve numbers for the vegetative treatment areas at each of the four locations. Adjustments were made to the model inputs, such as water table depth and the curve number of the VTA, to calibrate the model predicted results to match the monitored results at each of the four locations. The effectiveness of the SPAW model to predict hydrologic performance of a VTA was then evaluated.

Methodology – SPAW Pond Module

The second method used to model the hydraulic performance of the Iowa VTAs utilized the pond module. In this model scenario, the soil-water system was considered a reservoir, which could store rainwater and effluent. When the reservoir was completely filled, overflow (i.e. runoff) will occur. In this analogy, there are several methods in which water is added to the reservoir; these include rainfall, effluent application from the settling basin, or effluent application for a vegetative infiltration basin. Furthermore, there is no need to make the assumption of uniform effluent application, just that it occupies a certain portion of the space available in the storage reservoir, i.e. in the soil profile. There are also several mechanisms in which effluent is removed from the reservoir; these include evapotranspiration and seepage losses. For this modeling scenario, seepage losses would represent a decline in water table elevation or percolation of the effluent from the root zone. Appropriate numbers for several values must be determined in order to model VTAs. These include the storage capacity of the reservoir, the amount of infiltration into a dry pond bottom before the effluent storage begins to fill, and as previously mentioned the seepage rate. In this perspective of modeling VTA performance, all overflow volume is caused by completely saturating the soil profile, i.e. runoff is not caused by an infiltration rate below the effluent/rainfall application rate, but by no available storage capacity in the soil.

The storage capacity of the reservoir was approximated as the remaining air space in the soil profile when it is under equilibrium conditions with a specified water table depth. The formula used to determine this volume is shown in Equation 1. In this equation, *d* represents the depth of the water table, ή represents the porosity of the soil, θ_v is the volumetric soil water content (which is a function of soil water potential), and $Area_{VTA}$ which is the area of the VTA. The next step was to determine the depth of infiltration that would occur before the reservoir would start to fill with water. The maximum value for this variable is the difference in the soil water content of a soil profile at its equilibrium water content and the soil water content of the soil profile when a steady-state evaporative boundary is applied to the soil surface. The formula for this calculation is shown in Equation 2. In this equation $I_{dry\text{-}bottom}$ represents the depth of water infiltrated before the reservoir starts filling, $\theta_{v,equilibrium}$ represents the water content of an equilibrium soil profile, and $\theta_{v,evaporation}$ boundary represents the water content of the soil when a steady-state evaporative boundary is applied.

$$Storage = Area_{VTA}\int_0^d (\eta - \theta_v(z))dz \qquad \text{Equation 1}$$

$$I_{dry-bottom} = \int_0^d (\theta_{v,equilibrium}(z) - \theta_{v,evaporation\ boundary}(z))dz \qquad \text{Equation 2}$$

The final variable that needs to be determined is the rate of seepage from the reservoir. For these sites, this is the rate at which water table level is receding. Monitoring of the groundwater level versus time was used in determining this rate on sites where the data was available.

Methodology – ISU-VTA Model

The ISU-VTS models were also utilized to model the VTAs at two of the locations. The ISU-VTS models are fully described by Wulf in Alterative Technology and ELG Models for Open Cattle Feedlot Runoff Control (2005). An assessment of the performance of the ISU models at these locations for the 2006 monitoring year had previously been performed by Khanijo (2007). The results of Khanijo's assessment showed that the ISU models overestimated VTS performance; predicting no system release at all four of the simulated locations. Additional monitoring undertaken by ISU has shown that several of the initial parameters used in this modeling effort were incorrect; specifically the water table depth, water table seepage rate, and the hydraulic conductivity of the soil. Monitoring and experimentation has allowed these modeling inputs to be improved to more accurately represent the physical system; after making these improvements it is necessary to again quantify model performance.

For this simulation the goal was to focus on the hydrology of the VTA only, thus these simulations were only run for two of the systems; Central Iowa 1 and Northwest Iowa 1 which are stand-alone VTA systems.

Results and Discussion – SPAW Field Module

A comparison between the SPAW Field Module model results and the monitored results at each of the four sites is shown below in Tables 2 and 3. Table 2 shows a comparison of the predicted release amount from the modeled VTA and the monitored VTA. In all four cases, the SPAW model of the site predicted less release from the VTA than was actually monitored, in most cases by roughly ½ of the total release volume. The largest percent error was seen in the Northwest Iowa 2 site, part of this large deviation may have been caused by the relatively small volumes of release, as the absolute deviation between the two values is quite small. A second method of evaluating the model is to check the modeling efficiency at each location. The Nash-Sutcliffe modeling efficiency (NSE) calculated based on daily release volumes is shown for each of the locations in Table 3. The Nash-Sutcliff model efficiency is a statistic used to assess the predictive power of hydraulic models. A value of one implies that the modeled results perfectly match the observed data, while a value of zero implies that the model predictions are as accurate as the mean of the observed data. The value of the Nash-Sutcliff efficiency can also be less than zero, which would imply that the mean value of the observed data has more predictive power than the modeled value. At all four locations the modeling efficiency was greater than zero, which indicates the model is tracking temporal performance with at least reasonable accuracy. It also can be noted that the model performance was better at stand-alone VTA locations than at locations with a VIB-VTA system. Based on this limited data set, it can not be stated with certainty that this will always be the case, but for these four locations the trend is evident with modeling efficiency at stand-alone VTA sites at values above 0.5 and at VIB-VTA sites at values of 0.16 to 0.34. The PBIAS measured the average tendency of the ISU-VTA simulated data as compared to the SPAW simulated data. In this case, a value of 0 indicates the two models predict similarly, a positive value would indicate that the model would underestimate the volume of outflow and a negative value would indicate the model overestimates the volume of outflow in comparison to monitored value. The third statistic used is the ratio of the root mean square error to the standard deviation of the measured data (RSR); the RSR is calculated as the ratio of the root mean square error between the modeled results and the monitored results divided by the standard deviation of the monitored data (Moriasi, 2007). This statistic has a range of zero to positive infinity, with the optimum value being zero. Moriasi also provides guidelines for when these statistics indicate satisfactory model performance; for flow modeling these are, a NSE > 0.50, a RSR < 0.70, and PBIAS of less than plus or minus 25%. At all four locations the PBIAS is out of the range suggested to be acceptable by Moriasi. The NSE and the RSR were in the acceptable region for both VTA only systems, i.e. Central Iowa 1 and Northwest Iowa 1.

Table 2. Comparison of the measured and modeled cumulative release volumes over the monitoring period (4/1 – 10/31/2007). Modeling results determined with field module of SPAW.

Site	Modeled VTA Release m^3	Monitored VTA Release m^3
Central Iowa 1	6,214	11,743
Central Iowa 2	868	1,576
Northwest Iowa 1	1,338	2,803
Northwest Iowa 2	12	42

Table 3. Nash-Sutcliffe modeling efficiency (NSE), percent bias (PBIAS), and ratio of the root mean square error to the standard deviation of the measured data (RSR) of the of the field module of the SPAW model for four VTAs located in Iowa. Modeling statistics were determined based on a daily release comparison over the monitoring period (4/1 – 10/31/2007).

Site	NSE	PBIAS	RSR
Central Iowa 1	0.57	47	0.66
Central Iowa 2	0.34	45	0.81
Northwest Iowa 1	0.57	52	0.66
Northwest Iowa 2	0.16	71	0.92

Also shown in Figures 2 through 5 are time series plots for each location comparing daily values of the measured and modeled VTA release volumes. These plots allow a visual comparison of the results. For each plot, possible reason for the differences between the modeled and monitored results will be discussed.

Central Iowa 1

A comparison of the SPAW Field Module modeled results for Central Iowa 1 is shown in Figure 2. This system is a settling basin followed by a stand-alone VTA. The model follows the same general trend of when VTA release occurrs. A major difference between modeled and monitored performance occurs in July, where the model continues to predict releases from the VTA while none where recorded. This may be due to the model over-predicting actual soil moisture during these times. The assumption in modeling the VTA was that it was covered with a cool season grass, which would typically be near a dormant stage during this period; however, the actual VTA exhibited vegetation growth during this time. Thus, evapotranspiration may have been underestimated. This model also showed a tendency to underestimate the amount of release that occurred from large events. The largest deviation between modeled and monitored results occurred from a release event on 4/24 and 4/25. For this event, the model drastically underestimated the amount of VTA release that was measured; only 1/3 of the total release volume was modeled. However, there is evidence that a measurement error occurred at the settling basin outlet. During this event, the producer completely emptied his settling basin, but only 1,190 m^3 of outflow from the solid settling basin outlet was measured by the monitoring equipment. The basin has a full volume of approximately 3,500 m^3 and it went from full to empty, so the expected SSB release volume should be closer to 3,500 m^3. The settling basin release and rainfall are the driving forces for causing runoff from the VTA. Therefore, an error that causes an underestimate of SSB release would result in the model under-predicting the amount of release from the VTA. During the event, 15.2 cm (6 inches) of rainfall were recorded, amounting to 2,334 m^3 of water added to the VTA from rainwater. Summing the volume of effluent monitored to be released from the settling basin and from rainfall, only 3,524 m^3 of water were added to the VTA; however, 4,562 m^3 of effluent was monitored exiting the VTA. Thus, even if the SPAW model predicted all of the applied effluent and rainfall to be converted to runoff from the VTA, the model would still under-predict the release. Also of note is that on the dates 8/24 through 8/27 no data was available for the amount of effluent exiting the VTA. This was a very rainy period and water ponded at the VTA outlet, causing extraneous depth readings in the measurement flume. Thus, no release volume from the VTA is available for this event. The model also under-predicts the volume of effluent released from events on 8/5, 8/21, and 8/28. Channeling of flow was noted to occur during these events. This flow channeling may have resulted in reduced contact time between the effluent and the VTA, which would result in a reduction in the volume of infiltration on the VTA. During September and October, the estimated release volumes follow closely with those monitored. Removing the data from the 4/24 – 4/25 event, which is known to have measurement errors from the calculation of the modeling statistics, would give a NSE of 0.58, a PBIAS of 34%, and a RSR of 0.65.

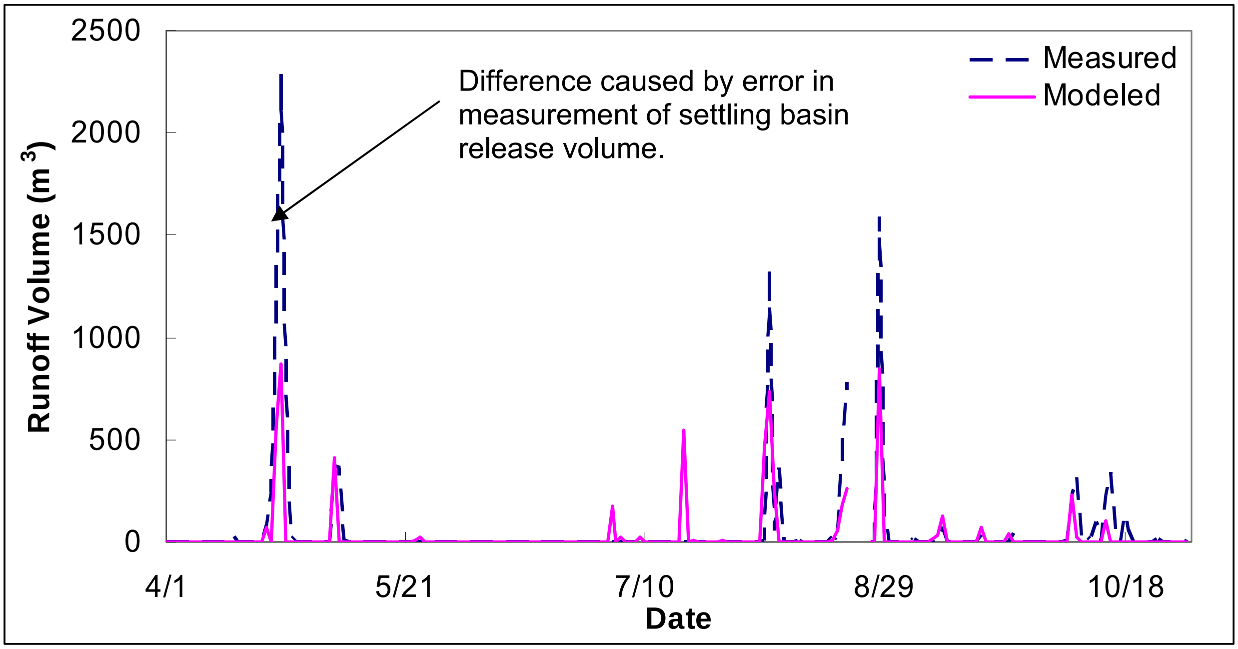

Figure 2. Comparison of the SPAW Field Module modeled release volumes and the measured release volumes for Central Iowa 1. The difference between the modeled and measured results on 4/25 is caused by a measurement error in the volume of effluent released from the settling basin.

Central Iowa 2

The comparison of the SPAW Field Module modeled and measured effluent release volumes for Central Iowa 2 are shown in Figure 3. The temporal distribution of modeled and measured runoff follow the same pattern, usually having very similar values; however, for the two large VTA release events monitored to occur on 8/20 and 10/13 the measured volume of release greatly exceeded the modeled release volume. This probably was caused by an error in measurement of flow exiting the VTA outlet. This site had a drainage problem at the exit of the VTA that caused standing water in the flume to occur from larger rainfall events. For the release event occurring on 8/19 and 8/20, the equivalent depth of rainfall and effluent applied was 9.4 cm (3.7 inches); 509 m^3 of effluent was recorded exiting the VTA during this event. The equivalent depth of water applied to the VTA area only amounts to 300 m^3. For the event on 10/13, an equivalent depth of 9.4 cm (3.7 inches) of rainfall and effluent were applied to the VTA; 324 m^3 of effluent were recorded exiting the VTA, while only 225 m^3 of rain and effluent were applied to the VTA surface. Again, this would suggest that the volume of effluent recorded exiting the VTA was larger than the value which actually occurred. At this location, the SPAW model estimated several releases in late July and early August; no effluent release was measured during this period. This could have been caused by an underestimation of the amount of drying due to evapotranspiration. Correcting the two events on 8/20 and 10/13 so that the measured volume of effluent exiting the VTA is equal to the maximum amount of release that could have occurred would improve the NSE of the SPAW results from 0.34 to 0.83; furthermore, the PBIAS would be reduced from 45% to 17%. These results would indicate that the hydraulic performance of the VTA is satisfactorily described by the field module of SPAW.

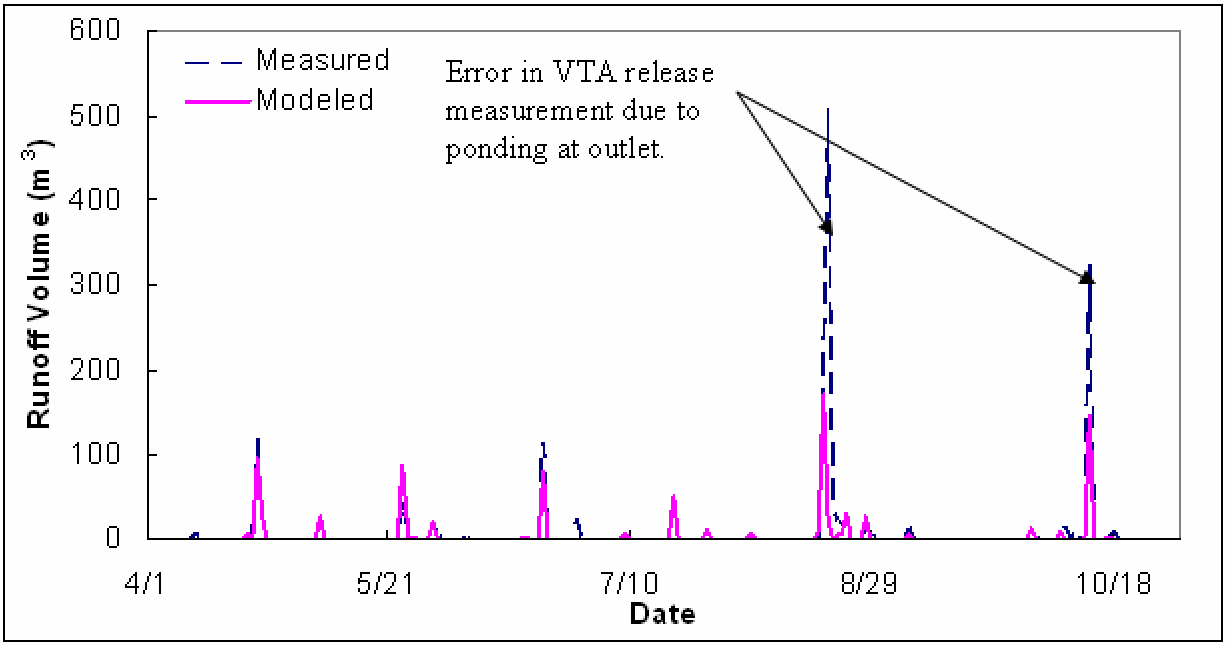

Figure 3. Comparison of the SPAW Field Module modeled release volumes and the measured release volumes for Central Iowa 2.

Northwest Iowa 1

The comparison of the Northwest Iowa 1 SPAW Field Module modeling and monitoring results are shown in Figure 4. This site had two different periods in which release was recorded exiting the VTA. These occurred in spring and in the fall, with no effluent release recorded during the summer. The SPAW model of this system under-estimated the volume of release for all the early spring events. There are several possible reasons for this. For the release event that occurred on April 1, there was release from the solid settling basin; however, monitoring equipment could not be installed due to system adjustments the producer had made. Since solid settling release volumes were unavailable, the modeling release results are due to rainfall only, whereas the actual VTA release resulted from both precipitation and effluent application onto the VTA. Several smaller releases in the spring were also not predicted with the SPAW model, this could have been caused by less evapotranspiration occurring than predicted by the SPAW model or higher soil moisture conditions in the VTA then was modeled. These higher soil moisture conditions may have been caused by a seasonal water table, high soil moisture levels from spring snowmelt, or unmonitored releases from the settling basin before sensor installation. SPAW predicted several small release events in late July that did not occur; this was probably due to an underestimation of the amount of evapotranspiration that was occurring. Cool season grasses were used to represent the vegetation on the VTA; however, the actual VTA had a mixture of vegetation types that may have caused larger than anticipated evapotranspiration. A large portion of the yearly discharge volume for this site occurred in the fall. SPAW does a reasonable job of predicting when this would occur; however, the volume of effluent released from the VTA on October 18 is drastically underestimated by SPAW. SPAW does a good job of predicting the release volume that occurred previously on October 15, but fails to carry this prediction accuracy to the next event. This would seem to suggest that the large amount of runoff occurring on this date is related to the VTA being saturated from the previous event, while the SPAW model of the system simulated that the soil has dried enough to infiltrate much of effluent from the event. It is believed that this rainy period in October may have caused an elevated water table, limiting the amount of effluent the VTA could successfully infiltrate.

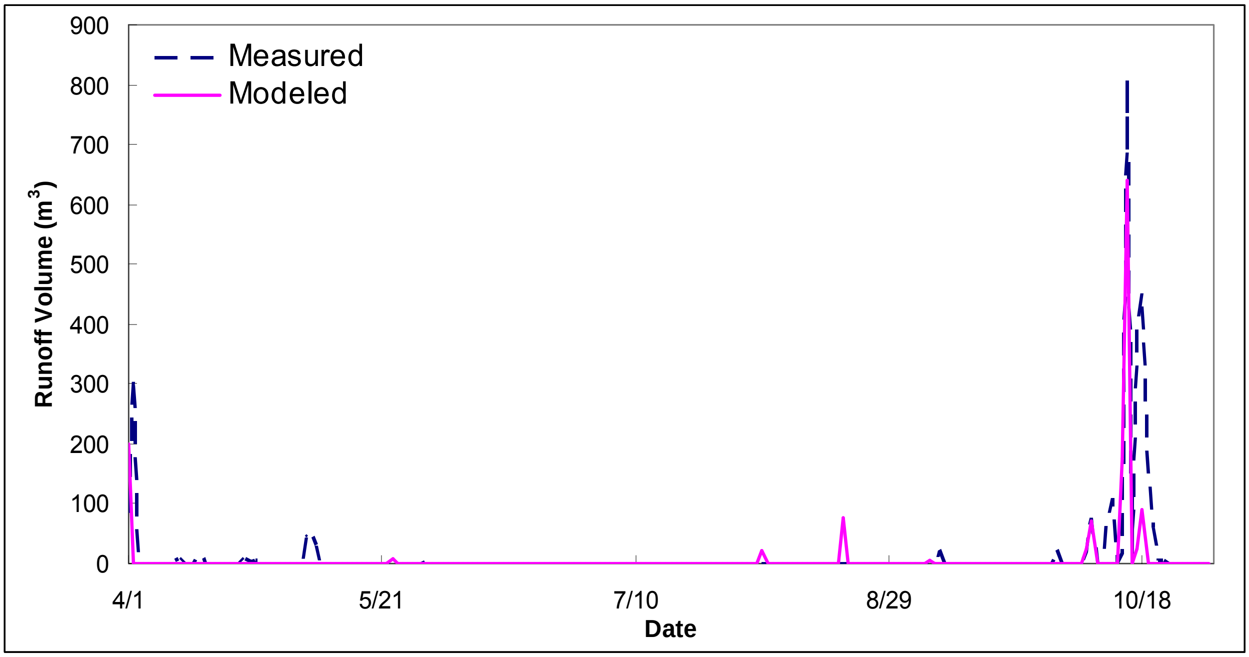

Figure 4. Comparison of the SPAW Field Module modeled release volumes and the measured release volumes for Northwest Iowa 1.

Northwest Iowa 2

A comparison of the SPAW Field Module modeling and monitoring results for Northwest Iowa 2 are shown in Figure 5. At this site only one period of release was recorded from the VTA, this occurred in early spring. The SPAW model of this system underestimates the amount of discharge that occurred due to this release, but still predicted release in July when none was actually recorded. It is believed that the release from the VTA in the beginning of April may have been caused by high soil moisture levels resulting from a high seasonal water table as well as large amounts of moisture due to snow melt. During the rest of the year, this site experienced no release from the VTA. This site is known to have a deep groundwater table that is higher in the spring than in the summer; in addition, the producer ripped horizontal trenches in the VTA, which served as depression storage during precipitation events. This depression storage resulted in greater contact time between the effluent and the soil increasing the available time for infiltration, causing a reduction in the amount of release from the VTA. In addition, this system experienced uniform effluent application to the VTA, which resulted in sheet flow across the VTA, increasing contact time and therefore the opportunity for infiltration to occur.

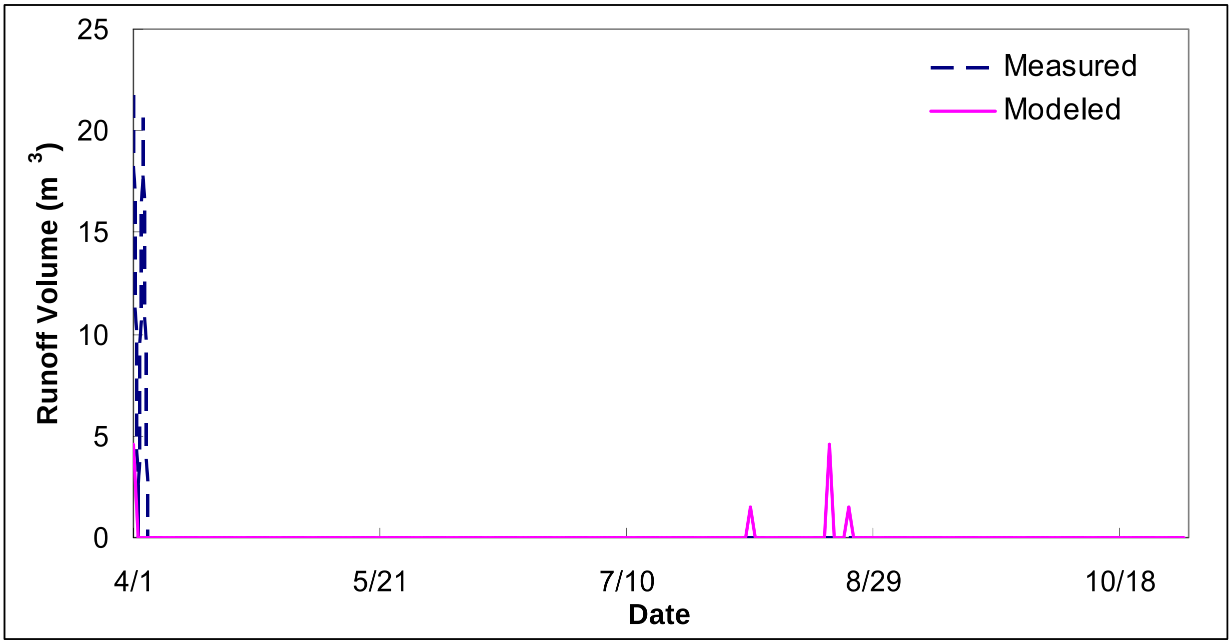

Figure 5. Comparison of the SPAW Field Module modeled release volumes and the measured release volumes for Northwest Iowa 2.

Results and Discussion – SPAW Pond Module

As stated, the SPAW pond module was also used to simulate the hydraulic performance of the VTA. As seen in Table 4, the SPAW model of each site again underestimated the total volume released from the VTA; for these locations the percent error in the total release over the monitoring period ranged from 13 to 52%; as shown by the PBIAS statistic provided in Table 5. The PBIAS improved at all locations except Northwest Iowa 1, where it remained constant, as compared to the field module predictions. At Northwest Iowa 1, a large portion of this prediction error results from under-predicting the release volume on 10/18. The NSEs for each of the four locations are also displayed in Table 5. The modeling efficiency was better at each of the locations when the pond module was used rather than the field module; however, the inputs required are more difficult to determine. This indicates that the pond module provided a bettor temporal indication of when runoff would occur. The RSR also improved at each of the four locations, indicating less residual difference between the modeled and measured results than was obtained with the field module of SPAW. Therefore, the pond module of SPAW provides a better method of simulating performance of these systems than the filed module, specifically for high water table locations; however, to gain this increase in accuracy the modeler must be able to accurately determine the required properties.

Table 4. Comparison of the measured and modeled cumulative release volumes over the monitoring period (4/1 – 10/31/2007). Modeling results determined with pond module of SPAW.

Site	Modeled VTA Release m^3	Monitored VTA Release m^3
Central Iowa 1	8,770	11,743
Central Iowa 2	900	1,576
Northwest Iowa 1	1,344	2,803
Northwest Iowa 2	37	42

Table 5. Nash-Sutcliffe modeling efficiency (NSE), percent bias (PBIAS), and ratio of the root mean square error to the standard deviation of the measured data (RSR) of the of the pond module of the SPAW model for four VTAs located in Iowa. Modeling statistics were determined based on a daily release comparison over the monitoring period (4/1 – 10/31/2007).

Site	NSE	PBIAS	RSR
Central Iowa 1	0.77	25	0.48
Central Iowa 2	0.39	43	0.78
Northwest Iowa 1	0.62	52	0.61
Northwest Iowa 2	0.26	13	0.86

Graphs comparing the SPAW Pond Module modeled performance and monitored performance are again provided. These comparisons are shown in Figures 6 through 9. For each plot, possible reasons for the differences between the modeled and monitored results are again briefly discussed.

Central Iowa 1

Figure 6 shows the comparison for Central Iowa 1. The release event occurring on 4/25 is again drastically underestimated due to measurement errors, but the release prediction for the events on 8/5 and 8/21 have been drastically improved in comparison to those predicted by the field module. The model again shows good prediction accuracy through September and October. A release was predicted to occur in July although none occurred. As stated earlier, this may be due to an under-prediction in the amount of evapotranspiration that was occurring. This modeling effort shows that one of the major difficulties facing this system is the limited space in the soil profile for infiltrating the effluent; this leads to times when the soil profile is completely saturated. Specifically, every predicted overflow in this modeling scenario would result in the soil profile being modeled as completely saturated. Thus, in this case the overflow amount becomes very sensitive to the volume of rainfall and effluent that is applied to the system. In addition, this analysis assumes that the entire storage capacity of the soil can be utilized; i.e. their is no channeling of flow that would limit the area of the VTA that is actually utilized. Channeling of flow may result in areas that are not completely saturated and would cause an overestimate of performance. Removing the data from the 4/24 – 4/25 event, which is known to have measurement errors, from the calculation of the modeling statistics would give a NSE of 0.76, a PBIAS of 11%, and a RSR of 0.49. This would indicate satisfactory performance of the model according to all three categories.

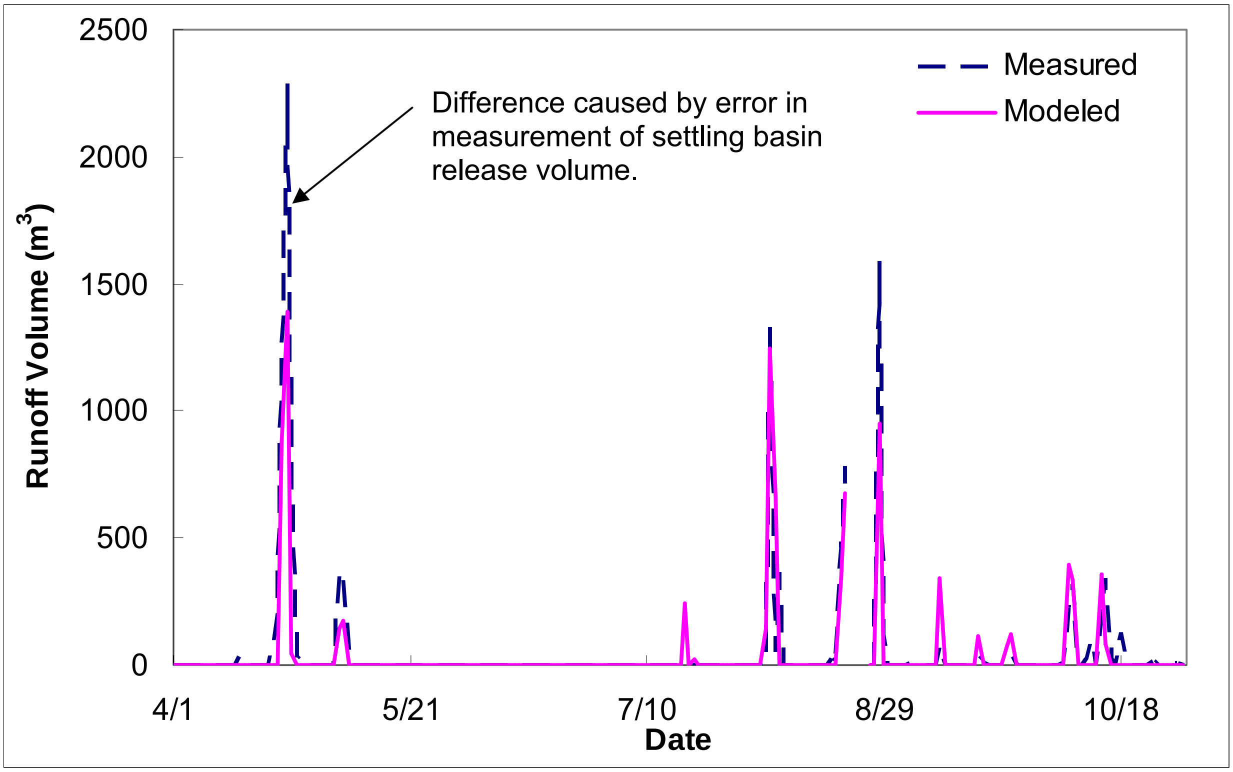

Figure 6. Comparison of the SPAW Pond Module modeled and monitored release volumes for Central Iowa 1.

Central Iowa 2

Figure 7 provides a comparison for Central Iowa 2. The model again follows a similar temporal pattern of when VTA release would occur with an underestimation of release volume on 8/19 and 10/13. If the volume released from these two events is reduced to the amount of effluent and rainfall applied to the VTA, as was done earlier in the comparison of the field module, the modeling efficiency improves from 0.39 to 0.83. The PBIAS would also be improved from 43% to 13%. Again this would indicate that the SPAW Pond module can be used to satisfactorily describe the hydraulic performance of the VTA. In this case, the model performance provided by the pond module is slightly better than that of the field module. For this location, the pond module also provides an indication of the challenges to successfully installing a VTA at this location. The soil profile has a limited storage capacity that is often exceeded by the depth of rainfall alone; therefore, even though this location utilizes a VIB to delay the application time of the feedlot effluent onto the VTA, the site still experiences VTA release.

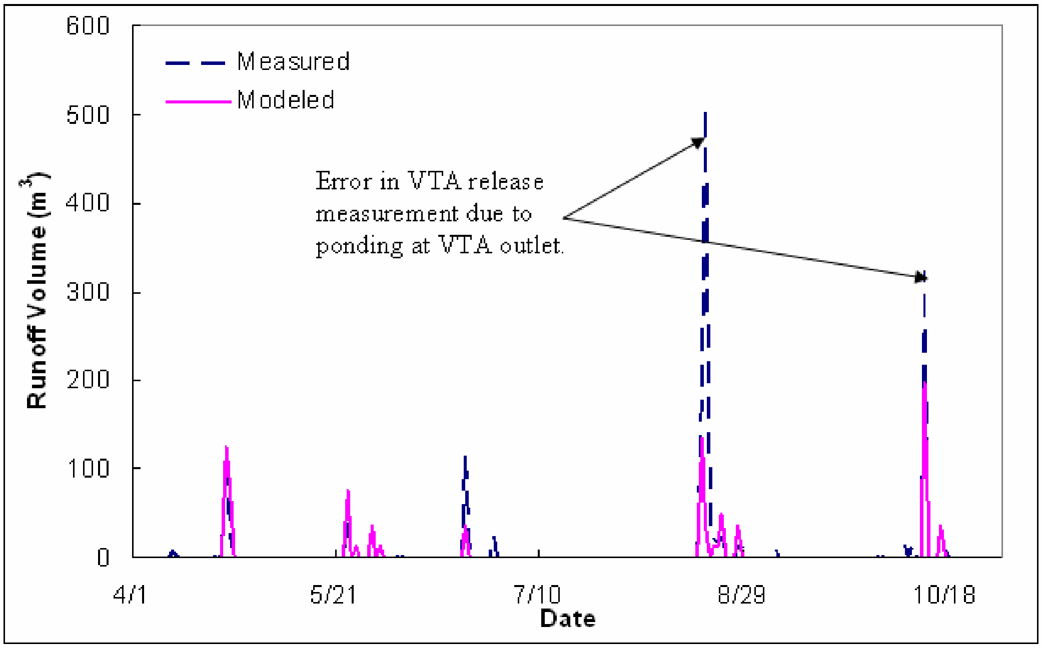

Figure 7. Comparison of the SPAW Pond Module modeled and monitored release volumes for Central Iowa 2.

Northwest Iowa 1

Figure 8 shows comparisons for Northwest Iowa 1. For Northwest Iowa 1, the model again missed small runoff events throughout the spring and underestimated the volume released from the VTA during the fall. This model also shows that a period of saturation may have occurred in the fall and resulted in the releases during this period, although again the volume released from the VTA on the 10/18 event is severely under-predicted. The small runoff events that occurred in the spring are again sensitive to both the volume measurement and storage capacity of the VTA.

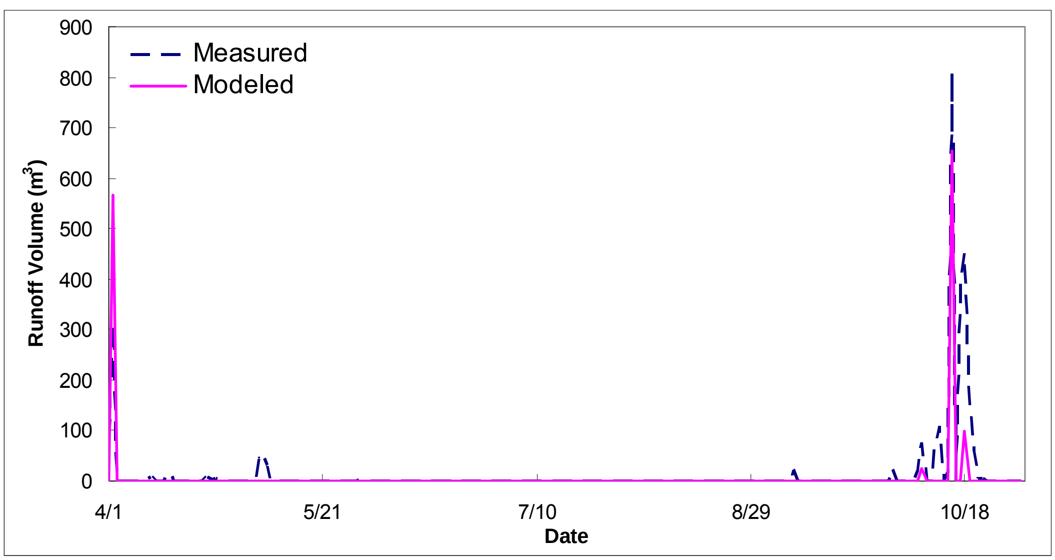

Figure 8. Caparison of the SPAW Pond Module modeled and monitored release volumes for Northwest Iowa 1.

Northwest Iowa 2

Figure 9 shows the comparisons for Northwest Iowa 2. For this simulation, it was necessary to set a high soil moisture level in the spring in order to induce overflow from the modeled reservoir; this would indicate either that the soil moisture level was high during the springtime snowmelt, or that this release event was related to the application rate of effluent/rainfall onto the VTA and not true saturation of the soil profile.

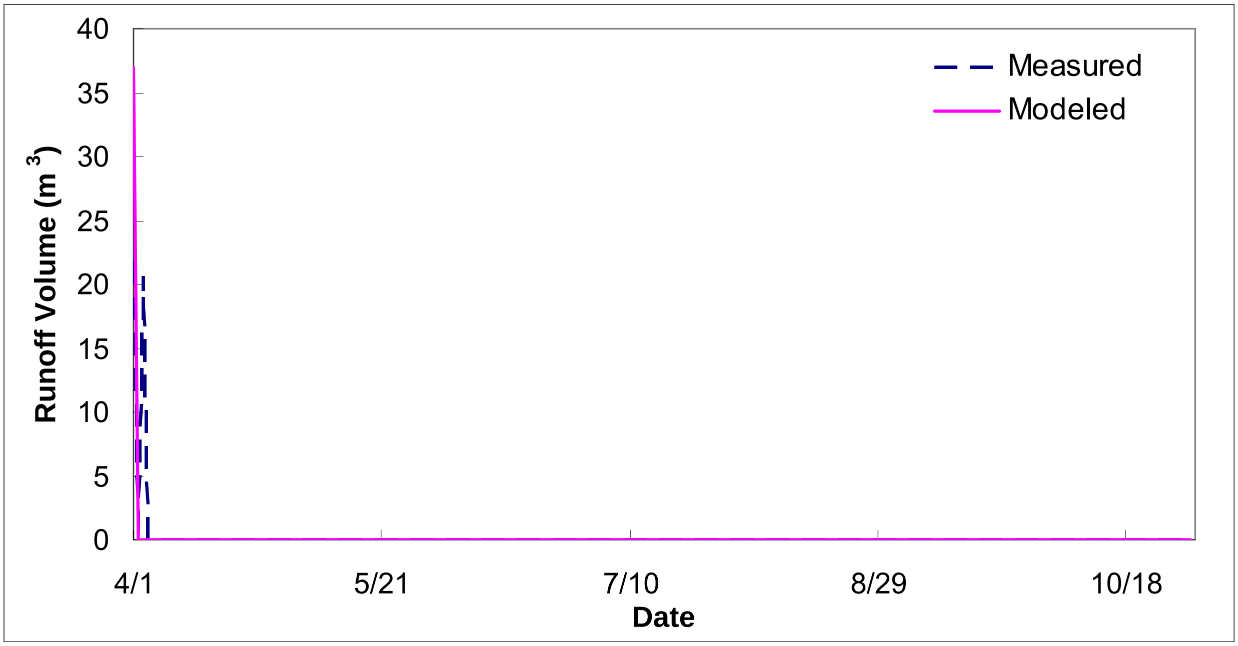

Figure 9. Caparison of the SPAW Pond Module modeled and monitored release volumes for Northwest Iowa 2.

Results and Discussion – ISU-VTA Model

The ISU-VTA Model was used to simulate the hydraulic performance of the VTA. As seen in Table 6, the ISU-VTA model of each site underestimated the total volume released from the VTA; for these locations the percent error in the total release over the monitoring period ranged from 60.2 to 100%; as shown by the PBIAS statistic provided in Table 7. The NSEs for the two locations are also shown in Table 7; they show that in both locations the ISU-VTA models struggled to follow the temporal pattern of when runoff would occur. Detailed investigations have shown that the ISU model

Table 6. Comparison of the measured and modeled cumulative release volumes over the monitoring period (4/1 – 10/31/2007). Modeling results determined with the ISU-VTA Model.

Site	Modeled VTA Release m^3	Monitored VTA Release m^3
Central Iowa 1	4,623	11,743
Northwest Iowa 1	0	2,803

Table 7. Nash-Sutcliffe modeling efficiency (NSE), percent bias (PBIAS), and ratio of the root mean square error to the standard deviation of the measured data (RSR) of the of the pond module of the SPAW model for four VTAs located in Iowa. Modeling statistics were determined based on a daily release comparison over the monitoring period (4/1 – 10/31/2007).

Site	NSE	PBIAS	RSR
Central Iowa 1	0.39	60.6	0.78
Northwest Iowa 1	-0.03	100	1.06

Graphs comparing the ISU-VTA model prediction of performance and monitored performance are again provided. These comparisons are shown in Figures 10 through 13. For each plot, possible reasons for the differences between the modeled and monitored results are again briefly discussed.

Central Iowa 1

At this location, the ISU-VTA model substantially underestimated most of the release volumes. The model did predict the volume of release from the events on 8/5 and 8/28 with reasonable accuracy; however, most of the other release events were substantially under-predicted. The ISU-VTA model, like both SPAW models, again predicted a release on 7/18, while none actually occurred. This is a surprising occurrence since the model showed a systematic pattern of underestimating the release volume in all other cases.

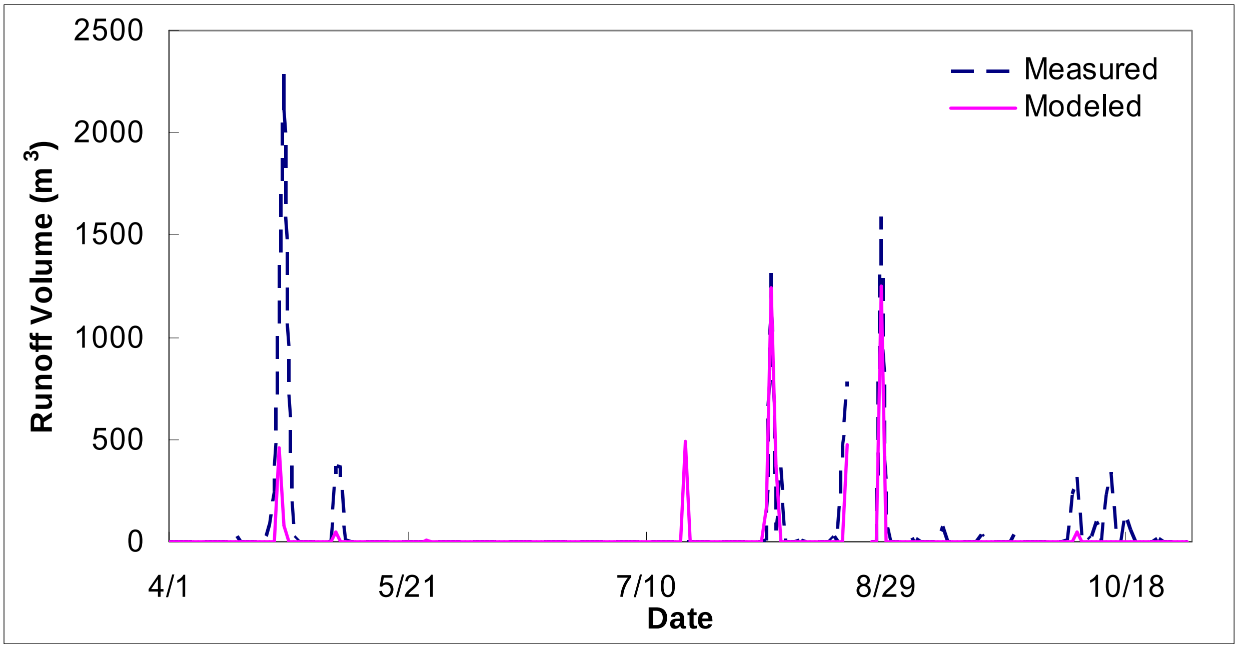

Figure 10. Caparison of the ISU-VTA model results and monitored release volumes for Central Iowa 1.

Northwest Iowa 1

At this location the ISU-VTA model predicted no releases from the VTA. This was caused by the model over-predicting the room available in the soil profile. This illustrates that the ISU-VTA model has difficulty simulating the soil profile under high water table conditions. At both this location, and Central Iowa 1, the ISU-VTA model predicted substantial drying of the soil profile; this drying did not occur in the SPAW simulations.

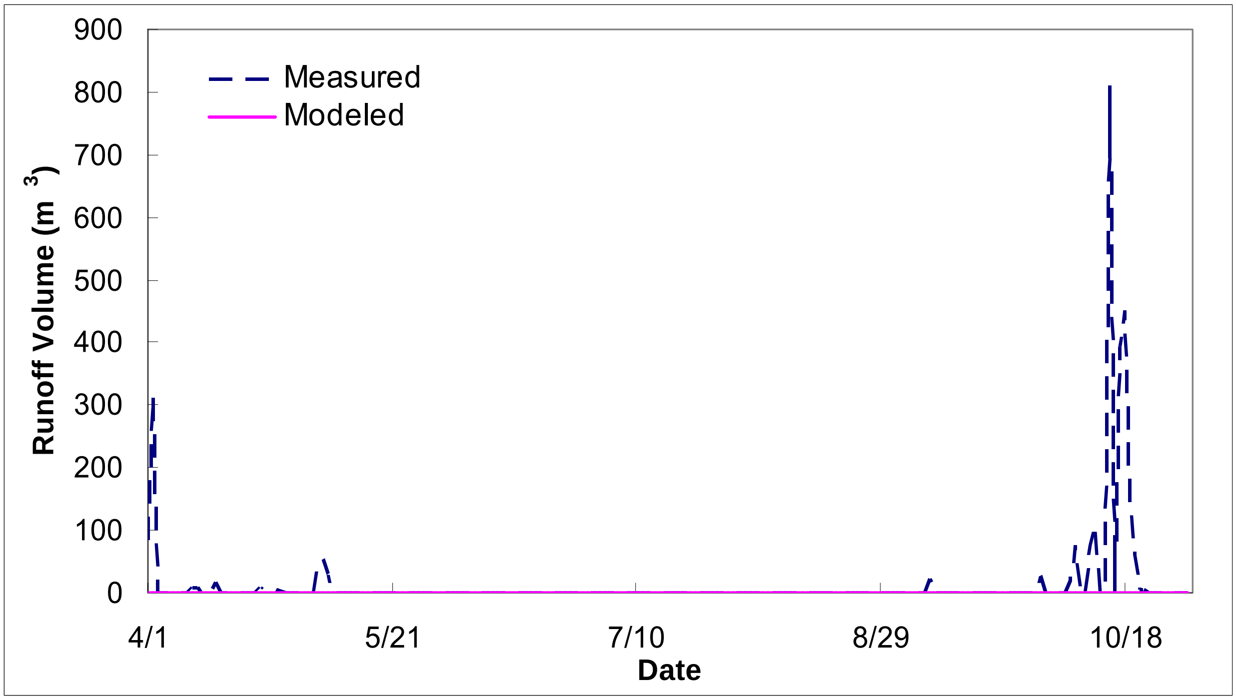

Figure 11. Caparison of the ISU-VTA modeled results and monitored release volumes for Northwest Iowa 1.

Conclusions

The results of this analysis showed that modeling a VTA with either the field module or the pond module in SPAW has potential for predicting the hydraulic performance of VTAs. The Nash-Sutcliffe modeling efficiency for the field module of SPAW was 0.57 for both SSB-VTA systems. For the VIB-VTA systems there was less agreement between the model predicted and the monitored performance; however, at Central Iowa 2 it is believed that measurement error resulting from ponding at the VTA outlet flume may be causing a substantial portion of this deviation. Correcting the monitored volumes of effluent release to be equal to the amount of effluent and rainfall applied to the VTA on this date improved modeling efficiency at this site to 0.83. In all cases, the SPAW models of the system underestimated the amount of release from the VTA; however, in several cases it did provide a temporal pattern of when system release did occur. In order to have accurate results at these four sites it was important that the curve number used on each site, as well as the water table depth, be accurately selected.

The pond module of the SPAW model also proved to be a viable option for modeling VTA performance. The inputs required to model the VTA were more complicated to obtain in this case; however, the modeling efficiency for each site was improved over that provided by the field module. The reservoir analogy taken in modeling the VTA provides an indication of the importance in the proper site selection of a vegetative treatment system. Specifically, it is seen that during wet times, the soil profile becomes saturated. This causes any effluent application or rainfall to be converted almost entirely to runoff and released from the VTA. This occurs due to the limited empty pore space in the soil profile at several of these locations.

Although there is room for improvement in these modeling results, the predictive power of SPAW provides more guidance into how a VTA will perform than that currently provided by the ISU-VTA model under the same site conditions. Based on these results, SPAW is a viable tool for determining the hydraulic performance of a VTA and can be used to determine the proper size of a vegetative treatment system required to meet specified levels of hydraulic performance; however, there are several limitations to using the SPAW model, among these are that nutrient transport is not considered. The hydraulic modeling techniques utilized for the pond analysis in this study are being incorporated into both the ISU-VTA and the ISU-VIB/VTA models. Specifically, the ISU-VTA model has shown a tendency to overestimate the amount of evaporative drying that occurs when a high water table is present

References

Blume, H. 2006. Vegetated treatment areas to utilize feedlot runoff. ASABE Paper No. 064075. St. Joseph, Mich.: ASAE.

EPA 2008. National Pollution Discharge Elimination System. Available at: http://cfpub.epa.gov/npdes/index.cfm. Accessed 4 January 2008.

EPA. 2006. *Federal Register*. 40 CFR Parts 122 and 412, Revised national Pollutant Discharge Elimination System Permit Regulation and Effluent Limitation Guidelines for Concentrated Animal Feeding Operations in Response to Waterkeeper Decision; Proposed Rule. 30 June 2006. 71(126): 37744 - 37787

Gross, J. and C. Henry. 2007. A “sprinkler” vegetative treatment system. *Proceedings of the 2007 International Symposium on Air Quality and Waste management for Agriculture*. ASABE Paper No.701P0907cd

Khanijo, I., R. Burns, L.Moody, M. Helmers, J. Lawrence, C. Pederson, D. Andersen. 2007. Vegetated treatment system models: modeled vs. measured performance. *Proceedings of the 2007 International Symposium on Air Quality and Waste management for Agriculture*. ASABE Paper No. 701P0907cd

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

Moffitt, D.C. and B. Wilson. 2004. Evaluating the design and management of waste storage ponds – Part II. ASAE Paper No 044072. St. Joseph, Mich.: ASAE.

Moffitt, D.C., Wilson, B., and Willey, P. 2003. Evaluating the design and management of waste storage ponds receiving lot runoff. ASAE Paper No. 034129. St. Joseph, Mich.: ASAE.

Moody, L., C. Pederson, R. Burns, and I. Khanijo. 2006. Vegetative treatment systems for open feedlot runoff: project design and monitoring methods for five commercial beef feedlots. ASABE Paper No. 064145. St. Joseph, Mich.: ASABE.

Moriasi, D.N., J.G. Arnold, M.W. Van Liew, R.L Bingner, R. D. Harmel, and T.L. Veith. Model Evaluation guidelines for systematic quantification of accuracy in watershed simulations. *Transactions of ASABE* 50(3): 885-900

Saxton, K.E., Willey, P.H., and Rawls, W.J. 2006. Field and Pond Hydrologic Analyses with the SPAW Model. ASABE Paper No. 062108 St. Joseph, Mich.: ASABE

Saxton, K.E. and Willey, P.H. 2004. Agricultural Wetland and Pond Hydrologic Analyses Using the SPAW Model. *Self-Sustaining Solutions for Stream, Wetlands, and Watersheds; Proceedings of the 12-15 September 2004 Conference*. ASAE Number 701P0904

Saxton, K. 1983. Soil water hydrology: simulation for water balance computations. *New Approaches in Water Balance Computations. Proceedings of the Hamburg Workshop, Augus 1983.* IAHS Publications Number 148.

Smith, S., T. Trooien, S.D. Pohl, R.A. Persyn, and H.D. Werner. 2007. Performance of a vegetated treatment system simulation model. *Proceedings of the 2007 International Symposium on Air Quality and Waste management for Agriculture*. ASABE Paper No. 701P0907cd.

Sweeten, J., R. Miner, and C. Tengman. 2003. Fact sheet #1 A Brief History and Background of the EPA CAFO Rule.

Tolle, S.M. 2007. Modeling alternative treatment systems for confined animal feedlots operations (CAFO) in Kansas. MS thesis. Manhattan, Kansas, Kansas State University. Department of Biological and Agricultural Engineering.

Wulf, L and J. Lorimor. 2005. Alternative Technology and ELG Models for Open Cattle Feedlot Runoff Control. Model Descriptions and Users Guide. Ames, IA: Iowa State University.