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Comparison of the Soil-Plant-Air-Water Model and the Iowa State University-Effluent Limitation Guidelines Model to Replicate Holding Basin Performance

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Abstract

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Keywords
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Comparison of the Soil-Plant-Air-Water Model and the Iowa State University-Effluent Limitation Guidelines Model to Replicate Holding Basin Performance

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Abstract. *In Iowa, all open beef feedlot operations over 1,000 head are required to have runoff control systems. Iowa regulations allow the use of vegetative treatment systems (VTS) on open beef feedlots that meet regulatory siting requirements. For a National Pollutant Discharge Elimination System (NPDES) permit, the runoff control performance of VTSs must meet or exceed the performance of traditional runoff containment basins as predicted by the Iowa State University-Effluent Limitations Guideline (ISU-ELG) model. The ISU-ELG model is based on a model developed by Koelliker in 1975 to predict the performance of a holding basin at controlling feedlot runoff. In this paper, the criterion used to determine if a particular day is a "dewatering day" is investigated to determine its effect on basin performance, for wetter areas in Iowa the number of drying days has a large effect on basin performance, where as for the drier northwest region of Iowa this effect is limited. This paper compares results from the ISU-ELG model to results obtained using the Soil-Plant-Air-Water (SPAW) model to simulate traditional feedlot runoff containment basin performance. The SPAW model uses a soil moisture criterion to determine if conditions are acceptable for land application of basin effluent. The results show that the ISU-ELG model over-predicts performance of traditional containment systems in comparison to the SPAW model at all five locations investigated.*

Keywords. feedlot runoff control, Effluent Limitation Guideline Model, SPAW, containment basin

Introduction

Water 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 (Sweeten, 2003). These effluent limitation guidelines historically required collection, storage, and land application of the feedlot runoff. In Iowa the current guideline for beef feedlot runoff control for concentrated animal feeding operations (CAFO) is removal of all settleable solids and no effluent discharge resulting from precipitation events less than or equal to the 25-year, 24-hour precipitation event (Iowa Department of Natural Resources, 2006).

The Iowa regulations for feedlot runoff control facilities on CAFO operations were recently modified to allow the use of alternative treatment systems when performance is equivalent to or exceeds that of a traditional system (Federal Register, 2003). As part of the permitting of alternative treatment technologies, a comparison of the median annual overflow over a 25-year period between a traditional containment system and the proposed alternative treatment system is required. This comparison is made by performing site-specific modeling of both a theoretical traditional system and proposed alternative treatment system. In addition to playing a key role in the initial permitting of these alternative treatment systems, modeling of the traditional containment system is required to ensure that the installed alternative treatment system is achieving a level of control equaling or exceeding that of the traditional containment system. This comparison is made on a yearly pollutant mass load exiting the runoff control system (EPA, 2008). In Iowa, traditional containment system performance is predicted using the Iowa State University-Effluent Limitations Guideline Model (ISU-ELG Model) implemented according to the guidelines described in Appendix A of the Iowa AFO/CAFO Regulation (Iowa Department of Natural Resources, 2006). One option available to producers is a containment basin sized to contain all runoff from the 25-year, 24-hour precipitation event from all contributing drainage areas. Land application of the effluent collected in the basin must begin on the first day that conditions are suitable (Iowa Department of Natural Resources, 2006). Modification of the feedlot runoff-control regulations to allow use of alternative treatment systems has renewed interest in predicting control provided by runoff control systems, as evidenced by the development of models to determine the runoff control achieved by vegetative treatment systems. Examples of these models include the Iowa State University-Vegetative Treatment Area Model (ISU-VTA Model), the Iowa State University-Vegetated Infiltration Basin / Vegetative Treatment Area Model (ISU-VIB/VTA Model) (Wulf, 2005), and runoff control system models developed for Kansas (Tolle, 2007). Thus far, little research has been done to determine if the ISU-ELG Model is providing reasonable prediction of the performance a traditional containment system would achieve, especially under Iowa conditions.

Background

There is a long history of modeling the performance of traditional containment systems on open beef feedlots. This modeling effort can be traced back to the EPA's release of effluent limitation guidelines in 1972. Shortly after the creation of the effluent limitation guidelines, Koelliker developed a model to predict runoff control achieved by a traditional containment system following the effluent limitation guidelines (Koelliker, 1975). This model is a continuous watershed model operating on a daily time step to estimate the runoff control of the containment system. The model uses the curve number method to determine the runoff volume from the feedlot surface, and the runoff volume is then routed into a holding pond. The holding pond is simulated using a mass balance with inflows of runoff from the feedlot and direct precipitation onto the holding pond and outflows of evaporation, overflow, and land application of effluent. In this model, Koelliker did not specifically consider the disposal area, but instead created a set of guidelines to determine when land application was appropriate. Koelliker considered land application appropriate if: daily precipitation for each of the three previous days is less than 0.05 inches, the average daily temperature is above freezing, there is no snow on the ground, the soil is not frozen, and more than 10% of the basin's total volume is filled with effluent. Using this model, Koelliker demonstrated that a period of chronic rainfall, in addition to storms in excess of the 25-year, 24-hour storm, could cause basin overflow. Furthermore, Koelliker suggested that by including more detailed disposal criteria, his ELG Model could be refined (Koelliker, 1975). Additional modeling to evaluate the effect of chronic rainfall on total containment systems was investigated by Wensink for Oregon locations (Wensink, 1975). Wensink recognized that runoff events in Kansas represented mainly catastrophic rainfall events, where as in western Oregon chronic rainfalls characterized the climate. In his investigation, Wensink performed a simulation similar to that of Koelliker and noted the amount of overflow, the date, and the precipitation that caused this overflow. Based on this data the legality of the overflow was determined, i.e. was it caused by a storm event of equal or greater magnitude to the 25-year, 24-hour event. This allowed Wensink to determine that many of the overflows where caused by events of lesser magnitude than the 25-year, 24-hour event. Based on the results of the study, he designed a second model that used what he termed the "Sufficient Design Technique" to help size containment structures to prevent discharge from events of lesser magnitude than the 25-year, 24-hour storm (Wensink, 1975).

Based on these earlier modeling attempts, Zovne developed a model that took into account the soil moisture in the disposal area (Zovne, 1977). He considered the disposal area to be a soil-water reservoir that was recharged by both precipitation and land application, and depleted by evaporation and deep drainage. There were three components in this model; the feedlot surface generating the runoff effluent, the effluent wastewater storage facility modeling pond level, and the disposal area that had a form of soil moisture accounting that enabled the modeling of soil conditions in the disposal area. Based on the soil conditions in the disposal area, a decision was made about the appropriateness of land application. In Zovne's analysis, a percentage of available moisture in the root zone above 90% was the threshold value for delaying land application. Anschutz used this model to study important variables in designing runoff control systems. For irrigation disposal systems, he found that moisture deficit was the most important factor (Anschutz, 1979). Moisture deficit was defined as the difference between the mean evaporation from a lake and the annual precipitation.

More recent interest in modeling holding pond performance has been provided by Wulf and Lorimor (2003). Wulf and Lorimor created the ISU-ELG model to determine the performance of a traditional containment system under Iowa conditions. The ISU-ELG model is a modified version of the Koelliker model. The ISU-ELG model operates on a daily time step with runoff volumes from the contributing drainage area calculated using the NRCS/SCS curve number method. This flow is then routed into a containment basin. The flow entering the basin has the concentrations shown in Table 1. These concentrations are used to calculate the mass of contaminants entering the basin. The concentrations of nutrients in the basin are then adjusted to account for both water loss due to evaporation and water addition from rainfall directly onto the containment basin surface. The adjusted concentration is used to determine the mass of nutrients removed from the basin due to either land application or basin overflow. In this model, Wulf and Lorimor (2005) used the same guidelines as Koelliker for determining when land application was appropriate. These guidelines were deemed appropriate for Kansas conditions, but no effort was made to verify these assumptions for Iowa conditions.

Table 1. Nutrient Concentrations in Containment Basin used in Iowa State ELG Model.

Contaminant	Earthen Lot (mg/L)	Concrete Lot (mg/L)
Total Kjeldahl Nitrogen	65	97.5
Ammonium Nitrogen	60	75
Total Phosphorus	20	30
Total Solids	2000	3000
Chemical Oxygen Demand	2650	3975

The Soil-Plant-Air-Water (SPAW) Model has been used to simulate the performance of waste containment structures. Moffitt performed a comparison of Soil-Plant-Air-Water (SPAW) and the National Resources Conservation Services Animal Waste Management (AWM) program to test the temporary storage component of AWM (Moffitt, 2003). In this analysis, AWM was used to size the temporary storage component of the basin. Moffitt then used SPAW to examine the basin performance on a daily time step (Moffitt, 2003). Moffitt also utilized SPAW to model the pond levels in four wastewater storage ponds located on dairies in Oregon (Moffitt, 2004). These dairies had lot areas ranging from 232 to 11,655 m^2 (0.06 to 2.88 acres) which contributed runoff to the holding ponds. In this study, Moffitt demonstrated good general agreement between the modeled levels and the experimentally determined levels, with deviations between the results possibly caused by issues such as operators deviating from their waste management plans, inaccuracies in measurement of the level in the containment structure, and differences in actual and modeled manure and wastewater inputs (Moffitt, 2004). This study showed that SPAW provided a model that could predict the performance of a waste storage pond if the system was operated according to the nutrient management plan. Specifically Moffitt states that a model is only as good as the operators' ability to follow their operating/nutrient management plans (Moffitt, 2004). Moffitt also points out that there are several factors that effect application time, these are the condition of the field on which the containments structures contents are to be applied and the application time in relation to the crops nutrient demand (Moffitt, 2003).

Given that actual system performance is directly related to management decisions made by the farmer, it becomes very important to define what is a reasonable management plan that the operator can be expected to use to manage wastewater basins. The Nebraska Department of Environmental Quality has released two guidance documents providing information on suggested containment basin operation. In the guidance document on holding pond operation they specify that land application must occur on all dewatering days until the holding pond is able to contain all runoff from a 25-year, 24-hour event (Nebraska Department of Environmental Quality, 2005). A dewatering day is defined as a day that has weather conditions and soil conditions suitable for land application of livestock wastes (Nebraska Department of Environmental Quality, 2003). Proper soil conditions are such that the amount of liquid applied should not exceed the capacity of the soil to store the moisture in the root zone of the crop. The amount of liquid the soil can hold is determined by taking the current moisture level of the soil and subtracting this value from the field capacity (Nebraska Department of Environmental Quality, 2003). This idea of manure application timing based on soil moisture has also been recommended to producers in the Wisconsin Agriculturist (Hanson, Matt, 2007) and Hoard's Dairyman (Weisenberger, 2007). Hanson discusses the effect of soil texture on the moisture holding capacity of soil and recommends keeping a moisture budget to determine if effluent application is acceptable (Hanson, 2007). Weisenberger extends that analysis stating that no application of manure should occur when the moisture content in the top four inches exceed 35% due to the risk of runoff (Weisenberger, 2007).

As stated previously, Moffitt reported the use of SPAW in modeling the depth of effluent in a containment basin (Moffitt, 2004). In his investigation, Moffitt made the assumption that during the scheduled application period conditions would be acceptable for land application. This made it easier to model the performance of the containment basin. More recently, Saxton reported an update to the SPAW model that allows the user to perform an irrigation budget for a field (Saxton, 2004). The use of the irrigation budgeting can be used to determine when effluent application onto the application area would be appropriate from a soil moisture standpoint.

Objective

This paper compares the simulation results obtained using the Iowa State University-Effluent Limitations Guideline model and SPAW to determine if the ISU-ELG model provides a reasonable prediction of containment structure performance in Iowa.

Methodology

The first item investigated is the sensitivity of the ISU-ELG Model to the number of dry days required after a precipitation event before land application can proceed. In the ISU-ELG model, this variable is equivalent to setting the soil moisture at which land application is considered appropriate. In the ISU-ELG model to date, a value of three days has been used; this follows the guidelines suggested by Koelliker for his original containment basin model. The sensitivity of the model to this assumption is investigated for five hypothetical feedlots across the state of Iowa; these feedlots are located in Sioux City, Red Oak, Ames, Sac City, and Waterloo. A map provided in Figure 1 shows these site locations. Each of the simulations was performed for a 26-year period using site-specific historical weather data. The model was run ten times at each location varying the number of dry days required before land application could begin. Land application then proceeded at a rate of one-tenth of the total containment basin volume until either rainfall occurred or less than one-tenth of the basin volume was filled with effluent. The amount of discharge was then normalized at each site as average annual quantity of discharge per hectare of feedlot area. The size of the 25-year, 24-hour event at each of the locations is shown in the Table 2. This storm size was used to determine the size of a containment basin required to hold all feedlot runoff and direct precipitation onto the containment structure.

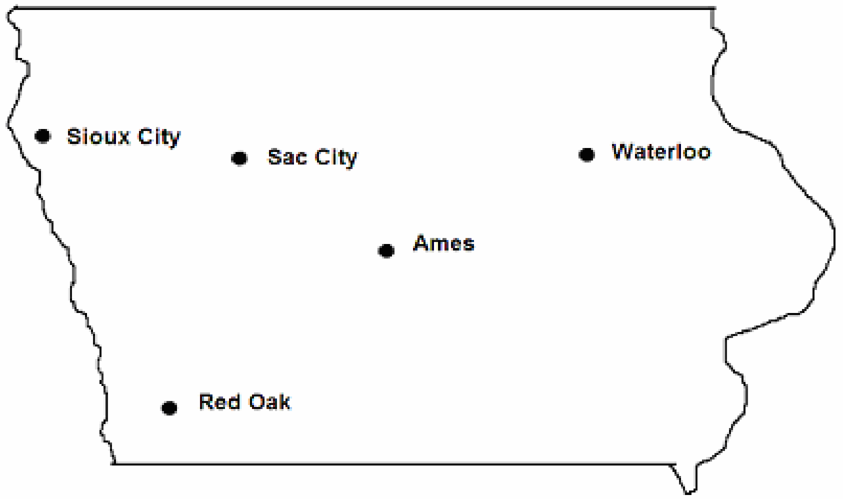

Figure 1. Locations of the five hypothetical feedlots used in the simulation.

Table 2. 25-Year, 24-Hour Storm Size for Five Locations in Iowa

Location	25-year, 24-hour Storm Size mm (inches)
Ames	129.5 (5.1)
Red Oak	129.5 (5.1)
Sac City	129.5 (5.1)
Sioux City	124.5 (4.9)
Waterloo	127.0 (5.0)

Each of these simulations was also performed using the SPAW model. The SPAW model was used to simulate all parts of the feedlot hydrology, including runoff from the feedlot, storage in a containment basin, and land application. SPAW, like the ISU-ELG Model, uses the NRCS/SCS curve number method to determine the runoff volume from the feedlot. The curve numbers entered into the SPAW model were the same as the values programmed into the ISU-ELG Model, which are 91 and 94 for earthen and concrete surfaced feedlots respectively, under normal antecedent moisture conditions (AMC II), and 97 and 98 for earthen and concrete feedlots respectively, under wet antecedent moisture conditions (AMC III). Stage-storage dimensions where entered in the SPAW model so that it replicated the basin geometry used in the ISU-ELG Model. Finally, the land application area was modeled in SPAW such that land application would occur whenever the moisture level in the root zone reached 95% of the field capacity. The amount of irrigation supplied would replenish the moisture content of the root zone up to field capacity. Again, each of the simulations was run for a 26-year period using site-specific historical weather data. The model was run repeatedly at each location with different land application areas. The average annual discharge at each site was again normalized by determining the average annual discharge on a per hectare of feedlot area basis.

The results of both modeling efforts were then compared to determine if the original hypothesis of beginning land application three days after a precipitation event is a reasonable management plan based on the soil moisture in the application area. The number of dry days required before land application could begin was then adjusted to calibrate the ISU-ELG model so that the average annual discharge per hectare of feedlot predicted by the ISU-ELG Model and the SPAW model were approximately equal. A comparison of the yearly discharges between the SPAW and ISU-ELG Model was then made.

Results and Discussion

The following figure shows how the performance of a traditional containment basin varied, as predicted by the ISU-ELG Model, when the number of dry days required before land application could begin was varied. This analysis was conducted for five locations to represent the weather conditions expected throughout Iowa. The locations of Ames, Red Oak, Sac City, and Waterloo, showed the same general trend of increasing discharge when more time was required before land application could begin. Sioux City also showed this trend, but to a much lesser extent. As can be seen in Figure 2, the assumption about the amount of time required for the land application area to dry before effluent application can begin has a pronounced effect on performance for the majority of Iowa. The model’s sensitivity to this variable makes it important that the actual number of dry days required before land application can commence is accurately chosen.

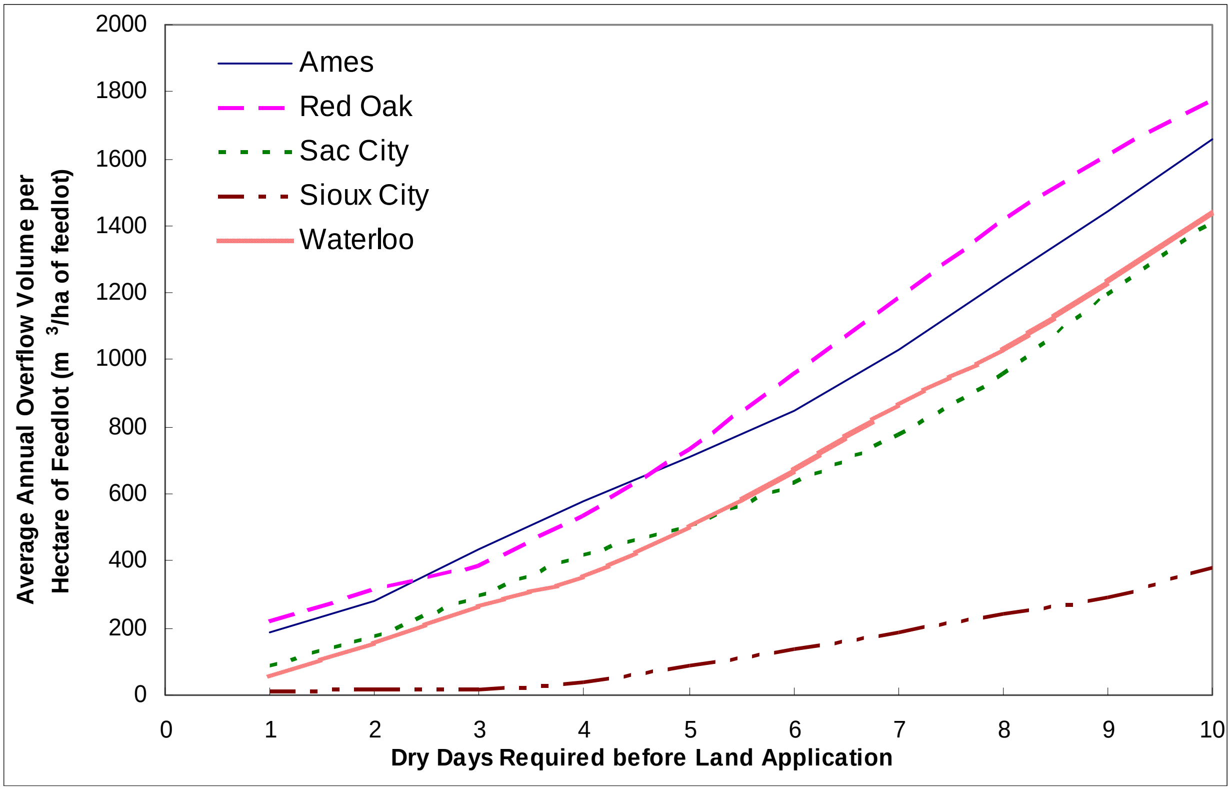

Figure 2. Sensitivity of the ISU-ELG Model to the number of dry days required before land application can begin for five cities in Iowa.

A regression analysis was used to quantify how system performance changed with the number of dry days required before land application could begin. Examples of this regression analysis for the feedlot at Ames and Sac City are shown in Figure 3. In this figure, the two dashed lines represent a 90% confidence interval for the average annual basin overflow volume per hectare of feedlot surface. The average annual overflow volume per hectare of feedlot for each dry day requirement is marked in the figure. A regression line was fit to the average data; the best-fit line was used to assess the ISU-ELG Model's sensitivity to the dry day requirement. For the Ames location, the analysis shows that for every day of drying required before land application commences, on average an extra 163 cubic meters of basin overflow per year per hectare of feedlot would occur. Whereas for Sac City, on average an extra 143 cubic meters of basin overflow per year per hectare of feedlot would occur. Similar results were obtained for Red Oak and Waterloo. The results from the regression analysis of Sioux City were quite different from the other locations, and are also shown in Figure 3. In modeling the Sioux City feedlot, changing the dry day requirement from one to three days had very little effect on the overall performance of the runoff control structure; thus, in this case the regression was only performed on dry days three through ten. A table showing sensitivities to the dry day requirement for each of the five locations is shown in Table 3.

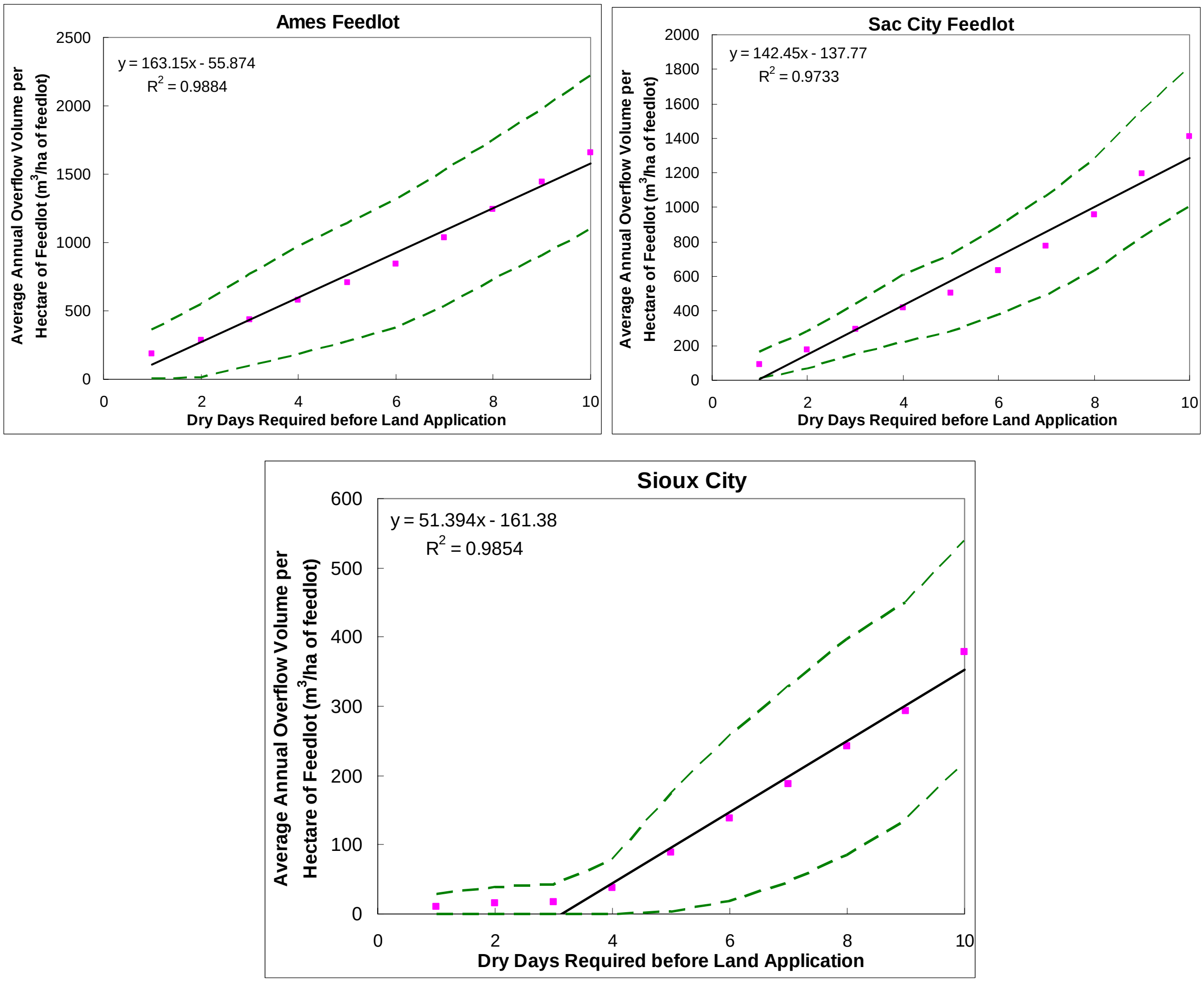

Figure 3. Regression analysis to determine the sensitivity of the ISU-ELG Model to the number of dry days required before land application could begin. The dashed lines represent 90% confidence intervals on the average annual overflow volume per hectare of feedlot. The boxes, with a solid regression line, represent the average annual overflow volume per hectare of feedlot. Both Ames and Sac City showed similar trends; however, Sioux City showed a much lower sensitivity to the number of dry days required.

Table 3. The table below shows the sensitivity coefficient of the ISU-ELG model to the number of dry days required before land application can begin.

Location	m^3 overflow per hectare of feedlot per year per dry day required before land application (ft^3 overflow per acre of feedlot per year per dry day required before land application)
Ames	163.2 (2332)
Red Oak	184.2 (2632)
Sac City	142.5 (2036)
Sioux City	51.4 (734)
Waterloo	154.7 (2211)

The result of the SPAW analysis is shown in Figure 4. In this case, the performance of the runoff control system is a function of the land available for application of the feedlot runoff, since a larger area will allow application of more effluent every time the disposal criteria is reached. For all five locations, it was assumed that the land application area would be planted to corn and irrigation could occur regardless of the crop size, i.e. irrigation was only limited by the soil moisture criteria. In this case, the basin could be completely emptied, i.e. there was no minimum treatment volume required to remain in the containment structure. As can be seen in Figure 4, four of the locations, Ames, Red Oak, Sac City, and Waterloo again showed a similar trend in response to the land application area available. For the Sioux City feedlot, a smaller disposal area was required and the system achieved a greater level of control than at the other locations. Figure 4 also illustrates that increasing the application area only has an effect on the performance of the containment system up to a ratio of five hectares of land application per hectare of feedlot surface, after this point there is a relatively small increase in system performance for increasing the application area. This is because at a certain point in each case the performance of the system is no longer limited by the size of the application area, but is instead limited by the temporal pattern of soil moisture in the land application area. Due to the drier climate in northwestern Iowa, a smaller application area is required per hectare of feedlot surface than in the areas that receive more rainfall, and therefore naturally maintain a wetter soil profile. The soil moisture status is a function of several variables; among these are the volume and time distribution of rainfall, the soil texture, and the time distribution of evapotranspiration.

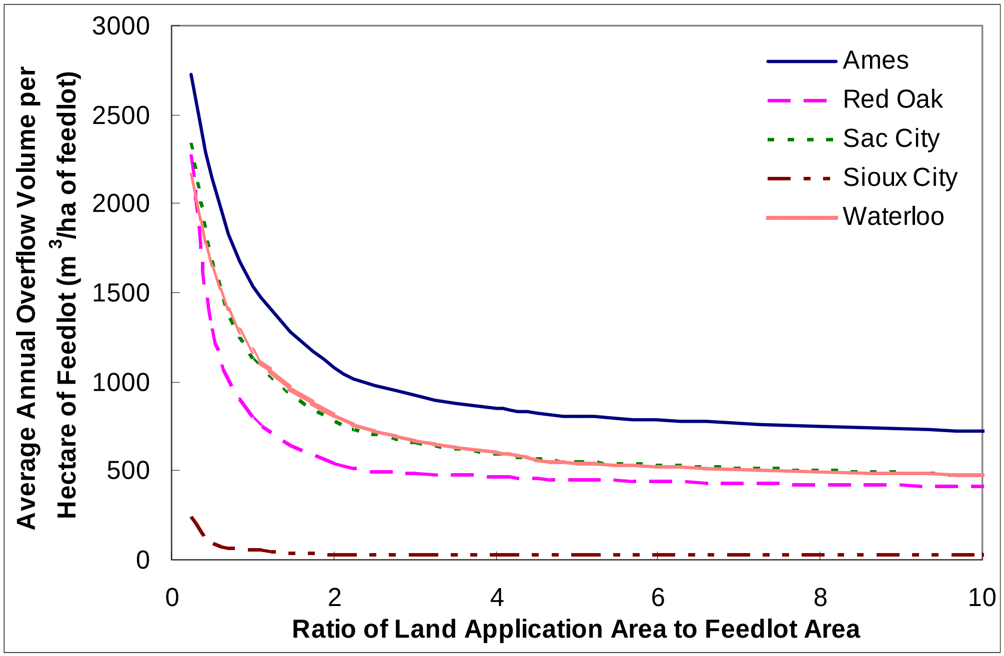

Figure 4. The Figure above shows a sensitivity analysis of a containment basin, as predicted by the SPAW model, to the ratio of land application area to feedlot area for five locations in Iowa.

As mentioned previously, the ISU-ELG model was originally developed based on the model Koelliker developed for predicting containment basin performance in Kansas. In this model, Koelliker assumed that land application would be possible three days after a rainfall event based on Kansas conditions. The ISU-ELG model has never been calibrated and no adjustment was made for Iowa conditions. A comparison between the performances predicted by the SPAW model and the ISU-ELG Model can provide some insight into how well the assumption of three days before land application commences fits Iowa conditions. Based on these results, it is then possible to calibrate the ISU-ELG model by adjusting the number of dry days required after a rainfall event to obtain the same performance as predicted by the SPAW model, which bases land application timing on the modeled soil moisture. This calibration is shown for Ames, Red Oak, Sac City, Sioux City, and Waterloo in Figures 5, 6, 7, 8, and 9 below. The calibrations were made on the average annual discharge volume per hectare of feedlot. For Ames, waiting approximately five days after the rainfall before land application makes average annual discharge equivalent. For Sac City, between four and five days makes the modeling procedures equivalent with a similar result for Waterloo. Sioux City and Red Oak both have relatively good agreement when the release day criterion is left at three dry days before land application. This is caused by the substantially drier climate around Sioux City; the annual precipitation at this location was 66 cm (26 inches), this is similar 72.6 cm (28.6 inches) of precipitation averaged in Kansas. In addition, the similarity between the SPAW and ELG model results for Red Oak resulted from higher evaporation rates in this location. The results of the calibrated number of dry days required to obtain similar results to the SPAW model is shown in Table 4.

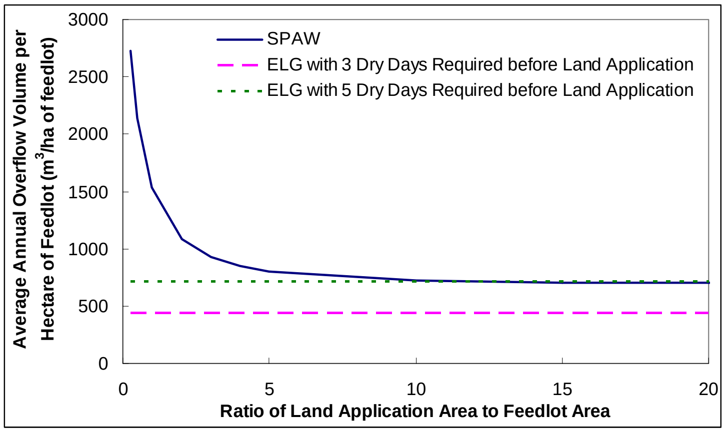

Figure 5. Calibration of ISU-ELG Model and SPAW for performance of a traditional containment system operated on conditions in Ames, Iowa.

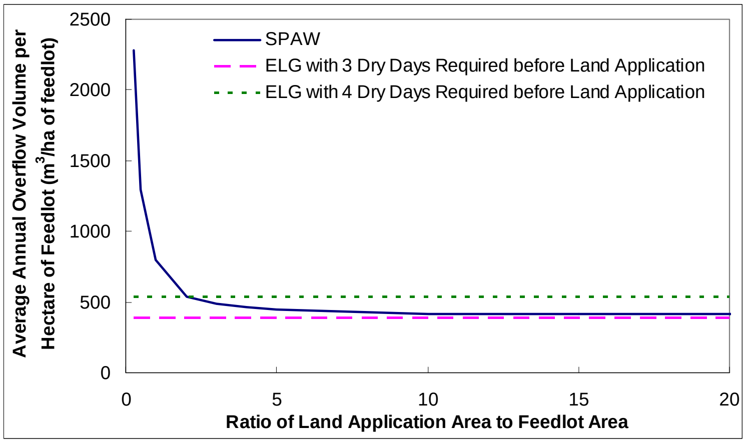

Figure 6. Calibration of ISU-ELG Model and SPAW for performance of a traditional containment system operated on conditions in Red Oak, Iowa.

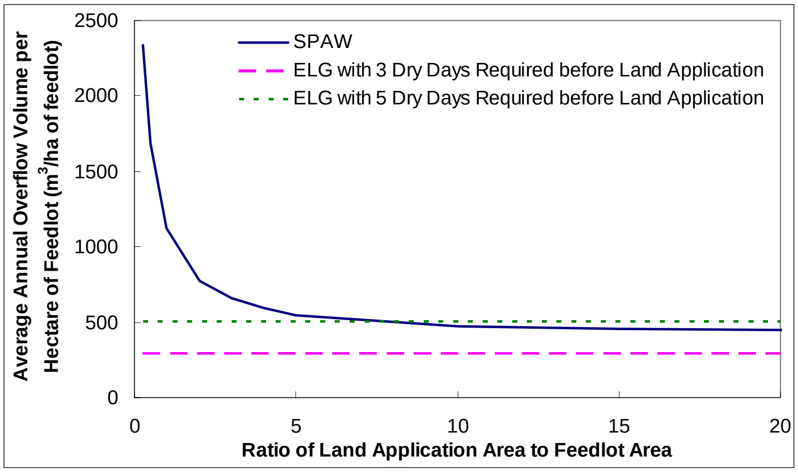

Figure 7. Calibration of ISU-ELG Model and SPAW for performance of a traditional containment system operated on conditions in Sac City, Iowa.

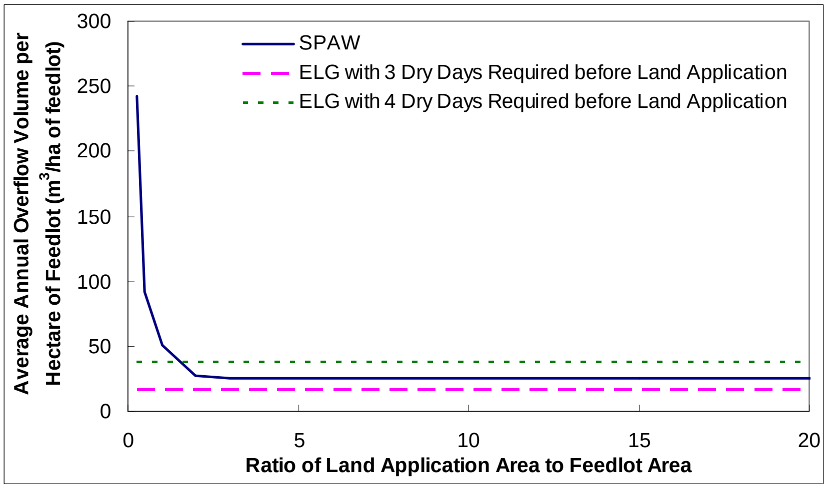

Figure 8. Calibration of ISU-ELG Model and SPAW for performance of a traditional containment system operated on conditions in Sioux City, Iowa.

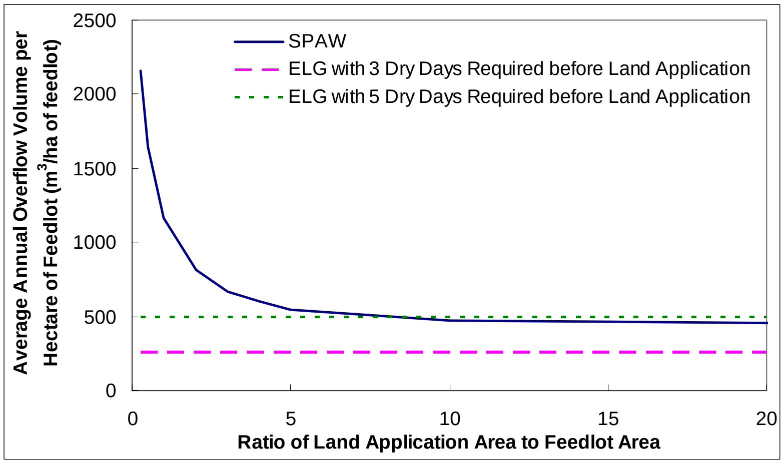

Figure 9. Calibration of ISU-ELG Model and SPAW for performance of a traditional containment system operated on conditions in Waterloo, Iowa.

Table 4. The table below shows the calibrated number of dry days required to make the SPAW model and the ISU-ELG model have approximately equal average annual discharge per acre of feedlots surface.

Location	Calibrated Number of Dry Days before Land Application
Ames	5
Red Oak	3
Sac City	5
Sioux City	3
Waterloo	5

A second way to conceptualize these results would be to compare the predicted average annual yearly overflow volumes for both the SPAW and ISU-ELG models. This comparison is shown in Table 5. For most of Iowa, the SPAW model predicts one and half times the effluent discharge volume predicted by the ISU-ELG model. The exception to this statement is Red Oak, where SPAW only predicted 1.1 times as much annual overflow as the ISU-ELG model. It is also important to note that the ratio of the two predictions for Sioux City is 1.5. In this case, the overflow volumes predicted by both models were very small. This large ratio is a result of the small overflow volumes predicted for this location. This can be verified by examining Table 6, which displays the percent runoff control predicted at each location. There was almost no change in the percent of runoff controlled at both Red Oak and Sioux City, where as for Ames, Sac City, and Waterloo, a sizeable decrease in the predicted control is seen in the SPAW model predictions as compared to the ISU-ELG model.

A second method of modifying the ISU-ELG model would be to utilize the ratio between the two predictions as a multiplication factor to correct the ISU-ELG model annual predicted overflow volume to be equal to that of the SPAW model. Applying this correction factor would maintain the current definition of chronic rainfall (precipitation events within three days of each other). Applying this correction factor would make the average annual release volume predicted by the ISU-ELG model to be equal to the average annual release volume simulated by SPAW.

Table 5. The table below shows a comparison of the average annual yearly overflows predicted by the ISU-ELG and the SPAW Models. The third column displays the ratio of the SPAW prediction to the ISU-ELG prediction.

Location	Average Annual Yearly Overflow Predicted by ISU-ELG Model m^3/ha of feedlot	Average Annual Yearly Overflow Predicted by SPAW Model m^3/ha of feedlot	Ratio of SPAW Prediction to ISU-ELG Prediction
Ames	435.6	704.3	1.6
Red Oak	388.4	415.6	1.1
Sac City	296.5	444.6	1.5
Sioux City	16.3	25.0	1.5
Waterloo	263.5	455.3	1.7

Table 6. The percent runoff control as predicted by the ISU-ELG and the SPAW model for each of the five locations.

Location	**ELG Model Calibrated**	**SPAW**
Ames	86.3%	77.8%
Red Oak	89.0%	88.2%
Sac City	90.2%	85.3%
Sioux City	99.2%	98.7%
Waterloo	90.4%	83.4%

The next three figures, Figures 10, 11, and 12, show a comparison between the ISU-ELG model results and the SPAW model on a year-by-year basis. Both the original ISU-ELG model, with the three dry-day criterion before land application, and the calibrated ISU-ELG model are shown in the site comparisons. As can be seen even the calibrated ISU-ELG model does not follow the same temporal pattern as SPAW in predicting when basin discharges will occur. Only a slight improvement in the temporal distribution of when the runoff occurs is realized from calibration of the ISU-ELG model to the SPAW model. Figure 10 shows a year-by-year comparison of the cumulative yearly overflow volumes on a per hectare of feedlot basis for Sac City. In this case, the uncalibrated ELG model predicted basin overflow for 13 out of the 26 year, after calibration basin discharge was predicted in 15 of the 26 year. The SPAW model also projected basin discharge in 15 of the 26 years modeled. For Sioux City, the ISU-ELG modeled predicted two years with discharges, while the SPAW model projected three years with discharge, according to both models most of the projected discharge occurs in 1972. In 1979 SPAW projected almost 148 m^3 of basin overflow, while no overflow was predicted by the ISU-ELG model. This resulted from a wet September, which kept modeled soil moisture levels elevated in the SPAW model, limiting land application opportunities. The ISU-ELG model did not predict an overflow during this time period because the precipitation events occurred more than three days apart, which allowed dewatering the containment basin. The year-by-year simulations results for Sioux City are shown in Figure 11. For Waterloo, shown in Figure 12, 1993 accounted for a large portion of the discharge volume in all three modeling scenarios. For Waterloo the original ISU-ELG model projected 8 years with a discharge, after calibration 14 of the years had a discharge. The SPAW model projected 19 years with discharge for this site.

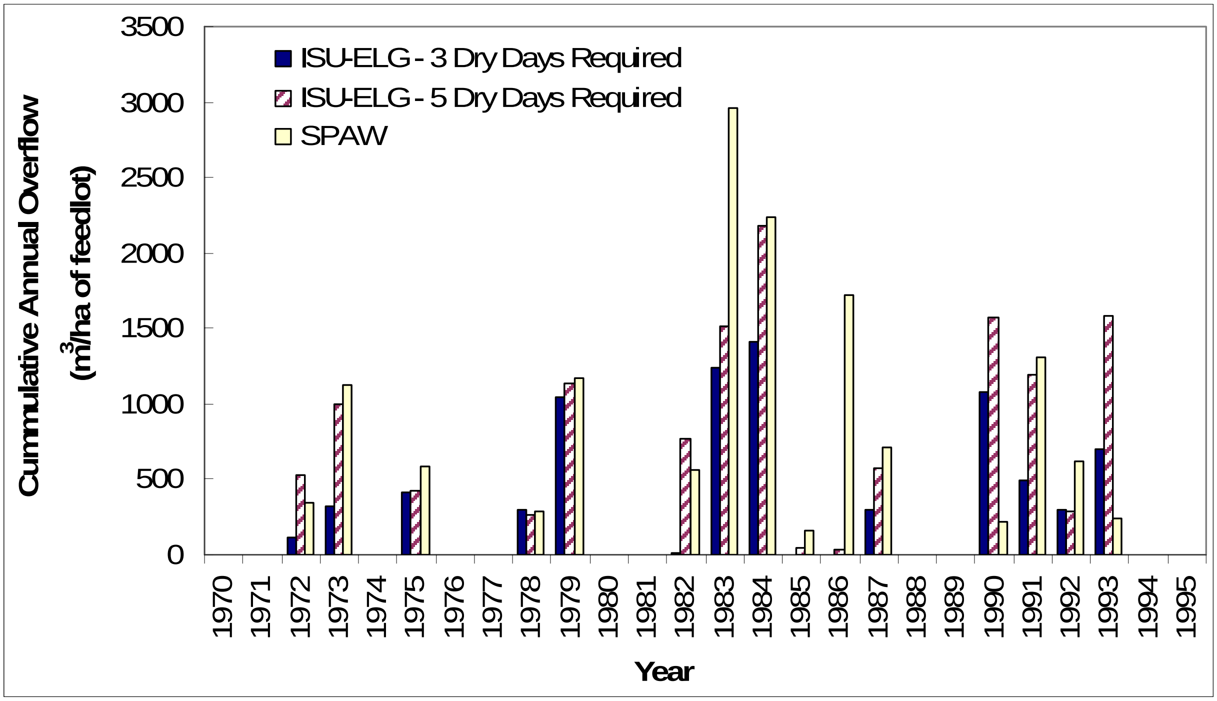

Figure 10. Temporal distribution of basin overflow volumes on a per hectare of feedlot basis for the Sac City, Iowa.

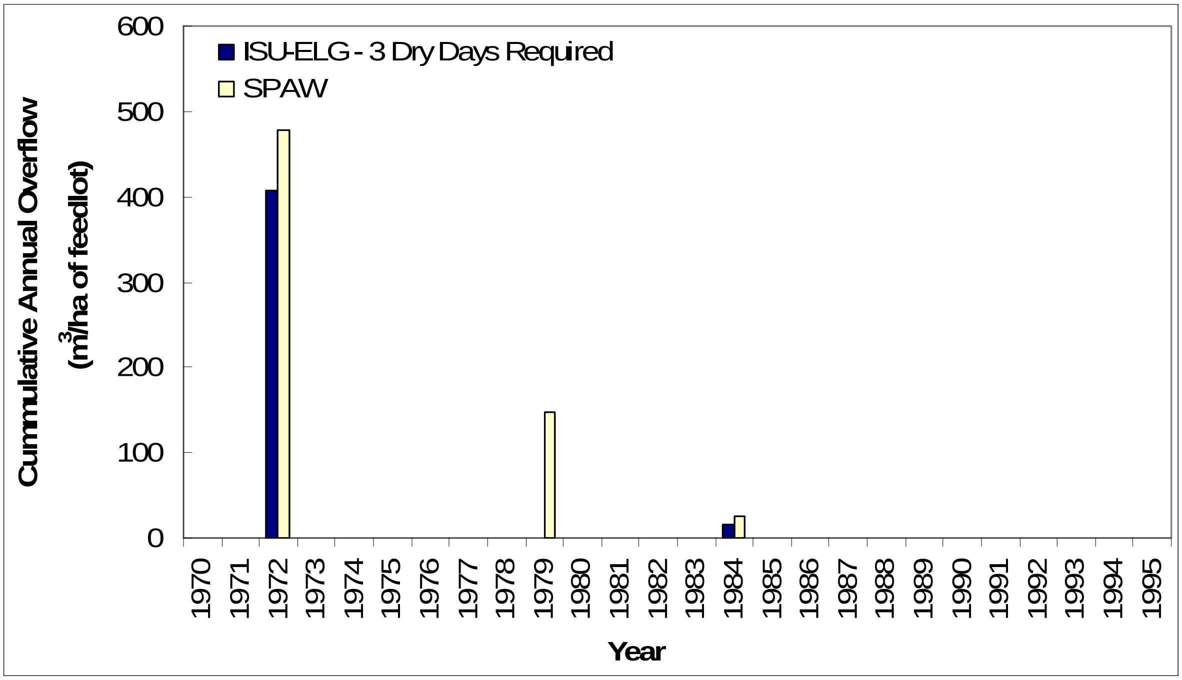

Figure 11. Temporal distribution of basin overflow volumes on a per hectare of feedlot basis for the Sioux City, Iowa.

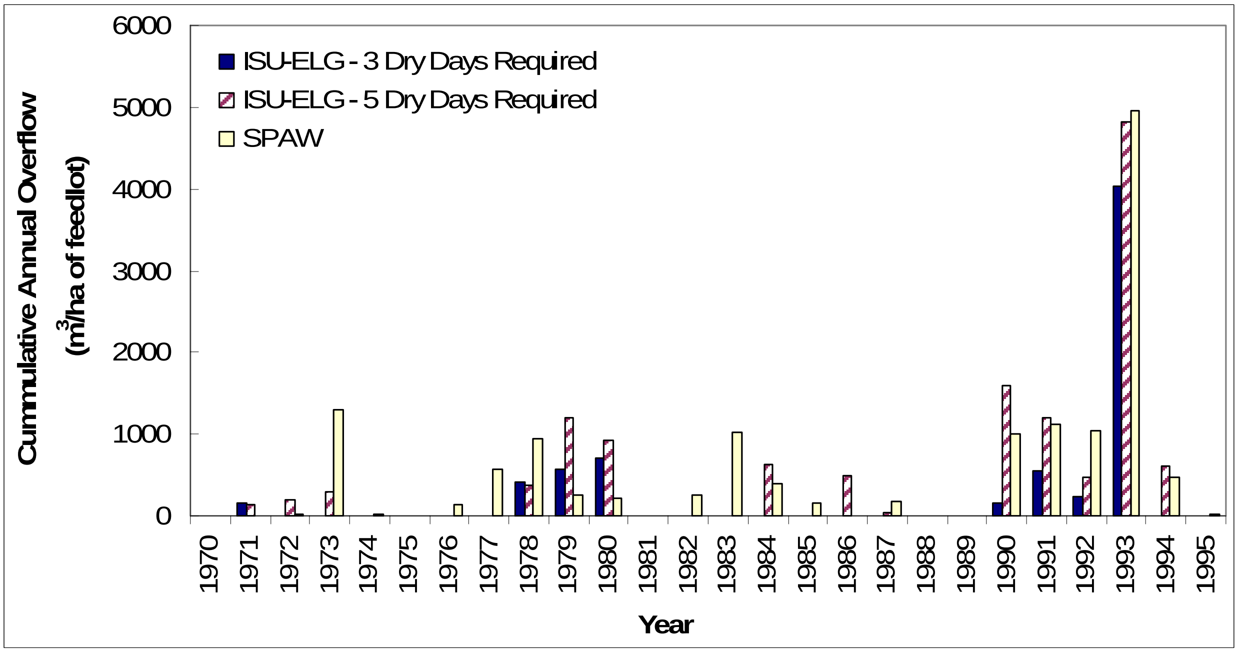

Figure 12. Temporal distribution of basin overflow volumes on a per hectare of feedlot basis for the Waterloo, Iowa.

As recommended by Moriasi (2007), three modeling statistics, along with a graphical comparison, where used to assess the agreement between the two models. The modeling statistics used where the Nash-Sutcliffe efficiency (NSE), the percent bias (PBIAS), and the ratio of the root mean square error to the standard deviation of the SPAW model results (RSR). These statistics were determined for the ISU-ELG model in both calibrated and un-calibrated form. The NSE indicates how well a plot of the observed data versus the modeled fits the one-to-one line (Moriasi, 2007); the NSE is a value between negative infinity and one. A NSE of one means that the models showed a perfect match; any value less than zero would indicate that the use of the mean value of the SPAW model is a better predictor of performance than use of the ISU-ELG model results. The PBIAS measured the average tendency of the ISU-ELG 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 ISU-ELG model would underestimate the volume of overflow and a negative value would indicate the ISU-ELG model overestimates the volume of overflow in comparison to SPAW. The third statistic used is the RSR; the RSR is calculated as the ratio of the root mean square error between the ISU-ELG simulation and the SPAW simulation divided by the standard deviation of the SPAW simulated 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%. The statistics for both the calibrated and un-calibrated ISU-ELG model in comparison to the SPAW simulation are shown in Table 7. Each of these modeling statistics provides an important piece of information about the comparison of these two models. It is important that the models have very little percent bias, as this value provides information on the tendency of the model to either under or over predict the amount of basin overflow. In all cases, both calibrated and un-calibrated, the ISU-ELG model predicts less basin overflow than the SPAW model. The NSE provides information on temporal variation between the two models, values close to one would indicate that the models were predicting similar amounts of release during the same years. Thus the statistic provides information about whether both types of systems are stressed by the same weather patterns. Thus for the case of Sioux City, which has a high NSE, the assumption of commencing land application three days after a precipitation event seems to cause a similar temporal pattern of when basin overflow would occur as that predicted by the soil moisture criterion predicted by SPAW; however, the percent bias indicates that the ISU-ELG model constantly under-predicts the release volume. After calibration, the ISU-ELG model provided satisfactory performance in comparison to SPAW at three locations; at the Sioux City location, the PBIAS is larger than the accepted value. At the Sac City location, the NSE is slightly lower then the suggested value while the RSR is slightly higher; however, this site showed good agreement in the average annual overflow volume. This would imply that after calibration the ISU-ELG model provide good agreement between the average volumes of overflow; but not the desired temporal agreement between the ISU-ELG and SPAW models.

Table 7. The table below shows the Nash-Sutcliffe modeling efficiency, the percent bias, and the root mean square error - standard deviation ratio of the ISU-ELG model in comparison to the SPAW model. These statistics are shown for both the calibrated and uncalibrated ISU-ELG models.

	ISU- ELG Model – Un-calibrated			**ISU-ELG Model - Calibrated**		
Location	**NSE**	**PBIAS**	**RSR**	**NSE**	**PBIAS**	**RSR**
Ames	0.58	46	0.65	0.59	12	0.64
Red Oak	0.75	13	0.50	0.75	13	0.50
Sac City	0.37	46	0.79	0.42	8	0.76
Sioux City	0.89	35	0.34	0.89	35	0.34
Waterloo	0.73	51	0.52	0.79	8	0.46

Conclusions

The ISU-ELG model currently under-predicts the amount of discharge that would occur from a traditional containment structure when compared to the SPAW model for all five locations investigated. At Red Oak and Sioux City, the differences in discharge volumes were relatively minor, while the Ames, Sac City, and Waterloo locations showed large discrepancies. It is believed that the drier climate in Sioux City contributed to soil moisture conditions that make the three dry days before land application assumption appropriate. Over the 26-year simulation period used in modeling runoff containment facility at Sioux City the average yearly rainfall was 66 cm (26 inches), which is very similar to the 72.6 cm (28.6 inches) average for Kansas. This would suggest that Koelliker’s assumptions for when land application is appropriate were justified for the Kansas conditions he developed the model for. Even at the Sioux City location the ISU-ELG model showed a large percent bias, although there was no difference in the percent control reported by the ISU-ELG model and the SPAW model. Red Oak, Iowa, although located in a wetter climate region, had higher evaporation rates and a soil texture in the disposal area that contributed to improved drainage and drying of the soil profile. This increased drying of the soil also made the three-day assumption more appropriate than for other locations around Iowa. For the remaining three locations it was determined that the sites required approximately five days before beginning land application to calibrate the average annual discharges to match the SPAW model.

The sensitivity of the ISU-ELG Model to the criterion of number of dry days required before land application could begin was tested. For most locations it was determined that on average approximately 150 cubic meters of discharge per hectare will be generated for everyday that it takes for the application area to dry to a moisture content that would be fit for land application. The Sioux City simulation showed a much lower sensitivity to the dry day criterion. The Nash-Sutcliffe modeling efficiency was used to compare the ELG model and SPAW model results on yearly annual discharge. The uncalibrated ELG model was found to have a modeling efficiency ranging from 0.37 to 0.89. After calibration, the modeling efficiency was increased to range from 0.42 to 0.89. Therefore, even after calibration, the two models still displayed different temporal patterns of when discharge would occur. In its uncalibrated form the PBIAS statistic ranged from 13-51%, after calibration, this value was improved to 8-35%.

To increase the similarity between the ISU-ELG and SPAW model’s predictions; modification of the ISU-ELG model is required. There are several options available to perform these modifications. One option would be to perform a calibration of the ISU-ELG models to determine the number of dry days required in the ISU-ELG model to make the average annual overflow volume per hectare of feedlot equal to that predicted by the SPAW model; in this manner the ISU-ELG model can be modified to more accurately represent soil moisture conditions. A second alternative would be to develop a scaling factor to adjust the ISU-ELG model average discharge to be equal to the volume predicted by the SPAW model. The advantage of using this method is that it would keep the temporal pattern of basin overflow the same, i.e. the definition of chronic rainfall is not changed from the modification. A third option available would be the use of the SPAW model to determine the amount of basin overflow that would occur. One difficulty in simulating the hydrology of the feedlot waste management system with SPAW is that three simulations must be performed, one for the feedlot surface, one for the land application area, and one for the liquid level in the containment basin. The fourth option available would be to add a soil moisture modeling component to the ISU-ELG model. Making this addition to the ISU-ELG model would allow the entire system to be simulated by a single model run, simplifying the simulation procedure.

Future research will focus on modeling how land application of the feedlot runoff may cause higher amounts of surface runoff and deep percolation in the disposal area. In addition, a study using DrainMOD to model land application of effluent in high water table soils is planned.

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