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Comparison of the Iowa State University Effluent Limitation Guidelines Model with the Soil-Plant-Air-Water Model for Evaluating Containment Basin Performance

Daniel S. Andersen
Iowa State University, dsa@iastate.edu

Robert T. Burns
Iowa State University

Lara B. Moody
Iowa State University

Matthew J. Helmers
Iowa State University, mhelmers@iastate.edu

Robert Horton Jr.
Iowa State University, rhorton@iastate.edu

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Abstract

This article compares results from the Iowa State University Effluent Limitations Guidelines (ISU-ELG) model to results obtained using the Soil-Plant-Air-Water (SPAW) model to simulate feedlot runoff containment basin overflow volume. The objective was to verify that the ISU-ELG model was providing a reasonable prediction of basin overflow. The ISU-ELG model uses a set of guidelines to determine if land application is acceptable, whereas the SPAW model uses a soil moisture criterion. The criterion for determining if a particular day was suitable for land application of basin effluent was investigated to determine the effect on basin overflow volumes. The results show that the ISU-ELG model overpredicted the percentage of feedlot runoff controlled in comparison to the SPAW model at all five locations investigated. For wetter areas in Iowa, the number of drying days had a large effect on basin overflow volumes, whereas for the drier northwest region of Iowa, this effect was limited. Possible methods of improving the ISU-ELG model predictions include adding a soil moisture accounting function to model moisture levels in the land application area or calibrating the number of drying days required before land application can commence. Alternatively, the SPAW model can be used, but this requires additional user inputs and increases complexity in modeling the runoff control system.

Keywords

Containment basin, Effluent Limitation Guidelines model, Feedlot runoff control, SPAW

Disciplines

Agricultural Science | Agriculture | Agronomy and Crop Sciences | Bioresource and Agricultural Engineering

Comments

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COMPARISON OF THE IOWA STATE UNIVERSITY EFFLUENT LIMITATION GUIDELINES MODEL WITH THE SOIL-PLANT-AIR-WATER MODEL FOR EVALUATING CONTAINMENT BASIN PERFORMANCE

D. S. Andersen, R. T. Burns, L. B. Moody, M. J. Helmers, R. Horton

ABSTRACT. *This article compares results from the Iowa State University Effluent Limitations Guidelines (ISU-ELG) model to results obtained using the Soil-Plant-Air-Water (SPAW) model to simulate feedlot runoff containment basin overflow volume. The objective was to verify that the ISU-ELG model was providing a reasonable prediction of basin overflow. The ISU-ELG model uses a set of guidelines to determine if land application is acceptable, whereas the SPAW model uses a soil moisture criterion. The criterion for determining if a particular day was suitable for land application of basin effluent was investigated to determine the effect on basin overflow volumes. The results show that the ISU-ELG model overpredicted the percentage of feedlot runoff controlled in comparison to the SPAW model at all five locations investigated. For wetter areas in Iowa, the number of drying days had a large effect on basin overflow volumes, whereas for the drier northwest region of Iowa, this effect was limited. Possible methods of improving the ISU-ELG model predictions include adding a soil moisture accounting function to model moisture levels in the land application area or calibrating the number of drying days required before land application can commence. Alternatively, the SPAW model can be used, but this requires additional user inputs and increases complexity in modeling the runoff control system.*

Keywords. *Containment basin, Effluent Limitation Guidelines model, Feedlot runoff control, SPAW.*

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 U.S. Environmental Protection Agency (EPA) in charge of developing runoff control guidelines (Anschutz et al., 1979). As a result, the EPA released the Effluent Limitation Guidelines (ELGs), which described the design and operating criteria for concentrated animal feeding operation (CAFO) waste treatment systems (Sweeten et al., 2003). The ELGs historically required collection, storage, and land application of feedlot runoff. In Iowa, the current guideline for CAFO beef feedlot runoff control was written to require removal of all settleable solids and no effluent release resulting from precipitation events less than or equal to the 25-year, 24-hour precipitation event (Iowa DNR, 2007).

Regulations for feedlot runoff control facilities on CAFOs were recently modified to allow the use of alternative treatment systems when performance, based on nutrient mass release, is equivalent to or exceeds that of a containment system (EPA, 2003). Permitting alternative treatment technologies requires a comparison, through site-specific modeling, of the median annual nutrient release from a containment system and the proposed alternative treatment system (EPA, 2006). Additionally, modeling of a containment system is required to evaluate if the installed alternative treatment system is achieving a performance equivalent to the containment basin based on yearly pollutant mass release (EPA, 2008). In Iowa, site-specific 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 Regulations (Iowa DNR, 2007). One containment option available to producers is a basin sized to contain all runoff from the 25-year, 24-hour precipitation event from all contributing drainage areas. For this option, land application of the collected effluent must begin on the first day that conditions are suitable (Iowa DNR, 2007).

Modification of the feedlot runoff regulations to allow use of alternative treatment systems renewed interest in predicting the performance of runoff control systems, as evidenced by the development of models to predict the performance of vegetative treatment systems. Examples of these models include the Iowa State University Vegetative Treatment Area model (ISU-VTA model), the Iowa State University Vegetative Infiltration Basin / Vegetative Treatment Area model (ISU-VIB/VTA model) (Wulf and Lorimor, 2005), and runoff

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The authors are **Daniel S. Andersen, ASABE Member Engineer,** Graduate Research Assistant, **Robert T. Burns, ASABE Member Engineer,** Professor, **Lara B. Moody, ASABE Member Engineer,** Program Manager, and **Mathew J. Helmers, ASABE Member,** Associate Professor, Department of Agricultural and Biosystems Engineering, Iowa State University, Ames, Iowa; and **Robert Horton,** Distinguished Professor, Department of Agronomy, Iowa State University, Ames, Iowa. **Corresponding author:** Daniel S. Andersen, Department of Agricultural and Biosystems Engineering, Iowa State University, 3155 NSRIC, Ames, IA 50011; phone: 515-294-3153; fax: 515-294-4250; e-mail: dsa@iastate.edu.

control system models developed for Kansas (Tolle et al., 2007). Accuracy of the ISU-ELG model to predict containment basin performance is key to alternative treatment system design and installed system evaluation. However, thus far little research has been done to determine if the ISU-ELG model is providing reasonable prediction of the performance that a containment system would achieve, especially under Iowa conditions.

OBJECTIVE

This article compares the modeled basin overflow volumes obtained using the ISU-ELG and Soil-Plant-Air-Water (SPAW) models to simulate a containment basin and land application feedlot runoff control system. This analysis was performed to determine if the ISU-ELG model provides a reasonable prediction of containment basin overflow volumes under Iowa climatic conditions. The analysis was performed for five locations throughout Iowa. At each location, actual site-specific historical weather data were used in modeling system performance. Based on the difference in modeled performance, suggestions are made to improve the ISU-ELG model prediction in comparison to the SPAW model prediction.

BACKGROUND

There is an extensive history of modeling the performance of containment systems on open beef feedlots. This modeling effort can be traced back to the EPA's release of the ELGs in 1972. Shortly after their creation, Koelliker et al. (1975) developed a model to predict runoff control achieved by a containment system designed and operated according to the ELGs. The model was a continuous watershed model that operated on a daily time step and estimated the runoff control provided by the containment basin. The model used the Natural Resource Conservation Service/Soil Conservation Service (NRCS/SCS) curve number method to determine the runoff volume from the feedlot surface. This runoff was then routed into a holding pond. The holding pond volume was simulated using a water balance with inflows of runoff from the feedlot and direct precipitation into the holding pond, and outflows of evaporation, overflow, and land application of effluent. In this model, Koelliker et al. (1975) did not specifically consider the disposal area, but instead created a set of guidelines to determine when land application was appropriate. They (Koelliker et al., 1975) considered land application appropriate if: daily precipitation for each of the three previous days was less than 1.3 mm (0.05 in.), the average daily temperature was above freezing, there was no snow on the ground, the soil was not frozen, and more than 10% of the basin's total volume was filled with effluent. Using this model, Koelliker et al. (1975) demonstrated that a period of chronic rainfall could cause basin overflow. Furthermore, Koelliker et al. (1975) suggested that by including more detailed disposal criteria, their ELG model could be refined.

Wensink and Miner (1975) performed a similar modeling effort to evaluate the effect of chronic rainfall on total containment systems for Oregon locations. They recognized that runoff events in Kansas represented mainly catastrophic rainfall events, whereas in western Oregon chronic rainfalls characterized the climate. In their investigation, Wensink and Miner (1975) noted the amount of overflow, the date, and the precipitation that caused this overflow. Based on these data, the legality of the overflow was determined, i.e., if it was caused by a storm event of equal or greater magnitude than the 25-year, 24-hour event. This allowed them to determine that many of the overflows were caused by events of lesser magnitude than the 25-year, 24-hour event. Based on the results of the study, they designed a second model that used what they termed the "sufficient design technique" to help size containment structures to prevent basin overflow from events of lesser magnitude than the 25-year, 24-hour storm. This was done by adjusting the basin size iteratively throughout the model run whenever a containment basin overflow occurred.

Based on these earlier modeling attempts, Zovne et al. (1977) developed a model that took into account the soil moisture in the disposal area. They considered the disposal area to be a soil-water reservoir that was recharged by both precipitation and land application, and depleted by evapotranspiration and deep drainage. There were three components in this model: the feedlot surface, which generated the runoff effluent; the effluent wastewater storage facility, which modeled the holding pond level; and the disposal area, which performed a soil moisture accounting procedure and 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 this analysis, a percentage of available moisture in the root zone above 90% was the threshold value for delaying land application. Anschutz et al. (1979) used the Zovne et al. (1977) model to study important variables in designing runoff control systems. For irrigation disposal systems, they found that moisture deficit was the most important factor. Moisture deficit was defined as the difference between the mean evaporation from a lake and the annual precipitation.

Recent interest in modeling holding pond performance has been provided by Wulf et al. (2003), who created the ISU-ELG model to determine the performance of a containment system under Iowa conditions. The ISU-ELG model was developed as a modified version of the Koelliker et al. (1975) model. The ISU-ELG model was written to operate on a daily time step, with runoff volumes from the contributing drainage area calculated using the NRCS/SCS curve number method. This flow was then routed into a containment basin. The flow entering the basin was modeled with concentrations of 65 mg L^{-1} of total Kjeldahl nitrogen, 60 mg L^{-1} of NH_3-N, 20 mg L^{-1} of total phosphorus, 2,000 mg L^{-1} of total suspended solids, and 2,650 mg L^{-1} of chemical oxygen demand, as suggested by Wulf and Lorimor (2005). These concentrations were used to calculate the mass of specific parameters entering the basin. The concentrations of the parameters in the basin were then adjusted to account for both water loss due to evaporation and water addition from rainfall directly into the containment basin. Although not accounted for in this model, these concentrations would be subject to change during containment in the basin. For instance, ammonia-nitrogen could be lost due to volatilization, solids and phosphorus could settle out of suspension during containment, and COD could be lost by degradation of organic matter in the effluent. The adjusted concentration was used to determine the mass of specific parameters 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 et al. (1975) for determining when land application was appropriate. These guidelines were deemed appropriate for Kansas climatic conditions, but no effort was made to verify these assumptions for Iowa climate conditions.

The Soil-Plant-Air-Water (SPAW) model was developed by Saxton et al. (2006) to simulate the daily hydrology of agricultural fields and ponds, including waste containment structures. Moffitt et al. (2003) performed a comparison of SPAW and the NRCS Animal Waste Management (AWM) program to test the temporary storage component of AWM. In this analysis, AWM was used to size the temporary storage component of the basin. Moffitt et al. (2003) then used SPAW to examine the basin performance on a daily time step. In a separate study, Moffitt and Wilson (2004) utilized SPAW to model the pond levels in four wastewater storage ponds located on dairies in Oregon. The watershed areas ranged from 232 to 11,655 m^2 (0.06 to 2.88 acres) for these holding ponds. In this study, Moffitt and Wilson (2004) demonstrated good agreement between the SPAW modeled levels and the experimentally determined levels as evidenced by the high Nash-Sutcliffe modeling efficiency (0.9) and the low bias (<1%) of the model results (model statistics were calculated based on the results for dairy one in the Moffitt and Wilson, 2004, study). Deviations between the modeled and monitored results were possibly caused by issues such as operators deviating from their waste management plans, inaccuracies in containment structure level measurement, or differences in actual and modeled manure and wastewater inputs (Moffitt and Wilson, 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 and Wilson (2004) stated that a model is only as good as the operators' ability to follow their operating/nutrient management plans. Moffitt and Wilson (2004) also pointed out that there were several factors that affect application time, including the field conditions on which the containment structures contents were to be applied, and the application time in relation to the crops nutrient demand.

Given that actual system performance was noted to be directly related to management decisions made by the farmer, it has become very important to define a reasonable management plan that the operator could 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. The guidance document on holding pond operation specifies that land application must occur on all dewatering days until the available holding pond capacity is able to contain all runoff from a 25-year, 24-hour event (NDEQ, 2005). A dewatering day is defined as a day with weather and soil conditions suitable for land application of livestock wastes (NDEQ, 2003). Proper soil conditions are defined 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 (NDEQ, 2003). This idea of manure application timing based on soil moisture was also recommended to producers by the *Wisconsin Agriculturist* (Hanson, 2007) and *Hoard's Dairyman* (Weisenberger and Madison, 2007). Hanson (2007) discussed the effect of soil texture on the moisture holding capacity of soil and recommended keeping a moisture budget to determine if effluent application is acceptable. Weisenberger and Madison (2007) extended the analysis, stating that no application of manure should occur when the moisture content in the top 10 cm (4 in.) exceeds 35% due to the risk of runoff.

As stated previously, Moffitt and Wilson (2004) reported the use of SPAW in modeling the depth of effluent in a containment basin. In their investigation, Moffitt and Wilson (2004) assumed that the containment basin would be completely emptied during the non-critical storage period. This made it easier to model the performance of the containment basin, as conditions in the land application area did not need to be modeled. More recently, Saxton and Willey (2004) reported an update to the SPAW model that allows the user to perform an irrigation budget for a field. The irrigation budgeting could be used to determine when effluent application onto the application area would be appropriate from a soil moisture standpoint.

MATERIALS AND METHODS

The ISU-ELG and SPAW models were used to model the performance of traditional containment basin runoff control systems on five hypothetical feedlots located throughout Iowa. These hypothetical feedlots were located in Ames, Red Oak, Sac City, Sioux City, and Waterloo (fig. 1). The containment basin was sized to hold all feedlot runoff and direct rainfall resulting from a 25-year, 24-hour storm at all locations. The storm sizes for the five locations ranged from 125 to 130 mm, while average precipitation ranged from 660 to 920 mm (table 1).

Along with the average annual precipitation and evapotranspiration, it is also important to consider the inter-storm time periods, as this is when effluent application would occur. On average, the locations had between 256 and 270 dry days per year (table 2). However, only 112 to 137 days are part of

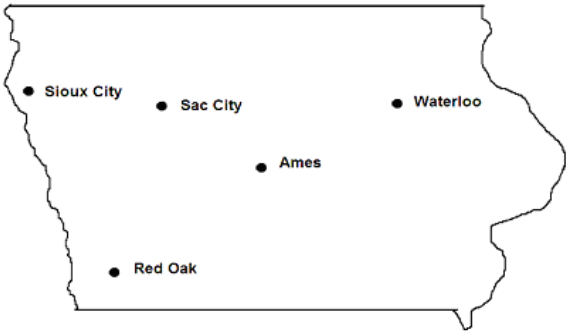

Figure 1. Locations in Iowa of the five hypothetical feedlots used in the simulation.

Table 1. 25-year, 24-hour storm size, average annual precipitation, and average annual evapotranspiration for five locations in Iowa. Averages ±1 standard deviation are shown for precipitation and evapotranspiration depths over the 26-year modeling period.

Location	25-year, 24-hour Storm Size (mm)	Annual Precipitation (mm)	Annual Evapotranspiration (mm)
Ames	130	890 ±230	730 ±30
Red Oak	130	920 ±220	720 ±30
Sac City	130	850 ±200	700 ±30
Sioux City	125	660 ±140	700 ±30
Waterloo	127	840 ±190	660 ±30

Table 2. Number of dry days per year for each of the five locations.

	Length of Dry Day Interval					
Location	1 Day	2 Days	3 Days	4 Days	5 Days	6 Days
Ames	270	213	170	137	112	91
Red Oak	266	206	161	127	101	81
Sac City	267	210	168	135	109	88
Sioux City	266	208	164	130	104	83
Waterloo	256	193	146	112	86	66

a four-day dry interval, indicating that if three to four days of drying are required before effluent application is appropriate, then the opportunity for effluent application has been reduced by half. Furthermore, these data indicate that while Sioux City has approximately the same number of precipitation events as the wetter locations, the events are smaller in general. Also of note are the substantially fewer three-, four-, five-, and six-day dry intervals in Waterloo than in the other locations.

The ISU-ELG model was developed by Wulf and Lorimor (2005). This model was based on the Koelliker et al. (1975) effluent limitations guideline model and used many of the same procedures to determine the performance of a runoff containment basin. The ISU-ELG model required user inputs of weather, feedlot, and containment basin parameters (table 3). Weather inputs included daily minimum and maximum temperatures, the daily precipitation depth, the daily pan evaporation, and the pan coefficient. Feedlot parameters included the area of the feedlot, the slope (in percent) of the feedlot surface, the direction that the feedlot slope faces, and the length-to-width ratio of the feedlot. The containment basin was designed based on the expected runoff volume and direct rainfall from the 25-year, 24-hour storm event. Additional inputs for the containment basin included depth, pumping rate, hours of pumping per day, and the number of days after a rainfall event before pumping can begin, i.e., the number of drying days required before land application can commence.

Table 3. Model inputs required by the ISU-ELG and SPAW models to simulate the containment basin runoff control system.

ISU-ELG Model Inputs	SPAW Model Inputs
Weather	
Daily max. temperature	Daily max. temperature
Daily min. temperature	Daily min. temperature
Daily precipitation	Daily precipitation
Daily potential evaporation	Daily potential evaporation
Pan evaporation coefficient	
Feedlot	
Feedlot area	Feedlot area
Surface type (earthen/concrete)	Surface curve number
Slope and slope direction	
Aspect ratio (length/width)	
Containment Basin	
Design storm size	Stage-storage rating
Pumping rate	Spillway height
Hours of pumping per day	Irrigation stop pumping limit (lower limit)
Land Application Area	
	Area
(Not applicable)	Soil layer thicknesses
	Soil texture by layer
	When to land apply
	How much to land apply

In the ISU-ELG model, the NRCS/SCS curve number method was used to determine the runoff volume from the feedlot surface. A volume balance was then performed to determine the volume of effluent in the containment basin. Terms in this volume balance included inflows of runoff from the feedlot surface and direct rainfall into the containment basin. Outflows included evaporation from the containment basin (estimated as the product of potential evaporation, the pan coefficient, and the surface area of the effluent in the basin) and the amount of effluent land applied. One limitation of the ISU-ELG model is that it does not explicitly model what is occurring in the land application area. Instead, it uses a set of criteria to determine if land application is acceptable. These criteria are that the average daily temperature is above freezing, the average temperature over the three previous days was greater than 3.3°C (38°F), the feedlot is free of snow, there was no rainfall today, there was less than 1.3 mm (0.05 in.) of rainfall during the required number of drying days, and the basin contains more effluent than can be land applied in one day. Effluent application is not limited based on the presence or absence of a crop, but in general over 90% of effluent is applied between 1 April and 1 November, i.e., during the typical growing season. If land application is predicted by the model to occur, then the amount of effluent land applied is equal to the product of the pumping rate and the hours of pumping per day. For the ISU-ELG simulations, land application was modeled to proceed at a rate of one-tenth of the total containment basin volume per day, as suggested in Appendix A of the Iowa CAFO/AFO Regulations (Iowa DNR, 2007), until either rainfall occurred or less than one-tenth of the basin volume was filled with effluent. The amount of basin overflow was normalized at each site as average annual quantity of overflow per hectare of feedlot area.

As mentioned, the SPAW model was created by Saxton et al. (2006) and can be used to simulate the hydrology of waste containment systems. For this study, the SPAW model was used to simulate all parts of the feedlot hydrologic system, including runoff from the feedlot, storage in a containment basin, and land application of the runoff effluent. Three runs of the SPAW model were required to perform a simulation of the containment basin runoff control system. These runs were a field simulation of the feedlot surface to determine runoff volumes, a field simulation of the land application area to develop the land application schedule, and a pond simulation to determine the volume of overflow from the containment basin. Weather data used in these simulations included daily minimum and maximum temperatures, daily precipitation depth, and daily evaporation. To simulate the runoff volume from the feedlot, several input files needed to be created. These included a management plan for the feedlot surface and a soil file that provided soil layer thicknesses and textures. Additionally, an NRCS/SCS curve number had to be provided to calculate the runoff volume. The curve number entered into the SPAW model for these simulations was the same as the value programmed into the ISU-ELG model, i.e., 91 for an earthen feedlot under normal antecedent moisture conditions (AMC II).

The land application area was modeled in SPAW with the use of the SPAW field module. Modeling the land application area required several additional input variables, including the soil texture in the land application area, a management plan for when and how much effluent to land apply, and the rooting depth of the crop. For this analysis, the rooting depth was as-

Table 4. Soil textures and layer thickness in the five land application areas.

	Ames		Red Oak		Sac City		Sioux City		Waterloo	
Layer	Depth (cm)	Texture[a] (% S, Si, C)	Depth (cm)	Texture[a] (% S, Si, C)	Depth (cm)	Texture[a] (% S, Si, C)	Depth (cm)	Texture[a] (% S, Si, C)	Depth (cm)	Texture[a] (% S, Si, C)
1	0-33	L (40, 34, 26)	0-33	SiCL (3, 65, 32)	0-33	L (40, 35, 25)	0-38	SiCL (5, 62, 33)	0-30	L (36, 41, 23)
2	33-76	L (40, 37, 23)	33-69	SiCL (3, 65, 32)	33-76	L (41, 35, 24)	38-109	SiL (4, 75, 21)	30-94	SiCL (45, 27, 28)
3	76-101	L (42, 39, 19)	69-163	SiCL (4, 68, 28)	76-101	L (43, 38 ,19)	109-137	SiL (22, 57, 21)	94-127	L (46, 30, 24)
4	101-244	L (50, 35, 15)	163-244	SiL (4, 70, 26)	101-244	L (50, 35, 15)	137-211	SiL (9, 68, 23)	127-241	SL (54, 31, 15)

[a] S = sand, Si = silt, C = clay, L = loam, SiCL = silty clay loam, SiL = silty loam, SL = sandy loam.

sumed to be 1.2 m (4 ft) at all locations. These simulations were performed such that land application occurred whenever the moisture level in the root zone reached 95% of the field capacity. The amount of irrigation supplied replenished the moisture content of the root zone up to field capacity. For all five locations, it was assumed that the land application area would be planted to corn, and land application could occur regardless of the crop size, i.e., land application was only limited by the soil moisture. Based on the supplied soil texture, SPAW calculated additional hydraulic soil properties such as the soil-water retention curve, the hydraulic conductivity, and the bulk density of the soil. A representative soil for each of the five locations was determined by use of the USDA web soil survey applet. Soil texture information, along with thicknesses of the soil layers, was entered into the SPAW model (table 4). The water balance for the field simulated all major hydrologic processes, including runoff, infiltration, land application, evapotranspiration, soil water redistribution, and percolation. The daily runoff for the field was estimated with the use of the NRCS/SCS curve number method. Infiltration was calculated as the difference between the daily rainfall depth and the daily runoff depth (Saxton et al., 2006). Evapotranspiration was calculated as the product of the crop coefficient, estimated by the SPAW model, and the daily potential evaporation. Soil water redistribution and percolation were estimated using Darcy tension-conductivity methods.

The final model run was of the containment basin and was simulated with the use of the pond model. Inputs for this model run included the previously mentioned weather data, stage-storage dimensions of the containment basin, depths of pond inlets and outlets, and sizes of the feedlot and land application areas. For these simulations, stage-storage dimensions of the containment basin were entered to replicate the basin geometry used in the ISU-ELG model. In these simulations, the basin could be completely emptied, i.e., there was no minimum treatment volume required to remain in the containment structure. Processes simulated by the pond module included side slope runoff into the basin, rainfall into the basin, evaporation, spillway overflow, and irrigation from the pond onto the land application area. Side slope runoff was calculated with the NRCS/SCS curve number method, surface rainfall was the volume of rainfall falling directly on the ponded surface, and evaporation was calculated using the evaporation data from the weather file and the surface area of the effluent. Irrigation from the pond was calculated based on the schedule developed for the previously modeled land application area and the size of the land application area.

The first investigation was a sensitivity analysis of the ISU-ELG model to the number of dry days required after a precipitation event before land application could proceed. In the ISU-ELG model, this variable was determined to be equivalent to setting the soil moisture at which land application was considered appropriate. In the ISU-ELG model to date, a value of three days has typically been used, based on guidelines suggested by Koelliker et al. (1975) for their original containment basin model used in Kansas. The sensitivity of the model to this assumption was investigated for the five hypothetical feedlots across the state of Iowa. Each of the simulations was performed for a 26-year period, 1970 through 1995, using actual site-specific historical weather data. This time period was chosen because complete weather files for all five locations were available. In addition, as current National Pollution Discharge Elimination System (NPDES) permit requirements state that comparison between alternative-technology runoff control systems and a containment basin must utilize at least 25 years of weather data (Moody et al., 2006), a period of at least this length was required. It is also believed that this 26-year period is representative of the climate of the region. The model was run ten times at each location, varying the number of dry days required before land application could begin. A regression line was fitted to the average annual overflow volume to assess the ISU-ELG model's sensitivity to the dry-day requirement.

Each of these waste management systems was also simulated using the SPAW model. Again, each of the simulations was run for a 26-year period, 1970 through 1995, using site-specific historical weather data. The model was run repeatedly at each location with varying land application area dimensions. The average annual overflow from the containment basin was normalized by dividing by the feedlot area.

The results of both modeling efforts were compared to determine if the original hypothesis of beginning land application three days after a precipitation event was a reasonable management plan based on the soil moisture in the application area. As recommended by Moriasi et al. (2007), three modeling statistics, along with a graphical comparison, were used to assess the agreement between the two models. The modeling statistics used were the Nash-Sutcliffe efficiency (NSE), the bias, and the ratio of the root mean square error to the standard deviation (RSR) of the SPAW model results. These statistics were determined for the ISU-ELG model in both calibrated, i.e., with a site-specific number of drying days, and uncalibrated forms. Data comparisons were made on an annual basis. The NSE was used to indicate how well a plot of the observed data versus the modeled values matched the one-to-one line (Moriasi et al., 2007). The NSE was developed to have a value between negative infinity and one. An NSE of one indicated that the models showed a perfect match. Values less than zero indicated that the use of the mean value of the SPAW model was a better predictor of performance than the ISU-ELG model results. The bias measured the average tendency of the ISU-ELG simulated data as compared to the SPAW simulated data. In this case, a value of zero indicated that the two models predicted similarly, a positive value indicated that the ISU-ELG model underestimated the volume of overflow, and a negative value indicated the ISU-ELG model overestimated the volume of overflow in comparison to SPAW. The third statistic used was the RSR, which was 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 et al., 2007). This statistic was developed to have a range of zero to positive infinity, with the optimum value being zero. Moriasi et al. (2007) provided guidelines for when these statistics indicate satisfactory model performance. Their suggestion for flow modeling was NSE > 0.50, RSR < 0.70, and bias of less than ±25%. If two models predicted different volumes of basin overflow, then the number of dry days required before land application could begin was adjusted to calibrate the ISU-ELG model so that the average annual overflow volume per hectare of feedlot predicted was similar to the SPAW model simulation.

RESULTS AND DISCUSSION

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 adjusted (fig. 2). The Ames, Red Oak, Sac City, and Waterloo locations showed the same general trend of increasing basin overflow volume when more time was required before land application could begin. Sioux City also showed a trend of increasing overflow volume, but to a much lesser extent than the other four locations. The assumption of the time required for the land application area to dry before effluent application could begin had a pronounced effect on runoff control for the majority of Iowa (fig. 2). The model's sensitivity to this variable made it important to accurately choose the number of dry days required before land application began.

A regression analysis was used to quantify how system performance changed with the number of dry days required before land application could begin. For the Ames location (fig. 3a), the analysis showed that for every day of drying required before land application commenced, on average an extra 163 cubic meters of basin overflow per year per hectare of feedlot would occur, whereas for Sac City (fig. 3b) on average an extra 143 cubic meters of basin overflow per year per hectare of feedlot would occur. The results obtained for Red Oak and Waterloo were similar to those for Ames and Sac

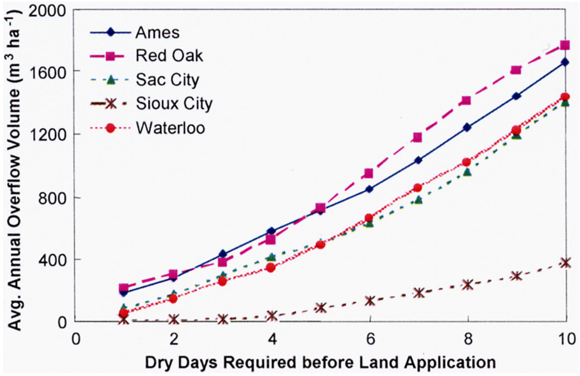

Figure 2. Sensitivity of the ISU-ELG model to the number of dry days required before land application could begin for five locations in Iowa.

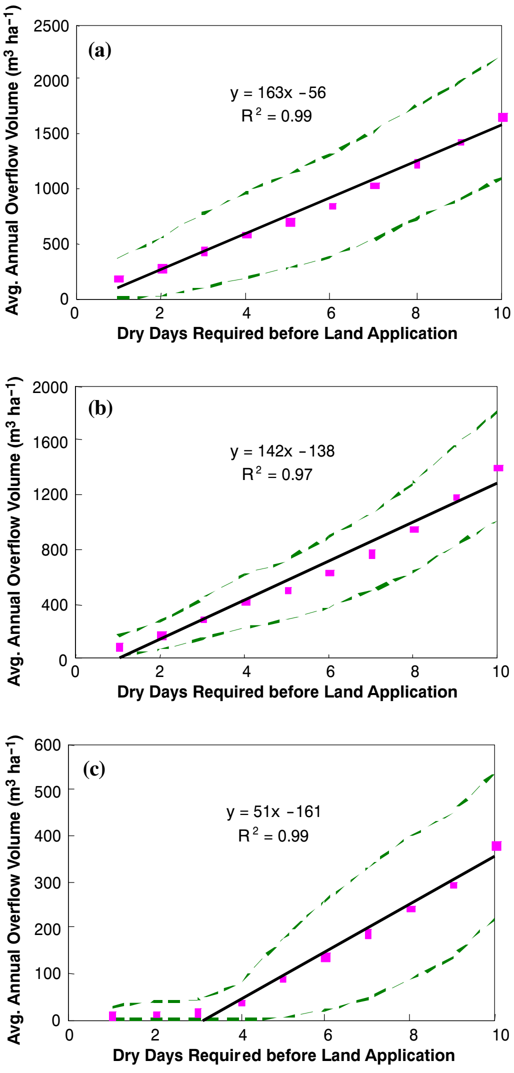

Figure 3. Regression analysis to determine the sensitivity of the ISU-ELG model to the number of dry days required before land application could begin: (a) Ames, (b) Sac City, and (c) Sioux City. Dashed lines represent 90% confidence intervals of the average annual overflow volume per hectare of feedlot. Data points with a solid regression line represent the average annual overflow volume per hectare of feedlot.

Table 5. Sensitivity coefficient of the ISU-ELG model to the number of dry days required before land application could begin.

Location	Overflow Volume,[a] m^3 overflow per hectare (ft^3 overflow per acre)
Ames	163 (2,332)
Red Oak	184 (2,632)
Sac City	143 (2,036)
Sioux City[b]	51 (734)
Waterloo	155 (2,211)

[a] m^3 overflow per hectare (ft3 overflow per acre) of feedlot per year per dry day required before land application.

[b] Only the data for three through ten required dry days were considered in calculating the sensitivity coefficient.

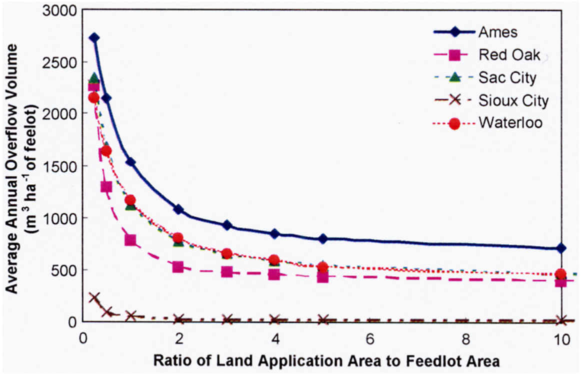

Figure 4. Sensitivity analysis of a containment basin, as predicted by the SPAW model, to the ratio of land application area to feedlot area for five locations in Iowa.

City, with 184 and 155 additional cubic meters of overflow per year per hectare of feedlot occurring, respectively. The result from the regression analysis for Sioux City was quite different from that of the other locations (fig. 3c). 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. At the Sioux City location, the temporal pattern of rainfall consisted of larger storms with a longer period between the storms in comparison to the other sites. Sensitivities to the dry-day requirement ranged from 51 to 184 m^3 ha^{-1} of feedlot (table 5).

For the SPAW analysis the performance of the runoff control system was a function of the land available for application of the feedlot runoff, since a larger area would allow application of more effluent every time the disposal criteria were reached. Ames, Red Oak, Sac City, and Waterloo again showed a similar trend in response to the land application area available (fig. 4). 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 had 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 was a relatively small increase in system performance for increasing the application area. This was because at a certain point in each case the performance of the system was no longer limited by the size of the applica-

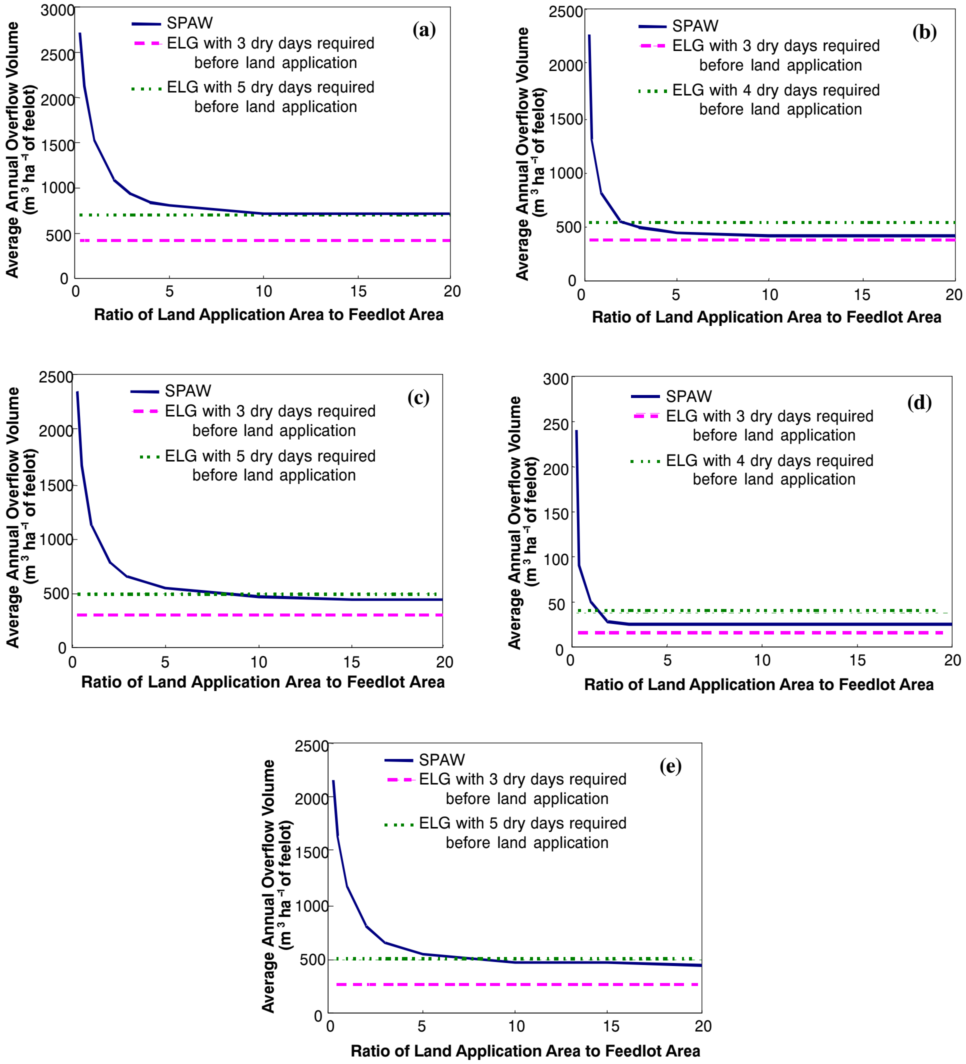

Figure 5. Calibration of ISU-ELG model dry-day requirement to match SPAW predicted performance: (a) Ames, (b) Red Oak, (c) Sac City, (d) Sioux City, and (e) Waterloo.

tion area, but was instead limited by the temporal pattern of soil moisture in the land application area. Due to the drier climate in northwestern Iowa (table 1), a smaller application area was required per hectare of feedlot surface than in the areas that received more rainfall and therefore naturally maintained a wetter soil profile.

As mentioned previously, the ISU-ELG model was originally developed based on the model that Koelliker et al. (1975) developed for predicting containment basin performance in Kansas. In that model, Koelliker et al. (1975) assumed that land application would be possible three days after a rainfall event based on Kansas conditions. The ISU-ELG model had never been calibrated, and no adjustments had been made for Iowa conditions. A comparison between the performances predicted by the SPAW model and the ISU-ELG model has provided some insight into how well the assumption of three days before land application fits Iowa conditions. Based on these results and using the SPAW results as the measure of comparison, it was 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 based land application timing on the modeled soil moisture. This calibration is shown for Ames, Red Oak, Sac City, Sioux City, and Waterloo (fig. 5). The calibrations were made on the average annual overflow volume per hectare of feedlot. For Ames, waiting approximately five days after the rainfall before land application made the average annual overflow volumes equivalent. For Sac City, between four and five days made the modeling procedures equivalent, with a similar result for Waterloo. Sioux City and Red Oak both had relatively good agreement when the release day criterion was left at three dry days before land application. This was caused by the substantially drier climate around Sioux City; the annual precipitation at this location was 66 cm (26 in.), which is similar to the 72.6 cm (28.6 in.) of precipitation averaged in Kansas. In addition, the similarity between the SPAW and ELG model results for Red Oak appear to be due to improved drainage in the soils typical of this region. The results of the calibrated number of dry days required to obtain results similar to the SPAW model ranged from three to five (table 6). The amount of overflow projected by the ISU-ELG model was not a function of the land application area available, as this model assumed that sufficient land area would be available to land apply 10% of the total containment basin volume every time the land application criteria area were met. The SPAW model actually simulated soil moisture in the land application area; thus, the land application area plays a key role in system performance, as the volume of effluent that could be land applied was a function of the size of the land application area and the soil moisture status in this area.

A second way to analyze these results was to compare the predicted average annual yearly overflow volumes for both the SPAW and ISU-ELG models (table 7). For most of Iowa, the SPAW model predicted 1.5 times the effluent overflow volume predicted by the ISU-ELG model when the three drying day criterion was used. The exception to this was Red Oak, where SPAW only predicted 1.1 times as much annual overflow as the ISU-ELG model. It should also be noted that the ratio of the two predictions for Sioux City was 1.5. In this case, the overflow volumes predicted by both models were small. This large ratio was a result of the small overflow volumes predicted for this location. This can be verified by examining the percentage runoff control predicted at each location (table 8). There was almost no difference in the percentage of runoff controlled at both Red Oak and Sioux City, whereas for Ames, Sac City, and Waterloo, a sizeable difference in the predicted control was seen in the SPAW model predictions as compared to the ISU-ELG model. Moreover, the results (tables 7 and 8) provided a chance to investigate how effective a containment basin designed to hold all runoff from a 25-year, 24-hour storm was at controlling feedlot runoff. As can be seen, the ISU-ELG model projected between 16 and 436 m^3 of overflow per hectare of feedlot area per year, whereas the SPAW model projected between 25 and 704 m^3 of overflow. This amounts to 86% to 99% runoff control projected by the ISU-ELG model and 78% to 99% by the SPAW model. As can be seen, although the same design standard was used throughout the state, i.e., containing all feedlot runoff and direct precipitation from a 25-year, 24-hour storm, the level of performance could vary greatly, as could the average annual yearly overflow volume.

The ISU-ELG model could also be modified by using the ratio of basin overflow projected by the SPAW and ISU-ELG models as a multiplication factor to correct the ISU-ELG model's predicted annual overflow. 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 equal to the average annual release volume simulated by SPAW.

A comparison between the original ISU-ELG model with the three dry-day criterion, the calibrated ISU-ELG model

Table 6. Calibrated number of dry days required to match ISU-ELG and SPAW model predictions of effluent release.

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

Table 7. Comparison of the average annual 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.

	Average Annual Yearly Overflow (m^3 ha^{-1} of feedlot)		Ratio of SPAW Prediction to ISU-ELG Prediction
Location	Predicted by ISU-ELG Model	Predicted by SPAW Model	
Ames	436	704	1.6
Red Oak	388	416	1.1
Sac City	297	445	1.5
Sioux City	16	25	1.5
Waterloo	264	455	1.7

Table 8. Percent runoff control as predicted by the ISU-ELG and SPAW models for each of the five locations.

Location	ELG Model (%)	SPAW Model (%)
Ames	86	78
Red Oak	89	88
Sac City	90	85
Sioux City	99	99
Waterloo	90	83

(with an adjusted number of drying days), and the SPAW model results on a year-by-year basis was made. Even the calibrated ISU-ELG model did not follow the same temporal pattern as SPAW in predicting when basin overflows would occur. Only a slight improvement in the temporal distribution of when the runoff occurred was realized from calibration of the ISU-ELG model to the SPAW model. For Sac City, the uncalibrated ISU-ELG model predicted basin overflow for 13 out of the 26 years, after calibration basin overflow was predicted in 15 of the 26 years (fig. 6). The SPAW model also projected basin overflow in 15 of the 26 years modeled. For Sioux City, the ISU-ELG model predicted two years with overflows, while the SPAW model projected three years with overflows. According to both models, most of the projected overflows occurred in 1972 (fig. 7). In 1979, SPAW projected almost 148 m^3 of basin overflow, while the ISU-ELG model predicted no overflow. 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 period because the precipitation events occurred more than three days apart, which allowed dewatering of the containment basin. For Waterloo (fig. 8), 1993 accounted for a large portion of the overflow volume in all three modeling scenarios. For Waterloo, the original ISU-ELG model projected eight years with an overflow; after calibration, 14 years had an overflow. The SPAW model projected 19 years with an overflow for this site.

Modeling statistics for both the calibrated and uncalibrated ISU-ELG model in comparison to the SPAW simulation are shown in table 9. Each of these modeling statistics provided an important piece of information about the comparison of these two models. It was important that the models had very little bias, as this value provided information on the tendency of the model to either under- or overpredict the amount of basin overflow. In all cases, both calibrated and uncalibrated, the ISU-ELG model predicted less basin overflow than the SPAW model. The NSE provided information on temporal variation between the two models. Values close to one indicate that the models predicted similar amounts of release during the same years. Thus, the statistic provided information about whether both models predicted that the system was stressed by the same weather patterns. For Sioux City, which had a high NSE, the assumption of commencing land application three days after a precipitation event seemed to cause a similar temporal pattern of when basin overflow would occur as that predicted by the soil moisture criterion calculated by SPAW; however, the bias indicated that the ISU-ELG model constantly underpredicted the release volume. After calibration, the ISU-ELG model provided satisfactory performance in comparison to SPAW at three locations. At Sioux City, the bias was larger than the accepted value. At Sac City, the NSE was slightly lower than the suggested value while the RSR was slightly higher; however, this site showed good agreement in the average annual overflow volume. Overall, these results implied that, after calibration, the ISU-ELG model provided good agreement between the average volumes of overflow, but without the desired temporal agreement between the ISU-ELG and SPAW models.

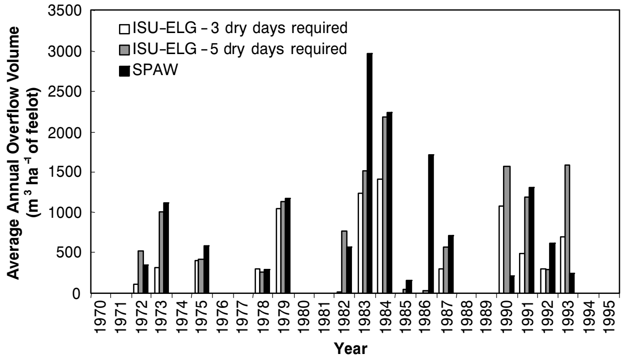

Figure 6. Temporal distribution of basin overflow volumes for Sac City, Iowa.

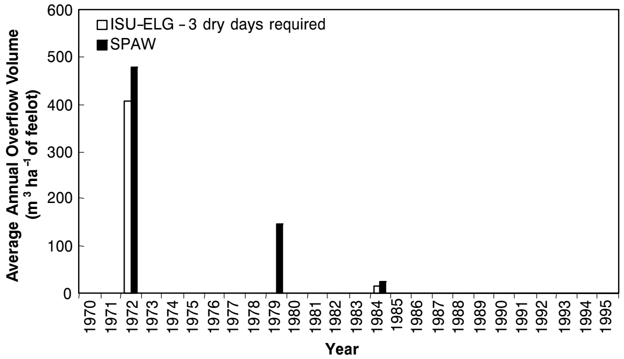

Figure 7. Temporal distribution of basin overflow volumes for Sioux City, Iowa.

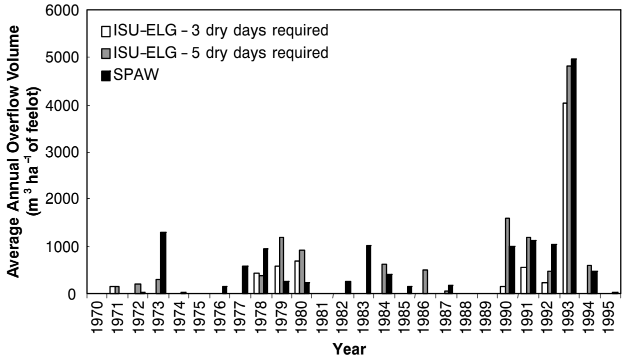

Figure 8. Temporal distribution of basin overflow volumes for Waterloo, Iowa.

Table 9. Nash-Sutcliffe modeling efficiency (NSE), bias, and the root mean square error to standard deviation ratio (RSR) of the ISU-ELG model in comparison to the SPAW model. Statistics are shown for both the calibrated and uncalibrated ISU-ELG models. Bold values indicate satisfactory model performance.

	Uncalibrated ISU-ELG Model			Calibrated ISU-ELG Model		
Location	NSE	Bias	RSR	NSE	Bias	RSR
Ames	**0.58**	46	**0.65**	**0.59**	**12**	**0.64**
Red Oak	**0.75**	**13**	**0.5**	**0.75**	**13**	**0.5**
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**
Satisfactory performance	>0.5	<±25%	<0.7	>0.5	<±25%	<0.7

CONCLUSIONS

The current ISU-ELG model underpredicted the amount of overflow that occurred 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 overflow 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 made 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 in.), which was very similar to the 72.6 cm (28.6 in.) average for Kansas. This suggested that the assumptions that Koelliker et al. (1975) made for timing of land application were appropriate for the dryer Kansas climatic conditions for which the model was developed. Even at the Sioux City location, the ISU-ELG model showed a large 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 a soil texture in the disposal area that contributed to improved drainage and drying of the soil profile. This increased drying of the soil and made the three dry-day assumption more appropriate than for the 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 overflow volume 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 overflow volume per hectare would be generated for every day required for the application area to dry to a moisture content that would be suitable 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 overflows. The uncalibrated ISU-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 overflow would occur. In its uncalibrated form, the bias statistic ranged from 13% to 51%. After calibration, this value was improved to 8% to 35%.

To increase the similarity between the ISU-ELG and SPAW model predictions, modification of the ISU-ELG model is required. There are several options available to perform these modifications. One option is to perform a calibration of the ISU-ELG model 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 is to develop a scaling factor to adjust the ISU-ELG model average overflow volume 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 by the modification. A third option is the use of the SPAW model to determine the amount of basin overflow. One difficulty in simulating the hydrology of a 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 is 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.

The results of this study imply that feedlots in Iowa are currently forced to land apply under less than ideal conditions to avoid overflow of a containment basin during chronic rainfall events. This need to apply during wet soil conditions undoubtedly makes it more difficult for producers to comply with the effluent limitations guidelines for open feedlots. By modifying the model to better account for chronic rainfall conditions, required containment volumes will be increased. This would provide producers with more flexibility about when to apply effluent. Making these changes would potentially allow better management of nutrients in the feedlot runoff and lead to a reduction in both containment basin overflows as well as nonpoint-source pollution from land application of the feedlot runoff, resulting in improvements in water quality.

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REFERENCES

Anschutz, J. A., J. K. Koelliker, J. J. Zovne, T. A. Bean, and M. J. Peterson. 1979. Sizing components on open feedlot runoff-control systems. *Trans. ASAE* 22(4): 803-808.

EPA. 2003. 40 CFR Parts 9, 122, 123, and 412: NPDES permit regulation and effluent limitation guidelines and standards for concentrated animal feeding operations. *Federal Register* 68(29): 7176-7274.

EPA. 2006. 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. *Federal Register* 71(126): 37744-37787.

EPA. 2008. National pollution discharge elimination system. Washington, D.C.: U.S. Environmental Protection Agency. Available at: http://cfpub.epa.gov/npdes/index.cfm. Accessed 4 January 2008.

Hanson, M. 2007. Soil influences manure application. *Wisconsin Agriculturist* (Dec.): 40.

Iowa DNR. 2007. Chapter 65: Environmental protection, Appendix A: Open feedlot effluent control alternatives for open feedlot operations. In *Iowa Administrative Code*. Des Moines, Iowa: Iowa Department of Natural Resources.

Koelliker, J. K., H. L. Manges, and R. I. Lipper. 1975. Modeling the performance of feedlot-runoff control facilities. *Trans. ASAE* 18(6): 118-1121.

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

Moody, L. B., C. Pederson, R. T. 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. 2007. Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. *Trans. ASABE* 50(3): 885-900.

NDEQ. 2003. What are dewatering days? Environmental guidance document 03-135. Lincoln, Neb.: Nebraska Department of Environmental Quality. Available at: www.deq.state.ne.us/Publica.nsf/408d508d4bac3a05862568730067f445/0a13555d527a5c9206256d35006365c2?OpenDocument. Accessed 27 December 2007.

NDEQ. 2005. Basic holding pond operation. Environmental guidance document 05-134a. Lincoln, Neb.: Nebraska Department of Environmental Quality. Available at: www.deq.state.ne.us/Publica.nsf/1ddd539d20b2b73986256870007b30a8/31f4340ca403beaf06256d350062ba08?OpenDocument. Accessed 3 January 2008.

Saxton, K. E., and P. H. Willey. 2004. Agricultural wetland and pond hydrologic analyses using the SPAW model. ASAE Paper No. 701P0904. St. Joseph, Mich.: ASAE.

Saxton, K. E., P. H. Willey, and W. J. Rawls. 2006. Field and pond hydrologic analyses with the SPAW model. ASABE Paper No. 062108 St. Joseph, Mich.: ASABE.

Sweeten, J., R. Miner, and C. Tengman. 2003. A brief history and background of the EPA CAFO rule. *Manure Matters* 10(1). Available at: www.p2pays.org/ref/15/14479.pdf.

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.

Weisenberger, A., and F. Madison. 2007. So, when is a good time to spread manure? *Hoard's Dairyman* 152(10): 385.

Wensink, R. B., and J. R. Miner. 1975. A model to predict the performance of feedlot runoff control systems at specific Oregon locations. *Trans. ASAE* 18(6): 1141-1145, 1151.

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

Wulf, L. W., J. C. Lorimor, and S. W. Melvin. 2003. Modifications to feedlot runoff containment systems in Iowa. ASAE Paper No. 701P1203. St. Joseph, Mich.: ASAE.

Zovne, J. J., T. A. Bean, J. K. Koelliker, and J. A. Anschutz. 1977. A continuous watershed model for evaluation and design of feedlot runoff control systems. *ASCE J. Irrig. and Drainage Eng.* 102(IR1): 79-92.