Modification of the Iowa State University-Vegetative Treatment Area Model

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Abstract
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Keywords
Vegetative treatment area, VTS, feedlot, run-off, modeling

Disciplines
Agriculture | Bioresource and Agricultural Engineering

Comments
This is an ASABE Meeting Presentation, Paper No. 096299.

This conference proceeding is available at Iowa State University Digital Repository: http://lib.dr.iastate.edu/abe_eng_conf/255
Modification of the Iowa State University-Vegetative Treatment Area Model

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Written for presentation at the
2009 ASABE Annual International Meeting
Sponsored by ASABE
Grand Sierra Resort and Casino
Reno, Nevada
June 21 – June 24, 2009
Abstract. Vegetative Treatment Systems (VTSs) are currently being used at several open beef feedlots across Iowa as an alternative to traditional feedlot runoff containment systems. There are two types of VTS: a VTA system which is comprised of solids settling basin (SSB) followed by a vegetative treatment area (VTA), and a VIB-VTA system which is comprised of a solids settling basin followed by a vegetative infiltration basin (VIB) and a VTA. Iowa State University developed two computer models to simulate VTS performance. When model predictions were compared with data collected from four Iowa sites, the models were found to under predict the VTA outflow, VIB outflow, and nutrient concentrations in the SSB outflow. This paper focuses on the modifications made to the Iowa State University VTA model. To identify the problems with the model, the graphical and numerical outputs were examined for values that were either not reasonable or did not fit the expected behavior of the system. Three major problem areas were identified in the VTA model: an extremely high rate of water removal from the VTA, incorrect calculation of soil moisture, and incorrect tracking of the water table (especially in high water table situations). Each of these problems was isolated and the code controlling this function of the model was examined. Potential solutions were tested to see if they accurately simulated VTS behavior. If successful, the solutions were then implemented. These modifications and their impact on model performance are discussed in this paper.

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Introduction

Vegetative Treatment Systems (VTSs) are an alternative technology for controlling runoff from open cattle feedlots. VTSs present an alternative to the traditional containment basin system used by many cattle producers. VTSs are used in two main forms: a solid settling basin (SSB) followed by a vegetative infiltration basin (VIB) and a vegetative treatment area (VTA), or a solid settling basin followed by a VTA only. The VTSs are designed to release equal or less pollutant mass than a traditional containment basin at the same location. For open feedlots in Iowa, a traditional containment basin is considered to include a solids settling basin followed by a detention basin. The regulated parameters are ammonia, BOD$_5$, COD, chloride, pH, total phosphorus, total dissolved solids, total kjendahl nitrogen (TKN), total suspended solids, nitrate-N, orthophosphate, and fecal coliforms.

Vegetative Treatment Systems are important because they offer a lower cost manure management option than a traditional containment basin. For a producer with 1500 head of cattle, which classifies the operation as a large CAFO (Concentrated Animal Feeding Operation), construction of a VTS will cost approximately $66/head (Khanijo, 2008), whereas a traditional containment system for Iowa will cost around $143/head (Lawrence, 2006). Therefore, utilizing a correctly sized and sited VTS can save the producer about $80 per head when compared to a traditional containment basin.

Siting and sizing have been shown to be extremely important factors in VTS performance (Koelsch et al., 2006). There are nine evaluation criteria used to judge a site: available area, soil permeability, water table depth, subsoil, slope, spreaders, berms, flooding potential, and proximity to waters of the state (Iowa Department of Natural Resources, 2004). Many approaches have been suggested for sizing VTS’s, ranging from using the size of the feedlot to using equations based on influent and effluent concentrations. What is needed is a siting and sizing method that is simple to use and is accurate when compared to field results.

To help with this, Iowa State University developed two models to simulate the two VTS types (Wulf, 2005). Four Iowa beef cattle feedlots were modeled using 26 years of historical weather data from each site. Based on the model results, VTSs were built at these sites. After 9 months of monitoring, the data from the sites was collected and compared to the predicted performance by the models. The models were found to over predict performance of the VTAs and VIBs (Khanijo, 2007), i.e. the model under predicted the volume of discharge from the VTAs and VIBs. These models are required to verify the design of a VTS and they have to be run before producers can obtain NPDES permits.

This paper describes the process used to modify the ISU-VTA model to improve its simulation of VTS performance. Over predicting hydraulic performance was the main problem with the ISU-VTA model, and it was traced to three main sources: an extremely high rate of water removal from the VTA, incorrect calculation of soil moisture, and incorrect tracking of the water table.

Materials and Methods

Wulf and Lorimor (2005) developed the ISU-VTA model to simulate the performance of a SSB-VTA system. The ISU-VTA model uses daily time-step weather data to calculate daily feedlot runoff. The weather data includes the daily high and low temperatures, precipitation, dew point, potential evapotranspiration, daily evaporation, and evaporation coefficient. Within the model, the calculated runoff is collected in a SSB and later released to the VTA. The VTA is divided into 100 sections lengthwise, and the effluent is tracked as it flows down the VTA. The model factors in evapotranspiration, infiltration, and seepage as they affect the effluent volume through the
VTA. The modeled concentrations of various parameters are initially set based on feedlot and SSB specifications. These concentrations are then diluted based on the amount of water added or subtracted as the effluent flows through the system. The model also takes into account direct precipitation onto the VTA and SSB (Wulf, 2005).

Sources of Error

As mentioned previously, Khanijo et al. (2007) found that the ISU-VTA model was over predicting performance of the VTAs. Table 1 shows the average difference between modeled and measured discharge per event for each beef site. The model under predicted the discharge from the VTAs, particularly Central IA 1 and Northwest IA 1, which were the two sites with a SSB-VTA system. Possible sources of error for these performance differences were identified by examining the graphical and numerical outputs and looking for values that either were not reasonable or did not fit the expected behavior of the system. Some of the observed errors were dismissible, as it was evident that they were caused by other errors. An example of this was the miscalculation of the percent control of the system. Values were ranging from negative values to over 100% because the numbers used to calculate them were miscalculated themselves. Using this interrelation between the outputs, three main sources for the errors were identified. The model had an extremely high rate of water removal from the VTA, it did not correctly calculate soil moisture, and it did not track the water table correctly.

Table 1. Average difference between modeled and measured event outputs for each site

<table>
<thead>
<tr>
<th>Site</th>
<th>Average difference between modeled and measured discharge, m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central IA 1</td>
<td>-187.06</td>
</tr>
<tr>
<td>Central IA 2</td>
<td>-32.57</td>
</tr>
<tr>
<td>Northwest IA 1</td>
<td>-166.77</td>
</tr>
<tr>
<td>Northwest IA 2</td>
<td>-48.47</td>
</tr>
</tbody>
</table>

Figure 1 shows the process followed to make modifications to the ISU-VTA model. First, one of the main problem areas was selected. Then, an algorithm in the code that contributed to the error calculation was located. The algorithm was stepped through line-by-line and examined for any erroneous calculations or bad variable values. Based on what was observed, a correction was developed and implemented into the model. The correction was then tested by running the model, and the model results were examined to evaluate the correction. If the correction did not meet acceptance criteria, then a new correction was developed. If the correction did meet acceptance criteria, then a different problem area was selected and the process started over.
Table 2 shows the feedlot and VTS parameters used during these model runs. Maintaining constant parameters ensured that changes in model results were solely from the corrections being tested.

Table 2. Feedlot and VTS parameters used during model runs.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feedlot Area</td>
<td>3.08 ha (7.6 acres)</td>
</tr>
<tr>
<td>Feedlot Slope</td>
<td>3%</td>
</tr>
<tr>
<td>Surfaced?</td>
<td>Yes</td>
</tr>
<tr>
<td>Basin Depth</td>
<td>0.91 m (3 ft)</td>
</tr>
<tr>
<td>Storm Size</td>
<td>12.7 cm (5 in)</td>
</tr>
<tr>
<td>Pipe Diameter</td>
<td>15.2 cm (6 in)</td>
</tr>
<tr>
<td>VTA Length</td>
<td>314 m (1030 ft)</td>
</tr>
<tr>
<td>VTA Width</td>
<td>48.8 m (160 ft)</td>
</tr>
<tr>
<td>VTA Slope</td>
<td>0.50%</td>
</tr>
<tr>
<td>Water Table Depth</td>
<td>1.83 m (6 ft)</td>
</tr>
<tr>
<td>Seepage Rate</td>
<td>0.51 cm (0.2 in)</td>
</tr>
</tbody>
</table>

**Modifications Made to VTA Model**

The first problem identified was the behavior of soil moisture in the top soil layer. As observed in Figure 2, the top soil moisture stabilizes at roughly 12% moisture content with upward spikes during rain and runoff events. This minimum value corresponds to the wilt point of the soil layer. After these rain and runoff events, the moisture content of the top soil plummets back to the wilt point. This behavior suggested a problem with the removal of water from the top soil layer, either through evapotranspiration or seepage. The fairly steady values for the bottom and sub-soil layer moistures, combined with the mid-soil's less extreme behavior, pointed toward the...
evapotranspiration calculation. Upon further examination, the daily water loss to evapotranspiration was calculated correctly. The problem was the subtraction of water from the soil moisture. The code was subtracting cumulative evapotranspiration instead of the daily evapotranspiration. This led to a larger and larger amount of water being subtracted from the soil moisture until it reached the wilt point of the layer. After changing from cumulative to daily evapotranspiration in the soil moisture calculation, soil moisture behavior was observed similar to Figure 3.

Figure 2. Moisture content of soil layers averaged across all VTA sections before evapotranspiration computation was modified.
Figure 3. Moisture content of soil layers averaged across all VTA sections after evapotranspiration calculation was modified.

Figure 4 shows the soil moisture behavior after the evapotranspiration calculation was modified. The soil moisture is behaving correctly, except for the instances where the moisture drops to zero. These instances when the moisture appears to drop to zero are actually times when the soil moisture outputs a divide by zero error. This error still needs to be addressed.

As Figure 5 shows, the model was not able to track the water table correctly. The original calculation for seepage is shown as Equation 1. The variables WaterTableDepth and Bottom_seepage are input by the user of the model and Seepage and H2OTable are calculated by the model.

\[
\text{seepage} = \text{bottom\_seepage} \times \left( \frac{\text{WaterTableDepth}}{\text{H2OTable}} \right)^{1.5}
\]

Equation 1

Where:

- Seepage is the daily flux of water through the soil (cm³/cm²/day)
- Bottom_seepage is the initial flux of water through the soil (cm³/cm²/day)
- WaterTableDepth is the initial depth to the water table (cm)
- H2OTable is the present depth to the water table (cm)

This equation was intended to limit the seepage rate once the water table had dropped substantially and increase the seepage rate when the water table was high (Wulf, 2005). However, when the water table reaches the land surface a divide by zero error will be encountered. To avoid this, a new seepage rate calculation was developed. It is shown as Equation 2.
\[ \text{seepage} = \text{bottom}_-\text{seepage} \times \exp\left(1 - \frac{\text{H2O}Table}{\text{WaterTableDepth}}\right) \]  

\text{Equation 2}

Where the variables are defined the same as previously, i.e.
- Seepage is the daily flux of water through the soil (cm$^3$/cm$^2$/day)
- Bottom_seepage is the initial flux of water through the soil (cm$^3$/cm$^2$/day)
- WaterTableDepth is the initial depth to the water table (cm)
- H2OTable is the present depth to the water table (cm)

This equation gives the same basic behavior as Equation 1. It increases the seepage rate when the water table rises and decreases the seepage rate when the water table drops. Dividing by the initial depth of the water table eliminates the divide by zero error. A comparison of the two equations is show in Figure 4 with initial conditions of seepage at 2.5 cm (1 inch) per day and a water table depth of 101.6 cm (40 inches). Below the initial water table depth, the two equations behave very similarly. However, when the water table is shallower than the initial condition they behave quite differently. The old seepage equation (Equation 1) experiences a rapid increase while the new seepage equation (Equation 2) experiences a more gradual increase in the seepage rate. After changing the seepage equation, the water table behaved more realistically as seen in Figure 6.

Figure 4. Seepage rate versus water table depth for original and revised seepage functions for initial conditions of bottom seepage of 2.54 cm/day and water table depth of 1.02 meters.
Figure 5. Water table depth under VTA before change to seepage calculation

Figure 6. Water table depth under VTA after change to seepage calculation
**Results and Discussion**

The changes made to the ISU-VTA model had a significant impact on the outputs from the model. As shown in Figure 7, the soil moisture behavior has changed dramatically from what was previously observed in Figure 1. Other than the days where soil layer moisture dives to zero, the model accurately simulates behavior of the soil moisture in a VTA.

![Figure 7](image)

**Figure 7.** Moisture content of soil layers averaged across all VTA sections after modifications were made.

The most visible improvement in the VTA model was the decrease in daily water balance errors. The water balance shows the difference between the amount of water in the VTA in the form of storage, percolation, and releases compared to the amount of water inputs to the VTA. A positive value means more water was input to the VTA than can be accounted for in storage, percolation, and releases. A negative value means that more water was in storage, percolation, and releases than was input. Before modifications were made the water balance error was positive. This may have been caused by the high evaporation rate, which removed water from the VTA and prevented outflow from the system.

**Conclusions and Recommendations**

The ISU-VTA model is moving closer to accurately predicting VTA behavior; however, there are still changes that need to be made. Lowering the evapotranspiration, fixing a divide by zero error in soil moisture, and changing the seepage calculation caused the soil layer moisture and water table behavior to be much closer to expected values and behaviors.
Further work is still needed on the model to further refine its performance. For example, soil moisture drops to zero after the soil profile becomes saturated. After the remaining problems are addressed, the model will be calibrated using data collected from six Iowa feedlots. The model will then be tested against data collected from beef sites located in Nebraska, South Dakota, and Minnesota that were not used to calibrate the model. The results of this comparison will provide a measure of the accuracy of the model and dictate what happens to the model next. If the model outputs are still inconsistent with the measured data from the feedlots, then more work will need to be completed on the model to reduce the gap between the modeled and measured VTS behavior. If the model matches measured data from the feedlots, then the model will be ready to be tested versus feedlots from Iowa’s surrounding states to judge model flexibility. These results will determine if it can be used for conditions outside of Iowa.

References

Iowa Department of Natural Resources. 2004. Siting criteria: non-basin technology for waste treatment systems for open feedlots. Shared by Gene Tinkler, IDNR, by personal communications, July 2004


