USING GIS REMOTE SENSING AND WATER QUALITY MODELING TO ESTIMATE ANIMAL WASTE POLLUTION POTENTIAL

I. Chaubey[1], P. Srivastava[2], L. Han[3], S . N. Addy[4], and X. Yin[5]

AUTHORS: [1]Biological and Agricultural Engineering Department, 203 Engineering Hall, University of Arkansas, Fayetteville, AR 72701; [2]Arkansas Department of Environmental Quality, University of Arkansas, Fayetteville, AR 72701; [3] Department of Geography, University of Alabama Tuscaloosa, AL 35487-0206; [4]Center for Business and Economic Research, University of Alabama, Tuscaloosa, AL 35487-0206; [5] Bentley Systems, Inc. Corresponding author: I. Chaubey (chaubey@comp.uark.edu).

ABSTRACT

Watersheds having a dense population of poultry production facilities frequently receive relatively high rates of poultry litter application. This often leads to surface and ground water pollution problems. The State of Alabama recently adopted an animal waste disposal regulation that requires farmers to adapt a waste management practice considering rate of application and watershed and land use characteristics. The objective of this study was to develop an animal waste pollution potential index (AWPPI) that can be used by farmers and regulators to rank areas based on susceptibility to nonpoint source (NPS) pollution from land application of poultry litter. This study was conducted in a watershed with an area of 56 mi^2. The AWPPI was developed as a function of manure application rate, nutrient availability rate, and delivery ratio. The watershed data required for this method were derived from 7.5 minutes USGS digital elevation models. High resolution infrared aerial photos were used to derive information about number and location of poultry houses in the watershed. Two indices, N-based and P-based AWPPI, were evaluated in this study. No significant difference was found between the two indices. The AWPPI was found to be significantly correlated to poultry house density in a watershed and ratio of litter application area to watershed area. This method presents a simple approach to identify areas having higher susceptibility to NPS pollution and where best management practices may need to be implemented to reduce NPS pollution from animal waste application.

INTRODUCTION

Agncultural nonpoint source pollution (NPS) created by excessive application of fertilizer and pesticides and improper animal waste management is one of the most damaging and widespread threats to the environment (National Research Council, 1989). Improper animal waste management has gained increasing attention in the past decade, and land application of animal manure has been the focus of many studies. Excessive land application of animal manure is common in regions where animal production is concentrated. This leads to surface and ground water pollution problems that are potentially threatening to human health and recreational activities.

Poultry production is the largest agricultural industry in Alabama. Alabama ranks third nationally, behind Georgia and Arkansas, in both quantity and cash value of poultry production (Alabama Agricultural Statistics, 1998). For the past 20 years, growth in the poultry industry has contributed to potential pollution of the state's water resources due to excess land application of poultry litter to farmland. Recently, the State of Alabama adopted a regulation that requires animal producers to implement Best Management Practices (BMPs) to minimize surface and groundwater pollution, if the animal manure is applied at higher than agronomic rates. Currently, the Alabama Department of Environmental Management recommends the application rate be based on soil N content and agronomic N requirements. If the poultry litter application rate is higher than the agronomic N requirement or if it is applied in an area with higher susceptibility of loss to receiving water bodies, a BMP that minimizes the off-site transport of nutrients to receiving streams must be implemented.

There is a need to identify the areas where poultry litter may or may not be applied. Several researchers have used water quality models to identify such 'hot spots' within a watershed that may potentially be the principal source of NPS pollution. However, most of these models are very complex in nature and suffer from the limitation of large input data requirements. Most of these models cannot be easily used by people outside the academic and research community due to these limitations. There is a need to develop a simple methodology that can be easily used by farmers and regulators to identify areas that may not be suitable for animal manure application or which may need implementation of BMPs to minimize NPS pollution.

The objective of this research was to develop an Animal Waste Pollution Potential Index (AWPPI) that can be used to rank areas based on the potential of nutrient transport from land application areas to the receiving streams. One criterion used to develop this methodology was to minimize the input data requirements so that a user can easily construct an input data file from readily available information.

MATERIALS AND METHODS

This study was conducted in the Crooked Creek watershed in Cullman County, Alabama. Cullman County is the largest poultry producing county in Alabama. The poultry industry has expanded rapidly in this region in the past decade and represents the major source of agricultural income. Crooked Creek has been identified in the 303 (d) list of Alabama streams having water quality problems from intense animal feeding operations. The water quality parameters of concern in this creek are nitrogen (N), organic enrichment, and pathogens. Nutrient runoff from land areas to which poultry litter has been applied is believed to be one of the principal sources of NPS pollution in this region. Figure 1 shows the location of poultry houses within the Crooked Creek watershed. Watershed characteristics are shown in Table 1.

The primary purpose of developing the AWPPI was to identify areas that have a high susceptibility for nutrient losses to receiving streams. It can be used to provide a relative ranking of the suitability of particular areas for land application of animal manure with minimum potential impact on stream water quality. The methodology outlined by Heatwole and Shanholtz (1991) was used to develop the AWPPI. The Heatwole and Shanholtz model estimates the waste pollution index as a function of waste load, land slope, and distance to stream. The index is estimated both for the animal production site and for the surrounding crop and pasture areas where animal manure is potentially applied. The most sensitive parameters for this model are the site load and the site deliver ratio. Based upon the data from two counties in Virginia, the authors concluded that the model reflected a primary response to the suitability of the site itself but was also affected by the suitability of the surrounding area.

The potential delivery of nutrients from the treated areas to the receiving streams is estimated as a function of nutrient application rate, a nutrient availability factor, and a delivery ratio. Mathematically, it can be represented as

$$AWPPI = \frac{1}{A}\sum_{i=1}^{n} L_i * a_i * AF * DR_i$$

where L is the nutrient loading rate in lb/A, AF is availability factor, DR is delivery ratio, and a is the area (acres) of the field treated with poultry litter, i = 1, 2, 3, ...n is the number of fields in a subwatershed where litter is applied.

The availability factor represents the fraction of nutrients that move into runoff from surface-applied manure. Heatwole and Shanholtz (1991) have suggested a value of 0.05 for the nutrients applied in the field and 0.06 for the nutrients lost from the confinement areas. The delivery ratio is the function of available pollutant load that reaches the nearest stream. It can be calculated as a function of the flow distance between the point where manure is applied and the receiving stream and slope along this flow path,

$$DR = e^{-k_1 d SF}$$

$$SF = SF\min + e^{-k_2(S+S_o)}$$

where d is distance to the stream (ft), S is slope along that distance (ft/ft), k_1, k_2 So and SFmin are parameters. Slope factor affects the delivery ratio by changing the flow distance (d) as the slope changes. SFmin was included to maintain the greater importance of distance over slope in the delivery ratio (Heatwole and Shanholtz, 1991).

The model was developed in ArcView GIS environment. Basic data needed to estimate AWPPI are watershed topography, location of poultry production facilities, area where poultry litter is applied, and poultry litter production rate. Watershed topography data were obtained from 7.5 minutes, 1:24000 Digital Elevation Models (DEMs) from U.S. Geological Survey. The Crooked Creek watershed was divided into 159 subwatersheds based on stream channel network and watershed drainage characteristics. The advantage of dividing the watershed into a set of subwatersheds based on channel network is that once the subwatersheds are ranked based on AWPPI, individual stream sections most susceptible to NPS pollution in a watershed can be identified. Any subsequent watershed management plan can focus on protecting these segments of streams. Stream characteristics, flow direction, and flow accumulation were derived for each subwatershed. Average flow path distance (d) and average slope (s) along the flow path was estimated using ArcView for each subwatershed.

Six color infrared aerial photos with 1-meter resolution were used to derive the land use and location of the poultry houses within the watershed. Color infrared aerial photo film is manufactured to record green, red, and the photographic portion (0.7 to 0.9μm) of the near-infrared scene energy in its three emulsion layers. The result is a false color film in which blue images result from objects reflecting primarily green energy, green images from objects reflecting red energy, and red images from objects reflecting near-infrared portion of the spectrum. Poultry houses, along with other urban and built up lands, appear in very bright tones and can be easily identified from the color infrared aerial photos. After image registration and rectification, the aerial photos were mosaiced and resampled at 20 x 20 m resolution for further analysis. Green band, along with a high-pass filter, was used to screen out poultry production facilities. The major characteristic of the poultry houses in the aerial photo is that they are shown in bright straight parallel lines. Using the technique of on-screen digitizing, all the poultry houses were converted to a point coverage in ArcView GIS.

Input parameters needed to develop AWPPI are nutrient loading rate, nutrient availability factor, and delivery ratio from field to stream. The amounts of total poultry litter, as well as total N and phosphorus (P), produced were obtained from literature values. Each poultry house was estimated to hold 20,000 broilers producing 100 tons of litter per year. Assuming a N content of 4.0% and P content of 1.5% (Edwards and Daniel, 1992), total N and total P production were estimated as 8800 lb N and 3300 lb P per house per year. Nutrient availability factor used for poultry litter was 0.22 for N and 0.09 for P (Robinson and Sharpley, 1995). Estimation of delivery ratio requires values for slope factor, average flow length from field to stream and average slope along this flow path. A value of SFmin = 0.60 was used for steep slopes. Values for the parameters $k^1 = 0.049\ ft^{-1}$, $k^2 = 16.1$, and $So = 0.057$ were used as suggested by Heatwole and Shanholtz (1991). Average flow length from field to the nearest receiving stream and average slope along this flow path were obtained using ArcView GIS.

Site specific data about the area of the watershed where poultry litter is applied are very difficult to obtain. Average farm size in Cullman County in Alabama is 94 acres (Alabama Farm Statistics, 1998). It was assumed that poultry litter from each house was applied in the surrounding 94-acre farm land.

RESULTS AND DISCUSSION

Animal waste pollution potential from surface application of poultry litter was estimated for losses of both N and P. The basic statistics for N- and P-based AWPI are shown in Table 2. A difference between the N- and P-based AWPPI was due to the differences in nutrient loading rates for N and P in each farm and nutrient availability factor. Even though the values for AWPPI are different for N- vs. P-based rankings, no difference in subwatershed rankings was indicated for the two methods. Figure 2 shows the N-based AWPPI ranking of the subwatersheds. A correlation analysis showed a significant correlation between N and P based AWPI ($r^2 = 0.999$, $p < 0.001$). Hence, the subsequent discussion is based on AWPPI for N losses. It should be noted that the AWPPI discussed here does not consider the current practices implemented at a particular site. For example, a BMP, such as vegetative filter strips, may reduce the actual losses of nutrients and may lower the ranking of the site based on pollution potential.

The AWPPI for the Crooked Creek ranged from 0 to 4.09 (Table 2). The minimum AWPPI was obtained for the subwatersheds where no poultry house was located or where poultry litter was not applied. Factors affecting AWPPI for a subwatershed are delivery ratio, nutrient application rate, and subwatershed area. The delivery ratio is affected by watershed topography. A high slope and shorter distance from the land application area to the stream results in a high delivery ratio. Application of poultry litter near streams or in areas with steep slopes would result in a high AWPPI. Nutrient application rate depends upon density of poultry houses in a subwatershed (number of houses per square mile of subwatershed area) and total farm area available for application of poultry litter. A regression analysis between AWPPI and poultry house density indicated a significant correlation ($r = 0.60$, $p < 0.01$). This indicates that a large number of poultry houses present in a watershed will result in a high AWPPI. This can be expected if no significant litter is exported outside the watershed.

Another variable that influences AWPPI ranhng is the ratio of farm area where poultry litter is applied to the subwatershed area. A ratio of "1" would indicate that poultry litter is applied in the entire watershed, whereas, a ratio of "0" would indicate that no poultry litter is applied in the watershed. This ratio was larger than 0.95 for all subwatersheds having AWPPI greater than 2.0. A regression analysis indicated that the ratio of litter-applied area to the watershed area was significantly correlated ($r = 0.41$, $p > 0.01$).

The ranking of areas based on AWPPI discussed in this paper presents a simplified approach to identify the area susceptible to NPS pollution from poultry litter application. Figure 2 shows that such ‘hot spots’ in a watershed can be very effectively identified using this approach. Traditionally, hydrologic/water quality models have been used to identify such areas and to develop watershed management plans to reduce NPS pollution. Most of these models are very complex in nature and require large input data sets. Preparation of input data sets before these models can be run can be a tedious and time consuming task. These models also need to be calibrated for site-specific conditions before they can be used to make reliable watershed response predictions. In many cases, farmers or regulators may be interested only in identifying the areas where a new poultry house can be located or where poultry litter can be applied without a significant risk to NPS pollution. The methodology presented here can be used to screen such areas. Another advantage of this method is that all the watershed characteristic data can be developed from DEMs, readily available at no cost from U.S. Geological Survey. This method can also be used for other types of animals, if the data about animal manure application rate and area where the manure is applied are available. One of the limitations of this approach is that it can not quantify the exact response of a watershed under certain land use and management conditions. If the effect of certain land use changes on water quality needs to be assessed to evaluate a BMP's effectiveness, a more complex hydrologic/water quality model will have to be used. The AWPPI also does not estimate the sediment erosion from the field and transport of sediment-attached N and P from the field to the stream. Runoff losses of N from the land areas treated with animal manure are mostly in the dissolved form. Phosphorus is attached to the sediment and a significant portion of the P moves with eroded soil particles. Researchers have also shown that continuous build up of P in soil can increase potential for P transport in runoff (Robinson et al., 1995). The AWPPI for agricultural areas having significant erosion problem should also consider sediment-attached nutrient transport.

Recently, Internet-based GIS application for natural resource management has generated interest. The methodology presented here can be effectively used to generate countywide or statewide Internet-based AWPPI using GIS. Currently available computing and GIS technology offer the capability to develop such applications. Watershed topography and stream network hydrology data can be assembled and watersheds can be delineated for a county and stored on the Internet-based GIS In order to see the suitability of a particular area for animal waste application, a farmer may only need to click in the watershed where waste will be applied and input information about waste application rate. This type of application may eliminate the need for costly watershed reclamation programs from NPS pollution.

ACKNOWLEDGEMENT

Funding for this research was provided by the School of Mining and Energy Development at the University of Alabama. Authors would like to thank Erin Eppling, GIS technician in the Biology Department, for assistance with some of the GIS work.

REFERENCES

Alabama Agricultural Statistics. 1998. Bulletin 40. Alabama Agricultural Statistics Service, Montgomery, AL.

Edwards, D.R. and T.C. Daniel. 1992. Environmental impacts of on-farm poultry waste disposal – A review. Bioresource Technology 41:9-33.

Heatwole, C.D and V.O. Shanholtz. 1991. Targeting animal waste pollution potential using a geographic information system. Trans. ASAE 7(6):692-698.

National Research Council. 1989. Alternative Agriculture. Washington, D.C. National Academy Press.

Robinson, J.S. and A.N. Sharpley. 1995. Release of nitrogen and phosphorus from poultry litter. J. Environ. Qual. 24:62-67.

Robinson, J.S., A.N. Sharpley and S.J. Smith. 1995. The effect of animal manure application on the forms of soil phosphorus. In K. Steele (Ed.). Animal Waste and Land Water Interface. CRC Press, Boca Raton, FL.

Table 1. Crooked Creek watershed characteristics.

Watershed Area	56.4 mi ^{2}
Land use	
Forest	61%
Pasture and Cropland	38%
Urban	0.5%
Other	0.5%
Number of poultry houses	144

Table 2. AWPPI for Crooked Creek Watershed based on N and P losses from poultry litter.

Statistic	AWPPI(Nitrogen)	AWPPI(Phosphorus)
Mean	0.377	0.057
Range	0-4.09	0-0.61
Variance	0.35	0.008

Figure 1. Drainage network and location of poultry houses in Crooked Creek watershed.

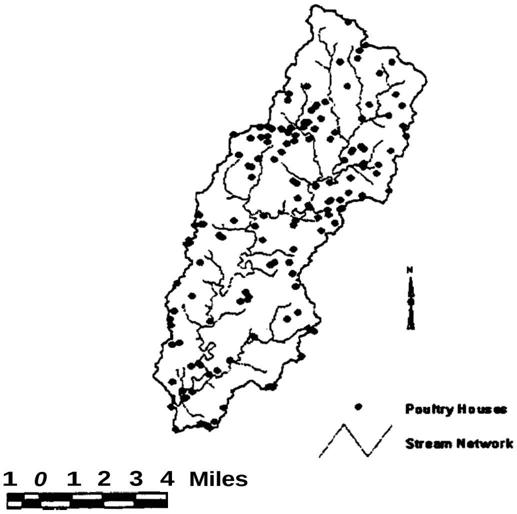

Figure 2. AWPPI ranking of subwatersheds in Crooked Creek watershed