ANIMAL WASTE MANAGEMENT

Measuring the Cost of Restricting Access to Cropland for Manure Nutrient Management

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ABSTRACT

In the area of animal manure management, an issue of concern is the slope of cropland to which manure can be applied without fear of surface runoff of nutrients and other environmental contaminants. Regulators and environmentalists favor a 12% slope limit while agriculturalists favor a slope limit set at 18%. The purpose of this research is to assess the impact on manure management cost of an environmental policy that restricts the slope of cropland to which swine (Sus scrofa) manure can be applied from 18 to 12%. Using a geographical information system, U.S. Geological Survey land use and land coverage maps and digital elevation maps are scanned to identify crop production areas suitable for manure management. Economic impacts are measured by translating changes in area suitable for manure applications into distances that manure must be transported. Results indicate that restricting manure application to a slope of <12% is likely to impact a region of significant pork production in Kentucky. This more restrictive slope policy increased the manure management cost of feeder operations producing 5000 head annually by as much as $0.35 head⁻¹ (a 7% reduction in net return) across 85% of the state's agricultural area.

WITH INCREASED INTEGRATION of the livestock industry comes ever larger confined-animal feeding operations (CAFOs) and associated manure stocks. These manure stocks are a growing concern of both the farming and nonfarming public, who fear eventual contamination of surface water and ground water, nutrient and mineral toxicity of soil, and excessive odors. Yet, properly managed, manure can augment soil organic material and provide crop nutrients.

In August 1997, Kentucky Governor Paul Patton imposed a 90-d moratorium on the issuance of construction permits for new swine-production facilities. The Governor imposed this moratorium largely in response to public concern surrounding proposed investment in western Kentucky by two large, integrated swine-production companies. Some feared that then-current state environmental regulations were not adequate to protect surface water and ground water from contamination by such large production facilities.

During the moratorium, the Division of Water (DOW) in the Natural Resources and Environmental Protection Cabinet (NREPC) was instructed to develop new (emergency) regulations for the state. One issue debated during this period was the slope of cropland to which manure could be applied without fear of surface runoff of nutrients and other contaminants. Regulators and environmentalists favored a 12% slope limit while agriculturalists favored an 18% limit. Current regulations impose the 12% limit, but the General Assembly has yet to make that requirement law. Hence, controversy surrounding the slope restriction is not yet settled.

Agriculturalists contend that an 18% restriction is sufficient to avoid manure runoff. Moreover, they argue that a 12% restriction will eliminate large areas otherwise suitable for manure management, increasing the transportation costs associated with managing the manure. They also conjecture that, to offset these higher transportation costs, entrepreneurs will attempt to locate new facilities in flatter areas of the state, concentrating the industry and possibly exacerbating the impact of manure nutrients on surface water and ground water.

The research has two goals: (i) to assess the cost of reducing the maximum permissible slope to which swine manure can be applied from 18 to 12% and (ii) to identify regions in the state where growth of the swine industry is more likely to occur as a consequence of differences in production cost. The analysis uses a geographical information system (GIS) computer software package. Although the current study is limited to Kentucky, the methodology should be applicable to larger regions.

Conceptual Model

Sufficient cropland on which to apply manure is the key to manure management. Regulators in most states, including Kentucky, require manure management plans that specify the crops to which manure will be applied. This requirement proposed to assure that manure applications do not exceed the capacity of the environment to absorb them.

The capacity of an area to absorb manure depends on several factors: (i) the proportion of the area in cropland (α); (ii) the proportion of the cropland suited to receive manure applications (β); (iii) the proportion of suitable cropland available to receive manure (γ); and (iv) the proportion of suitable cropland already receiving manure and, hence, not available for further applications (δ). With information on these four factors,

Abbreviations: AMC, additional distance charge; BC, base charge for transporting manure; DEM, digital elevation model; GIS, geographical information system; KFBM, Kentucky Farm Business Management Program; LULC, land use and land coverage; RA, required area; SI, suitability index; TLC, total land cost; TMC, total manure-management cost.

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a suitability index (SI) that reflects the capacity of an area to assimilate manure application can be defined as the inverse of the product of the four factors (Fleming et al., 1998; Fleming, 1999).

\[
SI = 1/(\alpha\beta\gamma\delta) \quad [1]
\]

No spatial data exist for \(\delta\) or \(\gamma\). As a consequence, \(\gamma\) and \(\delta\) are restricted to values of 1 (Eq. [2]). These restrictions act to understate SI because only the natural absorptive capacity of an area is measured for a given crop rotation. In reality, as manure is applied to crops, less area remains to which additional manure can be applied (available and suitable cropland is fixed within a given region). This fact is reflected in a decreased value of \(\delta\), which implies an increased SI. Because many farmers do not want manure on their land, \(\gamma\) will also be <1. Reasons for this reluctance include: (i) Manure is often available when farmers are conducting other field operations, (ii) some farmers believe that manure applicators compact their soils, and (iii) some do not believe that the N content of manure is consistent enough for them to reduce their commercial fertilizer applications.

\[
SI = 1/(\alpha\beta) \quad [2]
\]

The SI is linked to swine production cost via the cost of transporting manure to application fields (Fleming et al., 1998). The SI inflates the distance a producer would have to travel to apply swine manure to crops. Specifically, in areas where there is little crop ground or where that crop ground is unsuitable for manure application, a producer must travel farther to deliver manure to crops. In such a case, SI is large. The greater SI is, the farther one must travel to deliver manure stocks (increased transportation costs). Alternatively, a smaller SI indicates a greater capacity for the area to absorb animal manure nutrients (hence, lower transportation costs).

To illustrate, consider the following example. Required area (RA, measured in hectares) is the area actually needed to manage manure stocks (Fleming et al., 1998). Unfortunately, RA does not always translate into area immediately available at the site where hogs are produced. If the area of interest is 100% suitable cropland, then SI is 1, meaning that RA is immediately available (transportation costs are nearly zero). However, if cropland comprises only 25% of an area, and half of the available cropland is unsuitable for manure applications, then SI is 1/(0.25 \times 0.5), or 8. This means that the swine producer has to search over 8 ha to find 1 ha needed for manure management. If 1000 ha are required for manure management in this area, then the swine producer will have to haul manure over an 8000-ha area at a considerable cost.

Total manure-management cost (TMC, in dollars) is the sum of total land cost [TLC] (for manure application areas), a base charge for transporting manure (BC), and an additional distance charge [AMC] (Eq. [3]; see Fleming, 1999). To simplify the analysis, it is assumed that the cropland needed (or required) for manure management is known (this is required cropland, or RA).

In turn, this fixes the quantity of manure (in liters) that is being transported to application fields as well as the number of hogs that are being produced. Within the context of this study, these restrictions imply that TLC and BC in Eq. [3] are fixed. Specifically, with respect to the parameter TLC, it is assumed that the cost of acquiring RA does not change; the only change occurs in the area over which we must search to find fields to meet RA. Land acquisition costs (TLC) may also increase as SI increases; however, these changes in cost are not considered here.

\[
TMC = TLC + BC + AMC \quad [3]
\]

With these restrictions, changes in land suitability (SI) will impact the TMC only through changes in the AMC. Again, larger values of SI imply that swine producers must travel farther to deliver manure stocks. Equation [4] is an expression for AMC where the parameter \(\theta\) is the rate of increase in the unit distance charge ($/L-km) as distance to application fields increase, \(QH\) is the amount of liquid manure (L/ha) transported to fields, and \(Z\) adjusts cost depending on whether a return trip is necessary to deliver manure (Fleming et al., 1998). If manure is hauled to cropland because a return trip is necessary, \(Z\) is assigned the value of 2. If manure is pumped to application fields, then \(Z\) is assigned the value of 1 (there is no return trip). The RA (ha), multiplied by 0.01 to convert to square kilometers, is divided by \(\pi\) to yield the radial distance in meters. The square-root terms disappear in this equation because \(\theta\) is also a function of distance (Fleming et al., 1998).

\[
AMC = Z_\theta(QH \times RA) \left( \frac{RA \times 0.01}{\pi \times \alpha \times \beta} \right) \quad [4]
\]

Given AMC (or TMC), it is possible to calculate the impact on manure management costs of policies that alter the capacity of manure application areas. Again, in Kentucky, current policy restricts manure applications to cropland with slopes up to 12%. By making illegal manure applications to cropland with slopes in excess of 12%, this policy essentially defines suitability. Hence, the economic impact of a 12 vs. 18% slope policy can be measured by changes in \(\beta\), the proportion of cropland agronomically and/or legally suited for receiving manure. Equation [5] shows the change in manure management cost, measured in dollars per liter of manure applied, for changes in policy that impact the suitability of manure application areas.

\[
\Delta TMC = \Delta AMC = Z_\theta(QH \times RA) \left( \frac{RA \times 0.01}{\pi} \right) \left[ \frac{1}{\alpha\beta_{18}} - \frac{1}{\alpha\beta_{12}} \right] \quad [5]
\]

Geographical Analysis

Calculating total manure cost and the change in this cost as a result of a more restrictive manure application policy requires knowledge of \(\alpha\) and \(\beta\). Both are spatial parameters that vary by location. These parameters also depend on the size of the area for which they are de-
fined. As the area increases, \( \alpha \) and \( \beta \) decrease and SI increases (other things being equal).

Because \( \alpha \) and \( \beta \) are spatial parameters, a computerized GIS was used to measure them. The parameter \( \alpha \), for example, is measured by calculating the proportion of agricultural land within a defined area. Similarly, \( \beta_{12} \) (Eq. [5]) is measured by calculating the proportion of agricultural land within a defined area with a slope <12%. Although GIS is well suited to measure these values, assembling the data requires knowledge of basic cartography and advanced computer programming skills.

The distance a producer is willing to transport manure stocks depends on the type of manure transported and the application technology used. Generally, unlike dry manure and litter, swine manure application is restricted to areas near the production facility. More concentrated (slurry) manure is hauled in large tank wagons or trucks. In Kentucky, 60 to 70% of all finishing houses use deep pits that store manure as slurry (R. Coffey, personal communication, 1999). Transportation costs, in-field time constraints, and other practical concerns effectively limit travel distances to \( \leq 8.05 \) km. Lagoon gray water can also be hauled, but the volume of liquid and materials to be hauled makes hauling impractical. Lagoon gray water is usually pumped (via irrigation pumps) to application fields; this technology is largely limited to distances of \( \leq 3.29 \) km from production facilities.

This study assumes that Kentucky producers will transport manure (in gray water, slurry, or dry forms) no more than 24.14 km (15 miles), a distance chosen to accommodate as many manure transportation technologies and management strategies as possible. Cell values for \( \alpha \) and \( \beta \) (and, eventually, SI and manure management cost) are calculated for an area of 24.14-km radius originating from the center of each cell (see Appendix).

Calculating \( \alpha \) and \( \beta \) is not tied to any particular area or legal boundary (e.g., a county or state). However, along the state’s northern boundary defined by the Ohio River, special procedures were employed to adjust cell values when the surrounding area was \( < 1831.1 \) km\(^2\) (707 square miles, or 452 389 acres). These procedures were employed because bridges across the Ohio River are limited, and anecdotal evidence suggests that little animal manure crosses the Ohio River. A count grid was created, which the Focalsum command in Arc/Info uses to count the number of cells, within a 24.14-km radius of a particular cell, that are also within the state of Kentucky. This count grid ensures that Arc/Info properly calculates \( \alpha \) and \( \beta \) for cells within 24.14 km of the Ohio River.

The next step was to create a grid (or coverage) representing land uses suitable for spreading swine manure. The U.S. Geological Survey land use and land coverage (LULC) digital data derived from 1:250 000 and 1:100 000 scale maps were selected to bring the land-use component into the analysis. This data is scaled similar to the digital elevation model (DEM) data (see Appendix). Land in the LULC data set is segregated into 1 of 9 main classes (including agricultural uses) and into 1 of 37 subclasses. With respect to agriculture, four subclasses of land use are identified: croplands and pastures (LULC Code 21); orchards, groves, vineyards, nurseries, and ornamental horticulture areas (LULC Code 22); confined feeding operations (LULC code 23); and other agricultural land (LULC Code 24). Because this project is concerned with land that is suitable for manure management, LULC Code 21 (cropland and pastures) is the focus of this investigation.

Little modification of the LULC data was required. Essentially, a 200-m grid (of cells) was laid over the LULC coverage, and each cell was assigned the dominant LULC code. Once completed, the LULC grid is used to calculate \( \alpha \), the percentage of total area devoted to crops and pasture. The Focalsum command in Arc/Info is used to iterate across every cell in the grid and, at each cell, to count the number of surrounding cells within a 24.14-km radius that hold the value of 21. The total number of cells within the 24.14-km radius then divides this sum. The result of this calculation is assigned to the corresponding cell in a new grid (called the alpha grid) that holds the value of \( \alpha \) for an area with a 24.14-km radius. Fig. 1, actual data grid images illustrate creation of the alpha grid from the LULC coverage.

Two values of \( \beta \), the proportion of crop or pastureland suitable for manure applications, are calculated: \( \beta_{12} \), the percent of suitable area with slope of \( \leq 12\% \), and \( \beta_{18} \), the percent of suitable area with a slope of \( \leq 18\% \). Calculating \( \beta_{12} \) starts by laying the 12% slope grid over the LULC grid and physically linking the two data sets. The Focalsum command is then used to iterate across every cell in the grid and, at each cell, to count the number of surrounding cells within a 24.14-km radius that hold joint values of 1 for slope and 21 for crop type. The total number of cells within the 24.14-km radius then divides this sum. The result of this calculation is assigned to the corresponding cell in a new grid (the beta12 grid) that captures the spatial distribution of \( \beta_{12} \). Given the alpha and beta12 grids, a grid for SI12 (SI given a 12%
Results

Suitability indices were calculated for the state of Kentucky. Twenty-five percent of the crop-growing regions of the state (the western two-thirds of the state) have SIs of ≤2 (Table 1). Likewise, 53% of the state has a SI < 3, 69% is < 4, and 80% is < 5. A SI of 2 implies that 2 ha are needed to find 1 ha of cropland on which to spread swine manure. Regions with higher SI values (>4) are found in northern Kentucky (the Louisville, Cincinnati, and Lexington metropolitan areas), south-central Kentucky (the southern Lincoln Trail area comprised of Casey, Adair, Russell, Pulaski, Cumberland, Clinton, and Wayne counties), and the Ohio Valley area of west-central Kentucky (Hancock, Ohio, McLean, and Hopkins counties as well as Muhlenberg, Butler, Grayson, and Breckinridge counties).

These areas with higher SI values are consistent with expectations. The northern Kentucky region is the fastest-growing area in the state in terms of commerce and industry. As agricultural land is converted to urban use, there is less land available for manure management or other agricultural uses. The south-central region is topographically more diverse (hilly), which limits the availability of suitable area (slopes tend to exceed 18%).

The higher SI values in western Kentucky are more difficult to explain. This area corresponds with the western Kentucky coalfield. Much of the area has been strip-mined and is not available for agricultural uses (at least the area is not classified as crop- or pastureland). With continued reclamation of this area, especially areas designated as prime farmland, more cropland will become available, hence reducing SI. The extent to which SI is reduced will depend on regulatory changes that now prohibit manure applications on all reclaimed land except prime farmland.

According to Kentucky Agricultural Statistics Service (1999), for the 1997–1998 crop year, the western Kentucky region contained five of the state’s top 10 swine-producing counties (Hopkins, McLean, Breckinridge, Grayson, and Butler). For these counties, a higher SI can have a significant impact on manure management cost. Table 2 uses Eq. [4] to translate SI into monetary terms. The values reported in Table 2 ($ L^{-1}$ liquid manure delivered) do depend on the cropland needed to manage manure stocks at agronomic rates (RA) and are based on the following assumptions. Manure is surface-applied by tank wagon to corn (Zea mays L.), soybean (Glycine max (L.) Merr.), wheat (Triticum aestivum L.), and bermudagrass (Cynodon dactylon (L.) Pers.) in rotation at a rate of 281.345 611 L/ha (Fleming, 1999; Thom, 1997). These areas with higher SI values are consistent with expectations.
Fig. 2. Difference in Suitability Index (SI) when liquid manure applications are restricted to cropland with <12% rather than 18% slope.

counties in west-central Kentucky. However, it is not possible to determine if other cost advantages, such as lower feed costs or better access to markets, may offset higher manure management costs. If this is not the case, then over time, such swine operations are likely to shift from these west-central counties (and other areas with higher index values) to other western Kentucky counties that are not part of the coalfield.

The story for large commercial operations is much clearer. Better market access and/or lower-cost inputs are unlikely to overcome manure management costs that are as much as $16 per head more than for similar operations in areas with a lower SI. This significantly higher cost is due to the large quantity of material that must be delivered in an area where cropland is relatively scarce. Currently, only a few large commercial operations, such as the one assumed here, exist in Kentucky. These results imply that such companies could potentially reduce their manure management costs by locating in areas with lower SI values. As a consequence, growth of a commercial swine industry, should it occur, will likely be in western Kentucky counties outside of the coalfield.

The final portion of this analysis concerns the impact on manure management cost of restricting the slope of cropland to which swine manure can be applied from 18 to 12%. Figure 2 reports differences in SI when liquid manure applications are restricted to cropland with <12% rather than 18% slope. For two-thirds of the state, a more restrictive manure application policy would increase SI by \( \leq 0.25 \) (Table 1). However, the impact is more significant in some areas. Results indicate that a more restrictive policy will have the greatest impact in the northern, west-central, and south-central regions of the state. In the northern and west-central regions, SI was increased by at most 1 unit while in the south-central region, SI was increased by at least 2 units. The large change in SI in the south-central region is due to this region being more mountainous. Here, switching from 12 to 18% slope significantly increases the amount of suitable cropland.

Table 3 and Fig. 3, which express changes in SI in monetary terms, can be used to assess the economic impact of a more restrictive manure application policy. Given the assumptions discussed previously, these results show that manure management costs in 85% of the studied area (Table 1) are increased by as much as $0.35 per head as a result of the policy. Yet there are regions of greater impact, including west-central Kentucky where most of the state’s hogs are produced. Here a 1-unit increase in SI is expected to increase the manure management cost of a large family-owned swine producer by $0.1314 per 1000 L of delivered material or $0.70 per finished head. Similarly, a large commercial operation would see manure management costs increase by $0.7884 per 1000 L or $4.22 per finished head. In the south-central region of Kentucky, where a more restrictive application policy would increase SI by at least 2 units, the average family operation is expected to pay an additional $1.41 per head.

Between 1994 and 1998, swine-producing members of the KFBM earned an average of $99.53 per hog produced but paid $65.13 per head on feed costs and $39.62 per head on other costs (Ibendahl et al., 2000). Over the 5-yr period, KFBM producers earned average net returns (over all costs) of $5.22 per head. In the best year (1996), KFBM producers earned average net returns of $13.33 per head, and in the worst year (1998), they lost $37.85 per head. The size of the KFBM farms is not reported but likely represent the average Kentucky
Table 3. Added cost of manure management ($ per 1000 L) when liquid manure applications are restricted to cropland with <12% rather than 18% slope derived using Eq. [5].†

<table>
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<th>RA§</th>
<th>0.25</th>
<th>0.50</th>
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† $Z$ is 2 and $\theta$ is 0.204 per 1000 L of manure (Fleming, 1999; J. Lorimor, personal communication, 1996). To calculate impact in $/ha$, multiply table value by 281.346. To calculate impact in $/head$ of finished hogs, multiply table value by 5.356. To calculate total cost of the policy ($), multiply table value by 281.346 $/RA$. These values assume that manure is surface-applied by tank wagon to corn, soybean, wheat, and bermudagrass in rotation at a rate of 281 345.611 L/ha (Fleming, 1999; Thom, 1997). This application rate is also based on the nutrients derived from finished hogs (76.2 kg average weight gain) that excrete 31 879.85 liters of manure per 453.59 kg of pork produced (Thom, 1997).

‡ SI, suitability index.

§ RA, required area.

**Fig. 3. Increase in manure management costs ($/head finished) paid by 5000 (upper figure) and 32 000 (lower figure) head finishing operations when liquid manure applications are restricted to cropland with <12% rather than 18% slope.**
family farm swine producer. For these farms, a $0.70 to $1.41 per-head increase in manure management costs represents a 5 to 11% reduction in net returns in a good year and a 2 to 4% reduction in a bad year. But in a bad year, net returns are already negative.

The results of this investigation are sensitive to the assumed values for δ, the proportion of suitable cropland already receiving manure, and γ, the proportion of suitable cropland available to receive manure. In this study, because no spatial data exist, δ and γ are restricted to values of 1. These restrictions act to understate SI, and hence understate the added cost of swine manure management. Yet this analysis shows that restricting the slope of cropland to which swine manure can be applied results in a 2 to 11% reduction in net return. More realistic values of δ and γ only act to further reduce net income. However, it must be noted that reasonable value of δ could be based on Census of Agriculture numbers on animal units, cropland, and agronomic recommendations for nutrient applications.

Calculating the total economic impact of a restrictive manure management policy on Kentucky swine producers requires knowledge of the size and general location of each producer. Unfortunately, this information is not currently available. However, the results of this investigation do suggest possible regional impacts. Specifically, as a result of the policy, Kentucky’s swine industry would be expected to minimize cost and migrate (relocate or locate) into western counties outside the coalfield.

CONCLUSIONS

To capture scale economies, swine facilities continue to expand in size, and larger concentrations of animals give rise to larger concentrations of manure. If sufficient cropland is available in the vicinity of the production facility, and if manure nutrients are applied to crops at agronomic rates, then expanded swine production will result in minimal environmental damage. In short, the effect of swine production on the quality of surface water and ground water depends on the assimilative capacity of the region and management practices of each individual farm.

The capacity of the environment in an area to assimilate manure nutrients is set by nature. But regulations that restrict swine manure applications restrict access to the natural capacity of the environment to assimilate manure nutrients. For example, Kentucky producers are required to apply swine manure to (crop or pasture) land following a certified nutrient management plan filed with the state. The nutrient plan, based on the amount of N in manure and crop N requirement, details the location and types of crops to which manure is to be applied. Furthermore, swine producers are prohibited from applying swine manure to land with a slope >12% or to land with <0.46 m of soil to bedrock. The first part of this regulation restricts the availability of suitable area. The second part defines what portion of total available area is suitable for manure applications.

These concepts of availability and suitability give rise to the SI defined in this investigation. The question addressed here concerns the state’s restriction on manure applications to land with a slope >12%. Agricultural interests view an 18% restriction as sufficient to avoid manure runoff into surface waters. They believe that a 12% restriction will eliminate significant area otherwise suitable for manure management, resulting in higher manure management costs and increased concentration of the industry in flatter regions of the state.

The results of this study may support these claims. Restricting applications to slopes <12% rather than 18% increased manure management cost by as much as $0.35 per head across 85% of the state’s agricultural area. This represents a 7% reduction in average net return (which is negative). This result applies to the typical Kentucky producer, who markets 5000 finished head annually. For very large firms (32,000 head finished annually), manure management costs were increased by as much as $2.11 per head. A 7% reduction in net return is significant, especially in periods of low swine prices when net returns are likely negative. Yet this reduction in net return is observed even under the best case scenario where δ, the proportion of suitable cropland already receiving manure, and γ, the proportion of suitable cropland available to receive manure, are both assumed to be 1. These restrictions act to understate SI, and hence understate the added cost of swine manure management.

Faced with lower net returns, the swine producer can make one of several choices: (i) adopt a technology that reduces the cost of manure management, (ii) move to another region of Kentucky where the cost of manure management is less, (iii) move to another state where the cost of manure management is less, or (iv) go out of business. Adding microbial phytase to feed, which reduces the P content of swine and poultry manure by up to 35%, is an example of a technology that reduces the cost of manure management. A 7% reduction in net return is also an economic disincentive for firms looking to locate in Kentucky. Indeed, no out-of-state swine firms have filed for construction permits since 1997.

Perhaps more importantly, the results indicate that a more restrictive slope policy is likely to impact a region of significant pork production in Kentucky. Producers in five of the top 10 Kentucky swine-producing counties pay higher manure management costs because of factors that restrict the availability and suitability of cropland in their area. This alone is sufficient incentive for swine producers in these counties to migrate to nearby, less costly areas. Yet these are also the counties more severely impacted by the 12% slope policy. Adding the cost of the 12% slope policy to manure management costs that are already relatively high is expected to accelerate movement of firms out of these counties. Essentially, this migration will occur as firms in higher cost counties cease business and new firms locate in less expensive areas. Hence, the results support the claim by industry that swine production could become more concentrated in counties outside of the coalfield, especially in extreme western Kentucky (the Jackson Purchase region).
The conclusions of this investigation apply to Kentucky. However, the methodology is easily applied to other regions of the USA. The scale of this methodology is limited only by the availability of slope and LULC data and by the processing speed of one’s computer. This model can also be improved upon in a number of ways. Future research will attempt to measure the parameters $\delta$ and $\gamma$. These parameters were set to 1 in this investigation, resulting in understated SI values and costs associated with a 12% restriction. Specifically, it is hoped that improvements in remote sensing technology will allow for the identification of agricultural areas receiving manure. Currently, obtaining this data on a large scale is cost prohibitive.

Finally, the conclusions are based on cost minimization. In fact, the 12% slope restriction can be ruled inefficient only if the costs of the policy exceed the benefits. This investigation considers only half of the equation. Yet, because of the cost of obtaining reliable benefit information, this is not an unreasonable approach. Future work includes measuring environmental and other economic benefits associated with a 12% slope restriction.

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APPENDIX

This appendix provides some of the more technical information needed to replicate this work as well as justification, where necessary, for what was done. Initial construction of the necessary spatial data sets was attempted using a vector format. Eventually, the vector format was abandoned in favor of a raster format. Vector data are stored and processed as a collection of arc segments. Raster data, on the other hand, are stored as pixels with individual x-y coordinates. While vectors are excellent at representing houses and roads, they are very processor and storage intensive when representing continuously varying features.

For this analysis, cell size was set to 200 by 200 m. A cell represents an area to which values representing geographic, agronomic, or other information are assigned. This particular cell size represents a compromise between high resolution and reasonable computer processing time. As resolution increases, computational time increases exponentially.

Calculating the parameters $\alpha$ and $\beta$ required construction of two databases. Calculating $\alpha$ required land-use information for the state while $\beta$ required land-slope information. Each data set is unique in construction. The slope grid for Kentucky was created using U.S. Geological Survey 2-arc-second DEMs downloaded from the Kentucky Geological Society web site (http://www.uky.edu/KGS/gis/kgs_gis.html; verified 5 Oct. 2001). Elevation data for the state is broken into thirty-four 1:100 000 scale quads representing 8 DEMs. Each DEM is approximately 5180 km$^2$ (http://rmmcweb.cr.usgs.gov/elevation/2arcinfo.html; verified 5 Oct. 2001). Unfortunately, DEMs for the three eastern Kentucky quads were not available. Each DEM requires 1.2 megabits (MB) of storage memory (9.6 MB per quad), so 326.4 MB of memory is needed to store all available DEMs for the state. Once converted to the same geographic datum, the individual quads were joined to form a single grid (or elevation coverage). This grid was then resampled to the desired 200-m resolution using the computer program Arc/Info.

Next, the grid feature and Slope command in Arc/Info were used to calculate the slope of each cell in the elevation grid. Here, percent slope is defined as the rise of a section of land divided by its run multiplied by 100. Arc/Info is able to calculate both degree slope and percent slope. These are very different concepts, which are sometimes confused. The difference between these two measures of slope is clarified in the help files that accompany Arc/Info. Finally, the slope grid created above was used to form two new grids representing area with 0 to 12% slope and area with 0 to 18% slope. For the 12% grid, cells corresponding with slope values of $\leq 12\%$ are assigned the value of 1; all other cells are assigned the value of 0. The 18% grid is constructed similarly.

REFERENCES