

**Managing Land Application of Broiler Litter to Optimize
Economic Value and Water Quality**

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ABSTRACT

Annual broiler processing capacity in southwestern Missouri is expected to increase from 127 million birds in 1989 to 245 million birds in 1995, or 93 percent. Much of this growth is expected to occur in Barry county where an additional 42,400 acres, almost double current land requirements, will be needed for land disposal of broiler litter. Rapid expansion in broiler production in southwestern Missouri can increase the risk of surface and ground water contamination from land application of broiler litter because the area has karst topography and large openings in the aquifer. Contamination of water in this region could have adverse economic and health impacts because water-based recreation is a significant sector of the regional economy and groundwater is the major source of drinking water. This study: determines the amount and composition of litter removed from seven broiler houses; develops a geographic information system for determining how spatial variability in land use, soil types and hydrogeologic features, and limits on the locations and application of broiler litter to protect water quality affect the amount of litter applied and the number of broilers grown in the watershed; and develops an economic optimization model that determines the locations and rates of litter application on areas of the watershed that maximize the economic value of applied litter while protecting water quality. The study area is the Shoal Creek watershed located in Barry County.

Introduction

Rapid expansion in broiler production in southwestern Missouri can increase the risk of surface and ground water contamination from land application of broiler litter. Southwestern Missouri is especially vulnerable to water contamination from broiler litter because land application is the major disposal method and the area has karst topography and large openings in the aquifer (Env. Protec. Agency, 1987). Contamination of water in this region could have adverse economic and health impacts because water-based recreation is a significant sector of the regional economy and groundwater is the major source of drinking water.

From 1982 to 1987, the inventory of poultry (broilers, turkeys and layers) in Missouri's five southwestern counties (Barry, Jasper, Lawrence, McDonald and Newton) doubled from 6 to 12 million birds (Missouri Dept. of Nat. Res., 1989). Annual broiler processing capacity in this five-county region is expected to increase from 127 million birds in 1989 to 245 million birds in 1995, or 93 percent. All of this expansion is expected to occur in Barry County. Georges' broiler processing plant in Butterfield, Missouri accounts for 61 percent of the new broiler processing capacity in Barry county. Barry county is in a region where groundwater has nitrate-nitrogen levels exceeding 3 mg/l (Nielsen and Lee, 1987). Growth in broiler production in Barry county is estimated to require an additional 42,400 acres for land disposal of broiler litter. Currently, 46,200 acres are used for this purpose (Missouri Dept. of Nat. Res., 1989).

Total land within a 25-mile radius of Georges' processing plant exceeds the projected acreage required for land application of litter. However, spatial variability in land use, soil types and hydrogeologic features and high vulnerability to surface and ground water contamination limit the area suitable for litter application. Accounting for spatial variability in vulnerability to water contamination limits the locations and rates of litter application that protect water quality.

Purpose and Objectives

The purpose of this research is to develop a prototype geographic information system for evaluating the limits placed on broiler litter application and broiler production by alternative restrictions on locations and rates of litter application in a watershed, and determining litter management practices that maximize the economic value of applied litter without exceeding

prescribed limits for protecting surface and ground water quality.¹ The study is conducted in Shoal Creek watershed located just west of Georges' plant.

Specific research objectives are as follows:

1. To determine the quantity and composition of litter generated by broilers.
2. To develop a geographic information system for determining how spatial variability in land use, soil types and hydrogeologic features, and limits on the locations and application of broiler litter to protect water quality affect the amount of litter applied and the number of broilers grown in the watershed.
3. To develop an economic optimization model that determines the locations and rates of litter application on areas of the watershed that maximize the economic value of applied litter while protecting water quality.

Related Research

Litter Analysis

The chemical composition of a broiler litter sample can be determined with a high degree of accuracy by a qualified laboratory. These laboratory results are only as good as the quality of the sample collected. Therefore, procedures used in collecting and handling the sample are extremely important. The sample which is analyzed must be representative of the entire amount of litter that will be removed and spread.

Samples can be collected in the field at the point of application by placing containers in the field at intervals across the path of the spreader. Samples gathered this way would represent what is actually spread on a given point in a field. Laboratory analysis of samples obtained using this collection methodology may provide historical information about soil nutrient application to a particular site, but this does not describe the quantity and composition of the litter that is removed from a given poultry house and is of limited use in making spreading recommendations.

1. Litter management practices refer to the frequency with which broiler houses are cleaned out and the timing and procedures for applying litter to the land.

Sampling within the house is a more useful method of collection. Historically ten (10) spot samples have been taken at different points within the house. Since litter varies greatly within the broiler house, it is difficult to obtain a representative sample using this technique. This variation is evident by the wide range of values published by Auburn University (Payne and Donald, 1990). They reported percent nitrogen (N) on an average dry weight basis of 3.9 with a range of 2.1 to 6.0, phosphate (P_2O_5) of 3.7 with a range of 1.4 to 8.9 and potash (K_2O) of 2.5 with a range of 0.8 to 6.2. Even though this technique would provide information that could be used in making application recommendations, the wide range in analytical values limits its use.

In the process of removing the litter from the broiler house, several loads are hauled and spread. These loads of litter are generally assumed to weigh a given amount based on estimates. The actual quantities of litter produced on a per-broiler basis under differing production and management regimens has not been determined. House cleanout scheduling varies from one to two times per year, with differing numbers of flocks reared on the litter between litter removal. Litter cake may also be removed from the house between flocks when there is a problem with litter consistency.

Geographic Information Systems

Geographic information systems (GIS) have been used to organize, evaluate and display input and output data for evaluating the physical and economic impacts of agricultural management practices on nonpoint source water pollution. Prato et al. (1989) and Prato and Shi (1990) used a GIS to evaluate resource management systems and the economic efficiency of alternative policies for controlling erosion and surface water pollution in an agricultural watershed. The Soil Conservation Service (SCS) has developed a GIS to analyze potential water quality problems associated with land application of poultry and dairy wastes in the Illinois River Basin (Soil Cons. Ser., 1989). Several research studies being conducted in connection with the President's Initiative to Enhance Water Quality will employ a GIS.

Economics and Water Quality

Few studies have attempted to identify economically efficient and environmentally acceptable locations and rates of litter application for a watershed. Certain aspects of this problem have been analyzed. D'Itri and Walfson (1987) determined that groundwater contamination can occur by either deep percolation of dissolved nutrients or from surface pollution of losing streams, both of which are a common feature in southwestern Missouri (Missouri Dept. Nat.

Res., 1989).² Losing streams make a region highly vulnerable to groundwater contamination (Mesko and Berkas, 1986). While portions of southwestern Missouri have clay and fragipan soils that retard deep percolation, these soils exhibit wide variation in permeability (Rogers and Lentz, 1983).

The risk of contaminating surface and ground water by land application of broiler litter depends on many factors including the nitrogen (N) and phosphorus (P) content of the litter, application rates, soil type, land slope, vegetative cover, proximity to streams, depth to groundwater, vadose characteristics, topography and climate. Steele (1989) found that groundwater in a poultry producing area of northwestern Arkansas had nitrate-nitrogen concentrations that were 6 to 8 times greater than in a nearby wildlife area. Wolf et al. (1988) found that soil and environmental conditions are important determinants of potential nitrate contamination of surface and ground water from poultry manure/litter. Huneycutt et al. (1988) found that poultry litter should not be used on grass-legume mixtures and that N from broiler litter is less efficient than N from inorganic fertilizer. Gilmour et al. (1987) estimated the N, P_2O_5 and K_2O content of broiler litter. Gilbertson et al. (1979) estimated the quantities and nutrient content of livestock and poultry manure under different management practices.

Napit (1990), and Bosch and Napit (1991) used a linear programming (LP), transportation model to analyze the economic potential for more effective use of poultry litter in Virginia. Their results indicated that it is economical to ship litter from surplus to deficit areas. Pierce et al. (1989) used an LP approach to evaluate potential uses of swine manure to meet crop nitrogen needs. They found that it is profitable to hire labor to spread manure on a typical hog-corn farm in Iowa.

McSweeney and Shortle (1989) used a chance-constrained mathematical programming model to examine the fertilization decision for a mixed crop-livestock farm when farmers are risk averse and there are uncertainties about crop yield response to nitrogen content of dairy manure. Prato et al. (1989) used an LP approach to select farming systems for all fields in an Idaho watershed that maximized total net returns to all farmers in the watershed subject to a specified limit on total soil erosion.

Molnar and Wu (1989) surveyed all livestock producers in the two most agriculturally productive counties in Alabama and found that livestock producers generally value manure as a

2.A losing stream is a stream which is losing a significant portion of its flow to the subsurface.

fertilizer but frequently do not use it effectively. Harris (1988) documented changes in attitudes of Delaware broiler growers that had occurred since 1980. Manure spreaders were not calibrated and only 50 percent of the growers attempted to apply broiler litter to meet crop needs in 1981. Five years later, manure calibration had increased to 40 percent and litter application to meet crop needs had increased to 90 percent. Manure storage and analysis had also increased during this period.

Wolf et. al. (1988) found that 37 percent of the nitrogen in field applied hen manure was lost to the atmosphere through volatilization within eleven days of application. The best time for land application of litter is as near to the time of crop uptake as possible to avoid nutrient losses. The potential for nutrient losses is highest during the wetter times of the year (Beegle, 1990). However, the actual time for land application is usually affected by the plan of operation for the broiler house. Therefore, an appropriate time for clean-out might not be an appropriate time for land application to protect water quality. In these cases, storage of broiler litter might be beneficial.

Groundwater contamination by surface applied livestock waste is generally attributed to excessive application rates in cultivated crops or to excessive irrigation of irrigated cropland (Keeney, 1989). Magette et al. (1988) found that nitrate concentrations in groundwater below conventionally tilled corn to which broiler litter was applied was nearly equal to those in adjacent watersheds in which no litter was applied. Trials on pasture with applied broiler litter provided interesting results. Magette (1988) found that runoff was delayed and reduced with the addition of broiler litter. Giddens and Barnett (1980) found similar results with bermudagrass plots. Runoff was delayed and soil loss was near zero.

Westerman et. al. (1988) found that 40-50 percent of the organic nitrogen in broiler litter was available in the first few weeks and potentially 50-70 percent was available within 8-10 months. They found no significant variation in mineralization rates across soil types. Westerman and Overcash (1980) found that the concentration of potential pollutants were reduced by 90 percent within the first three days. McLeod and Hegg (1984) reported similar results with caged layer waste.

Potential water pollutants in broiler litter may be nutrients (nitrogen and phosphorus), oxygen-demanding materials, suspended materials, pathogens, toxic substances, and salts (Boyd, 1990). Bitzer and Sims (1988) developed the following formula to predict the amount of available nitrogen in poultry litter:

$$Na = .80Ni + .60No,$$

where: Na = available nitrogen; Ni = inorganic nitrogen; and No = organic nitrogen. This formula predicts 60 percent of organic nitrogen is mineralized in the first year and 20 percent of inorganic nitrogen is lost.

Methods and Procedures

This section discusses the methods and procedures for each of the three objectives addressed in this study.

Litter Analysis

In order to evaluate the potential effects of litter application on water quality, the quantity and composition of litter removed from a sample of broiler houses were determined. The houses were located within or in the area adjacent to the Shoal Creek watershed in Barry County, Missouri (Figure 1).

To conserve fuel usage during brooding, day-old broilers are placed in one section of the house that has supplemental heat. This area is identified as the brooding section and is separated using a retractable partition from the remainder of the house (growing section). When the broilers are approximately three weeks old the barrier is removed and they are given access to the total area of the building including the growing section. These two building sections were sampled and weighed separately to provide information with which to analyze optimum litter use.

Litter samples were collected from seven houses. Since broiler house equipment such as feeders, brooder stoves and watering devices are laid out running the length of the house, strip samples were taken across the width of the house on 30 foot intervals or at intervals equal to one thirteenth of the length of the building for buildings that were not 400 feet long. A 10-inch wide strip was removed to the dirt floor level and placed on adjacent 4' x 8' x .25" plywood sheets. The larger chunks of caked litter found on the plywood sheet were broken apart using the point of the shovel, and the litter was then thoroughly mixed by shovel on each of the plywood sheets. A representative sample portion (approximately one fourth to one third by volume) of the litter from each plywood sheet was placed in a large heavy duty plastic bag and identified by strip within house. Samples were sifted through a .25" hardware mesh screen using a hydraulic powered shaker box mounted on the 3 point hitch of a farm tractor.

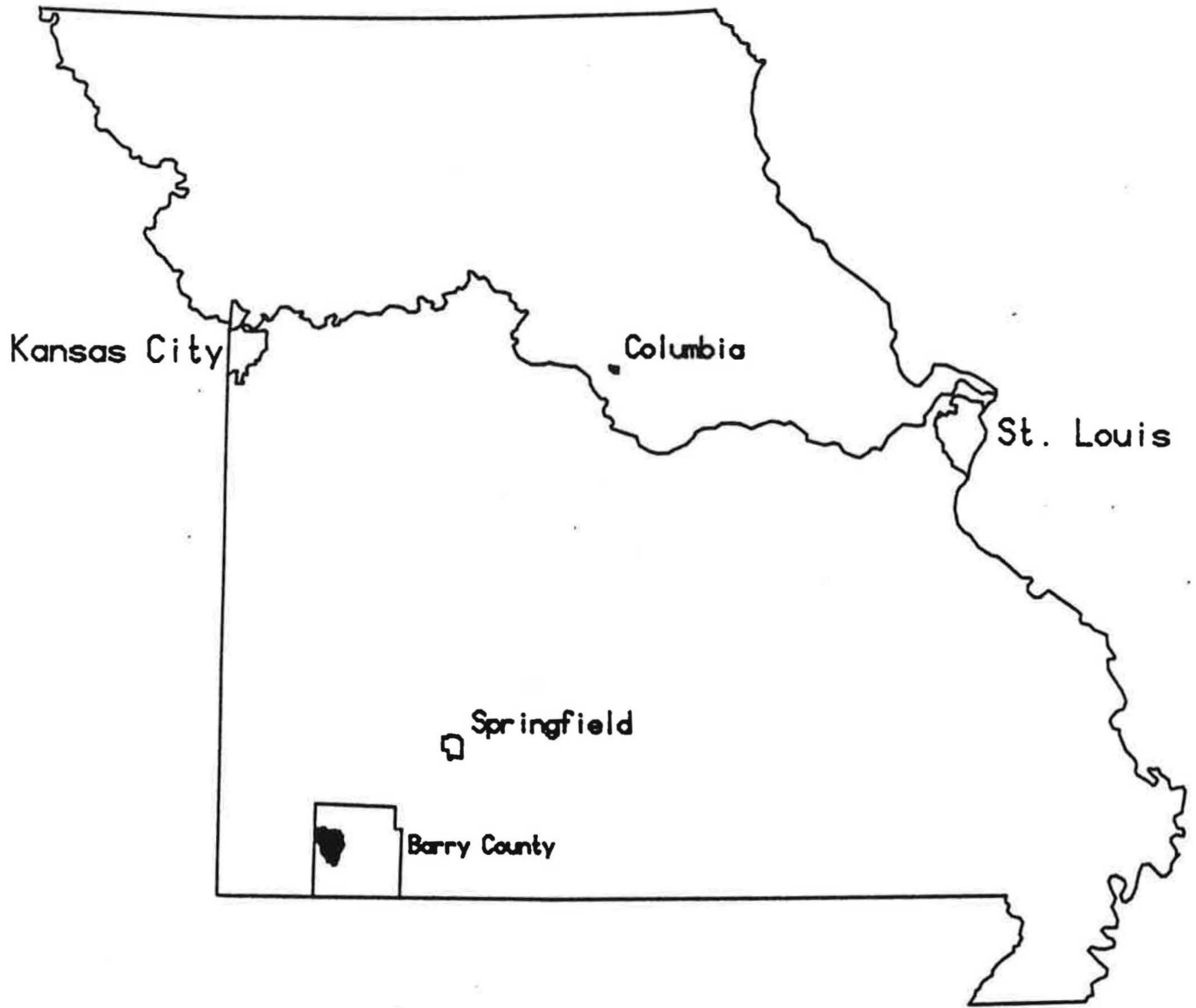


Figure 1. Locational Map for Study Area

Rocks not passing through the screen were picked out and discarded and the entire litter sample was then ground through a .25" hammer mill screen. Ground samples were mixed, subsampled and ground through a 2 mm screen in a Wiley mill. Individual strip samples were analyzed for moisture and nitrogen. Strip samples for each house were subsampled and remixed producing two composite samples representing the brooding and growing areas. These composite samples were analyzed for nitrogen, ammonia, nitrate, phosphorus, potassium, calcium, magnesium, sodium, sulphur, manganese, zinc, iron and copper.

After the samples had been obtained in the broiler house, the litter was loaded into a truck-mounted litter spreader with a skid-steer loader. The brooding and growing sections were weighed separately. Four Hi-way Loadmeter, Type A (Loadmeter Corporation, 1700 Union Avenue, Baltimore, MD 21211) truck scales were used to weigh each truck. One scale was used for each wheel and the total loaded weight minus the tare equalled the weight of litter removed. A summation of the loads weighed provide the total quantity of litter per section and house.

Geographic Information System

Approval of a waste management system by the Missouri Department of Natural Resources (MDNR) requires that enough land be available to receive the waste generated by the poultry enterprise. If this amount of land is not under the ownership of the poultry enterprise, a legally binding agreement must be drawn with adjacent landowners to allow the spreading of litter on their land.

A prototype GIS was developed for the purpose of determining the locations and application rates for broiler litter in the Shoal Creek watershed that would maximize the total amount of litter applied in the watershed while protecting water quality. The analysis was based on two approaches to litter application: a conservative litter management approach that limits application to 100 lb N per acre per year and an intensive litter management approach which allows up to 220 lb of N per acre per year. Specifically, the analysis involved: delineating subareas of the Shoal Creek watershed that were suitable for land application of broiler litter; developing a model that determines rates of litter application on fields in the watershed that maximizes the amount of litter spread while protecting water quality; and determining baseline data needed to analyze scenarios for broiler production and litter utilization in the watershed.

Database Creation

Inter-related spatial and tabular databases were created that could be queried via boolean operations. To facilitate sharing of databases with other agencies such as the MDNR and the Environmental Protection Agency (EPA), ARC/INFO GIS software was used. This software is one of the most common software packages for GIS. Spatial databases were mapped from or to a 1:24,000 scale base map, in most instances, the USGS 7.5 minute quadrangle. The Shoal Creek watershed fell within four quadrangles, namely, Exeter, Purdy, Rocky Comfort, and Wheaton (Figure 2). The watershed encompassed a total of 42,564 acres. Land cover breakdown for the watershed is presented in Table 1 and graphically in Figure 3. The digitized coverages and other data facts, listed in Appendix A, are available for further analysis. To aid in the assessment of suitable sites for litter application, tabular databases were created using information from the soil survey for Barry County. These tabular databases are listed in Appendices B and C. In addition to these databases, associated databases were created for the different scenarios which were modeled using the spatial analysis techniques available within ARC/INFO.

Table 1. Land Cover for Shoal Creek Watershed

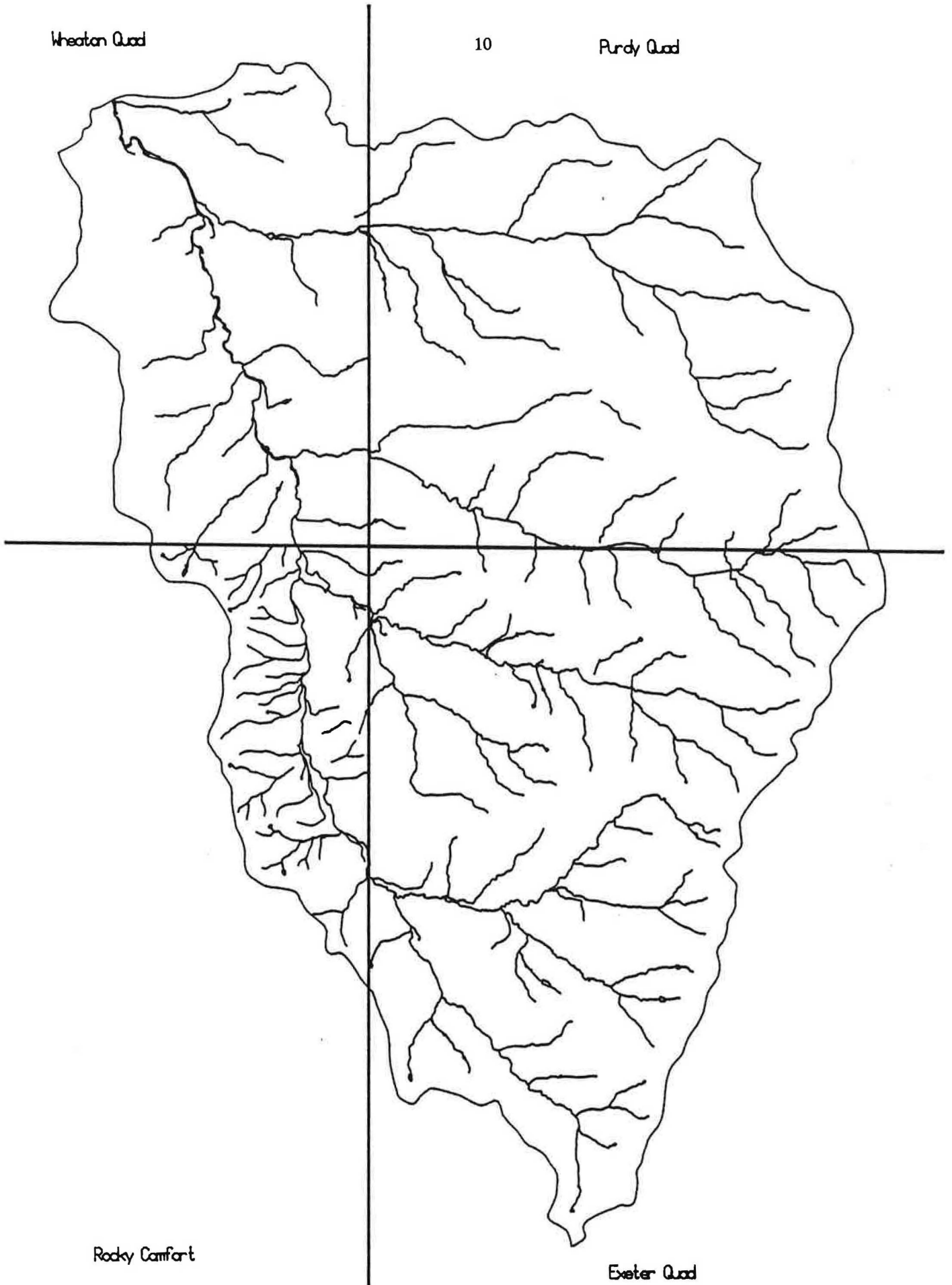
<u>Land Cover Type</u>	<u>Area (in Acres)</u>
Forest	3,992
Savannah	1,040
Grass / Pasture	33,884
Row Crop	3,001
Old Field	373
Urban	155
Orchard	66
Georges Plant	39
Water	15

Two approaches were used to determine loading of broiler litter within the watershed. The first approach is the Conservative Litter Management Approach (CLMA) described by Fulhage (1991a). Under the CLMA, land-area requirements are based on the application of 100 lb N per acre per year. No restrictions are placed on crops grown, nutrient uptake capability or waste/soil capability. Land area requirements in this approach are based on average levels of nitrogen in broiler litter and average annual litter production.

Wheaton Quad

10

Purdy Quad



Rocky Comfort

Exeter Quad

Figure 2. Four Quadrangles: The Shoal Creek Watershed

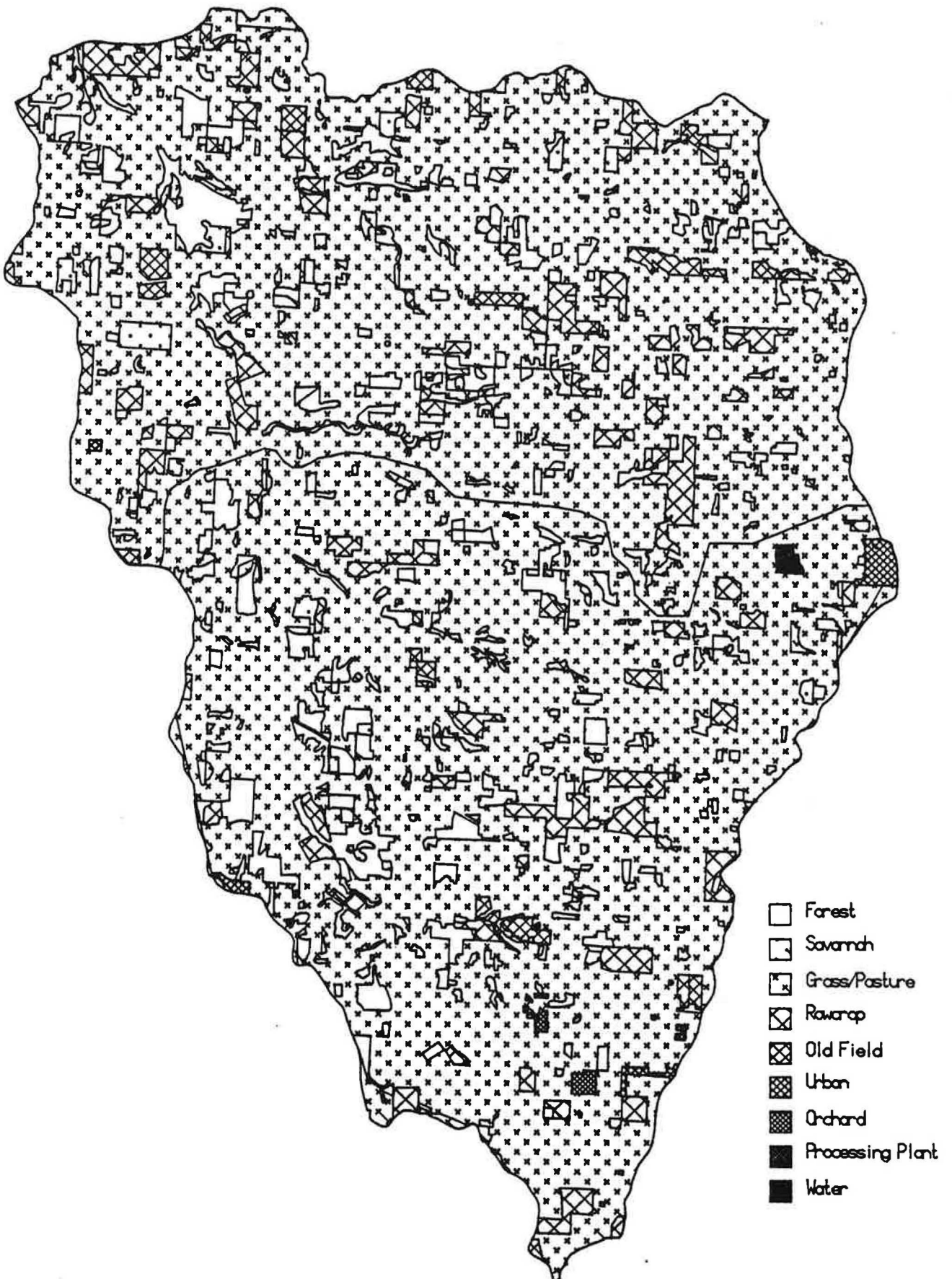


Figure 3. Land Cover / Land Use

The second approach is the Intensive Litter Management Approach (ILMA) described by Fulhage (1991b). This approach takes into account the nutrient uptake capability of the crop being grown and assumes that 25 percent of the applied nitrogen will be lost due to volatilization or other means. This approach recommends that soils information for the spreading sites be submitted with the permit application. At a minimum, soil permeability, soil type and slope should be included in the permit application. To calculate an estimate of the nitrogen loading factor for each soil/land cover combination in the watershed, three ranking factors were calculated and combined. A 'land-rank' parameter was calculated by assessing the economic value of broiler litter on any given land cover available for spreading. The spreading of litter on urban, forest, water, or orchards was not allowed. A 'soil-rank' parameter was calculated by assessing and combining four parameters within the soil survey database, namely flood frequency, depth to seasonal high water table, bedrock depth and permeability. The 'land-rank' and 'soil-rank' parameters were then multiplied to magnify the various differences to be found between the soil/land cover interchange to create the 'multi-rank' parameter. The best possible site for spreading litter had an assigned value of 130. The 'multi-rank' parameter was then scaled as a percentage ranging from 0 to 100 in order to rank the various combinations.

The maximum loading for each soil/land cover combination was determined by using the production assessments associated with each soil type and linking it to the actual land cover for that unit (Figure 4). All grasslands were assumed to be available for fescue hay production having a nitrogen consumption rate of 55 lb N per ton of hay. All rowcrop areas were assumed to be in winter wheat having a nitrogen consumption rate of 1.3 lb N per bu of wheat. The savannah and old field classes were assumed to require 100 lb N per acre per year. From these calculations, the Intensive Nitrogen Loading (I-N-Load) parameter was determined for all available land areas as defined by a land cover/soil intersection. When plotted over the study area, this parameter was visually very similar to the map showing the limitations of poultry waste spreading obtained from the Barry county soil survey (Figure 5). The I-N-Load was 'corrected' by multiplying it by the scaled 'multi-rank' parameter so as to incorporate the uniqueness of each parcel into the nitrogen loading assessment. Nitrogen loading assessments for both the CLMA and ILMA approaches were then translated into tons of applied broiler litter which in turn was used to determine the capacity of the watershed for broiler production. Realistically, not all land identified through the modeling is actually available or cost effective for spreading litter. Therefore, only 75 percent of available land is analyzed independently. The resultant analysis examines 100 percent and 75 percent availability.

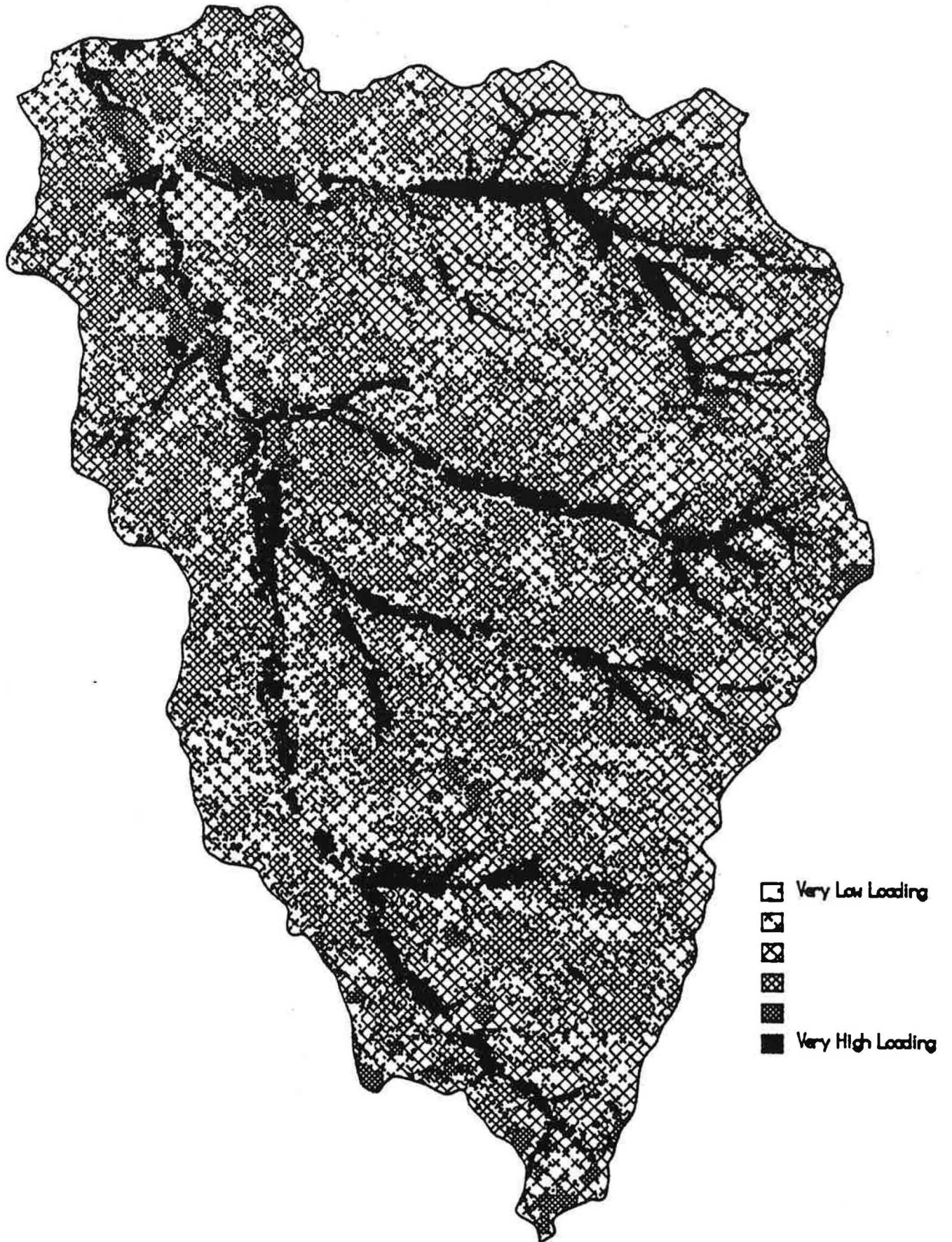


Figure 4. Poultry Waste Limitations - Modeling Results

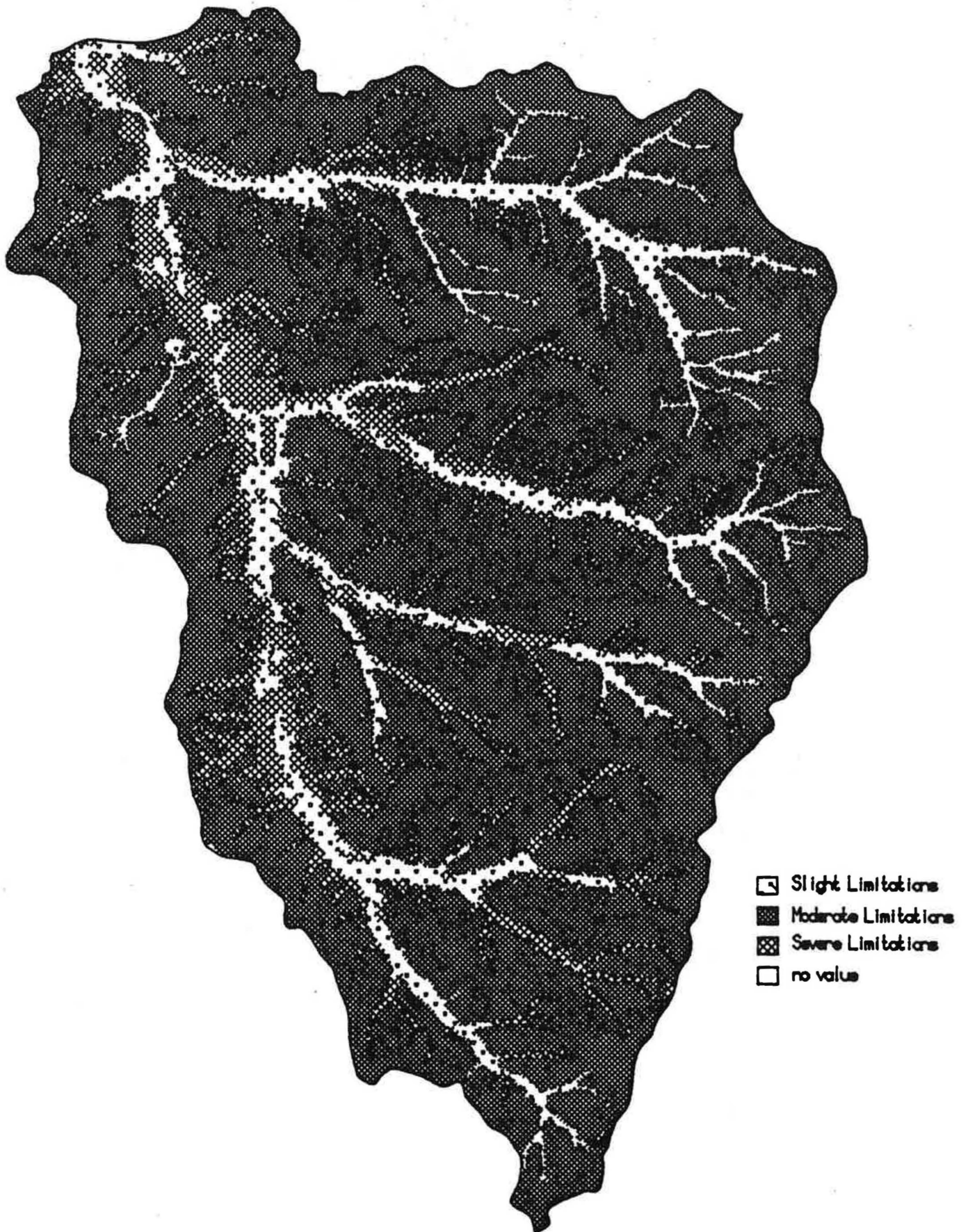


Figure 5. Poultry Waste Limitations - Soil Survey

The two approaches were used to evaluate four scenarios:

1. Do not use any guidelines for spreading litter within the watershed.
2. Use MDNR guidelines for spreading litter which include:
 - No spreading within 50 ft of roads, hydrological features such as streams, ponds, and lakes, or structures.
 - No spreading within 300 ft of a sinkhole.
 - No spreading on slopes greater than 10 percent
3. Use MDNR guidelines, however, remove the slope limitation.
4. Use MDNR guidelines, but incorporate the removal of 'occasional' and 'frequent' flooding areas as potential sites.

Economic Optimization Model

The economic analysis involved two aspects: developing a linear programming (LP) model that determines the optimal use of broiler litter and evaluating the economics of broiler production, litter management and forage production.

Overall Framework

Broiler litter is a by-product of broiler production. It is a valuable resource which can be used as a substitute for commercial fertilizer, a supplement for livestock feed, and other purposes. Improper utilization of broiler litter can result in nutrient losses and water contamination. Traditionally, broiler litter has been applied to pasture or cropland. The pressure on broiler growers to manage litter to protect water quality is increasing, especially in areas like southwestern Missouri where rapid increases in broiler production are expected.

Broiler litter is a source of fertilizer and has significant fertilizer value. Thus, broiler litter is a valuable resource. Much success has been achieved in substituting broiler litter for commercial fertilizer in places such as Maryland, Virginia, and Delaware. This substitution has significantly reduced fertilizer costs. Since improper use of litter can adversely affect water quality, broiler litter is considered as a potential water pollutant. Broiler litter can enter a water body by leaching through the soil and by runoff from areas where broiler litter has been applied to land. Only by preventing water pollution from broiler litter can its value as a resource be fully realized.

Land application is the major use of broiler litter. Both economic and environmental concerns require that the location and quantity of broiler litter applied to land be carefully selected. Environmentally acceptable rates of land application and economically optimum rates of land

application may not be consistent. Economic considerations dictate that crop nutritional requirements be met. For example, an economic optimum rate of 2 tons per acre for a crop may cause water quality problems. A lower application rate or no application may be required on soils having high leaching or runoff potential in order to protect water quality.

Agricultural producers who want to use litter may not be able to purchase it at a reasonable price due to high costs of transportation and handling. It may not be economical to store or to double handle litter. From a cost viewpoint, it is best to spread litter to fields directly from the poultry house. Application of broiler litter is often limited to areas near the source as the high bulk and moisture contents make it uneconomical to transport over a significant distance. Environmental concerns may require some storage.

The price at which broiler litter sells is influenced by the cost of labor, equipment operating costs, and the overhead associated with the physical clean-out operation of the broiler houses. This price may not reflect the fertilizer or feed value of litter. These factors complicate the decision to utilize broiler litter. In an attempt to capture these complex relationships, an LP model is developed. The model examines economic uses of broiler litter that protect water quality. It can be used to maximize the economic value of litter subject to attainment of water quality protection.

Litter Use Alternatives

Litter application to land is a major way of utilizing litter. However, land application must be managed and controlled. Application rate should be adjusted according to the content of the litter, the type of soil, the crops being grown, crop growth stage and weather conditions. Supplementary commercial fertilizers may be added so that the crop receives a balanced application of all nutrients.

The major problems and limitations of land application include: the limited availability of suitable land characterized by soil type, slope, contour and climate; the potential for substituting litter for commercial fertilizer; groundwater contamination due to high water table, over application, and poor management; the potential for surface water contamination due to runoff and erosion; increased costs; and nuisance complaints such as odor and flies.

Use of broiler litter must be efficient and cost effective for broiler growers, farmers who purchase litter, and middle-men who sell and buy litter. It must be profitable for contract-cleaners to clean, collect and transport broiler litter to land, and for farmers to spread litter.

Several questions arise regarding the use of broiler litter. Should broiler litter be substituted for commercial fertilizer? How does broiler litter compare with other livestock litters for land application? How much can farmers save by substituting broiler litter for commercial fertilizer? What other benefits and costs arise from using broiler litter instead of commercial fertilizer? What is the net social benefit of applying litter? Can these benefits be measured? Do some groups gain and other groups lose by using broiler litter? Are the gains greater than the losses? Should gainers compensate losers, and if so, how much? All these questions involve agronomic, economic and environmental considerations.

Another potential alternative is to feed litter to cattle. This option may prove to be economically feasible and profitable. Broiler litter has high feed value because of its relatively high energy and high protein content, of which about 45-67 percent is present as true protein (Muller, 1980). Litter must be properly processed before it can be utilized as a cattle feed. Feeding litter to cattle can reduce feed costs while improving livestock performance. When unfavorable weather conditions reduce production of livestock feed such as hay and corn, farmers may look for and willingly accept feed substitutes which are more economic. Feed shortages caused by unfavorable weather have been a powerful incentive to feed broiler litter. Broiler litter is often used to supplement limited supplies of other feed grains which occur when weather situations are poor.

One limitation of using composted litter to feed cattle is that it requires more equipment and labor than feed grains and legume forages. Mixing some corn grain and other palatable concentrate with composted litter is needed to stimulate consumption. These additional requirements hinder the sustained use of litter for beef cows. Litter feeding to beef cows thus tends to rise or fall depending on forage supplies and prices. When other traditional feeds such as hay and corn are abundant, less litter will be fed to beef cows.

The content of broiler litter varies from place to place. Muller (1980) listed eighteen factors that influence the chemical composition and nutritional value of broiler litter. For this analysis, average nutrient values based on samples taken from the study area will be used. For actual farm operations, litter tests will be necessary to determine the value of litter in a particular use.

There is evidence that broiler litter can be successfully and economically fed to beef cattle. A beef cattle farm that is 500 miles away from the source of broiler litter can obtain composted litter at a cost of about \$30 per ton, of which more than two-thirds is transportation cost.

Broiler litter is a low-cost source of protein and minerals for beef cattle. Use of composted litter would allow beef cattle producers to reduce feed costs and remain competitive and profitable. For example, a recent experiment in Iowa indicated success in feeding broiler litter to heifers. Savings in feeding costs were significant (Eaheart, 1991).

While the economic value of litter for feed appears to be higher than for land application, it has not been widely used as a feed due to high transport cost for litter and other reasons. Since there is much uncertainty regarding the feeding alternative, more scientific studies are needed before the potential of this alternative can be evaluated. Therefore, feeding of broiler litter will not be considered in the LP model.

Decisions on land application differ according to the type of farmer making the decision. Broiler processors have little to do with litter use. Broiler growers make decisions about whether to apply litter to their own land considering the fertilizer value of litter on different parcels, or to sell litter. The value of litter would be implicit if it is applied to a grower's own fields or explicit if it is sold to someone else. If applied to his own fields, the decision is how to maximize the value of the litter as fertilizer, net of costs of disposal. A forage producer would have to decide the optimal amount of litter to be purchased and applied to his fields.

A broiler grower owns broiler houses. Each house has 3-6 flocks a year. He hires a contract-cleaner to clean the house once or twice a year. Usually, a grower prefers once-a-year cleanout to save labor and time. Processors prefer cleaning out twice a year to enhance the quality of broilers. A broiler grower usually wants to sell litter at the time of cleanout. Cleanout usually occurs in spring or fall.

Since the broiler grower is interested in disposing of the litter, the amount of broiler litter available for land application can be assumed fixed. A forage producer is assumed to be a profit maximizer in choosing the level of broiler litter to apply to forage. The economic objective would be to maximize the total net return from land application of broiler litter while controlling the negative effects on water quality. This optimization problem can be solved by maximizing net value from utilizing litter on different fields in the watershed without environmental constraints, and re-solved by imposing constraints on land available for litter application and rates of application on different fields to protect water quality.

Linear Programming Model

The optimal utilization of litter can be formulated as an LP model. Consider maximizing an objective function subject to constraints:

$$\begin{aligned} \text{Maximize } & F = cu \\ \text{subject to } & Au \leq b \\ & u \geq 0 \end{aligned} \tag{1}$$

where:

c = $1 \times n$ vector of prices

u = $n \times 1$ vector of nonnegative choice variables (activities)

A = $m \times n$ matrix of technical coefficients

b = $m \times 1$ vector of constant resource limits.

The dual problem to (1) is:

$$\begin{aligned} \text{Minimize } & G = b'v \\ \text{subject to } & A'v \geq c' \\ & v \geq 0 \end{aligned} \tag{2}$$

where v = $m \times 1$ vector of nonnegative choice variables. Either (1) or (2) is said to be the dual problem to the other and both exist simultaneously. If u represents the choice variables, then v is the shadow prices, and vice versa. The shadow prices are known as the marginal value of inputs.

The Kuhn-Tucker (K-T) conditions are necessary and sufficient for a global extremum if the solution always occurs at a vertex of a convex solution space so long as the objective function is concave. For the LP problem in (1), the Lagrangian function is (3) and the K-T conditions are (4) through (9).

$$\text{Maximize } L = cu + v'(b-Au) \tag{3}$$

$$dL/du = c' - A'v \leq 0 \tag{4}$$

$$(dL/du)Iu = (c' - A'v)Iu = 0 \tag{5}$$

$$dL/dv = b - Au \geq 0 \tag{6}$$

$$(dL/dv)Iv = (b - Au)Iv = 0 \tag{7}$$

$$u \geq 0 \tag{8}$$

$$v \geq 0 \tag{9}$$

Shadow prices (v) for resources represent the potential increases in the value of the objective function when the corresponding resources are increased by one unit. They represent the economic value of additional units of scarce resources.

Matrix A contains fixed coefficients of resources used in the production of u . $A'v$ represents the imputed value of resources used in production. Since c represents the gross profits associated with activities u , condition (4) indicates that gross profits for an activity must be less than or equal to the imputed value of the resources. Condition (4) is linked to condition (5) in the sense that for any u_i whose gross profit is less than the imputed value of the corresponding resources, there must be no production. Conversely, if the gross profit from an activity is equal to the imputed value of resources expended on the activity, production occurs. Hence, either $u = 0$ or $c' - A'v = 0$. Conditions (6) and (7) are linked together in the sense that if a constraint is binding, $b - Au = 0$ and $v > 0$, and if a constraint is not binding, $b - Au > 0$ and $v = 0$, and hence (7). Conditions (8) and (9) state that for the maximization problem at hand, the choice variables (u) and the shadow prices (v) cannot be negative in the optimal solution.

Analyses performed with the LP model include: optimal solution for the current problem setting, changes in solution after modifying and/or adding more activities, changes in solution after modifying and/or adding more constraints, sensitivity analysis to examine the effect of b and/or c on the optimal solution (current solution remains optimal), reduced costs of X and shadow prices of b .

The LP model developed for the Shoal Creek watershed is based on the following assumptions:

1. Growth in broiler litter is exogenous;
2. Alternative uses of litter refers to the amount of litter applied to each field in the watershed;
3. There are no activities for buying litter from or selling litter to areas outside the watershed. Litter utilization is restricted to areas within the watershed. That is, the amount of litter available in the watershed is utilized or disposed within the watershed. All litter generated in the watershed is applied in watershed. This assumption can be relaxed to allow exporting of litter when there is a significant surplus litter and exportation is profitable. To protect water quality, litter may have to be sold outside the watershed;
4. Transportation cost for litter is the same throughout the watershed. That is, litter can be obtained for any field in the watershed at the same price;

5. Either commercial fertilizer or broiler litter, or both, can be used as fertilizer;
6. Broiler litter is applied at agronomic rates to ensure sufficient use of fertilizer and to avoid overloading the soil. Application rate is at a level that provides sufficient nutrients (specifically, nitrogen and phosphorus) for crop growth.

Under these assumptions, the LP model is as follows:

Maximize:

$$\begin{aligned}
 Z = & \sum_{i=1}^I \sum_{j=1}^J \sum_{k=1}^K \sum_{l=1}^L (P_j Y_{ijkl} - C_{ijkl}) - \sum_{m=1}^{12} P^l b^l B_m \\
 & - \sum_{i=1}^I \sum_{j=1}^J \sum_{l=1}^L (P^l b^l B_{ijl}) - P^{cfn} C_{FN} - P^{cfc} C_{FP} - P^{cfk} C_{FK}
 \end{aligned} \tag{10}$$

s. t.

$$\sum_{j=1}^J \sum_{k=1}^K \sum_{l=1}^L X_{ijkl} \leq F_i \quad \text{for all } i \tag{11}$$

$$\sum_{i=1}^I \sum_{j=1}^J \sum_{k=1}^K \sum_{l=1}^L \text{LABOR}_{ijklm} X_{ijkl} - LB_m = 0 \quad \text{for all } m \tag{12}$$

$$a^{nBL}_{ijl} - b^{n}_{ijl} X_{ijkl} \geq 0 \quad \text{where } k = BL \quad \text{for all } i, j, l \tag{13}$$

$$a^{pBL}_{ijl} - b^{p}_{ijl} X_{ijkl} \geq 0 \quad \text{where } k = BL \quad \text{for all } i, j, l \tag{14}$$

$$a^{kBL}_{ijl} - b^{k}_{ijl} X_{ijkl} \geq 0 \quad \text{where } k = BL \quad \text{for all } i, j, l \tag{15}$$

$$\sum_{i=1}^I \sum_{j=1}^J \sum_{l=1}^L B_{ijl} \leq \text{BLLIMIT} \tag{16}$$

$$C_{FN}_{ijl} - b^{n}_{ijl} X_{ijkl} \geq 0 \quad \text{where } k = CF \quad \text{for all } i, j, l \tag{17}$$

$$CFP_{ijl} - b_{ijl}^p X_{ijkl} \geq 0 \quad \text{where } k = CF \quad \text{for all } i, j, l \quad (18)$$

$$CFK_{ijl} - b_{ijl}^k X_{ijkl} \geq 0 \quad \text{where } k = CF \quad \text{for all } i, j, l \quad (19)$$

$$\sum_{i=1}^I \sum_{j=1}^J \sum_{l=1}^L CFN_{ijl} - CFN = 0 \quad (20)$$

$$\sum_{i=1}^I \sum_{j=1}^J \sum_{l=1}^L CFP_{ijl} - CFP = 0 \quad (21)$$

$$\sum_{i=1}^I \sum_{j=1}^J \sum_{l=1}^L CFK_{ijl} - CFK = 0 \quad (22)$$

$$\sum_{i=1}^I \sum_{j=1}^J \sum_{k=1}^K \sum_{l=1}^L s_{ijklw} X_{ijkl} \leq T_w \quad \text{for all } w \quad (23)$$

$$s_{ijklw} X_{ijkl} \leq T_{iw} \quad \text{for all } i, j, k, l, w \quad (24)$$

$$\sum_{i=1}^I \sum_{k=1}^K \sum_{l=1}^L X_{ijkl} \leq U_j \quad \text{for all } j \quad (25)$$

$$\sum_{i=1}^I \sum_{k=1}^K \sum_{l=1}^L X_{ijkl} \geq L_j \quad \text{for all } j \quad (26)$$

$$X_{ijkl} \geq 0 \quad \text{for all } i, j, k, l \quad (27)$$

where:

- X_{ijkl} = Area of field i in crop j with fertilizer k at level l . This is the decision variable to be determined by the mathematical programming model
- BL_{ijl} = Amounts of broiler litter associated with each X_{ijkl}
- CF_{ijl} = Amounts of commercial fertilizer associated with each X_{ijkl}
- LB_m = Labor used in month m
- P_j = price of crop j

Y_{ijkl}	=	Yield of crop j on field i with fertilizer k at level l
C_{ijkl}	=	Cost of producing crop j on field i with fertilizer k at level l, excluding fertilizing cost and labor cost
pbl	=	Price of broiler litter
$pcfn$	=	Prices of commercial fertilizer N
$pcfp$	=	Prices of commercial fertilizer P
$pcfk$	=	Prices of commercial fertilizer K
plb	=	Price of labor
F_i	=	Acres in field i
$LABOR_{ijklm}$	=	Labor requirement for producing crop j on field i with fertilizer k at level l in month m
a^N, a^P, a^K	=	Nutrient content (N, P and K) of litter
b_{ijl}^N	=	N requirements for producing crop j on field i with yield goal l
b_{ijl}^P	=	P requirements for producing crop j on field i with yield goal l
b_{ijl}^K	=	K requirements for producing crop j on field i with yield goal l
$BLLIMIT$	=	Quantity of broiler litter available
s_{ijklw}	=	Effect on water pollutant w for field i when growing crop j with fertilizer k at level l
T_w	=	Upper limit on total loading or concentration of water pollutant w
T_{iw}	=	Upper limit on the loading or concentration of water pollutant w for field i
U_j, L_j	=	Upper and lower limits on acreage planted in crop j.

Input parameters include: $P_j, Y_{ijkl}, C_{ijkl}, pbl, pcfn, pcfp, pcfk, plb, F_i, LABOR_{ijkl}, a^N, a^P, a^K, b_{ijl}^N, b_{ijl}^P, b_{ijl}^K, BLLIMIT, s_{ijklw}, T_w, T_{iw}$. Crop yields and costs (Y_{ijkl} and C_{ijkl}) can be

differentiated for each i, j, k, l . Water pollution limits can also be tailored to specific fields using equation (24). On each field, all possible litter uses and associated yield goals are identified, cost and return budgets for alternative litter uses and crops are constructed, and water quality effects for alternative litter uses are estimated. Nutrient content of broiler litter can be obtained from litter samples or literature values. Crop yield responses would be established for several reasonable yield goals and litter application rates. Annual availability of broiler litter can be estimated by the number of houses times annual production per house based on litter samples or literature values. Enterprise budgets are needed which reflect broiler litter application rates required for specific crops and yields, labor requirements, costs

of using litter, and net returns for different litter utilization practices (see section on economics of forage production). These budgets are used to develop the coefficients for the LP model.

Decision variables are: X_{ijkl} , BL_{ijl} , $(CFN_{ijl}, CFP_{ijl}, CFK_{ijl})$, CFN , CFP , CFK , LB_m . The GIS is used to obtain the land use, soil type, slope, and other relevant information. The watershed is then divided into different fields or land management units (LMUs) based on the information provided by the GIS. For example, the Shoal Creek watershed can be divided into I fields or LMUs (F_1, \dots, F_I) according to soil texture and slope, e.g., 16 field types if there are 4 soil textures and 4 slope categories.

The objective function of the LP model, represented by (10), equals the net return from utilizing litter. Note that costs of commercial fertilizer, broiler litter and labor are not included in C_{ijkl} . Costs for these items are explicitly stated in the objective function.

Constraint (11) represents the acreage restriction for each field; namely, the sum of the acreage for activities on each field should not exceed the area of the field. Constraint (12) represents monthly labor requirements. It can be further restricted so that total monthly labor requirements cannot exceed monthly availability of labor by adding a constraint $LB_m \leq LB_m^*$, where LB_m^* is monthly availability of labor. The labor constraint is important because broiler production activities may limit the amount of labor available for litter utilization.

Constraints (13)-(15) and (17)-(19) represent the minimum crop nutrition requirements from broiler litter and commercial fertilizer, respectively. Certain quantities of commercial fertilizer and/or broiler litter are required to achieve particular yield goals. Parameters a^N , a^P and a^K are the nutrient contents of N, P and K per unit of broiler litter expressed in commercial fertilizer equivalents. b_{ijl}^N , b_{ijl}^P and b_{ijl}^K are the nutrient requirements for N, P and K on field i

to grow crop j at fertilizer level l. The minimum crop nutrition requirements are met through either commercial fertilizer and/or litter. Restrictions can be set to meet only the nitrogen requirement from litter. Any shortages in P and K after using litter to meet N requirement are made up from commercial fertilizer. This assumes farmers do not take credit for excess P and K in litter.

Constraint (16) represents the availability of litter. The scenario that all litter generated in the watershed be used up for land application can be examined by changing the signs from "less

than or equal to" to "strictly equal to". Constraints (20)-(22) are three accounting constraints for total amounts of commercial fertilizer N, P and K, respectively.

Constraints (23) and (24) are two sets of water quality constraints. Constraint (23) indicates that the amount or concentration of a particular water pollutant produced by all activities in the watershed should not exceed an upper limit. Constraint (24) tells that pollutant levels for each field should be below an upper limit. The water quality effects (s_{ijklw}) can be estimated by process-type models such as AGNPS (Young, et. al., 1987), CREAMS (Knisel, 1980) or GLEAMS (Leonard, et. al., 1987). These effects depend on weather, particularly rainfall at the time of litter application, i.e. s_{ijklw} is a function of rainfall. Information on the distribution of rainfall at application time should be used in estimating s_{ijklw} . Constraints (25) and (26) impose upper and lower limits on the acreage devoted to each crop enterprise. Constraint (27) ensures that all decision variables are nonnegative.

Results and Discussion

Litter Analysis

Knowledge of the chemical composition of broiler litter is vital to proper utilization of the nutrients. Broilers are brooded in one section of the house and after approximately 3 weeks the partition is raised so both the brooding and growing sections are available. The houses in this study were cleaned out after 3 or 5 flocks. The feeding-management programs could produce several distinct litter types in terms of composition and quantities produced.

The brooding area produced the greatest quantity of litter on a per house and per square foot basis (Table 2). The three flock units had a mean brooding area litter weight of 10.31 lb/ft² with a range of 8.43 to 12.09. The growing area range for these units was 6.86 to 11.00 with a mean of 9.19 lb/ft². The five flock units had more litter per ft² than the 3 flock units; however, the differences in the litter weights of sections within the houses were similar to the 3 flock units.

The mean litter nitrogen (N) composition was 4.14 and 4.13 percent for the 3-flock units and 5.66 and 5.44 percent for 5-flock units for the starting and growing areas, respectively. There was between 0.86 and 0.42 percent N in the starting areas and between 1.02 and 0.31 percent N in the growing areas for the 3- and 5-flock units, respectively (Table 2). These data would support using 4.14 and 5.55 percent N in litter for 3-and 5-flock units. The ammonia values

Table 2. Weight and Chemical Analysis of Broiler Litter Samples From Seven Houses

House #	1	2	3	4	5	6	7
# Flocks	3	3	3	3	3	5	5
Litter, lb. (As-Is Basis)							
Brooding Section	89950	83850	100980	70830	87300	96720	150000
Growing Section	<u>78480</u>	<u>63550</u>	<u>83620</u>	<u>52150</u>	<u>71330</u>	<u>79840</u>	<u>123500</u>
Total	168430	147400	184600	122980	158630	176560	273500
Litter, lb. /sq ft (As-Is Basis)							
Brooding Section	10.71	9.98	12.02	8.43	10.39	12.09	15.00
Growing Section	<u>10.33</u>	<u>8.36</u>	<u>11.00</u>	<u>6.86</u>	<u>9.39</u>	<u>9.98</u>	<u>12.35</u>
Over All Area of House	10.53	9.21	11.54	7.69	9.91	11.04	13.68
Litter, lb. /sq ft (Dry Matter Basis)							
Brooding Section	7.58	6.94	9.22	6.29	7.56	8.48	11.60
Growing Section	<u>7.24</u>	<u>5.58</u>	<u>8.73</u>	<u>4.97</u>	<u>7.13</u>	<u>6.82</u>	<u>9.21</u>
Over All Area of House	7.42	6.29	8.99	5.66	7.36	7.65	10.40
Litter Analysis (Values on Dry Matter Basis)							
Brooding Section							
DM %*	70.79	69.56	76.71	74.66	72.81	70.13	77.30
N %	3.91	4.01	4.04	3.96	4.77	5.15	6.17
NH ₄ (mg N/100g)	1126	1211	694	1101	1257	1405	1098
NO ₃ (mg N/100g)	64	94	146	92	188	86	103
P %	3.12	3.80	3.07	2.88	2.40	2.96	2.96
K %	2.33	2.46	2.02	2.48	2.33	2.19	1.90
Ca %	3.32	3.76	3.26	2.59	2.15	2.84	3.26
Mg %	.65	.70	.56	.80	.78	.63	.66
Na %	.68	.77	.78	.64	.49	.79	.76
Su %	.48	.53	.47	.47	.49	.47	.53
Mn (ppm)	299	382	280	403	453	458	400
Zn (ppm)	112	153	88	283	318	161	185
Fe (ppm)	2273	1942	1547	1432	4246	992	945
Cu (ppm)	61	65	51	95	177	44	53
Growing Section							
DM %*	70.06	66.78	79.33	72.50	75.89	68.34	74.56
N %	4.06	4.06	3.90	4.31	4.32	5.28	5.59
NH ₄ (mg N/100g)	969	1564	835	1026	704	1214	1024
NO ₃ (mg N/100g)	213	97	62	270	213	242	241
P %	3.05	4.08	3.04	3.33	2.17	3.12	3.33
K %	2.73	2.21	2.46	2.10	2.55	1.42	1.96
Ca %	3.15	3.94	3.04	2.60	1.93	3.27	3.29
Mg %	.62	.79	.56	.87	.76	.67	.71
Na %	.76	.64	.62	.84	.53	.79	.78
Su %	.50	.47	.41	.53	.47	.49	.55
Mn (ppm)	299	444	306	429	453	470	447
Zn (ppm)	268	195	169	365	292	205	244
Fe (ppm)	2126	2102	1721	1724	3205	979	969
Cu (ppm)	80	57	53	132	180	47	70

*Percent dry matter (DM) of samples as removed from house (As-Is basis).

revealed that approximately 25 percent of the N is available in this form. Ammonia is lost quickly to the atmosphere when the litter is spread on the surface of the field. There is a very small quantity of the nitrogen in the nitrate form.

Phosphorus (P) values (Table 2) were somewhat variable among houses; however, the levels were not influenced by the number of flocks produced. The potassium (K) values show that the 5-flock values were lower than the 3-flock values. Numerical values between the brooding and growing sections were similar for P and K. These data would support the use of 3.09 and 2.22 percent P and K, respectively, in calculating fertilizer value. Some of the observed differences between the 3- or 5-flock K values may be attributed to variation in feeding programs.

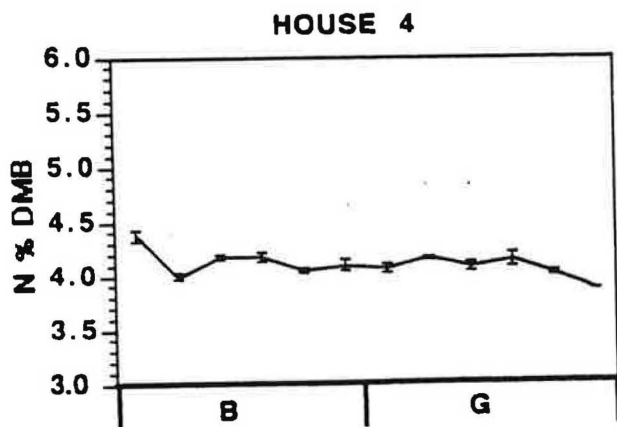
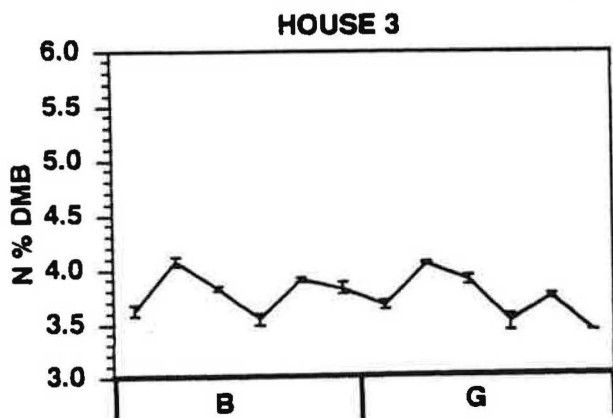
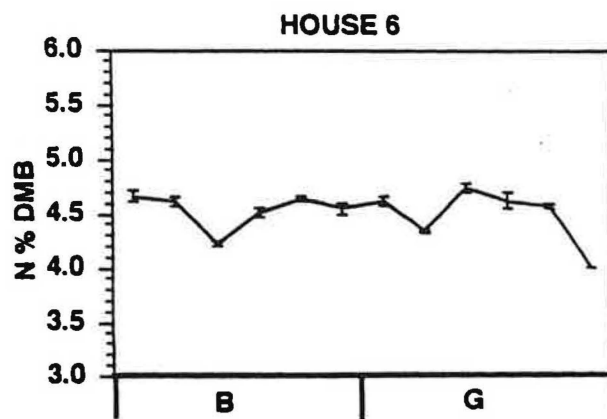
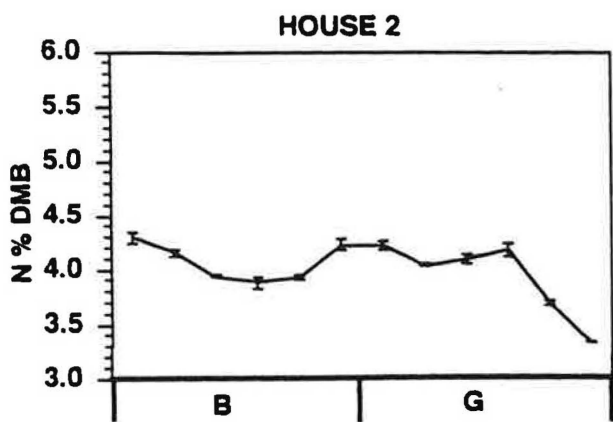
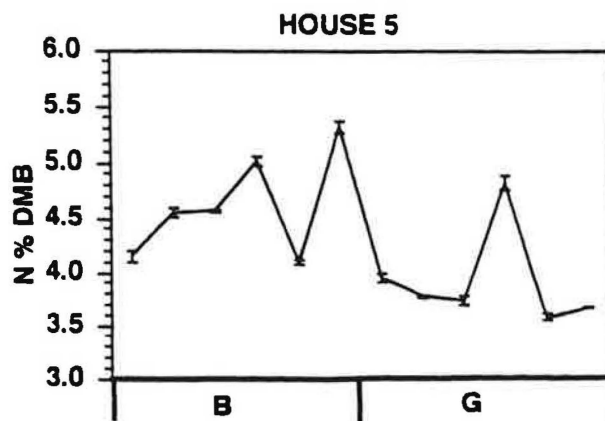
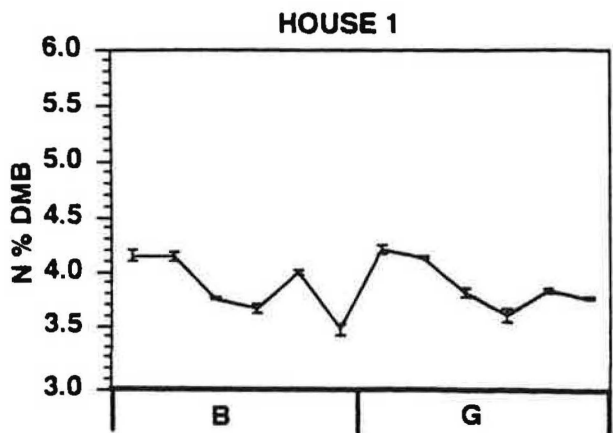
Several other mineral elements were studied. Results are given in Table 2. Copper (Cu) levels should not be a problem in a feeding or fertilizer program. Other elements tested for should not present a problem with the use of litter in agricultural applications.

Figure 6 describes the nitrogen composition of strips of litter on a house basis. The results vary within the brooding (B) and growing (G) sections of the houses. This would indicate a possible need for additional refinements in the sampling procedure. It would be desirable to grind and mix the entire strip prior to sub-sampling for laboratory analyses. This would be a reasonable task if only one strip sample was taken in each of the two sections within the house. Using the 7-flock data in Table 3, it appears that the 3rd and 9th strips best represent the means for house sections B and G, respectively.

Table 3. Percent Nitrogen on Dry Matter Basis for Brooding and Growing Sections of Broiler Houses*

House	1	2	3	4	5	6	7
Brooding Section							
Mean N% of All Strip Samples	3.79	4.07	3.80	4.14	4.62	4.56	5.55
N % of the Sample from the Third Strip Only	3.75	3.94	3.83	4.18	4.57	4.22	5.80
Growing Section							
Mean N% of All Strip Samples	3.88	3.93	3.76	4.06	3.92	4.52	5.09
N % of the Sample from the Ninth Strip Only	3.81	4.09	3.90	4.10	3.73	4.74	5.06

*Determined by averaging values for all strip samples compared to the value determined if only one strip from each section of a house was used.



B = Brooding Section of House
G = Growing Section of House
N % DMB = Kjeldahl Nitrogen on Dry Matter Basis

Figure 6. Litter Nitrogen Percentage for Strips Within Houses

Summed across all houses, these litter samples represent the production of over 580,000 broilers. Using these totals, the following results were obtained:

1. The quantity of litter produced by a single broiler in a 3-and-5 flock cleanout was 2.44 and 1.69 lb on an as-is basis and 1.79 and 1.24 lb on a dry matter basis, respectively.

2. Total nitrogen removed per broiler for houses with 3- and 5-flocks was .074 and .069 lbs., respectively. Approximately 75 percent of this nitrogen is available for plant use when the litter is spread on pasture land.

3. The phosphorus removed per broiler was .055 and .038 lb. for the 3- and 7-flock cleanouts, respectively.

4. A representative litter sample can be obtained by taking a strip sample midway in both the brooding and growing sections of the house.

Geographic Information System

Litter amounts, broiler production capacities and number of broiler houses required were generated for two cleanout scenarios, namely, once-a-year and twice-a-year, and two land availability scenarios, namely, 100 percent of all suitable land is available for litter spreading and 75 percent of suitable land is available for litter spreading. Calculations proceeded as follows. The current litter loading for the watershed was determined based on the 127 broiler houses that currently exist in the watershed. The current level of litter production for these houses was calculated for each cleanout scenario (see Table 4). In the case of twice-a-year cleanout (6 flocks per year), 16 million birds per year would be produced, creating approximately 19,860 tons of litter and 821 tons of potential nitrogen (at 4.13 percent N on a dry matter basis) for distribution within the watershed. Corresponding figures for once-a-year cleanout (5 flocks per year) are 13 million birds, 14,290 tons of litter and 794 tons of potential nitrogen (5.55 percent nitrogen on a dry matter basis). Under MDNR guidelines and assuming either 100 percent or 75 percent of the suitable land is available for spreading litter and either once- or twice-a-year cleanout, the Shoal Creek watershed would be at the capacities given in Table 5. These capacities ranged from a low of 48 percent for the CLMA/100 percent land availability/once-a-year cleanout scenario to a high of 74.2 percent for the ILMA/75 percent land availability/twice-a-year cleanout scenario.

Table 4. Current Level of Litter Production Based on Houses (127) Mapped

	Number of Birds	Tons Litter	Tons Nitrogen
Cleanout Once-a-Year	13,335,000	14,290	793.8
Cleanout Twice-a-Year	16,002,000	19,863	821.1

Table 5. Percent Capacity for Broiler Litter, Shoal Creek Watershed

Approach	Percent of Suitable Land Available for Application			
	100		75	
	1X*	2X**	1X	2X
CLMA	48.2	49.9	64.3	66.5
ILMA	53.8	55.7	71.8	74.2

*Once-a-year cleanout

**Twice-a-year cleanout

The combination of approaches and scenarios examined led to many different analyses and results. These results are summarized in Tables 6, 7, 8 and 9. Of the two litter management approaches analyzed, the CLMA consistently supported more birds due to the potential loading of 100 lb N per acre per year across all land cover and soil types. This loading is a conservative amount for many of the sites. However, when soils and land cover information are combined, the CLMA loading can be quite liberal. Therefore, the exclusion of soils information from an assessment of litter application can result in water quality degradation. This finding indicates the absolute necessity of including soils information in the evaluation of litter utilization and management alternatives.

Economics and Water Quality

This section is divided into two parts. The first part discusses the application of the linear programming model developed earlier and the second part discusses the economics of broiler production, litter utilization and forage production.

Discussion and Application of Linear Programming Model

The LP model determines the activity levels that maximize total net return from land application of broiler litter without exceeding limits on water contamination. Variations of the LP model can be used to evaluate the policy implications of different litter utilization practices and policies, and the sensitivity of litter use to changes in factors such as the market price of litter. Several variations are now discussed.

LPBASE: In this option, the current practices are entered into the LP model to produce the objective function value and all relevant information.

Table 6. Amounts of Nitrogen and Litter and Number of Houses and Birds for Alternative Litter Utilization Scenarios, Once-a-year Cleanout, 100 Percent Land Availability*

Approach		No Guide	MDNR		
			All Slopes	Restricted	Minus Flood
CLMA	Tons N	1,904.58	1,685.95	1,645.12	1,506.68
	Tons Lit	34,288.53	30,352.49	29,617.42	27,125.06
	#Houses	304.7	269.7	263.2	241.1
	#Birds	31,996,650	28,323,750	27,638,100	25,311,300
ILMA	Tons N	1,711.82	1,474.68	1,474.68	1,348.38
	Tons Lit	30,818.10	26,548.95	26,548.95	24,275.15
	#Houses	273.9	235.9	235.9	215.7
	#Birds	28,758,576	24,774,750	24,774,750	22,652,700

*Calculations assume that there are 5 flocks or 105,000 birds per house per year; an average of 112.52 tons litter/house/yr; and that the average N content of litter on a DM basis 5.555%.

TABLE 7. Amounts of Nitrogen and Litter and Number of Houses and Birds for Alternative Litter Utilization Scenarios, Twice-a-year Cleanout, 100 Percent Land Availability*

Approach		No Guide	MDNR		
			All Slopes	Restricted	Minus Flood
CLMA	Tons N	1,904.58	1,685.95	1,645.12	1,506.68
	Tons Lit	46,075.44	40,789.12	39,803.80	36,456.84
	#Houses	294.6	260.8	254.5	233.1
	#Birds	37,119,600	32,860,800	32,067,000	29,370,600
ILMA	Tons N	1,711.82	1,474.68	1,474.68	1,348.38
	Tons Lit	41,414.72	35,674.84	35,674.84	32,625.04
	#Houses	264.8	228.1	228.1	208.6
	#Birds	33,364,800	28,740,600	28,740,600	26,283,600

*Calculations assume that there are 6 flocks or 126,000 birds per house per year; an average of 156.4 tons litter/house/yr; and that the average N content of litter on a DM basis 4.134%.

Table 8. Amounts of Nitrogen and Litter and Number of Houses and Birds for Alternative Litter Utilization Scenarios, Once-a-year Cleanout, 75 Percent Land Availability*

Approach		No Guide	MDNR		
			All Slopes	Restricted	Minus Flood
CLMA	Tons N	1,428.44	1,264.46	1,233.84	1,130.01
	Tons Lit	25,722.07	22,762.80	22,211.45	20,343.62
	#Houses	228.6	202.3	197.4	180.8
	#Birds	24,003,000	21,241,500	20,727,000	18,984,000
ILMA	Tons N	1,283.86	1,106.01	1,106.01	1,011.28
	Tons Lit	23,113.86	19,904.79	19,904.79	18,205.74
	#Houses	205.42	176.9	176.9	161.8
	#Birds	21,569,100	18,574,500	18,574,500	16,989,000

*Calculations assume that there are 5 flocks or 105,000 birds per house per year; an average of 112.52 tons litter/house/yr; and that the average N content of litter on a DM basis 5.555%.

TABLE 9. Amounts of Nitrogen and Litter and Number of Houses and Birds for Alternative Litter Utilization Scenarios, Twice-a-year Cleanout, 75 Percent Land Availability*

Approach		No Guide	MDNR		
			All Slopes	Restricted	Minus Flood
CLMA	Tons N	1,428.44	1,264.46	1,233.84	1,130.01
	Tons Lit	34,548.76	30,591.84	29,841.12	27,338.72
	#Houses	220.9	195.6	190.8	174.8
	#Birds	27,833,400	24,645,600	24,040,800	22,024,800
ILMA	Tons N	1,283.86	1,106.01	1,106.01	1,011.28
	Tons Lit	31,061.04	26,760.04	26,760.04	24,460.96
	#Houses	198.6	171.1	171.1	156.4
	#Birds	25,023,600	21,558,600	21,558,600	19,706,400

*Calculations assume that there are 6 flocks or 126,000 birds per house per year; an average of 156.4 tons litter/house/yr; and that the average N content of litter on a DM basis 4.134%.

LPPROFIT: This LP model considers only the economic returns from litter utilization for the entire watershed. It assumes that litter users do not consider water quality effects when choosing litter management practices. Optimal use of broiler litter is determined so as to maximize net returns, ignoring water quality constraints. This decision framework can result in unacceptable water quality.

LPWATER: This LP model limits water quality contamination to acceptable levels. Water quality constraints reflect a social concern for the environment. Since imposing water quality constraints can decrease farm income, this model recognizes tradeoffs between economic returns and water quality. Note that the current utilization practices may not result in water quality problems.

LPMARKET: This version examines how changes in litter prices affect utilization, returns and water quality. This analysis is particularly relevant when different groups of farmers face different litter prices.

LPPOLICY: This scenario considers the effects of different policies. The following list illustrates the types of policy options that can be considered:

- Broiler litter is taxed which results in a higher litter price. This option is based on the polluter pays principle.
- A subsidy is given to litter users in order to encourage utilization practices that protect water quality. The subsidy is based on the principle that A should compensate B in order to reduce pollution when B has the right to pollute.
- A combination of taxes and subsidies is considered based on the assumption that both economic and environmental considerations have standing.

Changes in net returns and water quality would be examined by comparing the optimal litter utilization alternatives for the different scenarios. These changes can be used to compare welfare changes for broiler growers, litter users, and society. Alternative litter utilization and management practices may be needed to protect water quality. The socially-optimal utilization practices would generally reduce farm income, at least in the short run, when there is a discrepancy between farmers' and society's welfare. Farmers may require economic incentives to stimulate adoption of socially-optimal litter utilization and management practices. These incentives include taxes, direct subsidies and cost-sharing of practices.

While total net returns with alternative litter management practices may be higher at the watershed level, certain farmers may have no motivation to adopt these practices. It may be of no benefit and/or infeasible to some of them. Farm-level models could be used to analyze behavior in choosing the optimal utilization and management practices. Information on different farm types in the watershed would be useful in examining litter utilization.

The LP model can also be used to analyze several representative farms in Shoal Creek watershed. While this approach, which has been used extensively in applied agricultural economics, simplifies the analysis, much reality is lost and policy implications are limited due to large variation in the physical and economic characteristics of farms.

Other important considerations that could be incorporated in the LP models or used to modify the LP models include: timing of broiler house cleanout (spring and fall), litter storage, application time; water quality impacts of cattle manure; feeding litter to cattle; exporting litter outside the watershed; leaching through the root zone; risk tolerance levels for water pollutants; and chance-constraints for water pollution which account for variability in the nutrient content of litter.

Additional results and applications of the LP model are possible. A shadow price can be estimated for broiler litter at various levels of litter availability. If there is surplus litter, then the shadow price is zero. When litter availability is reduced to a certain level, then a positive shadow price can be estimated. Parametrically reducing the quantity of litter gives a step function that shows shadow price of litter as a decreasing step function of the quantity of litter. This step function can be regarded as the value marginal product of litter, or an input demand function for litter. The optimum level of litter can be determined by equating value marginal product to the price of litter. When a zero litter price is used in the LP model the quantity of litter available is the maximum amount that can be used in the watershed.

A value for litter based on current use can be estimated for a local area. This can serve as one basis for setting the price of the litter. Analysis can also be conducted to determine the economic value for litter. While a specific litter price is used in constructing enterprise budgets, this litter price is explicitly modeled to vary with prices of commercial fertilizers. Using the LP model, estimates can be derived for the litter price at which farmers have an incentive to use litter instead of commercial fertilizer, given current market conditions for commercial fertilizer. This price represents farmers' willingness to pay for litter. Since litter

cannot be separated into its nutrient components, the value of litter is different from the estimates based on nutrient content.

Farm income consequences of stringent constraints on water quality can be estimated from the LP model. Comparison can be made between the baseline (current practices) and the proposed practices in terms of economic returns and water quality. Several possible results would be: water quality can be maintained or improved without reducing farm income; water quality cannot be maintained or improved without reducing farm income; farm income can be increased without degrading water quality; farm income cannot be increased without degrading water quality. Comparisons can also be made between the optimal private choice and the optimal social choice of litter management activities.

Sensitivity analysis can be conducted to determine the effects of over-application of litter. Farmers are likely to over-apply broiler litter for various reasons. Many farmers do not fully take account of the fertilizer value of litter. Even if they want to, it is difficult to know what the true fertilizer value is relative to commercial fertilizer because litter is very heterogeneous and litter quality varies with many factors. A risk-averse farmer usually tends to use more litter than needed. If over-application is a common practice, then farm income can be increased, and at the same time, water quality can be improved relative to the current practice by reducing application rates.

The economic optimization model developed here determines the economic value of applying litter to land. The model maximizes total net returns in the watershed while limiting water quality contamination to an acceptable level. The model requires that enterprise budgets be constructed that consider average broiler litter application rates, labor requirements, costs associated with using litter, and net returns (returns minus costs) for different crops and yield goals. Process models are used to estimate water quality effects for different litter management practices. Budget data and results from the process models are integrated into an LP model that determines the spatially optimal quantity of litter application to land given the nutrient composition of litter, the profitability of alternative litter management strategies, and the potential for surface and ground water contamination in the watershed. The integrated model can also be used to evaluate the potential economic and water quality impacts of increasing the density of broiler houses, increasing growth in the broiler industry as well as various economic incentives and policies designed to utilize litter in an economically profitable and environmentally acceptable way.

Broiler Production, Litter Utilization and Forage Production

In this report, the economic value of broiler litter is considered in terms of its fertilizer value in producing forage. The following analysis describes the economics of broiler production, nutrient characteristics of litter, forage production and management, economics of forage production and implications for the LP model.

Broiler Production Broiler production is a very automated and efficient process. Broilers are marketed at an age of 6-8 weeks. After each flock, there is a down time period for cleaning and disinfecting. The frequency of litter cleanout varies from one annual cleanout (5 flocks) to cleanout after every flock. The most common cleanout schedules are one or two cleanouts per year (every 5 or 3 flocks, respectively). The frequency of flocks and cleanouts is largely influenced by the integrator. If the demand for broilers increases, flocks per year may go from 5 to 6 flocks.

While contracts vary from integrator to integrator, the grower typically supplies the building and labor and is responsible for utilities, facility maintenance, and property taxes (Osburn, 1990). The integrator stocks the buildings with day old chicks, provides feed and medication. The litter, and the related litter handling cost, is generally the responsibility of the grower.

Litter management decisions have little influence on the supply of birds. Two cleanouts (versus one cleanout) per year may influence flock health, but growers do not increase broiler production to increase litter supply. Broiler litter is then exogenously determined.

Any alternative litter handling method will only influence two lines in a broiler grower's budget; the litter handling cost and returns from the sale of litter. Broiler growers traditionally undervalue the nutrient value of litter. Returns from the sale of litter more than cover the cleanout cost so there is little incentive to improve returns from sale of litter.

The current market price for litter in southwestern Missouri is relatively stable at \$65 per load. Cleanout costs are about \$30 per load. Variation in truck load size, moisture and nutrient content of litter occurs within and among houses. The high variability makes efficient pricing of litter difficult. While weighing and sampling loads during cleanout would improve litter management, it would increase handling costs and labor requirements (labor is already very limited between flocks).

Nutrient Content of Litter The nutrient composition of litter is in a continual state of change. These changes speed up as the litter is handled and removed from the house due to mixing with oxygen and exposure to weather. These changes make it difficult to place an economic value on the litter. Once litter is surface applied, nitrogen is available for plant growth immediately through the inorganic forms contained in the litter, and less quickly through mineralization of the organic forms over a period of years.

Ammonia nitrogen is converted to nitrate nitrogen and utilized by the crop. Nutrients contained in surface applied litter set on top of the forage crop with the crop acting as a physical barrier between litter nutrients and the soil environment. Rainfall becomes an important transport mechanism for moving nutrients into the soil.

Nitrogen availability to the plant growth is reduced by ammonia volatilization, denitrification, surface runoff and groundwater leaching. Generally most of the ammonia nitrogen in the litter is lost in surface application. Actual loss depends on temperature, soil moisture, and rainfall. Denitrification is a process whereby nitrate-nitrogen is converted to nitrogen gases and lost to the atmosphere. While this can be a source of significant loss, it is not generally a problem if soil is not saturated for long periods of time.

Giddens and Barnett (1980) found that high rates of litter application on grassed areas increased infiltration with accompanying decreases in runoff. After the infiltration and nutrient assimilation capacity had been reached, surface runoff began. Higher litter application rates typically increase nutrient concentration in runoff. Nutrients that leave in surface runoff become water contaminants and are no longer available for plant uptake. Groundwater contamination from livestock waste occurs most frequently in areas that are cultivated and over irrigated (Keeney, 1989). The largest land use in the Shoal Creek watershed is forage production. While forages are generally less susceptible to runoff and leaching than cultivated crops, the karst topography of the area increases the likelihood that surface contaminants will enter groundwater.

Growers prefer spring cleanout to fall cleanout. This practice ensures that nutrient material in the litter is available for spring plant growth and reduces the heat generated by composting litter in the house during the warm summer months. The latter not only is important for reducing the inside temperature of the houses, but composting action degrades the nutrients through the respiration of bacteria.

Forage Production and Management The most predominant forage in the Shoal Creek watershed is tall fescue and tall fescue/clover mix. Fescue is a very hardy crop with minimal maintenance. Technically, a fescue pasture will last for decades. To be productive, fescue needs additional attention. There are two predominant problems with the monocrop fescue crop. Tall fescue is susceptible to an endophyte fungus problem that causes a condition known as "summer slump syndrome". Cattle gain less on fescue with high endophyte problems particularly during the summer months. The endophyte occurrence in fescue is related to fertility levels. The higher the nitrogen level applied to the fescue, the more common are the endophyte problems. Another condition that occurs in fescue is "fescue foot" which leads to health problems in cattle. The cause of this disease is not known, but there is evidence that high fertilization increases the incidence of "fescue foot." By mixing the kinds of forage the cattle ingest, both the endophyte and fescue foot problems can be reduced to a point where they no longer impair health and productivity in cattle.

Legumes are more palatable and generally a higher quality forage. By growing clover in tall fescue, endophyte and fescue foot problems are minimized and the clover fixes nitrogen from the atmosphere which reduces fertility needs of the fescue. Unfortunately, this works better in theory than in practice. Fertility must be carefully balanced so the fescue does not overtake the clover. The grazing patterns of cattle further complicates the problem. Clover is more palatable than fescue, causing cattle to selectively graze the clover. Increased grazing pressure on the clover increases the likelihood that fescue overtakes clover.

The tall fescue/clover intercrop is a much better forage for cattle, but it is also more work than a sole tall fescue stand. If tall fescue/clover stands are not carefully maintained, they revert back to the monocrop of tall fescue. Physiologically, tall fescue responds very well to high rates of fertilization. While it is possible to produce fescue with high nitrogen content by applying broiler litter at high rates, the resulting nitrogen content in fescue can be toxic to cattle (Scott, 1991). Upper limits of fertilization become imposed by palatability problems in cattle. Even though palatability problems are fescue specific, fescue remains the predominant pasture in Shoal Creek watershed due to its hardiness and the ease of maintenance.

Forage Budgets It is assumed that forage producers attempt to minimize the cost of producing forage. The current market price of litter (\$65/ton) makes litter a very inexpensive plant nutrient substitute for commercial fertilizer. Hence, litter is viewed favorably by the forage producer. Treating the value of broiler litter as a production input in forage production rather

than a waste product from broiler production justifies considering ways of enhancing the potential value of litter to the broiler grower.

Budgets were developed for tall fescue and tall fescue/clover pasture and hay management practices using cost and return data from the Missouri Farm Planning Handbook (1989). The values in this handbook are actual average costs and returns from related enterprises across Missouri and are based primarily on the Mail In Records program at the University of Missouri.

Yields and fertility rates were standardized across the three forage crops grown in the watershed, namely, a two cutting hay crop, a pasture crop, and a combination hay/pasture crop. The latter occurs when the first cutting of hay is removed in June and the second cutting is pastured as needed. Non-fertilizer costs for the hay/pasture crop were averaged between hay and pasture crops on the assumption that costs are distributed equally.

One target yield goal (medium) was used for all three crops with the exception of the pasture crop which has also a low yield goal. Management levels are based on yield rather than fertility level. A medium yield goal is possible with the addition of a legume to the forage, which substitutes higher management for a reduced fertilization rate. A high yield goal is physiologically possible, but is uncommon due to fescue problems discussed earlier.

Fertilization levels for hay and pasture were derived from Missouri Farm Planning Handbook recommendations and Agronomy Extension respectively. Hay fertilization rates are higher than for pasture due to the removal of dry matter (nutrients) with each hay cutting. A broiler litter fertilization rate of 2 tons litter (wet basis) per acre was chosen because it is a common rate in the Shoal Creek watershed. On a wet basis, 2 tons of litter has an approximate nutrient content of 89-67-48, N-P-K. Fertilizer rates and yields were checked against the fertilizer rate/yield functions derived from a four-year, tall fescue fertility study using commercial fertilizers and broiler litter (Huneycutt, et. al., 1988).

Animal Unit Months (AUM) were calculated as 1.43 AUM per ton of dry matter (or 1 AUM = 0.7 tons of dry matter). Prices for broiler litter were calculated on a per ton basis, rather than on the nutrient basis used in commercial fertilizer prices. A constant 6 ton load (wet basis) was assumed. Broiler litter nutrient values were used to assess potential yield goals. The broiler litter nutrient levels are fairly consistent with commercial nutrient levels, even after moisture and nutrient losses.

The cost of cleanout is a cost of producing broilers, so the grower faces a lower price for litter used on his own fields than the forage producer who pays the market price for litter. The litter price to the grower is referred to as the implicit price and the price paid by the forage producer as the market price. Market and implicit litter prices used in the forage budgets were calculated as follows.

	Market Price	Implicit Price
	-----	-----
Broiler litter market price/load (6 ton)	\$65.00	\$65.00
Growers' cleanout cost		- 30.00
Growers' cost of litter for own pasture	35.00	
Broiler litter price per ton	10.83	5.83
Price per acre (2 ton/acre rate)	21.66	11.66
Lime charge per acre	4.00	4.00
Total broiler litter price per acre	----- \$25.66	----- \$15.66

Commercial fertilizer prices were assumed to be \$0.25 per lb of N and P and \$0.15 per lb of K. In addition to the \$4 per acre lime charge, the hay and pasture and grass/legume budgets included a fixed \$3.50 per acre application charge for all commercial fertilizer applied. Broiler litter application cost is included in the \$65 per load market price.

Summary data for the enterprise budgets are shown in Table 10. Enterprise budgets for each crop are given in Appendix D. Of particular interest is the negative returns associated with traditional pasture management methods. This is due in large part to the inefficient selective grazing of cattle on an entire pasture. Cattle eat the most palatable, younger plants first, while other less palatable plants become older and tougher.

Implications for LP Model The economics of forage use in livestock production suggest that several acreage flexibility constraints be imposed on the LP model to ensure reasonable results. One constraint deals with the distribution of hay and pasture acreage. Even though pasture management shows negative returns, a certain percentage of the cattle diet will typically be pasture. If a lower limit is not placed on pasture acreage, the LP model will select all hay

Table 10. Summary of Per Acre Yields, Costs, and Returns by Forage Management Practice*

Crop and Mgmt. Level	Yield		Fert. Cost	Other Costs	Returns Over Variable Costs
	ton	AUM			
Hay					
Medium Commercial Fertilizer	3.2		\$52.50	\$75.07	\$14.18
Medium Broiler Litter (market)	3.2		25.66	73.73	42.36
Medium Broiler Litter (implicit)	3.2		15.66	73.23	52.86
Medium Grass/Legume	3.2		32.50	83.53	57.23
Pasture					
Low Commercial Fertilizer	2.1	3	20.50	13.63	(13.13)**
Medium Commercial Fertilizer	3.0	4.3	33.50	18.48	(21.87)
Medium Broiler Litter (market)	3.2	4.5	25.66	18.08	(12.24)
Medium Broiler Litter (implicit)	3.2	4.5	15.66	17.58	(1.74)
Medium Grass/Legume	2.8	4	18.50	21.93	(12.42)
Hay/Pasture					
Medium Commercial Fertilizer	1.5	2.1	33.50	46.30	2.68
Medium Broiler Litter (market)	1.5	2.1	25.66	45.91	10.91
Medium Broiler Litter (implicit)	1.5	2.1	15.66	45.41	21.41

*Dry matter, in tons, was included in the pasture budgets for yield comparative purposes.

**Negative value.

production and no pasture. Another acreage restriction that needs to be considered is the ratio of broiler grower-owned pasture to non-broiler grower-owned pasture. This restriction is needed to prevent the LP model from selecting more broiler grower-owned pasture than is reasonable based on ownership patterns in the watershed.

Integrating the suitable land use area estimates from the GIS database, the litter nutrient data from the litter samples, the forage production budgets and the water quality constraints into the LP model allows the model to generate shadow prices for litter. These shadow prices give a more appropriate value for broiler litter than the current market price. In addition, shadow prices can be used to evaluate pasture stand improvement with more palatable warm season grasses (like bermudagrass) or cool season grasses that use more nitrogen and are not susceptible to the endophyte and fescue foot problems of tall fescue (reed canary grass).

Shadow prices can also be used to evaluate the economics of building sheds for short-term storage of litter. Storage would increase litter handling cost to the broiler grower, but possibly reduce potential water quality problems by allowing the litter to be spread at a time when rainfall is more limited.

The LP model presented earlier is an annual model in the sense that yields, fertilization rates and water quality constraints are on an annual basis. Unfortunately, an annual model does not account for seasonal variability in plant growth, nutrient uptake and rainfall. Seasonal variability in these factors can significantly influence the risk of surface and ground water contamination.

Changing the LP model from an annual to a seasonal basis would increase the complexity of the model, but greatly enhance its usefulness in managing broiler litter. For example, since water quality constraints are much easier to satisfy in the summer than in the spring because of lower rainfall, more litter could be applied in the summer. This may entail installation of sheds to store the litter from the time of cleanout (normally in the spring) to the summer. On the other hand, rapid plant growth in the spring would accelerate plant nutrient uptake which, combined with increased infiltration and nutrient assimilation of broiler litter, could lower the infiltration/runoff threshold thereby reducing water contamination. A seasonal model would allow determination of the potential water quality benefits of delaying application of all or part of the available litter to the summer.

Converting the LP model from an annual to a seasonal basis would require seasonal information on weather and plant growth parameters. Furthermore, additional analysis would be needed to relate nutrient level, soil type, and rainfall to crop yield. A second model would be needed to describe nutrient decomposition at the surface. With the weather data and the nutrient decomposition and crop growth models, estimates could be generated for nitrogen volatilization, runoff, mineralization and plant uptake on an intertemporal basis.

Concluding Remarks

Growth and development in Missouri's broiler industry and the attendant increases in land application of broiler litter can be a potential threat to surface and ground water quality if not properly managed. This study analyses the quantity and composition of litter removed from a sample of seven broiler houses; uses a geographic information system to determine the amount

of litter applied to different areas of the watershed which complies with alternative water quality protection scenarios; develops an economic model which determines the optimal spatial distribution of litter in the watershed from an economic and water quality viewpoint and estimates the costs and returns for utilizing litter to produce forage crops (pasture and hay). The watershed used in this analysis is the Shoal Creek Watershed, west of Butterfield, Missouri. Further research is underway to complete the litter sampling and analysis for two additional broiler houses, to refine the data inputs, data outputs and scenarios for the GIS analysis and to develop the database needed to run the linear programming models. Information provided by this research should improve the ability of broiler growers, litter users and forage producers to obtain the highest possible value from broiler litter consistent with protecting water resources in southwestern Missouri.

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Appendices

Appendix A
Available ARC/INFO Files

Coverages:

Inset2	-----	State border and Barry County
Testcover5	-----	Land use for watershed with houses
Testcover6	-----	Land use for watershed without houses
Testgrid3	-----	40 acre grid for watershed
Testhome	-----	Points for homes in watershed
Testhouse2	-----	Houses for watershed
Testpoint2	-----	Points for sinks, ponds, and homes in watershed
Testpond	-----	Points for ponds in watershed
Testrdmv	-----	Roads for watershed moved 50m north
Testroads	-----	Roads for watershed (with 25 mph roads)
Testroads2	-----	Roads for watershed
Testshed	-----	The watershed boundary for Shoal Creek
Testsink	-----	Points for sinks in watershed
Testsoil	-----	Soils for watershed (un-linked)
Testsoil4	-----	Soils for watershed
Testspr2	-----	Springs for watershed
Teststrm	-----	Streams for watershed
Roadshed	-----	Roads for all watersheds
Sa-rdmv	-----	Roads for Barry County moved 50m north
Sa-rec	-----	Recreational areas for Barry County
Sa-roads	-----	Roads for Barry County
Sa-shed	-----	Watershed boundary for all four watersheds
Sa-spr	-----	Springs for Barry County
Sa-strm	-----	Streams for Barry County
Buffers:	-----	50 ft. buffer for Testhome
Homebuf50	-----	150 ft. buffer for Testhome
Homebuf150	-----	50 ft. buffer for Testhouse2
Housebuf50	-----	30 ft. buffer for Testpond
Pondbuf30	-----	70 ft. buffer for Testpond
Pondbuf70	-----	10 ft. buffer for Testroads2
Roadbuf10c	-----	50 ft. buffer for Testroads2
Roadbuf50c	-----	10 ft. buffer on gravel and 50 ft. buffer on paved for Testroads2
Roadrank	-----	30 ft. buffer for Testsink
Sinkbuf30	-----	320 ft. buffer for Testsink
Sinkbuf320	-----	30 ft. buffer for Testspr2
Springbuf30	-----	50 ft. buffer for Testspr2
Sprbuf50	-----	50 ft. buffer for Teststrm
Strmbuf50	-----	50 ft. buffer on primary, 35 ft. buffer on secondary, and 10 ft. buffer on tertiary for Teststrm
Strmrank	-----	50 ft. buffer of urban polygons from Testcover6
Urbanbuf50		

Unions:	-----	Union of Roadbuf50, Homebuf150, Pondbuf70, Springbuf50, Sinkbuf320, and Strmbuf50
Scenario-a	-----	Union of Pondbuf30, Homebuf50, Springbuf30, and Housebuf50
Scenario-b	-----	Union of Sc2-kiph, Strmrank, and Roadrank
Scenario-c	-----	Union of Sinkbuf320, Springbuf50, Pondbuf70, and Homebuf150
Sc2-kiph	-----	Union of Testsoil4 and Testaspect
Soilaspect	-----	Union of Testsoil4 and Testcover6
Soilcover	-----	Union of Testgrid3 and Soilcover
Soilcovgrid	-----	Union of Testsoil4 and Testslope
Soilslope		
TIN Generated	-----	Drape of streams
Coverages:		
Streamdrape	-----	Aspect for watershed
Testaspect	-----	Contour for watershed
Testcontour	-----	Lattice for watershed
Testlat	-----	Elevation for watershed
Testrange	-----	Slope for watershed
Testslope	-----	3dview for watershed from azimuth 35
Testview	-----	3dview for watershed from azimuth 170
Testview170	-----	Aspect
Wshed-aspect	-----	Contours
Wshed-cont	-----	Lattice
Wshed-lat	-----	Elevations
Wshed-range	-----	Slopes
Wshed-slope	-----	TIN
Wshed-tin	-----	3dview
Wshed-view		
Info files:	-----	Physical and chemical properties of the soil
Physchem2.new	-----	Precipitation by month
Precip.new	-----	General soil characteristics
Table2.new	-----	Temperature by month
Temper.new	-----	Contains phch, flod, pw, pw2
Relates		
	-----	Frequency of land capability classes by soil type
Landcapab.tab	-----	Frequency of soil type and cover type combinations
Soilcover.tab	-----	Frequency of cover types
Testcover6.tab	-----	Frequency of soil types
Testsoil4.tab		
Map Compositions:	-----	Testsoil4 by Land Capability Class
Capab	-----	Testcover6
Cover	-----	Testroads2, Testspr2, Teststrm, Testhouse2, and Testshed
Houses	-----	Testsoil4 by Percent Organic Matter
Organic	-----	Testsoil4 by Permeability

Perm	-----	Testsoil4 by Poultry Waste Value
Poultrywaste	-----	Testroads, Testclip, and Teststrm
Roads	-----	Sa-shed and Roadshed
Sheds	-----	Testslope vs. Testsoil4 by Slope Class
Slope	-----	Testsoil4
Soil	-----	Teststrm draped on Testview
Strmview		

LUTs:	-----	LUT for Capab
Capab.lut	-----	LUT for Organic
Organic.lut	-----	LUT for Perm
Perm.lut	-----	LUT for Testroads2 based on Testroads2-id
Roads.lut	-----	LUT for roads based on miles-per-hour
Speed.lut	-----	LUT for streams based on Streamcode
Stream.lut	-----	LUT for Poultrywaste
Waste.lut		

Keys:	-----	Key for Capab
Capab.key	-----	Key for Cover
Cover.key	-----	Key for Houses
House.key	-----	Key for Organic
Organic.key	-----	Key forPerm
Perm.key	-----	Key for Roads
Road.key	-----	Key for Soil
Soil.key	-----	Key for Springs
Spring.key	-----	Key for Streams
Stream.key	-----	Key for Poultrywaste
Waste.key		

Appendix B

Physical and Chemical Properties Derived from Soil Survey

ITEM	NAME	CODE	DESCRIPTION
Soil Map Symbol	mapsym		Soil symbol from soil survey
Label-id	label-id	1-99	Labeling code for soil maps
Percent Clay	pctclay	1	18 - 29%
		2	30 - 40%
		3	41 - 52%
Moist Bulk Density	moistblkdens	1	1.25 - 1.36 G/cc
		2	1.37 - 1.48
		3	1.49 - 1.60
Permeability	permeability	1	< .06 In/hr
		2	.06 - .2
		3	.2 - .6
		4	.6 - 2.0
		5	2.0 - 6.0
		6	6.0 - 20.0
Available Water Capacity	availwater	1	.07 - .11 In/hr
		2	.12 - .16
		3	.17 - .22
Soil pH	soilph	1	4.6 - 5.5 pH
		2	5.55 - 6.5
		3	6.55 - 7.5
Shrink/Swell Potential	shrink/swell	1	Low
		2	Moderate
		3	High
K-Factor	k	1	.17 - .25
		2	.26 - .34
		3	.35 - .43
T-Factor	t	1	Soil survey code
		2	
		3	
		4	
		5	
Percent Organic Matter	organicmtr	1	1 - 1.6%
		2	1.7 - 2.3%
		3	2.4 - 3%

Appendix C

General Soil Characteristics Derived from Soil Survey

ITEM	NAME	CODE	DESCRIPTION
Soil Map Symbol	mapsym		Soil symbol from soil survey
Label-id	label-id	1-99	Labeling code for soil maps
Percent Slopes	slopeclass	1	0 - 5%
		2	5 - 14%
		3	14 - 35%
		4	> 35%
Poultry Waste	poultrywaste	1	Slight
		2	Moderate
		3	Severe
Land Capability	landcapab	#1	e
		#2	s
		#3	w
			The Roman numeral is translated to Arabic and precedes the code. For example IIIe = 31.
Grain Sorghum	grainsorghum	0	Crop not grown
		1	47 - 64 bu
		2	65 - 81
		3	82 - 98
Winter Wheat	winterwheat	0	Crop not grown
		1	22 - 30 bu
		2	31 - 38
		3	39 - 46
Alfalfa Hay	alfalfa	0	Crop not grown
		1	3 - 3.6 tons
		2	3.7 - 4.3
		3	4.4 - 5
Tall Fescue Hay	fescue(hay)	0	Crop not grown
		1	1.3 - 2.3 tons
		2	2.4 - 3.3
		3	3.4-4.3

Tall Fescue(AUM)	fescue(aum)	0	Crop not grown
		1	.7 - 2.6 AUM*
		2	2.7 - 4.6
		3	4.7 - 6.5

*Animal Unit Month: The amount of forage or feed required to feed one animal unit (one cow, one horse, one mule, five sheep, or five goats) for 30 days.

Switchgrass	switchgrass	0	Crop not grown
		1	1 - 3.3 AUM
		2	3.4 - 5.6
		3	5.7 - 8

Improved Bermudagrass	ibg	0	Crop not grown
		1	4 - 5.6 AUM
		2	5.7 - 7.3
		3	7.4 - 9

Flood Frequency	flood	0	None
		1	Rare
		2	Occasional
		3	Frequent

High Water Table Depth	waterdepth	1	0 - 1 ft
		2	1 - 3
		3	4 - 6

High Water Table Kind	waterkind	0	Not given
		1	perched
		2	apparent

Bedrock Depth	bedrockdepth	1	0 - 20 in
		2	20 - 40
		3	40 - 60
		4	>60

Prime Farmland	primefarm	0	Not prime farmland
		1	Prime farmland
		2	Prime farmland if improved

Appendix D
Forage Enterprise Budgets

Appendix Table D1. Hay Enterprise Budgets

	Commercial Fertilizer	Broiler Litter (Market Price)	Broiler Litter (Implicit Price)	Grass/ Legume
Returns (\$/Ac)				
Yield (Tons/Ac)	3.15	3.15	3.15	2.8
Price (\$/Ton)	45	45	45	55
Gross Returns (\$/Ac)	142	142	142	154
Variable Costs (\$/Ac)				
Commercial Fertilizer				
N	P	K		
80	40	100	52.50	
0	40	100		32.50
Broiler Litter (2Tons/Ac)*				
N	P	K		
91	66	70	25.66	15.66
Establishment Costs (\$/Ac)	6	6	6	11
Labor Costs (7hr/Ac, \$4/hr)	28	28	28	28
Machinery Costs (\$/Ac)	30	30	30	32
Miscellaneous Costs (\$/Ac)	7	5	5	5
Interest (%)	6.08	4.73	4.23	5.53
Total Non-fertilizer Costs (\$/Ac)	75.07	73.73	73.23	83.53
Total Variable Costs (\$/Ac)	127.58	99.39	88.89	116.03
Returns Over Variable Costs (\$/Ac)	14.42	42.61	53.11	37.97

*Based on litter samples - wet matter basis.

Appendix Table D2. Pasture Enterprise Budgets

	Commercial Fertilizer (Low Mgmt)	Commercial Fertilizer (Med. Mgmt)	Broiler Litter Mkt Price	Broiler Litter (Implicit Price)	Grass/ Legume
Returns (\$/Ac)					
Yield (AUM/Ac)	3.0	4.3	4.5	4.5	4.0
Price (\$/AUM)	7	7	7	7	7
Gross Returns (\$/Ac)	21	30	32	32	28
Variable Costs (\$/Ac)					
Commercial Fertilizer					
N	P	K			
60	40	20			
30	20	10			
0	20	40			
	20.50		33.50		18.50
Broiler Litter (2Tons/Ac)*					
N	P	K			
91	66	70			
			25.66	15.66	
Establishment Costs (\$/Ac)	4	4	4	4	9
Labor Costs (\$4/hr) (Low, 1hr/Ac) (Medium, 1.5hr/Ac)	4	6	6	6	6
Machinery Costs (\$/Ac)	3	4	4	4	3
Misc. Costs (\$/Ac)	1	2	2	2	2
Interest (%)	1.63	2.48	2.08	1.58	1.93
Total Non-fertilizer Costs (\$/Ac)	13.63	18.48	18.08	17.58	21.93
Total Variable Costs (\$/Ac)	34.13	51.98	43.74	33.24	40.43
Returns Over Variable Costs (\$/Ac)	(13.13)**	(21.98)	(11.74)	(1.24)	(12.43)

*Based on litter samples - wet matter basis.

**Negative value.

Appendix Table D3. Mixed Hay and Pasture Enterprise Budgets*

	Commercial Fertilizer	Broiler Litter (Market Price)	Broiler Litter (Implicit Price)
Returns (\$/Ac)			
Yield (Tons/Ac)	1.5	1.5	1.5
Yield (AUM/Ac)	2.1	2.1	2.1
Price (\$/Ton)	45	45	45
Price (\$/AUM)	7	7	7
Gross Returns (\$/Ac)	82.50	82.50	82.50
Variable Costs (\$/Ac)			
Commercial Fertilizer			
N	P	K	
60	20	40	33.50
Broiler Litter (2Tons/Ac)**			
N	P	K	
91	66	70	25.66
Establishment Costs (\$/Ac)	5	5	5
Labor Costs (4.25hr/Ac, \$4/hr)	17	17	17
Machinery Costs (\$/Ac)	17	17	17
Miscellaneous Costs (\$/Ac)	4	4	4
Interest (%)	3.80	3.41	2.91
Total Non-fertilizer Costs (\$/Ac)	46.30	45.91	45.41
Total Variable Costs (\$/Ac)	79.80	71.57	61.07
Returns Over Variable Costs (\$/Ac)	2.70	10.93	21.43

*One hay cutting, balanced grazed.

**Based on litter samples - wet matter basis.