Trading Poultry Litter at the Watershed Level:

A Goal Focusing Application

by

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Abstract

We explore the transfer of poultry litter among watersheds incorporating both economic and environmental characteristics, and using a goal focusing approach. The results should be useful to producers and policy makers in the study area and in other areas where poultry production is linked to water quality, and contribute to a more sustainable poultry sector.

Introduction

Increasing production is often accompanied by increasing pollution, and agriculture is no different than any other industry in this regard. The potential for increased pollution is especially severe from concentrated production, which describes much of the U.S. poultry industry. Since the passage of the Clean Water Act in 1972, great progress has been made in the control of point sources of pollution. Further control of remaining point source problems is becoming increasingly less cost-effective. However, significant water quality problems remain unresolved. Hence, more attention is being placed on controlling runoff as the cause of impairment of the 55% of surveyed river length and 58% of surveyed lake area in the U.S. still having water quality problems (Sharpley et al., 1994).

This study is aimed at exploring ways to transfer poultry litter among watersheds in an area, taking into account economic characteristics (supply, demand and prices of litter), and environmental characteristics (vulnerability of the watersheds to P runoff). The study area is Hardy county in the Eastern panhandle of West Virginia, an important and rapidly growing poultry producing area and, by virtue of its proximity to the Potomac River and adjacent high population areas, a geographically sensitive one as well. The goal is to contribute to the sustainable growth of the poultry sector in the study area. The choice of the watershed level of analysis, perhaps unique for a study of this nature, is not arbitrary. Watersheds are considered the appropriate hydrologic unit for evaluating environmental processes such as runoff and nonpoint source pollution (Dixon, 1989). In addition, many water quality process models operate at the watershed level and, finally, watersheds are the focal point for implementation of many research and resource management programs (Prato and Wu, 1996).

Previous economic analyses include studies by Fritsch and Collins (1993), who investigate the feasibility of poultry litter composting, and Govindaswamy and Cochran (1995), who examine the feasibility of litter transport between regions. Both studies use models that rely mainly on economic criteria, to the exclusion of environmental criteria.

Procedure

Goal focusing (GF) is used. A variant of goal programming (GP) (other variants including lexicographic goal programming and weighted goal programming), each has specific attributes (discussed in Romero and Rehman, 1989, and Thompson and Thore, 1992) that make them useful in a particular setting. GF permits the introduction of "soft constraints" which can include those that the market does not explicitly consider (e.g., phosphorous run-off in this case); soft constraints can be violated in the model, but at a cost.

Thompson and Thore (1992) define the objective of the GF program as the satisfaction of the prior (non-goaled) program adjusted by the sum of all penalties. The costs ("penalties") that are levied may represent cash charges prescribed by a control authority or an ordinal system of priorities advocated by policy makers. The more urgent the goal, the greater the penalty for violation of the corresponding constraint. The larger the penalty associated with deviation from a goal, the more likely the satisfaction of the goal. The GF program still seeks the prior objective as long as the goals permit. The possibility of trade-offs is then introduced if all goals cannot be completely fulfilled.

The penalty weights are generated using Saaty's eigen-value approach (Saaty, 1977). This approach involves the derivation of weights by making pairwise judgements about the relative importance of criteria. Consider n objects are being compared according to their relative weights. Let the objects be $A_1, A_2, A_3, \ldots, A_n$ and their weights be $w_1, w_2, w_3, \ldots, w_n$. Let w be a column vector representing the n weights. The pairwise comparison matrix $\mathbf{A}$ can then be formed as:

$$\begin{array}{c|cccccc}
 & \boldsymbol{A_1} & \boldsymbol{A_2} & . & . & . & \boldsymbol{A_n} \\ \hline
\boldsymbol{A_1} & w_1/w_1 & w_1/w_2 & . & . & . & w_1/w_n \\
\boldsymbol{A_2} & w_2/w_1 & w_2/w_2 & . & . & . & w_2/w_n \\
. & . & . & . & . & . & . \\
. & . & . & . & . & . & . \\
. & . & . & . & . & . & . \\
\boldsymbol{A_n} & w_n/w_1 & w_n/w_2 & . & . & . & w_n/w_n
\end{array}$$

Let the entries of **A** be denoted a_{ij} such that all $a_{ij} > 0$. The matrix is a reciprocal matrix since $a_{ij} = 1/a_{ji}$. If **A** is multiplied by the transpose of w, $w^{T}=(w_1,w_2,w_3,...,w_n)$, the vector nw is obtained. From this, we get $\mathbf{A}w = nw$. If the matrix **A** is known given some scale, w can be recovered by solving $\mathbf{A}w = nw$ for w. That is, one must solve $(\mathbf{A} - n\mathbf{I})w = 0$ where **I** is the identity matrix of dimension n x n. Invoking the Perron-Frebonenius theory, the existence of a largest real positive eigenvalue of **A** is ensured since **A**'s entries are all nonzero. Such a system has a solution if, and only if, n is an eigenvalue of **A** (i.e., n is a root of the characteristic equation of **A**). When considering the matrix **A**, one observes that every row of **A** is a constant multiple of the first row (i.e., row $k = w_k$ * row 1). Because of this, **A** has unit rank. Therefore, except for the eigenvalue equal to n, all other eigenvalues, $\lambda_i = 0$ (I=1,2,...,n). Hence the solution to the above system is any of the columns of **A**. The solution differs by a multiplicative constant. To ensure that it is unique, the column of **A** chosen as the solution must be normalized.

To form the matrix **A** (given some scale), one must generally determine $C^{n}_{2} = n!/(n-2)!2! = n(n-1)/2$ entries a_{ij}. To determine **A**, one only needs to know n entries (any row of **A**) and use the cardinal consistency property $a_{ik} = a_{ij}a_{jk}$. The latter has the advantage of potentially reducing the number of comparisons to be made. Details on GF in particular and MCDM in general are contained in Romero and Rehman (1989) and Zeleny (1982).

It is becoming the trend in modern economic analysis to integrate ecological and environmental processes with economic analysis (Lee and Lovejoy, 1991). The procedure used here is consistent with this trend to the extent that it seeks to incorporate both the environmental and economic dimensions of the poultry litter problem at the watershed level in the study area. The economic dimension is represented by supply, demand and price of litter; the environmental dimension is captured by vulnerability to phosphorous run-off from soil to water, a major problem in poultry producing areas. The latter is represented by the phosphorous index (P-Index) model.

The P-Index model was developed by Lemunyon and Gilbert (1993) to provide field staff, watershed planners, and land users with a tool to assess the various land forms and management practices for potential risk of P movement to water bodies. The P-index model enables the ranking of sites according to the risk of P movement (Sharpley, 1995). Lemunyon and Gilbert assign a weighting factor to each of several pre-selected site characteristics (including soil, hydrology, and land management site characteristics) based on the extent to which each characteristic could cause P loss from that site. The higher the weight factor, the greater the resulting potential P loss. To calculate a site's vulnerability to phosphorus runoff, the actual measure of each site characteristic is multiplied by its respective weighting factor. The sum of all such products is then found. A site whose total of weighted rating values (TWRV) is less than 8 is said to have "low vulnerability" to P loss. If $8<\text{TWRV}<14$, then the site has "medium vulnerability." If $15<\text{TWRV}<32$, the site has "high vulnerability" and finally if $\text{TWRV}>32$ then the site has "very high vulnerability" to P loss. The

Bhumbla et al. (1996) version of the P-index model was selected for use here since it is best suited to the study area.

Overall, the analysis involves three main components (and several sub-components) as outlined below:

1. Identify watersheds within the Potomac River basin that have a potential P runoff problem (done by interviewing NRCS officials and Extension personnel in the study area), and develop a ranking of the watersheds based on vulnerability to P runoff (performed using the Lemunyon-Gilbert P-index model for site vulnerability).
2. Determine the supply of and demand for poultry litter in each watershed given current production and management practices (estimated using secondary data as described below).
3. Determine the optimal litter shipments among watersheds given multiple objectives (economic and environmental) and supply and demand constraints (done using a GF model and employing Saaty's eigenvalue approach).

***Step 1*: Ranking the Watersheds by Vulnerability to P Loss**.

Results from actual soil samples taken between 1995 and 1997 in the study area were used. The vulnerability ranking of the watersheds covering this area was done by placing the various fields (using the NRCS-assigned tract numbers of fields owned by farmers in the study area) in their respective watershed. After calculating vulnerability levels for each field, the average (weighted by acres) vulnerability value from representative fields across each watershed was calculated. Details on these calculations are presented in Jones et al. (1998).

Step 2: **Estimation of Poultry Litter Supply and Demand**.

Step 2a-1: **Poultry Litter Demand for Watershed *i***

Estimating the demand for poultry litter econometrically for each watershed is costly in data and time. Since individual farm-input mixes are unknown, a proxy for the demand for poultry litter is used. For this study, the demand for poultry litter in a watershed is calculated based on both the N and the P crop requirements separately for the various crops (lbs N or P/acre): corn, pasture and hay. To determine the number of acres in the various crop categories, GIS (ArcView 3.0), is employed. Landuse and watershed coverages of the study area are used for this purpose. These coverages, together with the crop N and P requirement information and the poultry nutrient analysis data, are subsequently used to estimate litter demand.

Step 2a-2: **Poultry Litter Supply in Watershed *i***

This is calculated based on the number of poultry houses and the number of growouts per year (obtained from secondary sources, PHIWQ, 1996). The tons of litter produced per watershed is therefore a sum of the product of the number of specific bird houses in the watershed and the estimated tons of litter generated annually per house.

Step 2a-3: **Transportation Cost Model**

LP is used to minimize the aggregate transportation cost of litter among watersheds given the supply of, and demand for, poultry litter by watershed. In reality the price of poultry litter varies (depending on factors such as the type of litter, its quality, and handling and storage); however, due to a lack of data, we assume that the price of poultry manure is constant and independent of quantity purchased (i.e., $P_m = k$ [constant] where P_m is the price of manure). We make the assumption that the system is a closed one. That is, the model does not allow for poultry litter leaving or entering the watersheds used in this study (if data are available, this assumption can easily be relaxed). The primal transportation problem then is:

minimize **(1)** $\sum_i \sum_j c_{ij} * Watershed_{ij}$

subject to **(2)** $\sum_j Watershed_{ij} = a_i$, **for i = 1,2,3,...,m**
(3) $\sum_i Watershed_{ij} \geq b_j$, **for j = 1,2,3,...,n and**
(4) $Watershed_{ij} \geq 0$, **for i = 1,2,3,...,m, j = 1,2,3,...,n**

where $watershed_{ij}$ is the quantity of poultry litter (in tons) transported from watershed *i* to watershed *j*; c_{ij} is the ton mile cost of transporting litter; a_i is the total supply of litter (in tons) in Watershed *i*; and b_j is the total demand for litter (in tons) in Watershed *j*.

A necessary condition that a feasible solution exists is that the total demand be at most as large as the total supply of poultry litter (if not, a penalty is attached to the shipment, consistent with the GF framework):

(5) $\sum_j b_j \leq \sum_i \sum_j Watershed_{ij} = \sum_i a_i$.

***Step 2a-4*: Unit Transportation Costs Among Watersheds**

The distance measure between pairs of watersheds is meaningless without anchor points or points of reference. One measure of proximity is the distance between any two watershed centroids. ArcView 3.1 is also used in this determination.

The cost of transportation between any two watersheds is a function of the distance between the two watersheds. For simplicity, it is assumed that trucking is the only mode of transportation, a realistic assumption in the study area. Transportation costs (obtained from PHIWQO, 1996) do not include loading charges since the prevailing practice is that the poultry litter suppliers load the litter themselves.

***Step 3*: Determining Optimal Shipment Patterns Among Watersheds**

Given the initial primal transportation cost problem, the new GF problem, including the potential of P loss across the various watersheds, is given as:

minimize (6) $\sum_i \sum_j c_{ij} * Watershed_{ij} + Mg^{+} + Ng^{-}$

subject to:
(7) $\sum_j Watershed_{ij} = a_i$, for i = 1,2,3,...,m
(8) $\sum_i Watershed_{ij} \geq b_j$, for j = 1,2,3,...,n
(9) $Watershed_{ij} \geq 0$, for i = 1,2,3,...,m, j = 1,2,3,...,n
(10) $\sum_i Watershed_{ij} - g^{+} + g^{-} = g$ for j = 1,2,3,...,n and
(11) $g^{+}, g^{-} \geq 0$

where g^{+},g^{-} and g are n-dimensional column vectors; g^{+} and g^{-} consist of entries g_j^{+} and g_j^{-} and represent positive and negative deviations, respectively, from goal g_j; M = [M_j] and N = [N_j] are n-dimensional penalty (or importance weight) row vectors; and the other variables are the same as defined previously. For this particular application, there are no penalties for negative deviations from the stated goals. Hence N = [0_j]. To determine penalty row vector M, Saaty's approach is used.

***Step 3a*: Estimation of Criteria Weights (Saaty's Approach)**

The major determining factor is row one in comparison matrix **A**, defined previously. Row one is obtained using the P ranking described previously in conjunction with the ranking made by PVSCD. Although the ranking is known, determining row one is somewhat subjective. To overcome this limitation, we explore three different importance intensity specifications reflecting different perceptions of the decision maker. The first row under the three intensity schemes is as follows: (1, 1, 8, 9), (1,7,8,9) and (1,9,9,9). The "1" reflects the fact that the Lost River watershed is ranked first. The numbers following this one reflect how Lost River is compared with the other three watersheds (North River, South Fork, South Branch, respectively), using Saaty's scale. For illustration, consider the second weighting scheme (1, 7, 8, 9) using Saaty’s scale. Invoking the cardinal consistency property yields the following reciprocal matrix:

	LR	**NR**	**SF**	**SB**
LR	1	7	8	9
NR	1/7	1	8/7	9/7
SF	1/8	7/8	1	9/8
SB	1/9	7/9	8/9	1

Any of the columns of this matrix gives an appropriate set of weights. However, to ensure uniqueness of the resulting weights generated from the importance intensity given, we normalize any one column to generate the unique weight vector of norm one. The resulting normalized weight vectors for the weighting specifications are:

$\mathbf{M}_1$ = (**LR,NR,SF,SB) =** (0.9767,0.1395,0.1221,0.1805),

$\mathbf{M}_2$ = (**LR,NR,SF,SB) =** (0.7022,0.7022,0.0877,0.0780), and

$\mathbf{M}_3$ = (**LR,NR,SF,SB) =** (0.9819,0.1091,0.1091,0.1091).

Results

The estimated vulnerability ratings for the four agriculturally-important watersheds in the study area (accomplished by implementing step 1 described in the previous section) are shown in Table 1. The higher the ranking, the greater the potential for P loss and, therefore, adverse water quality problems. Accordingly, Lost River is the most environmentally sensitive watershed and South Branch the least.

Table 1. Estimated Watershed Vulnerability Ranking

Watershed	Vulnerability Ranking
Lost River	one
North River	two
South Fork	three
South Branch	four

In addition to generating results for alternative penalty weight structures ($\mathbf{M}_1$ - $\mathbf{M}_3$, as described previously), results are generated for alternative poultry litter supply-demand scenarios, one each for litter demand based on crop N and crop P requirements, and the third scenario involving an increase in annual litter supply, as part of a sensitivity analysis. The three scenarios evaluated are listed in Table 2.

Table 2. Alternative Litter Supply-Demand Scenarios

Scenario	Description
S1	Annual litter demand based on crop P requirement
S2	Annual litter demand based on crop N requirement
S3	Increase of 10% in supply for all watersheds (litter demand fixed).

Next, the annual poultry litter supply and demand quantities by watershed were estimated (by implementing step 2); these results are presented in Table 3.

Table 3. Estimated Annual Supply-Demand for Poultry Litter by Watershed [a/]

Watershed	Annual Litter Supply (tons)	Annual Demand Based on Crop N Requirement (tons)	Annual Demand Based on Crop P Requirement (tons)
Lost River	24,870	9,863	10,875
North River	1,700	3,233	3,522
South Branch	19,445	17,512	19,704
South Fork	3,305	4,339	4,859
TOTAL	**49,320**	**34,947**	**38,960**

a/ Demand estimated by assuming a recommended (according to WV Extension Service) N application level of 150 lb/acre for corn silage and 50lb/acre for pasture; and P levels of 35 lb/acre and 26 lb/acre for corn silage and pasture, respectively.

Tables 4 to 6 show the optimal quantities of litter shipments, and associated total shipment cost (implementation of step 3), for each specified litter supply-demand scenario and penalty weight structure.

Table 4. Optimal Litter Shipments for Penalty Weight Structure One

Origin	Destination	Scenario 1	Scenario 2	Scenario 3
South Fork	South Fork	3,305	3,305	3,636
South Branch	South Branch	19,445	19,445	21,390
North River	North River	1,700	1,700	1,870
Lost River	South Fork	1,554	1,468	703
Lost River	North River	1,533	1,533	1,363
Lost River	Lost River	21,783	21,869	25,291
TOTAL COST		**$3,667**	**$3,592**	**$2,670**

Table 5. Optimal Litter Shipments for Penalty Weight Structure Two

Origin	Destination	Scenario 1	Scenario 2	Scenario 3
South Fork	South Fork	3,305	3,305	3,636
South Branch	South Branch	19,445	19,445	21,390
North River	North River	1,700	1,700	1,870
Lost River	South Fork	1,034	1,034	703
Lost River	North River	1,533	1,533	1,363
Lost River	Lost River	22,303	22,303	25,291
TOTAL COST		**$3,214**	**$3,214**	**$2,670**

Table 6. Optimal Litter Shipments for Penalty Weight Structure Three

Origin	Destination	Scenario 1	Scenario 2	Scenario 3
South Fork	South Fork	3,305	3,305	3,636
South Branch	South Branch	19,445	19,445	21,390
North River	North River	1,700	1,700	1,870
Lost River	South Fork	12,462	12,488	16,131
Lost River	North River	1,533	1,533	1,363
Lost River	Lost River	10875	10,849	9,863
TOTAL COST		**$13,157**	**$13,179**	**$16,092**

The first noteworthy result is that, regardless of the penalty weight structure, the optimal litter shipments do not differ much for S1 and S2 (litter scenarios based on crop P and crop N requirement, respectively). Next, under all scenarios and across all penalty weight structures specified, the transportation paths are similar although the quantities are quite different, showing the relative insensitivity of the results to changes in selected parameters. There are intrawatershed shipments in all cases; Lost River is the only watershed from which there also are interwatershed shipments, reflecting both the large supply of litter from this watershed as well as its status as the most environmentally vulnerable watershed. Basden et al. (1994) suggest that precisely such a transportation scheme is necessary (i.e., large volume of litter exports from Lost River) given the amount of litter produced relative to the amount of treatable land in this watershed.

The optimal solutions obtained under the different scenarios for weighting schemes $\mathbf{M}_1$ and $\mathbf{M}_2$ do not differ much. However, when the weighting scheme ($\mathbf{M}_3$) that takes Lost River as absolutely important (as per its vulnerability ranking) is considered, then, as expected, the quantity of litter remaining in Lost River is reduced drastically, with most of it shipped to South Fork. Of course, there are higher total economic (shipping) costs associated with this, as shown in Table 6; this has to be balanced against the potential improvement in environmental quality (not quantified here).

The different scenarios examined are intended to provide an illustration (results for additional scenarios are presented in Jones et al., 1998). Thus, if the supply of, and demand for, poultry litter are known ahead of time (they can easily be estimated as demonstrated here), a pre-selected agency in the region (such as the NRCS or Extension Service) could employ the preceding framework to determine optimal litter shipment patterns such that producer and societal objectives were simultaneously accomplished. These patterns would change over time as P vulnerability, transportation costs, and supply-demand characteristics changed (for example, soil tests are recommended every two to three years, causing possible changes in watershed vulnerability rankings). Furthermore, if actual shipment patterns among watersheds are known (this can be ascertained through surveys), they can be compared to optimal patterns (estimated by using the framework in this study for example) to determine where inefficiencies exist. Correcting these will require a cooperative effort among producers, local agencies and policy makers and would entail a larger geographical area (i.e., more watersheds) for implementation.

Conclusions

Poultry production is an important and growing activity in the study area. Accompanying the increase in production is an increase in waste, creating an associated waste disposal problem. Given the concentrated production of poultry and the fixed amount of treatable land available for landspreading poultry manure (which is the predominant litter disposal method in the region), there is the potential for pollution resulting from P runoff from the study area into bodies of water such as the Potomac River. Thus, this study was designed to examine the feasibility of poultry litter disposal taking into account both economic and environmental characteristics. Perhaps unique in this regard, the study was done at the watershed level of analysis. The analysis also demonstrates the richness and adaptability of the goal focusing technique.

Currently, a litter brokerage established by the Extension Service includes the study area, the purpose of which is to match individuals who want litter with poultry producers wanting to dispose of litter. This brokerage service has certainly helped mitigate the disposal problem and has resulted in some value-added to poultry litter. However, the environmental impacts of the litter transfer are not considered. This study accounts for economic and environmental characteristics simultaneously as a means of minimizing both adverse environmental impacts on water quality and aggregate transportation cost of litter. Intended primarily as an illustration, it can be expanded to a larger study area in this state or others where poultry production is tied to water quality.

The implementation of the prescribed optimal disposal options identified in this study is impossible without cooperation of all the agents involved. Poultry producers, farmers using the poultry litter as a soil amendment, the Extension Service, and government agencies (e.g., PHIWQO and NRCS) would have to work in concert to implement the estimated optimal solution. Incentives for compliance (or penalties for noncompliance) would have to be determined by the enforcement agency. How can such a subsidy/tax rule be set up? Instead of setting the weights based on a system of ordinal rankings, the decision maker can exogenously determine penalties (monetary charges) for both positive and negative deviations from the goals. To effect this, one must instead consider the dual problem. For each primal constraint there is an associated dual variable. Information about the variables that are of interest in determining the level of subsidy or tax is contained in the corresponding dual solution to the primal goal constraint (i.e., equation (10) in the primal model). If the optimal solution results in the goal being exceeded such that the deviation g_j^{+*} is positive for a given watershed then the dual solution for that watershed equals the negative of the unit penalty for excessive demand (dual solution j = - M_j). Alternatively, if g_j^{-*} is positive, then the dual solution equals the unit penalty for deficit demand (dual solution j = N_j). If, however, the optimal solution coincides with the goal, the dual solution j will be such that $N_j \leq$ dual solution $j \leq N_j$.

The study is limited primarily by data availability. If data are available, the above suggested extensions can be investigated. For larger study areas (which, ultimately, are needed to implement an actual poultry litter trading system), uniform data collection protocols will also be needed. Subsequently, a system of tradable pollution permits could be devised. To do this, future researchers would have to estimate the P abatement cost at a micro (e.g., watershed) level, for which more complex and/or dynamic water quality models (such as AGNPS) are needed to more accurately capture environmental quality impacts. If the marginal abatement costs are significantly different across watersheds, then this would enhance the feasibility of a marketable permit system based on the vulnerability to P runoff. Ultimately, such a system could maximize the effectiveness of market-based economic incentives, minimize the need for government intervention, and optimize development in the poultry industry.

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