APPLICATION OF A WATERSHED SCALE RANKING SCHEME FOR EVALUATING IMPACTS OF AFOs ON WATER QUALITY

R.K. Hubbard[1], W.L. Magette[2] and J.M. Sheridan[3]

AUTHORS: [1]Soil Scientist and [3]Hydraulic Engineer, Southeast Watershed Research Laboratory, USDA-ARS, P.O. Box 946, Tifton, GA; and [2]College Lecturer, Agricultural and Food Engineering, University College Dublin, Earlsfort Terrace, Dublin 2, Ireland.
REFERENCE: Proceedings of the 2001 Georgia Water Resources Conference, held March 26-27, 2001, at the University of Georgia. Kathryn J. Hatcher, editor, Institute of Ecology, the University of Georgia, Athens, Georgia.

Abstract. Nonpoint sources of nitrogen (N) and phosphorus (P) leaving the agricultural landscape can cause eutrophication of surface water with associated degradation of water quality. Land use managers need tools to assist in making informed land use decisions and prescribing management practices to minimize potential N and P losses to water resources. A ranking scheme including both management practices and hydrologic and landscape properties was devised by Magette for both farm and watershed scale use. The scheme includes factors and weights for 1) Nutrient Usage, 2) Condition of Receiving Waters, 3) Ratio of Land to Water, 4) Farmyard Conditions, 5) Nutrient Application Rates, 6) Nutrient Application Times, 7) Soil Test P, 8) Overland Flow Distance, and 9) Runoff Risk. This paper presents the concepts involved in applying multi-parameter assessments to the landscape and using the assessment results to provide additional land management information relative to animal feeding operations (AFOs). The assessments proposed are intended to be a first step toward providing an objective basis by which to make environmental decisions about land management, both at the field and watershed level. The paper also presents results of using the ranking system to compare two different watershed subareas having different intensities of AFOs and compares the ranking system results with observed water quality measurements.

INTRODUCTION

Pollution of surface and groundwaters from animal wastes is of growing environmental concern. High nitrogen (N) and phosphorus (P) loading rates to soils and waters can be associated with intensive animal operations. Concentrations of N in excess of 10 mg L^{-1} in the nitrate form render groundwater unsuitable as drinking water for humans (Alexander, 1972). Excess P entering surface waters can lead to eutrophication. The potential for P loss in runoff has been increased by inappropriate application of fertilizer and manure from intensive livestock operations (McFarland and Hauck, 1995). One strategy for dealing with nonpoint source pollution is to develop criteria to assess fields and watersheds for potential N or P loss and transport. Such criteria would enable managers to target the more critical diffuse nutrient sources and apply management practices to minimize these losses (Magette, 1998).

NEED FOR AN ASSESSMENT PROCEDURE

A framework is needed for evaluating specific soils, landscapes, farming systems, and their management for potential loss and delivery of nutrients to water bodies. Input data for existing process-based mathematical models by which to quantify predicted nutrient runoff potential for the various combinations of soils, landscapes and farming operations is limited. Thus, the use of indices that are based on scientific principles and relationships has been encouraged (Lemunyon and Gilbert, 1993; Magette, 1998; Gburek and Sharpley, 1998).

Several scientists have tried to categorize landscape/land use combinations for water pollution potential and use them in a ranking scheme with which to identify "critical areas" within a watershed. Maas et al. (1985) used a nine-step procedure including such factors as type of water resource (lake vs. river, drinking water source, etc.), nutrient application rate and timing, distance to nearest watercourse, and distance to impaired water resource to define areas that needed special attention in terms of nonpoint source pollution control. In the Chesapeake Bay watershed the State of Maryland developed a ranking scheme to prioritize subwatersheds on the basis of their contributions of N and P to the main stem of the bay. Assumptions included N being lost by both surface runoff and leaching, P being lost primarily in overland flow, and losses of N and P to receiving waters being worst from areas with short delivery distances. Lemunyon and Gilbert (1993) developed a more specific rating system solely for identifying the vulnerability of soils to lose P to overland flow. The systems included seven site characteristic factors (two transport factors and five P factors, of which soil test phosphorus (STP) was one) and arbitrarily assigned a weight to each. Aller et al. (1987) developed a ranking scheme primarily for evaluating the potential of groundwater contamination by human activity. The basis for the ranking procedure was seven factors typically easy to determine in a practical setting, namely: depth to water, net recharge, aquifer media composition, soil profile composition, topography, vadose zone attenuation, and hydraulic conductivity of the aquifer.

MAGETTE RANKING SCHEME

Magette (1998) developed a ranking scheme for both N and P losses from animal feeding operations. The ranking scheme can be applied at either the farm or watershed scale. The ranking scheme conceptually separates factors affecting the loss, transport and delivery of N and P from agricultural systems to receiving waters into watershed and farm factors.

Watershed Factors

A) Nutrient usage in the watershed – Chronic water quality impacts are the cumulative result of activity in a watershed.

B) Condition of the water resource– Surface waters that already suffer from nutrient enrichment require intensive efforts to restore them to good environmental health, including proportionally more protection from additional nutrient inputs than do comparable waters that do not suffer from such impacts.

C) Ratio of land to water – Because nutrient usage occurs on the land surface, watersheds in which the amount of land in relation to the amount of surface water is high would have the potential to contribute more nutrients to receiving waters than a comparable watershed with lower ratios, all other things being equal, especially the rate of nutrient usage (kg ha^{-1}).

Farm Factors

A) Farmyard conditions– For operations involving animal production, adequate manure storage is essential for properly utilizing manures at times when nutrients contained therein will be most likely to be utilized by plants.

B) Nutrient Usage Rate– All other things being equal, the more of a nutrient there is in an agricultural system, the more likely it is to be lost from the system.

C) Nutrient Application Timing– Applications of nutrients outside of periods when they will be readily utilized by growing plants increase the potential for loss of nutrients compared to applications that are timed according to plant needs.

D) Soil Test Phosphorus (STP)– Research in the U.S. has demonstrated a nearly 1:1 relationship between STP and P lost to overland flow; i.e the higher the level of STP, the higher the P lost in runoff.

E) Runoff Class – The predominant loss pathway for P is surface runoff. All other things being equal, a greater risk of P loss will coincide with those combinations of factors that create a higher risk of runoff, as compared to sites that have lower runoff risk.

USE OF THE MAGETTE NUTRIENT RANKING SYSTEM

The use of the Magette ranking system is based on three premises:

1) A combination of factors affects the losses of nutrients from agricultural systems and their subsequent transport to receiving water.

2) The extent to which each factor individually affects losses and transport varies in importance (i.e., weight).

3) The relative risk of losing nutrients depends on the magnitude of a given factor. The importance of an individual factor is represented by a 'weight' that varies numerically between 0 and 1. The relative risk associated with the magnitude (not the weight) of a given factor is represented by a qualitative measure ('low', 'medium' or 'high'), each of which has a numerical value for scoring purposes (low=1; medium=2; high=4).

A 'score' or 'rank' for a given combination of factors affecting loss and transport of nutrients is developed in two steps:

1) Multiply the weight of each factor by the relative risk associated with the magnitude of each factor.

2) Sum all of the products derived in step 1.

The assignment of weights and risks for factors in the Magette P ranking scheme is given in Table 1. Determination of 'risk' for the ranking scheme is based on final scoring. For the nine factors and three 'risk' levels 27 unique scores are possible, ranging from 7.2 to 28.8. The assigned risk score ranges are: low risk,

<10.8, medium risk, 10.8 - 21.6, high risk > 21.6.

Table 1. Magette Phosphorus Ranking Scheme

1) P usage in Catchment
Weight for Factor: 0.5
Phosphorus Loss and/or Transport Risk
Low (1) 0-5 kg P ha^{-1}
Medium (2) 5-10 kg P ha^{-1}
High (4) >10 kg P ha^{-1}

2) Condition of receiving waters
Weight for Factor: 0.5
Phosphorus Loss and/or Transport Risk
Low (1) Saline waters, non-impounded waters, free flowing rivers and streams w/o nutrient problems
Medium (2) Oligotrophic and Mesotrophic lakes
High (4) Eutrophic & Hypertrophic lakes, other special designation waters

3) Ratio of land to water
Weight for Factor: 0.75
Phosphorus Loss and/or Transport Risk
Low (1) Ratio <36:1
Medium (2) 36:1 < Ratio < 44.1
High (4) Ratio > 44.1

4) Farmyard conditions
Weight for Factor: 0.8 (or 0 if animals not utilized)
Phosphorus Loss and/or Transport Risk
Low (1) See Magette (1998)
Medium (2) See Magette (1998)
High (4) See Magette (1998)

5) P usage rate
Weight for Factor: 1.0
Phosphorus Loss and/or Transport Risk
Low (1) 0-5 kg P ha^{-1}
Medium (2) 5-10 kg P ha^{-1}
High (4) > 10 kg P ha^{-1}

6) P application time
Weight for Factor: 0.9
Phosphorus Loss and/or Transport Risk
Low (1) Spring or just prior to crop needs
Medium (2) Late summer or early fall
High (4) All other times

7) Soil test P (Morgan's test)
Weight for Factor: 0.8
Phosphorus Loss and/or Transport Risk
Low (1) 0-6 mg P L^{-1}
Medium (2) 6.1-15 mg P L^{-1}
High (4) >15 mg P L^{-1}

8) Overland flow distance
Weight for Factor: 0.75
Phosphorus Loss and/or Transport Risk:
Low (1) Further than catchment average
Medium (2) Catchment average
High (4) Less than catchment average

9) Runoff risk
Weight for Factor: 1.0
Phosphorus Loss and/or Transport Risk
Low (1) Sand, Textured Soils
Medium (2) Medium Textured Soils
High (4) Clayey Textured Soils

EVALUATION OF THE MAGETTE RANKING SYSTEM

An evaluation of the P portion of the Magette ranking system was recently completed with data provided by Ireland's Lough Derg and Lough Ree Catchment Monitoring and Management System Project. The Lough Derg and Lough Ree Catchment Monitoring and Management System Project was developed from July 1997-July 2000 in order to promote a catchment-based approach for reducing P inputs to rivers and lakes from all sources. Lough Derg and Lough Ree are part of the Shannon River Catchment.

Two subareas (Omard and Ballina) in the northeastern section of the Shannon Catchment were selected. Omard is 1.09 km^2 and Ballina is 1.24 km^2. Omard contains poorly drained soils which result in relatively rapid surface runoff and streamflow when rainfall in excess of infiltration rate occurs. Ballina contains a higher proportion of better drained soils than Omard and consequently has less surface runoff than Omard. Farmyard density at Ballina is approximately twice that of Omard. Use of the Magette P ranking system yielded composite scores of 16.5 for Omard and 10.3 for Ballina (Table 2).

The mean for molybdate reactive P (MRP) concentrations in streamflow for the record period were 0.144 mg L^{-1} and 0.0470 mg L^{-1} MRP for Omard and Ballina, respectively. Clearly there was a substantial difference in water quality between Omard and Ballina (factor of 3) and the Magette ranking model correctly identified that the P loss risk from Omard is greater than that for Ballina.

Table 2. P rankings for Omard and Ballina Sub-catchments

FACTOR	OMARD			BALLINA		
	Risk	Weight	Score	Risk	Weight	Score
1	4	0.5	2.0	1	0.5	0.5
2	2	0.5	1.0	1	0.5	0.5
3	2	0.75	1.5	2	0.75	1.5
4	1	0.8	0.8	2	0.8	1.6
5	4	1.0	4.0	1	1.0	1.0
6	1	0.9	0.9	1	0.9	0.9
7	1	0.8	0.8	1	0.8	0.8
8	2	0.75	1.5	2	0.75	1.5
9	4	1.0	4.0	2	1.0	2.0
TOTAL			16.5	TOTAL		10.3

The Magette P ranking scheme is currently being tested with data available from the Little River Watershed (LRW) located in SE Georgia (Figure 1). The tests are comparing subwatershed areas K and O. Subwatershed K is 16.7 km^2 in area while subwatershed O is 15.9 km^2. Subwatershed K has more land in forest than subwatershed O. Subwatershed O has a higher intensity of pasture and animal feeding operations than subwatershed K. Ultimately we will use the Magette model for comparisons of risks on much larger watershed systems such as the upper and lower sections of the Suwanee River Watershed, or portions of the Satilla River Watershed.

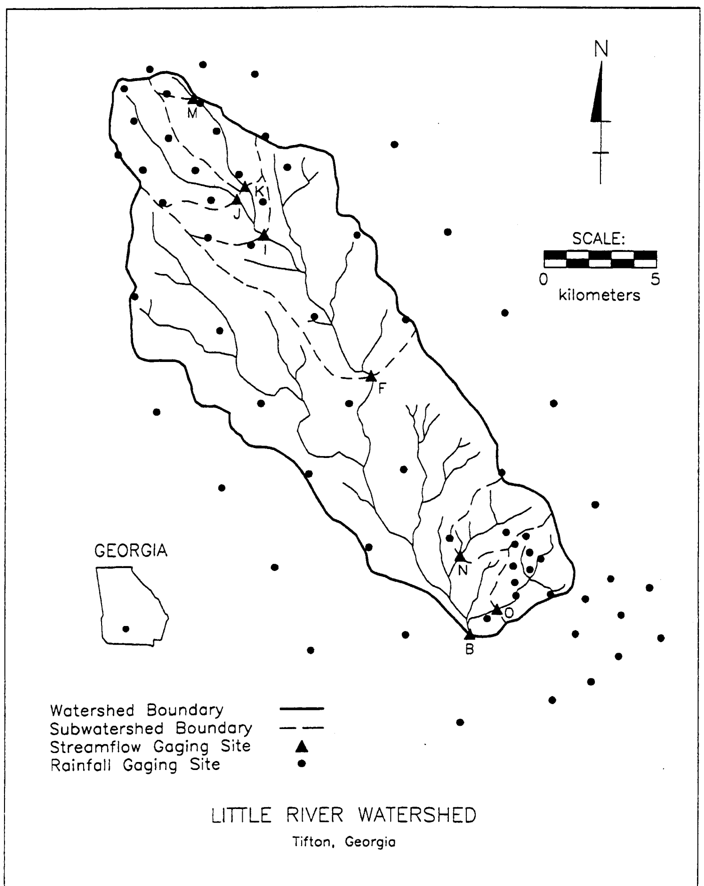

Figure 2. Little River Watershed and Subwatersheds.

REFERENCES

Alexander, M. 1972. Accumulation of nitrate. Washington, D.C.: *National Academy of Sciences*.

Aller, L.T., T. Bennett, J.H. Lehr, R.J. Pertty and G. Hackett. 1987. DRASTIC: A standardized system for evaluating ground water pollution potential using hydrogeologic settings. *EPA/600/2-87-035. U.S. Environmental Protection Agency,* Washington, DC, USA. 455 pp.

Gburek, W.L. and A.N. Sharpley. 1998. Hydrologic controls on phosphorus loss from upland agricultural watersheds. *J. Environ. Qual.* 27:267-277.

Lemunyon, J.L. and R.G. Gilbert. 1993. Concept and need for a phosphorus assessment tool. *J. Prod. Agric.* 6:483-486.

Maas, R.P., M.D. Smolen and S.A. Dressing. 1985. Selecting critical areas for nonpoint source pollution control. *J. Soil and Water Cons.* 40(1):68-71.

Magette, W.L. 1998. Factors affecting losses of nutrients from agricultural systems and delivery to water resources. IN: O.T. Carton (ed.) Draft guidelines for nutrient use in intensive agricultural enterprises. Teagasc, Johnstown Castle Research and Development Centre, Wexford, Ireland. Pp. 6-31.

McFarland, A. and L. Hauck. 1995. Livestock and the environment: Scientific underpinnings for policy analysis. Rep 1. Texas Institute for Applied Environ. Res. Tarleton State University, Stephanville, Texas.

ACKNOWLEDGMENTS

I would like to acknowledge data and assistance provided by Lough Derg and Lough Ree, Catchment and Management Group and that of Mr. Pat Duggan and Ms. Grace Glasgow.