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A Decision Support System for Water Quality Modeling

D.S. Yakowitz. L.J. Lane, M.ASCE, J.J. Stone, P. Heilman, R.K. Reddy[1]

ABSTRACT

A prototype Decision Support System (DSS) has been developed to evaluate the environmental and economic consequences of alternative farming practices. This system was developed to help protect our Nation's groundwaters and surface waters from potential contamination by fertilizers and pesticides used in agriculture. The DSS, with an embedded computer simulation model, ranks the feasible management practices using multiobjective decision theory. The method we have developed combines the use of graphically based scoring functions and some simple, yet powerful, linear programs to rank the alternative practices. This ranking is achieved in an objective manner under the guidelines of the decision maker. An example examining alternatives for a field near Tifton, Ga. illustrating the use of the system is presented. The prototype DSS is undergoing testing using data from several watersheds in the Deep Loess Soil Major Land Resource Area near Treynor, Iowa.

INTRODUCTION

As part of the USDA Water Quality Initiative, we have developed a prototype decision support system (PDSS) for the purpose of evaluating the effects of alternative management practices on surface and groundwater quality. The primary user group of the system is the Soil Conservation Service (SCS) although other user groups will include national and state agencies concerned with water quality problems. The objectives of developing a prototype are to: 1) illustrate the concept of a decision support system within the context of the water quality initiative, 2) implement multiobjective decision making within a decision support system, and 3) provide a framework for the development of an operational decision support system. The major components of the PDSS are a simulation model, a decision model, default data bases, input generators, output interpreters, and a system driver. The general use of the PDSS is to parameterize the simulation model for several different management practices and use the output of the simulation model in the decision model in order to choose which management practice is best for a given situation.

[1] USDA-ARS Southwest Watershed Research Center, 2000 E. Allen Rd., Tucson, AZ 85719

The decision model is based on multiobjective decision theory using dimensionless scoring functions (e.g., see Wymore, 1988). Scoring functions are used as a means of converting the values of the decision variables (i.e. runoff, sediment, nitrogen concentration, net income) which are in differing units and magnitudes to a common range of 0 to 1. The same decision variables are scored for a conventional management practice and for viable alternative management practices. The management practice with the highest aggregated score according to the method of Yakowitz and Lane (1992) is considered to be the best management practice.

The decision variables in the PDSS are generated by a modification of the Groundwater Loading Effects of Agricultural Management Systems (GLEAMS) model (Leonard et al., 1987). Modifications we have made of the model include the addition of a nutrient component, a crop growth component and an economic component.

Because the PDSS is a prototype, the input generators, output interpreters, and data bases are relatively simple. The input generators prepare the input files needed by both the simulation and decision models. The entire PDSS is being developed using the X-Windows system with the look and feel of the windows conforming to the *USDA-SCS Standard User Interface* (1990) conventions.

SIMULATION MODEL

The simulation model supplies decision variables to the decision analysis module by simulating the corresponding processes using a model built around the GLEAMS simulation model developed by the Agricultural Research Service to evaluate the effects of management practices on nonpoint source water pollution (Leonard et al., 1987). GLEAMS consists of three major components: hydrology, erosion/sediment yield, and pesticides. The hydrology model uses daily climate data to compute the water balance in the root zone. The erosion component computes estimates of rill and interill erosion on overland flow areas for each storm event. Sediment enrichment ratios are computed for use in the estimation of adsorbed pesticide transport. The pesticide chemistry component simulates the movement of pesticides over the surface and through the root zone. Surface losses of pesticides are those contained in surface runoff and absorbed to sediment. The vertical movement is through percolation. Other losses are by evaporation and plant uptake. The movement of pesticide metabolites is also simulated.

In addition to water balance, sediment loss and pesticide losses, the decision variables for the PDSS include nutrient losses. The nutrient component of CREAMS (Chemicals, Runoff, and Erosion from Agricultural Management Systems (Knisel, 1980)) has been added to GLEAMS. The nutrient sub-component simulates nutrient chemistry on a storm-by-storm basis. It predicts the amount of nutrients lost in runoff and sediment, and losses by leaching and plant uptake. The nutrients simulated in the model are nitrogen and phosphorous.

The crop growth component from another simulation model, the Erosion Productivity Impact Calculator or EPIC (Williams et al., 1983, 1989) is integrated into GLEAMS to simulate crop yields for different management practices. The major processes simulated include interception of radiation, conversion to biomass, nutrient and water uptake, and conversion of biomass to yield. Over 20 crops can be simulated including all major cereals and legumes, range grass and pine trees.

Given the crop yields, the net return to the farmer can be calculated in the economic module using a modified version of the Cost and Return Estimator (CARE), developed for the Soil Conservation Service (Midwest Agricultural Research Associates, 1988). CARE has been modified to provide multiple year simulations. The databases containing the necessary inputs and machinery for all operations from planting through crop drying are available in most states through the SCS. The farmer's cost of capital is considered, so the effect of changes in the interest rate on farm income, and thus indirectly on the recommended management practices, can be examined. Scalar values for discounted net returns, hours of labor per year and fuel consumption per year will be calculated for consideration as criteria in the multiobjective decision making module.

DECISION MODEL

The decision model combines graphically presented scoring functions suggested by Wymore (1988) with the decision rules developed in Yakowitz and Lane (1992).

In order to compare noncommensurable decision variables such as average annual amounts of runoff volume, nitrogen in sediment, crop yield and sediment yield, a scoring or value function is designed by the decision maker for each decision variable. These functions convert the predicted data from the simulation model to values on a 0 to 1 unitless scale. The decision variables for the conventional or baseline practice score 0.5 by definition. Once all of the alternatives have been scored relative to the conventional practice by the scoring functions, a score matrix is available to complete the analysis. Based on the normalized slopes of the scoring functions at the conventional practice value, an importance order of the decision variables is established. Best and worst composite scores for each alternative are determined by the solutions of two simple linear programs and these two composite scores are then aggregated to determine the preference ranking of the alternatives.

An example best illustrates the method. We consider three management practices on a field near Tifton, GA in the Southern Coastal Plain with Tifton sandy loams on 2 to 5% slopes. This example field from USDA-SCS (1984) has a drainage area of 72 acres and the conventional crop is continuous corn. The alternatives under consideration are **Conventional:** Continuous Corn, **Alternative #1:** Continuous Corn and a small grain winter cover crop and **Alternative #2:** Fair Pasture. Information on the farm operations for the first two are available in SCS (1984). Yearly chemical applications for the first two practices are identical: 115.0 kg/ha nitrogen (N), 30 kg/ha phosphorus (P), 2.8 kg/ha Atrazine, 2.6 kg/ha Carbofuran, 0.4 kg/ha Sevin. The third practice, Alternative 2 considers only a single application in the spring of 100 kg/ha of N. Ten years of daily rainfall were generated using CLIGEN (Nicks and Lane, 1989).

Scoring functions were designed for each of the criteria under consideration. For example for sediment yield a "more is worse" scoring function shown in Figure 1 was selected. The decision variables, predicted values from the simulation model (economic data obtained from Farmer (1992), not CARE subroutines), and scores appear in Table 1.

The importance order of the criteria is determined in the decision module using the absolute value of the slopes of the scoring functions at the baseline values which have been normalized to remove the dependence on the units of the decision variables. For example, the scoring function for sediment yield (shown in Figure 1) has a slope of -0.225 ha/t at 5.37 t/ha, the average annual value of sediment yield for the conventional practice. This slope is normalized to eliminate it's dependence on particular units by multiplying it by the difference between the maximum and minimum annual averages (18.7 and 0.92 t/ha respectively) for all 10 years of the simulation of the conventional practice. This yields a value of 4.01. Repeating this process for all of the decision variables and then ordering them in decreasing order yields the following importance order (numbers in parentheses are the normalized slopes of the corresponding scoring function at the conventional value): **1. N in percolation** (4.46) **2. Sevin surface loss** (4.45) **3. sediment yield** (4.01) **4. Net Income** (4.0) **5. Atrazine in percolation** (3.38) **6. Carbofuran surface loss** (3.19) **7. P surface loss** (2.51) **8. N surface loss** (2.50) **9. runoff** (2.10) **10. Atrazine surface loss** (1.78). This method of ordering the decision variables ranks those variables highest which have the potential for the greatest change in score when considering an alternative other than the conventional practice; the decision variable which is the most vulnerable is considered most important. The importance order of the decision variables may also be explicitly specified by the user of the PDSS.

Based on this importance order of the decision variables, best and worst composite scores are determined for each of the alternatives by solving the linear programs given in Yakowitz and Lane (1992). The solutions to these linear programs are the most optimistic and the most pessimistic composite scores (weighted averages) which are consistent with the importance order given above. Figure 2 illustrates the result. Note that Alternative 1 completely dominates the conventional practice while the result for Alternative 2 indicates that this alternative is highly sensitive to any weight vector consistent with the importance order. Clearly, given the importance order of the decision variables, alternative 1 is preferred. The practices are ranked in decending order of the average of the best and worst composite scores which for this example yields the following recommended ranking: **Alternative 1** followed by **Conventional** followed by **Alternative 2.**

FUTURE TESTING

The simulation and decision models of the PDSS are currently undergoing testing using data obtained from four watersheds monitored by The Deep Loess Research Station near Treynor, Iowa (Alberts et al., 1991). The data sets include long term records of climate, hydrology, soil loss, nutrient loss as well as data on land treatments, farm management and economics. This comprehensive data set includes all of the necessary ingredients for a complete evaluation of the PDSS. Additional data sets representing different agricultural systems are being developed as part of our ongoing research. Uncertainty and sensitivity analysis of the simulation and decision models will be conducted.

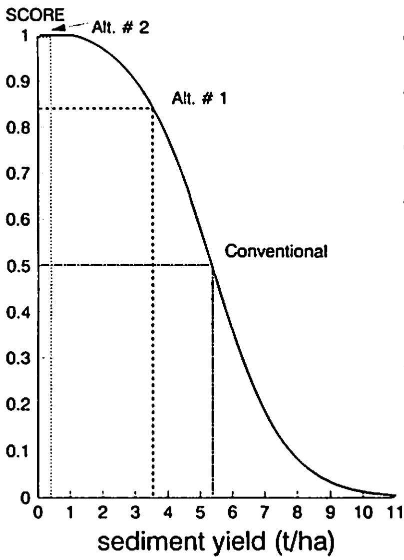

Figure 1: Scoring function for sediment yield.

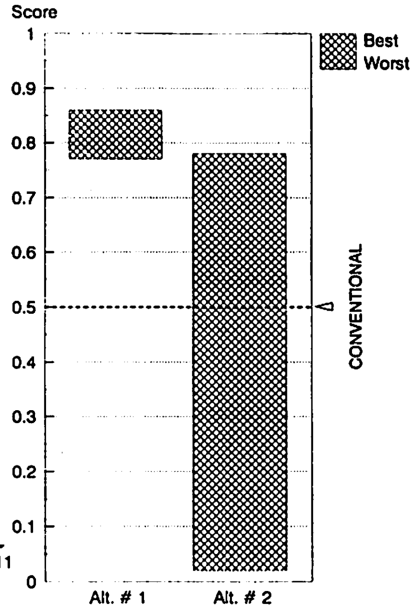

Figure 2: Best and Worst Range of Scores

	CONVENTIONAL VALUE	CONVENTIONAL SCORE	ALT. # 1 VALUE	ALT. # 1 SCORE	ALT. # 2 VALUE	ALT. # 2 SCORE
Runoff (mm)	80.07	0.5	58.21	0.86	14.12	1.0
Sed. Yield (t/ha)	5.37	0.5	3.55	0.84	0.32	1.0
N (surf.) (kg/ha)	10.14	0.5	6.84	0.79	0.91	0.99
N (perc.) (kg/ha)	19.63	0.5	16.92	0.86	25.38	0.02
P (surf.) (kg/ha)	4.73	0.5	3.25	0.78	0.47	0.99
Atraz. (surf.)(g/ha)	11.35	0.5	6.79	0.84	0.00	1.0
Atraz. (perc.)(g/ha)	0.97	0.5	1.07	0.40	0.00	1.0
Sevin (surf.) (g/ha)	7.07	0.5	4.31	0.83	0.00	1.0
Carbo. (surf.)(g/ha)	19.12	0.5	12.78	0.79	0.00	1.0
Net Income ($/ha)	109.00	0.5	120.00	0.71	106.00	0.46

Table 1: Decision variables, data from the simulation model and scores.

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