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A DECISION SUPPORT SYSTEM FOR EVALUATING THE EFFECTS OF ALTERNATIVE FARM MANAGEMENT SYSTEMS ON WATER QUALITY AND ECONOMICS

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ABSTRACT

A prototype Multi-Objective Decision Support System (MODSS) for water quality has been developed by the Agricultural Research Service at the Southwest Watershed Research Center in Tucson, Arizona. The Decision Support System uses a simulation model to predict the impact of alternative management systems on surface and groundwater quality as well as farm income. The results of the simulation, which includes modeling of hydrology, erosion, nutrient and pesticide transport, crop growth and economics, are analyzed with respect to the multiple objectives of reducing surface and groundwater pollution while maintaining or improving farm income. Often these objectives are in conflict and objectively discerning which practice is preferred can be a difficult task. The multi-objective decision making component of the decision support system makes use of dimensionless utility functions and the concept of importance order dominance. The MODSS allows the user to set up alternatives, choose the decision criteria, and accept or customize the decision mode settings. The results are presented graphically as well as in tabular form. The dominance of one practice over another, if it exists, is clearly evident in the graphical presentation. We illustrate the decision component of the MODSS with pictures of the screens from an example which uses the simulation results of several management alternatives on farmland in the Deep Loess Soil Major Land Resource Area near Treynor, Iowa.

KEYWORDS

Decision support systems; water quality; multi-objective; farm management systems

INTRODUCTION

In this paper we introduce a prototype Multi-Objective Decision Support System (MODSS) for water quality by briefly describing the components and illustrating its use with an example. The results from the MODSS for the simple example presented in this paper depend on the decision criteria selected and the importance assigned to each selected criterion.

The MODSS simulation component includes a user-friendly input file generator to set up each alternative and simulation models which simulate hydrology, erosion, pesticides, nutrients, crop growth and economics on a field scale [see Yakowitz et al. (1992) for a description of the components and references]. To consider

simultaneously the impact on economic, groundwater, and surface waters of alternative management systems, a multi-objective decision strategy was designed which takes the information provided by the simulations, or historical data to evaluate the set of feasible alternatives. The method combines graphically based scoring functions and simple, yet powerful, linear programs to rank the alternative practices (Yakowitz *et al.*, 1992,1993). This ranking is achieved in an objective manner under the guidelines of the decision maker. The MODSS decision module requires little interaction from the user because in the initial mode, default values based on the conventional (current) management system data are used to initialize the decision components. Once the initial mode is complete, the user of the system is allowed to modify the scoring functions (SFs) and/or the importance given to each decision criterion.

A BRIEF DESCRIPTION OF THE DECISION COMPONENT OF THE MODSS

To compare the non-commensurable decision criteria such as runoff volume, crop yield, and sediment yield, the MODSS converts the historic or predicted quantitative data from the simulation model to qualitative values between 0 and 1 using scoring functions which are initially set up by default in the MODSS (Yakowitz *et al.*, 1992). The conventional, or baseline system, scores 0.5 for each decision criterion by definition. Thus, a management system that performs better than the conventional for a certain criterion (i.e. less sediment yield) will score > 0.5 for that criterion and one that performs worse will score < 0.5 .

The next step is to rank the decision criteria in order of importance. The MODSS initially determines the importance order of the criteria based on properties of each criterion's scoring function near the conventional system value. In the interactive mode of the MODSS, the importance or priority order can be specified explicitly. For example, when policy or specific environmental problems are known, the user of the system may wish to impose a particular importance order on the decision process. Based on the established importance order of the decision criteria, best and worst composite scores are determined for each of the alternatives by solving two linear programs whose solutions are available in closed form. The objective values of these linear programs are the best possible and worst possible composite scores (weighted averages) that are consistent with the given importance order. The full range of possible scores for each alternative is then displayed and the alternatives ranked in descending order of the average of the best and worst composite scores (see Yakowitz *et al.*, 1993, for justification).

DECISION MODE OF THE MODSS

The long term data records from the watersheds in the Deep Loess Soil Major Land Resource Area near Treynor, Iowa make these watersheds ideal candidates for testing and evaluating the MODSS. For illustrative purposes, we present the results of evaluating several proposed alternative management practices on one of the watersheds.

Watershed #1 is an approximately contoured, 74.5 acre field that has been planted annually with corn (denoted by c) since research on the watershed was initiated in 1964. The tillage practice currently used is deep disking (Alberts, Hjelmfelt and Kramer, 1991). Twenty-four years of data from this watershed were used to calibrate the simulation model component of the MODSS.

In addition to considering the current management system on Watershed # 1, computer simulations of four other management systems, defined similarly to those in Chase and Duffy (1991), were performed in the simulation mode of the MODSS to predict the impact of these practices on the factors that affect water quality and farm income. The management systems considered are corn-soybean rotation (cb) under four different tillage practices: deep disking (dd), chisel plow (cp), ridge till (rt), and no till (nt). Thus, we will use the notation [rt_cb] to indicate the system which considers ridge till with a corn-soybean rotation. No costs or time lags for conversion of the watershed to an alternative practice or changes in capital equipment were considered. In addition, it was assumed that all management systems were equally affected by weed and insect pests.

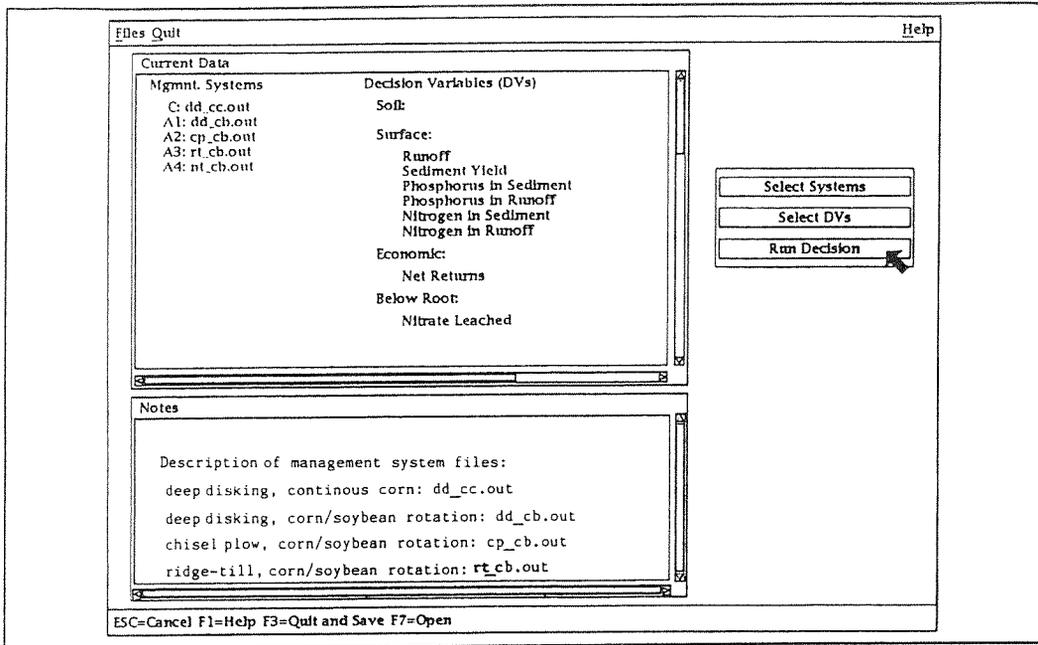


Figure 1. Screen of current selection – ready for initial decision mode

The conventional system [dd_c] received (in the simulation) 168 kilograms (kg) of nitrogen per hectare per year (N/ha/yr), while corn crops in the corn-soybean rotation received 140 kg N/ha/yr. At planting, a 28 kg N/ha application is simulated and the remaining N, in the form of anhydrous ammonia, was added after planting in split applications except in the case of the no till system which received the remaining N as a single application. Nitrogen was not applied on any of the soybean crops. Pesticide applications varied according to practice and rotation. However, to simplify our presentation of the MODSS, we will not consider the effects of pesticides on the decision making process in this example. The prices of corn and soybeans were assumed to be the average of the 1988-1990 prices, \$2.31/bushel and \$6.23/bushel respectively (Agricultural Statistics, 1991).

Once the practices are selected, the criteria or decision variables (DVs), also referred to in the literature as stressors or endpoints, need to be specified. A suite of DVs can be selected in MODSS from several available classes: soil, surface, below root zone, and economic variables. In this example we wish to base the decision analysis on the average annual values of the following : net returns, runoff, nitrate leached, sediment yield, phosphorus (P) in sediment and runoff, N in sediment and runoff.

Figure 1 illustrates a run of the MODSS in progress with the management systems and DVs chosen. The initial mode of the decision model can now be entered by selecting RUN DECISION. Immediately, the user sees the first of three views of the results. Figure 2 is a bar graph of the best and worst composite scores for each alternative given the initial mode settings of the system. Note that the best and worst composite scores for the conventional system, [dd_c], denoted by C, are both 0.5 by design. The size and the position of each bar relative to the others should be noted. Interpretation of the results is discussed in the next section.

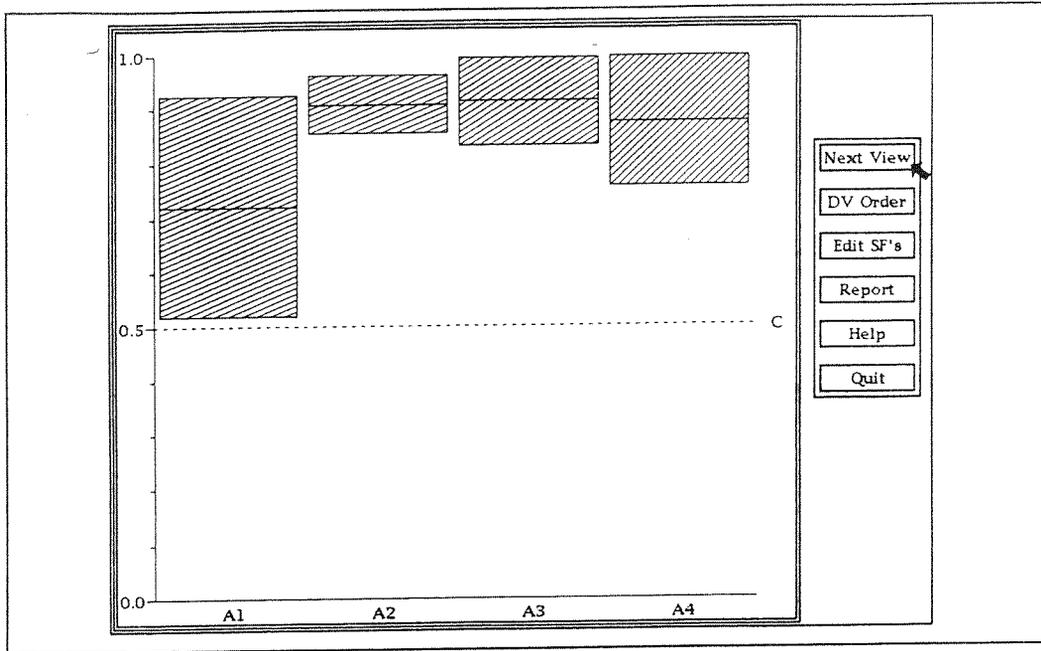


Figure 2. View of results - bar graph of best and worst composite scores.

An alternate view of the best and worst composite scores appears in Figure 3. Here we see a plot of the best versus worst composite scores for each alternative as well as for a theoretically "ideal" alternative which would have best and worst composite scores equal to 1. The Euclidean distance from each point to the ideal is indicated by the dotted lines.

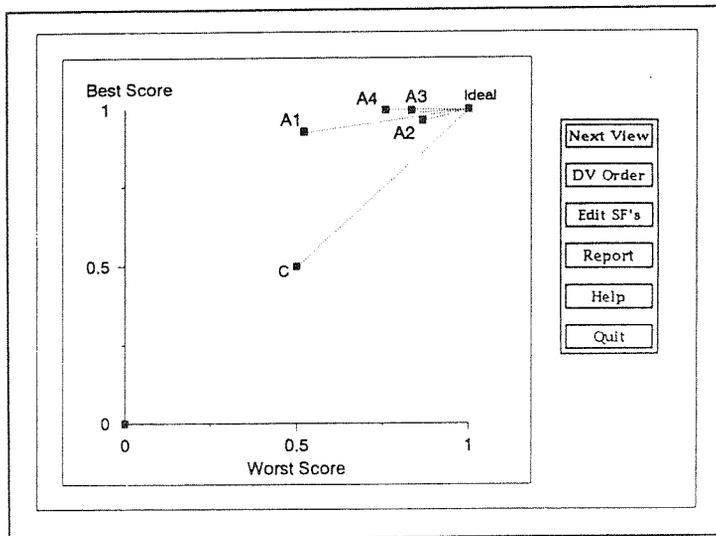


Figure 3. Best versus worst scores – distance to an "ideal".

The text view shown in Figure 4 reveals the ranking based on the average of the best and worst composite scores and the ranking based on the distance to the "ideal" in tabular form. The initial mode importance order and the score matrix are also available in the text view.

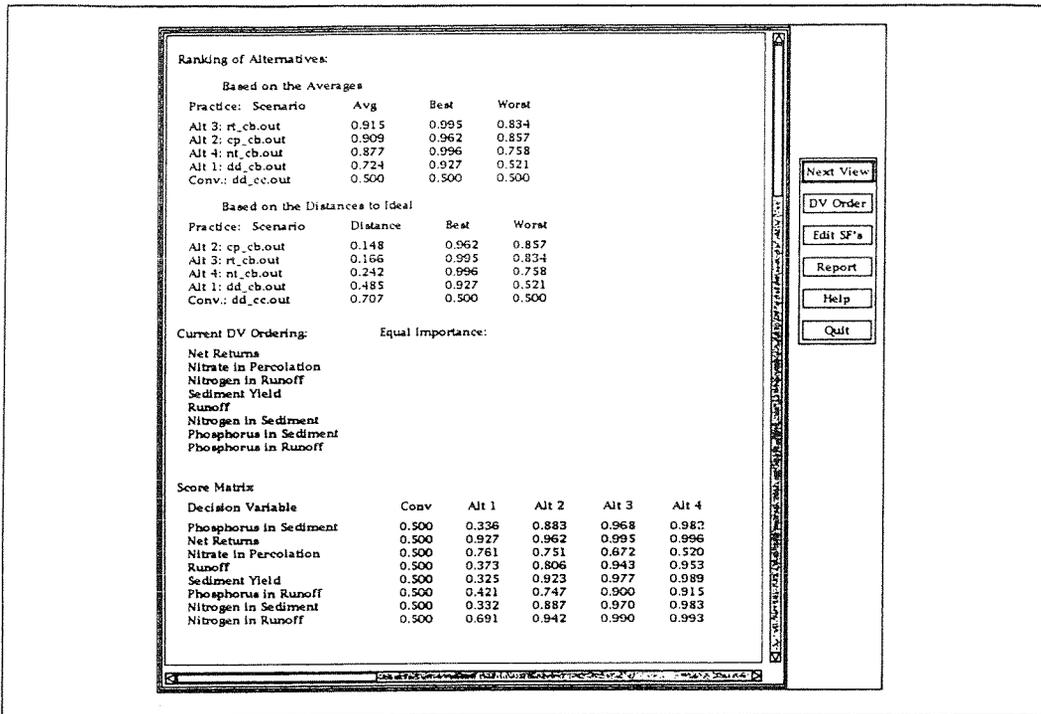


Figure 4. Text view of results - rank based on averages and distance to "ideal", importance order and score matrix.

The interactive mode of the MODSS is entered by selecting DV ORDER or EDIT SFs. The first selection allows the user to modify the decision variable importance order. This process is shown in progress in Figure 5 where the user is reducing the importance given to net returns by placing it lower in the list (fourth position instead of first). Equal importance of any two decision variables may also be specified. Once the modification is accepted, the decision model runs and the new results appear alongside the initial mode results for comparison purposes (Figure 6).

Selecting EDIT SFs allows the user to view or modify the scoring functions. In Figure 7a the scoring function for runoff is shown. The function is of "More is Worse" type, and the baseline value for the conventional system is indicated by the dotted line. At this point, the user can modify the existing thresholds (lower threshold and slope at the baseline value) at the lower left part of the screen by using the stepper boxes or typing directly into the text field. If a function of a different type or additional thresholds are desired, the user selects MODIFY and is presented with a pop-up window (Figure 7b) displaying the four generic function types currently in the system. By adjusting the threshold values and the slope at the baseline value, linear functions or step functions are also possible. In this example, the function type has been changed to a "More is Better" type with an upper threshold only. Once modification of the scoring functions has been completed, the decision routines are rerun automatically and new results displayed. As many as four views under different interactive decision mode scenarios can be viewed at the same time and deleted if other scenarios are desired.

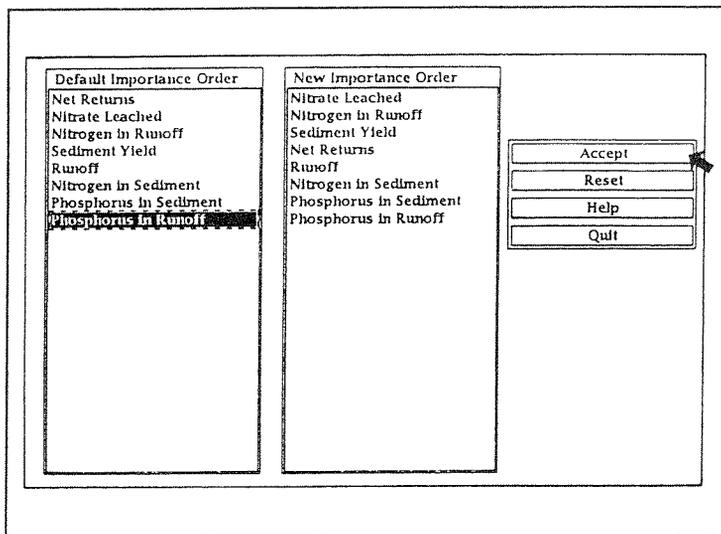


Figure 5. Modifying the importance order of the decision variables.

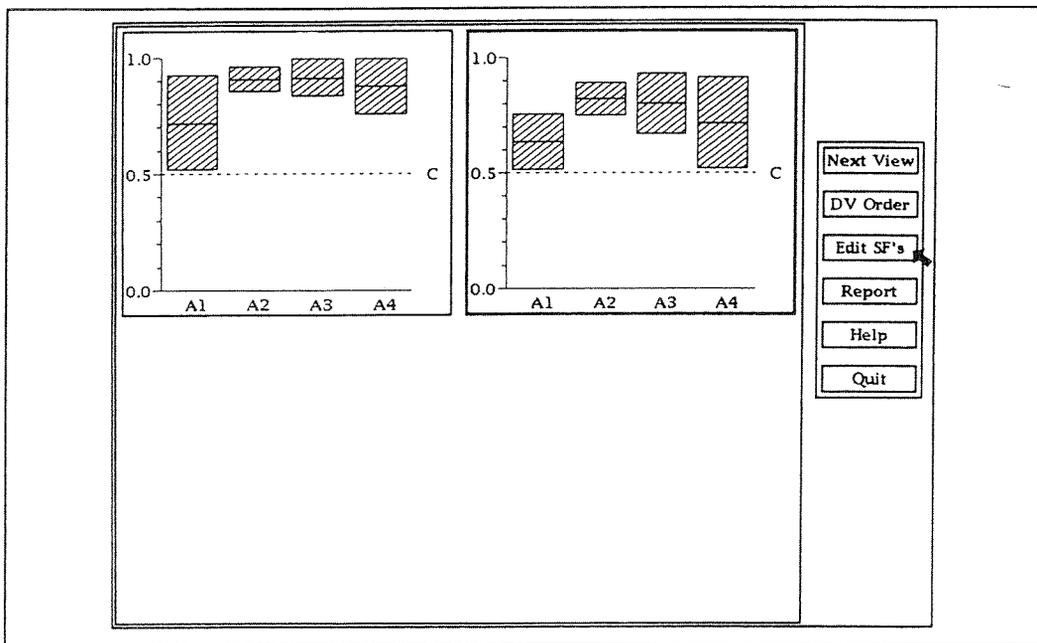


Figure 6. View of multiple results after modifying initial mode settings.

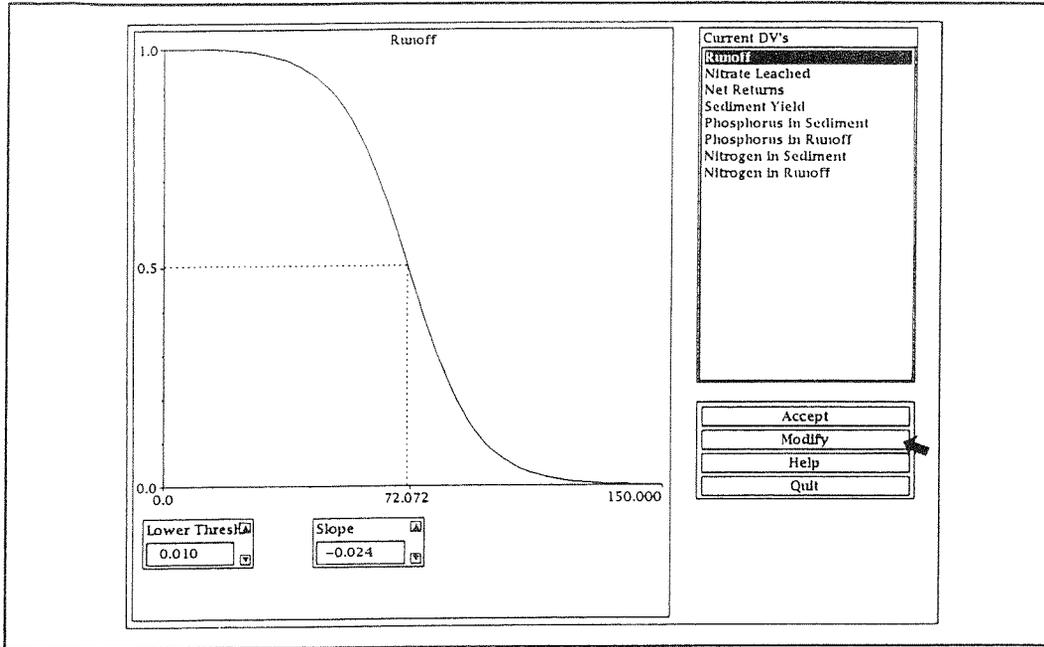


Figure 7A. Graph of scoring function for runoff.

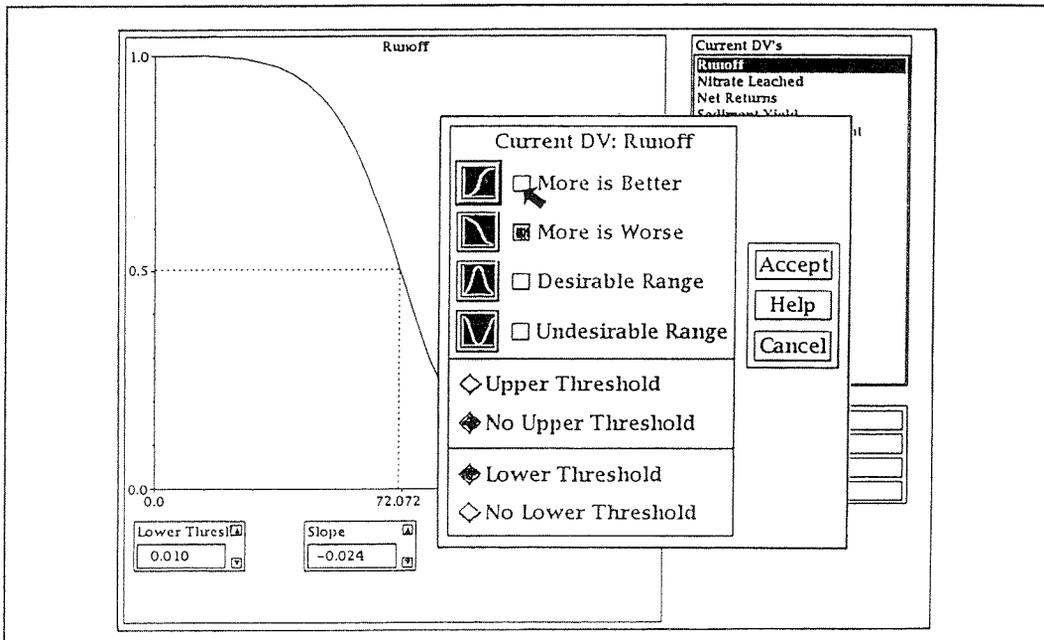


Figure 7B. Pop-up window for modifying scoring function class and thresholds.

INTERPRETATION OF RESULTS AND CONCLUSIONS

Interpreting the results of each decision run is a fundamental part of the MODSS. A detailed report of the initial mode results is provided as well as a description of the modifications made in the interactive mode and the impact of those actions on the results. In the initial mode, we see from the bar graph view, Figure 2, that all alternatives dominate the conventional system (i.e., their worst composite scores are higher than 0.5, the best composite score of the conventional system). The [dd_cb] system, labeled "A1", is more sensitive than the other systems to the initial mode importance order of the criteria and has a lower average indicated by the solid line at the midpoint of each bar. The composite score of the [cp_cb] system, "A2", is the least sensitive of all the systems to the initial mode importance order but has a lower best and average composite score than the [rt_cb] system, "A3". Since the averages for the [rt_cb] and [cp_cb] systems are close in value, and the two ranking methods do not agree on their rank positions (see Figure 4), there is no reason to prefer one system over the other given the current decision criteria and importance order. When the DV order was changed in the interactive mode, thus reducing the importance of net returns on the decision, the [cp_cb] system is preferred to [rt_cb] and [nt_cb] (see Figure 6). This is due to the greater emphasis put on nitrate leaching in the decision making process.

The MODSS was designed to handle the complexity of multiple alternative management systems and multiple objectives associated with non-point source pollution. New information such as additional decision variables can be incorporated readily. The screens were designed to be uncluttered and the system is easy to use. A major contribution of the MODSS is the new graphical and intuitive decision model which should lead to the selection of improved management systems provided the scoring functions and the relative importance order of the decision variables can be agreed upon.

We note that the example presented above does not take into account the losses of applied pesticides in runoff, percolation or with sediment. The inclusion of this information in the decision process is essential to evaluating the impact of each management system on water quality. Currently the MODSS is undergoing testing and is not yet ready for general release.

The example presented above was for illustrative purposes only and the results are not to be construed as an endorsement of a particular management practice or system. The MODSS was developed for the UNIX[®] operating system using the X-Window System[®] and the Motif[®] libraries (registered trademarks of AT&T, The Massachusetts Institute of Technology, and of the Open Software Foundation, respectively). The USDA neither guarantees nor warrants the standard of the products mentioned above, and the use of the names by the USDA implies no approval of the product to the exclusion of others that may also be suitable.

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