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A PROTOTYPE DECISION SUPPORT SYSTEM FOR FARM MANAGEMENT

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ABSTRACT

A prototype decision support system (PDSS) has been developed to evaluate the effects of alternative farm management systems on surface and groundwater quality, erosion and sediment yield, crop yield, and farm returns at the field-scale. Components of the PDSS include a decision model, simulation models, default databases, input file builders, and a system driver. The decision model is based on multiobjective decision theory incorporating scoring functions as a means of scaling (between 0 and 1) decision variables which have different units and magnitudes. The best and worst scores are calculated by assuming a preference order for the decision variables, and then solving simple linear programming problems to find the best possible (maximum) and the worst possible (minimum) scores. The management system with the highest average score is the recommended alternative. An example using data from an experimental watershed near Treynor, Iowa illustrates the use of the PDSS in recommending environmentally and economically sustainable conservation management systems. Some suggestions for the development of an operational multiobjective decision support system for water quality are proposed, as are some fundamental research problems where computers can be used to improve the scientific basis of decision making in agriculture.

KEYWORDS: decision support, water quality, BMP, management systems, multiobjective

INTRODUCTION

Uncertain weather, spatial and temporal variation in soils, pest population dynamics, changing technology, national and international market forces, increasing environmental awareness, cultural factors and the changing role of government all add to the complexity facing farmers in choosing management systems. A huge amount of information is required to develop agricultural systems which provide farmers with a decent standard of living, are sustainable and do not impose environmental damages on others. Computer based technology is increasingly being used to apply science to each farmer's site specific conditions to provide better and more complete information and to organize that information to improve natural resource management.

This paper, composed of three parts, focuses on the application of computers for decision making in agriculture to select farm management systems from among feasible alternatives. First, we argue that the selection of farm management systems is inherently a multiobjective

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problem, so that a multiobjective conceptual framework is needed. Next, we present a prototype of a multiobjective decision support system capable of helping select management systems that include consideration of farm income, the sustainability of the management system and offsite environmental effects, especially on water quality. Finally, we discuss enhancements and research needs for an operational multiobjective decision support system for selecting farm management systems.

NATURAL RESOURCE MANAGEMENT CAN BE LIMITED BY OUR TOOLS

The development of soil erosion prediction technology was recently summarized in Lane et al. (1992). The first major advance was the development of the Universal Soil Loss Equation, USLE, (Wischmeier and Smith, 1978), which has proven to be a powerful conceptual framework. A generation of soil conservationists have been able to estimate average long term sheet and rill erosion as the product of terms for rainfall erosivity, soil erodibility, slope length and steepness, and management and conservation practices. The USLE has recently been upgraded to the RUSLE model (Renard et al., 1991) which maintains the same form, but which modified the constituent factors and can be used in regions where the USLE was not applicable.

In order to apply the USLE as a management tool to maintain soil productivity, the concept of a soil loss tolerance was developed. The soil loss tolerance is an estimate of the amount of soil which can be lost due to erosion without affecting the long term productivity of that soil. A number of criticisms of the soil loss tolerance concept have been made, but perhaps the most important is that, when used as the sole criterion for environmental acceptability, only soil detachment is considered. It is impossible to tell from the USLE whether the detached soil is redeposited on the farmer's field or carried off the field into surface water, as the sediment yield. The sediment yield is extremely important in determining offsite water quality effects because nutrients and pesticides are often adsorbed to soil particles and transported with the sediment.

More comprehensive simulation models have been developed which can calculate deposition in addition to detachment and so estimate both sediment yield and sheet and rill erosion. The CREAMS model (Knisel et al., 1980) and the WEPP model currently under development (Lane and Nearing, 1989) both estimate sediment delivery based on sediment availability and the capacity of the flow to transport sediment. The sediment transport capacity is dependent on slope steepness and shape as well as other factors, so the amount of sediment transported out of a field is dependent on site specific characteristics. These more comprehensive models can be used for decision making which considers both on and off farm effects from erosion.

Economic estimates from Colacicco et al. (1989) indicate that off farm sediment damage may be almost twice as high as the on farm damage from soil erosion. For example, in the U.S. on farm damage in 1982 was estimated at roughly $1.2 billion while off farm damage was estimated at $2.2 billion (1980 $). Controlling sheet and rill erosion is a worthy goal and necessary for the sustainability of agriculture. However, if the offsite erosion damage from sediment is greater than the on-site damage, both objectives should be considered when selecting farm management systems. No single objective model or policy can capture the complexity of what are inherently multiobjective problems. As we now have simulation models which are able to provide information on both erosion and sediment yield, conservation decisions should be made within a conceptual framework capable of considering tradeoffs between conflicting objectives and which encourages the consideration of all information relevant to the selection of management systems.

The cornerstone of conservation planning in the U.S. is the Conservation Compliance Program, which limits participation in governmental agricultural programs to those farms which follow approved farm conservation plans. Currently, each state determines which practices are acceptable for the Conservation Compliance Program. A number of states have rules similar to the state of Iowa which requires that acceptable practices have a combined Cover and Practice (CP) factor in the USLE of less than or equal to 0.07. Farmers will modify their management systems through measures such as installing terraces or increasing residue cover until the CP factor is acceptable. The rationale is that, although a management system with an acceptable CP factor may not achieve the soil loss tolerance value, the farmer will have provided a reasonable effort to reduce erosion.

Although soil erosion is currently the primary conservation issue addressed in the Conservation Compliance Program, in the future other problems will be considered as well. Congress recognized the importance of water quality effects from agriculture in the 1990 Farm Bill by requiring that water quality effects of management systems in the Conservation Compliance Program also be considered by the year 2000. The Conservation Compliance Program is also a logical mechanism for the implementation of other environmental legislation such as the Coastal Zone Management Act, when related to agriculture.

The task of selecting preferred farm management systems while considering farm income, sustainability and water quality effects is a classic multiobjective problem. There are many potential pollutants, any one of which could render water unfit for human consumption or other potential uses. Management systems which limit runoff may steer pollutants toward groundwater. An added complication is the fact that some practices, such as reduced tillage, may require additional herbicide applications and thus increase the risk of polluting groundwater. In many cases site specific conditions such as proximity to a large urban area or a critical aquifer require a multiobjective method capable of considering tradeoffs between farm income, natural resource conservation and environmental protection. Given the complexity of selecting farm management systems, a software tool that incorporates a multiobjective decision making method, includes site specific information, is easy to use, conceptually sound, leads to more objective decision making and documents how decisions are reached would facilitate improved natural resource management in agriculture.

PROTOTYPE DECISION SUPPORT SYSTEM - AN EXAMPLE

Many methods for multiobjective decision making have been developed. See Janssen (1992) for a review of multiobjective decision support systems for environmental management. One practical multiobjective approach for the selection of shallow land burial systems for disposal of low level nuclear waste was presented in Lane et al. (1991). This method was extended and applied to the selection of agricultural management systems in Yakowitz et al. (1992). The Southwest Watershed Research Center of the Agricultural Research Service has implemented the above mentioned multiobjective decision making method in a Prototype Decision Support System (PDSS) as a tool for helping the user select better management practices (BMPs), or "management systems," when referring to integrated sets of crop rotation, tillage, nutrient and pesticide application practices.

The PDSS was developed to run under the Unix operating system and implemented using the X Window System and the Motif Libraries** in order to provide a graphical user interface. Components of the PDSS include databases, input file builders, simulation models, a decision model, and a system driver. Hernandez et al (1993) describe the user interface to the system

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driver and the input file builders which facilitate running the simulation model by using the databases to parameterize the simulation model.

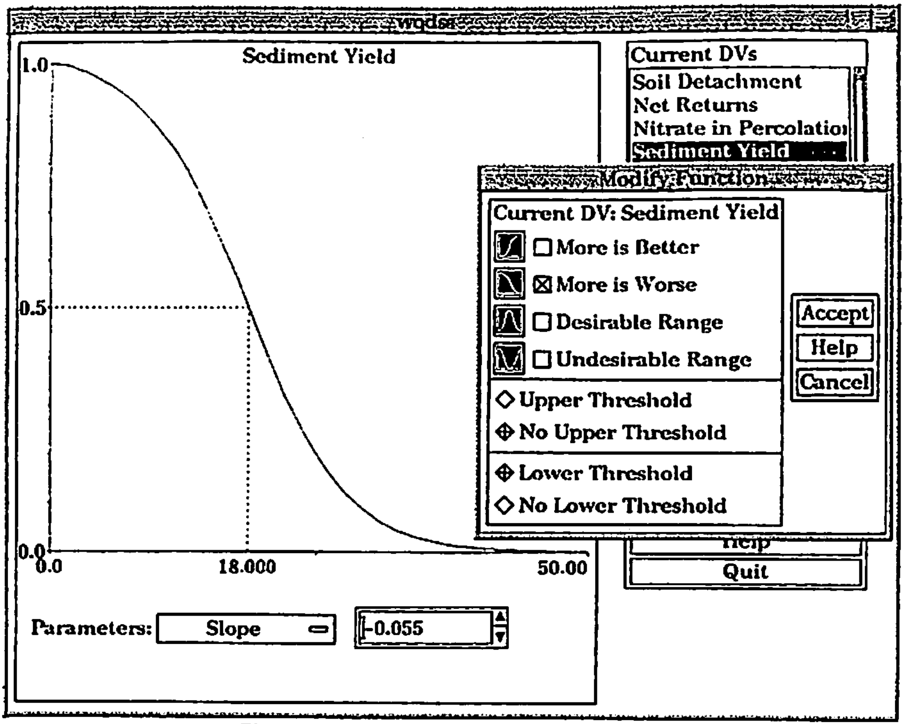
How the PDSS would be used to select a management system can best be explained by describing the implementation of the decision theory and then presenting an example. The simulation model is used to estimate the effect of alternative management systems on the variables of interest ("decision variables"). Typically the simulation is run and the annual average as well as the maximum and minimum values of all decision variables are used in the decision model. If observed data are available or other simulation models need to be used to estimate a particular decision variable, it is easy to include data from these other sources.

The current simulation model is a modification of the Groundwater Loading Effects of Agricultural Management Systems or GLEAMS model (Leonard et al, 1987). Modifications of the model include the addition of a nitrogen leaching component from CREAMS (Knisel et al, 1980) and the EPIC crop growth component (Williams et al., 1989). An economic model based on the Cost And Returns Estimator, or CARE (Midwest Agricultural Associates, 1988), model is used to compute the economic decision variables. The simulation model is capable of estimating the sediment yield, nutrient and pesticide loading in runoff and adsorbed to sediment to the edge of the field and the nutrient and pesticide leached below the root zone, as well as net returns for many management systems in rainfed agriculture.

The decision maker's problem is to define a set of feasible alternative management systems, determine which decision variables are to be used to compare the management systems, and then to select the management system providing the best overall results when considering all the decision variables. There are two basic problems which a multiobjective decision making method must resolve. The first problem is that different criteria are typically measured in different units. For example, in water quality decision making, pollutants can be measured as mass per unit area while net return to the farmer is measured in dollars per unit area. A simple way of making all the decision variables commensurable is to scale all of them to a measure of utility or score, between zero and one, where zero is as bad as possible and one is as good as possible. The expected results of each proposed management system in its own units must be mapped to a score.

To perform this mapping, a score function for each decision variable is needed. Wymore (1988) proposed a set of 12 basic scoring function shapes, which were reclassified to four basic shapes: more is better, more is worse, a desirable range and an undesirable range with the possibility of pinning one or both ends of the score function or to allow it to approach the score of 0.0 or 1.0 asymptotically (Figure 1). For example, sediment yield's score could be calculated using a "more is worse" scoring function with a score of 1.0 for no sediment emitted and the score approaching 0.0 asymptotically for greater emissions of the pollutant. A reference point is provided by constructing the score function so that the management system currently on the field is assigned the score of 0.5 for all decision variables (termed the "conventional" system). The PDSS calculates default scoring functions which the user can modify.

The second basic problem in multiobjective decision making is how to aggregate the scores to rank the management systems. The simplest method is to assign a weight to each score and then sum or multiply the scores together to arrive at a total score for each management system. Unfortunately, it is difficult to assign weights to decision variables. Atrazine moving into ground water may be considered more dangerous than sediment moving into surface water, but few people could readily agree whether the atrazine is two or four times more important than sediment.



Current DV: Sediment Yield
☐ More is Better
☒ More is Worse
☐ Desirable Range
☐ Undesirable Range
◇ Upper Threshold
◆ No Upper Threshold
◆ Lower Threshold
◇ No Lower Threshold

Parameters: Slope -0.055

Figure 1 Score Function for Sediment Yield

The aggregation method used in the PDSS requires an ordinal ranking in importance, or "importance order", of the decision variables (some of which may be equal to each other in importance). Simple linear programs are solved which consider all possible weight vectors consistent with the importance order ranking of decision variables to find the best and worst possible scores. These best and worst scores are then displayed graphically, as in Figure 2, which shows the conventional management system as the line labeled "C" because all of its scores are 0.5, being compared to four alternative management systems, labeled A1-4.

The default importance order was used to create Figure 2 by assuming that the decision variables with the steepest slope of the score function at the conventional practice are the most important. The top of each bar represents the best total score possible for that alternative which is consistent with the given importance order. Likewise, the bottom of the bar represents the worst possible score and the line in the middle is the average of the best and worst. The ranking of the management systems is determined by these average scores. The overall length of the bar indicates how sensitive a management system is to the weights which might be applied to the decision variables given the particular importance order of the decision variables. The worst scores for all alternatives are better than the conventional system, because they are above the horizontal line labeled "C". When the worst score for an alternative is better than the best score for another alternative, the first alternative is said to dominate the second alternative because, given the score functions and importance order, there is no way the weights on the decision variables can be changed which will give the second alternative a higher overall score than the first alternative.

An example illustrates the potential to consider multiple decision variables representing natural resource conservation, environmental protection, and economic evaluations in recommending

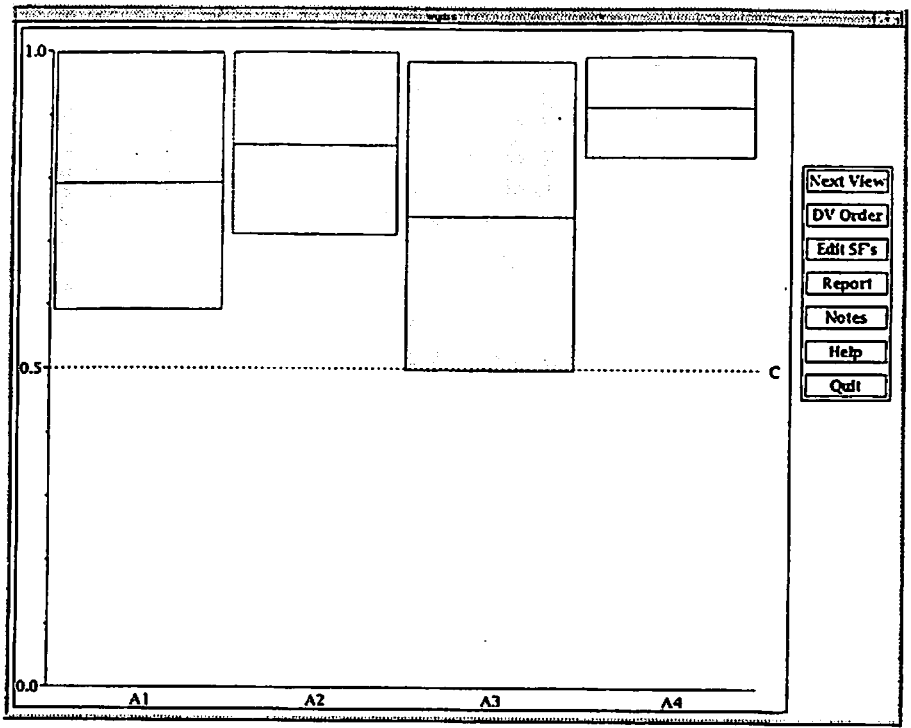


Figure 2 Best vs Worst Score

environmentally and economically sustainable conservation management systems. The data in Table 1 below show estimates of the effect of a number of soil conservation practices which have been studied at the Deep Loess Research Station in Treynor, Iowa. Five management systems are considered, deep disking with continuous corn and a grassed waterway is the conventional practice and four alternative management systems designed to reduce erosion and sediment yield. The four alternative practices are A1) pasture, A2) parallel terraces with ridge tillage and continuous corn, A3) level terraces with deep disking and continuous corn, and A4) ridge tillage and continuous corn with grass waterways. For simplicity, only four decision variables will be considered in this example. The RUSLE model was used to estimate the soil detachment. Observed values for sediment yield along with simulated values for nitrate leached and net returns from the modified GLEAMS model are the other three decision variables (see Table 1).If the only criterion was meeting a CP factor of .07, as is currently the case in Iowa, then deep disking with continuous corn, the conventional practice, would not be acceptable, but all of the alternative management systems would be and presumably the farmer would select the alternative with the highest net return. On the other hand, Figure 3 shows how the graphic capabilities of the X Window System used in the PDSS can allow the consideration of other objectives and help the decision maker understand the tradeoffs in the alternative management systems given different perspectives on the relative importance of different social objectives (decision variables). The graph in the upper left is the same as that in Figure 2 and shows the ranking of the practices based on the default importance order ranking (see Table 2). All the conservation management systems, as would be expected, do better than the deep disking continuous corn management system.

Table 1. Decision Variables Used in Example Farm Management System Selection

		USLE / RUSLE		Modified GLEAMS		
Practice	Label in PDSS	CP Factor	Soil Detachment t / ha	Sediment Yield t / ha	Nitrate Leached kg / ha	Net Returns $ / ha
Deep Disk CC - GWW	C	.10	76	18	36	231
Pasture	A1	.01	7	1	7	86
Parallel Terr. RT CC	A2	.02	16	1	29	212
Level Terr. DD CC	A3	.04	31	3	44	104
Ridge Till CC - GWW	A4	.03	25	2	20	306

The graph on the upper right shows the overall scores according how to someone primarily interested in off site effects might order the decision variables. All alternatives dominate the conventional system, and three alternatives, A1 (pasture), A2 (parallel terrace, ridge till, corn) and A4 (ridge till, corn with grassed water ways) produce similar results. The graph on the bottom left would be more accommodating to a farmer's preferences, emphasizing on-site effects. The superiority of alternative A4 (ridge till, corn with grassed water ways) under this ranking is evident. If one wanted to make the results even more dependent on the economics of the management systems one could increase the slope of the net returns score function in addition to modifying the importance order, as shown in the graph on the bottom right. Alternative 4 is even more clearly dominant.

The aforementioned example is intended to illustrate how the PDSS could be used rather than to recommend any particular management system. The selection of a management system would require a more extensive list of alternative management systems as well as more decision variables. Site specific consideration of off site effects would also be needed. Although in this example both the CP factor of the USLE (or RUSLE) and the multiobjective approach would probably result in the selection of the ridge till, corn and grassed waterway management system, that would not always be the case. If avoiding damage to an aquifer from nitrate percolation were considered extremely important (ranked first and changing the score function) pasture might be selected. Similarly, if soil detachment were considered very important, parallel terraces could be the selected practice (especially if subsidies could reduce the costs of installation and so increase net returns). The example does show however, how the PDSS could be used to compare importance orders or scoring functions to see how sensitive the overall desirability of the different alternatives is to the values assigned to the different objectives.

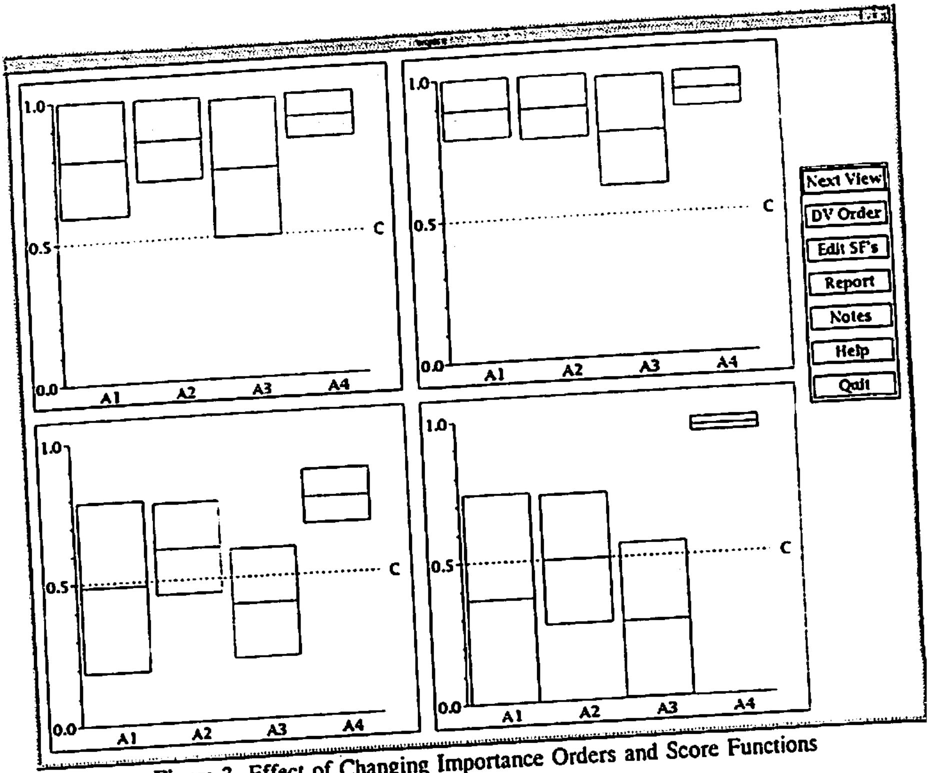


Figure 3 Effect of Changing Importance Orders and Score Functions

Table 2. Importance Orders of Decision Variables Used in Figure 3

Sediment Yield Net Returns Soil Detachment Nitrate Leached	Sediment Yield Nitrate Leached Soil Detachment Net Returns
Net Returns Soil Detachment Nitrate Leached Sediment Yield	Net Returns Soil Detachment Nitrate Leached Sediment Yield

It should be emphasized that the social values for the different objectives embodied in importance order ranking of decision variables and scoring functions are made explicit in PDSS, which is the first step in applying science to decision making. Furthermore, if involved could agree on the importance order of the decision variables and the score functi to use, then the recommendation of the preferred management system would be acceptable very little debate.

An important function of any decision support system is documenting the decisions reached the PDSS a report can be written showing the total score for each practice, the importance o and score functions used for the ranking, the score matrix and the raw data values (observe simulated). If conditions change, or a question arises as to how a decision is reached one could then repeat the decision making process.

ENHANCEMENTS AND FUTURE RESEARCH

The PDSS is a usable prototype as well as a framework for the development of an operational DSS. Potential users can try the prototype and suggest improvements and enhancements rather than having to design and build an operational DSS. The development of an operational DSS based on the PDSS will require the addition of enhancements as well as further research in decision theory.

An operational DSS would need additional simulation models depending on the type of agriculture, such as irrigated agriculture or range, as well as models capable of examining particular water quality problems in more detail than is possible in the modified GLEAMS, such as watershed scale problems would also need to be included. The PDSS has been designed to accept the output from additional models easily, however modifications to the Input File Builder would be needed to make additional models easy to use. Sensitivity analysis for each model would be useful in determining which parameters need special attention and which provide acceptable results given default values. Data acquisition, model calibration and verification on a regional scale would also be desirable. Links to additional simulation models capable of estimating the quantities of pollutants transported to water bodies of interest, through the vadose zone to groundwater or through surface water to a lake would complicate the analysis but be more realistic than models providing pollutant loads to the edge of the field or the bottom of the root zone.

The decision model in an operational DSS would also require enhancements. A process for defining scoring functions and importance orders of decision variables would have to be developed to consider off site factors. In some cases it may be possible to define economic damage functions for certain pollutants which would provide an objective means of developing the importance order and/or score functions, but in general both farmers and water users would probably have to be involved in the decision process. Oftentimes, when management systems are ranked some of the overall scores are very close to each other. Research is needed to determine just how well the decision model can distinguish between alternatives, and especially how uncertainty or error from the data and simulation models affect the selection of management systems. Similarly, enhancements are needed to facilitate consideration of how different assumptions about the environment, such as global climate change, would affect the selection of management systems.

The final requirement for an operational DSS would be a link to a policy development tool designed to analyze the incentives facing farmers to adopt certain management systems. Although some management systems may be excluded from consideration through the Conservation Compliance Program, there may be social benefits in providing incentives to adopt particular management systems from among those deemed acceptable. The ability to look at whole farm resource constraints will be needed, as a management system may be feasible on a single field, but not for all of the fields in a farm.

In addition to the enhancements needed for an operational DSS, a number of issues will need long term research before one can say that the scientific basis for multiple objective natural resource decision making has been established. To support a number of different simulation models, expert systems capable of helping the user define the problem, select the appropriate simulation model and interpret the results would be needed. Research is also needed to improve the decision model. For example, for most decisions annual average values of pollutant loadings are adequate. However, for pesticides posing threats to ecosystems or human health, the probability of exceeding a given loading or concentration during an extreme event would be a more appropriate decision variable than annual average loading. Another research topic is to develop algorithms to identify optimal management systems (having the highest overall score) given an importance order, score functions and a set of feasible management practices by combining different management practices to form management systems.

All decision making (with or without a computer) requires a simplification of the complexity of the real world so that the decision making process is manageable. Computers can be used in agriculture to incorporate complexity in the decision making process in a manageable way. As with the proverbial weak link in a chain, environmental decision making will be limited by the weakest of any of three technical factors: the availability of information, the conceptual framework which organizes the information and the tools which implement the conceptual framework. When the required databases are available, modern simulation models are capable of providing much of the information needed for informed decision making. Multiobjective decision making by means of importance order dominance and scoring functions is a practical way of incorporating society's conflicting objectives for agriculture. The PDSS is a usable prototype and framework for the development of an operational DSS for water quality which implements that multiobjective method.

Ultimately, the standard of living of farmers, the sustainability of agricultural production and the protection of the natural resources affected by agriculture will be determined by the technologies used in agriculture. If an operational DSS based on the PDSS is developed and used to help select these technologies, we will be more likely to achieve all three worthy goals.

REFERENCES

1. Colacicco, D., Osborn, T., and K. Alt. 1989. Economic damage from soil erosion, J. Soil Water Conservation, 44: 35-39.

2. Deep Loess Research Station, Treynor, Iowa, unpublished data.

3. Hernandez, M., P. Heilman, L.J. Lane, J.J. Stone, J.A. Abolt and J.E. Masterson II. 1993. A prototype shell for running field scale natural resource simulation models, Proceedings of the ASAE Conference *Application of Advanced Information Technologies for the Management of Natural Resources*, Spokane, Washington, June 17-19. pp. 142-149.

4. Janssen, R. 1992. *Multiobjective decision support for environmental management*, Kluwer Academic Publishers, Boston, 232 p.

5. Knisel, W.G. (Ed.). 1980. CREAMS: A field-scale model for chemicals, runoff, and erosion from agricultural management systems, Conservation Research Report No. 26, U.S. Department of Agriculture, Science and Education Administration. 643 p.

6. Lane, L.J., J.C. Ascough, and T.E. Hakonson. 1991. Multiobjective decision theory - decision support systems with embedded simulation models, Irrigation and Drainage Proceedings 1991, IR Div/ASCE, Honolulu, HI, July 22-26, pp. 445-451.

7. Lane, L.J., and M.A. Nearing (eds.). 1989. USDA-Water Erosion Prediction Project: Hillslope profile model documentation. National Soil Erosion Research Laboratory Report No. 2. (USDA-ARS: W. Lafayette, IN.).

8. Lane, L.J., K.G. Renard, G.R. Foster and J.M. Laflen. 1992. Development and application of modern soil erosion prediction technology - the USDA experience. Aust. J. Soil Research, 30: 893-912.

9. Leonard, R.A., W.G. Knisel, and D.A. Still. 1987. GLEAMS: Groundwater loading effects of agricultural management systems, *Transactions of the American Society of Agricultural Engineers*, 30(5), pp. 1403-1418.

10. Midwest Agricultural Research Associates. 1988. USER Manual - cost and return estimator, USDA-Soil Conservation Service, contract no. 54-6526-7-268. 77 p.

11. Renard, K.G., G.R. Foster, G.A. Weesies, and J.P. Porter. 1991. RUSLE, Revised universal soil loss equation. J. Soil Water Conservation. 46: 30-33.

12. Williams, J.R., C.A. Jones, J.R. Kiniry and D.A. Spanel. 1989. The EPIC crop growth model, *Transactions of the American Society of Agricultural Engineers*, 32(2): 497-577.

13. Wischmeier, W.H. and D. D. Smith. 1978. "Predicting Rainfall-Erosion Losses." Agriculture Handbook 537, (USDA Sci. and Educ. Admin.: Washington, D.C.)

14. Wymore, A.W. 1988. Structuring system design decisions. In: Systems Science and Engineering (Ed. C. Weimin), Proc. Intrl. Conf. on Systems Science and Engineering (ICSSE '88), July 25-28, 1988, Beijing, China. pp. 704-709.

15. Yakowitz, D.S., L.J. Lane, J.J. Stone, P. Heilman, R.K. Reddy. 1992. A decision support system for water quality modeling, Water Resources Planning & Management Proceedings of the Water Resources Sessions/Water Forum '92, EE, HY, IR, WR Div/ASCE, Baltimore, MD, August 2-6, 1992, p 188-193.