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FIELD SCALE MULTIOBJECTIVE DECISION MAKING: A CASE STUDY FROM WESTERN IOWA[1]

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ABSTRACT: Water quality issues in agriculture are growing in importance. A common theme is the provision of better information to decision makers. This study reports the trial of a prototype decision support system by the U.S. Department of Agriculture Natural Resources Conservation Service and the Agricultural Research Service in the NRCS Harrison County Field Office in 1998. Observed data collected at the Deep Loess Research Station (DLRS) near Treynor, Iowa, were extrapolated using a modified GLEAMS field scale simulation model that included a nitrogen leaching component and a crop growth component. An accounting tool was used to convert crop yield estimates into crop budgets. A model interface was built to specify the climate, soil, and topography of the field, as well as the management scenarios for the alternative management systems. For the Deep Loess Hills area of Harrison County, a total of six soil and slope groups, with 66 total combinations of management practices forming management systems, were defined and simulated based on previously calibrated data from DLRS. A multiobjective decision support system, the Water Quality Decision Support System, or WQDSS, was used to examine the tradeoffs in a comprehensive set of variables affected by alternative management systems with farmers in Harrison County. The study concluded that a multiobjective decision support system should be developed to support conservation planning by the NRCS. Currently, a larger scale effort to improve water quality decision making is underway.
(KEY TERMS: water quality; decision support systems; farm management model; agricultural hydrology.)

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INTRODUCTION

A fundamental conflict exists in any effort to improve the science used to manage agricultural land for water quality issues. Our best understanding of the physical processes controlling water quality comes when using a reductionist approach focusing on a single component of the overall system at a particular location. On the other hand, agriculture is an extremely complex system covering very large areas with many variations and interactions in the processes that control nonpoint source pollution.

Nevertheless, maintaining and improving water quality is such an important goal that society cannot be paralyzed by scientific uncertainty: some action must be taken. The obvious solution is to focus on the most important locations and issues, use the best information available, implement the best plan possible given current information, then modify the plan based on results while improving the science base over time. In essence, society has implemented that approach.

The problem is that over time, the list of issues too important to ignore has grown. Urban populations are placing increasing demands on waterways for both water supply and recreation. There is a growing recognition that ecosystems are dependent on adequate water quality and quantity. Many issues unrelated to water, such as animal habitat and agriculture's effect on the carbon cycle, need to be

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addressed simultaneously. Consequently, instead of focusing on a few problem locations and issues, impacts of management on water quality have to be addressed across large areas of agricultural land, for a large and growing list of resource issues. Ultimately, water quality issues have to be addressed at the field scale since that is the primary scale of agricultural management. The intent of this paper is to describe a structured approach to field scale decision making about multiple resource concerns, especially water quality on Midwestern croplands, and to illustrate the approach with a case study. With appropriate modifications, a similar approach could be used on rangelands and irrigated areas.

BACKGROUND

For decades, the foundation of technical assistance in U.S. agriculture has been the control sheet and rill erosion on cultivated fields. The approach is conceptually straightforward. The Universal Soil Loss Equation (USLE), or the Revised Universal Soil Loss Equation (RUSLE), is used to estimate erosion on a hillslope. The USLE and RUSLE are empirical models of the form:

$$A = RKLSCP \tag{1}$$

where A is soil loss in tons per acre, R is a rainfall/runoff erosivity factor, K is a soil erodibility factor, L is a slope length factor, S is a slope steepness factor, C is a cover management factor, and P is a support practice factor (Wischmeier and Smith, 1978; Renard *et al.,* 1997). With the USLE and an estimate for the maximum acceptable soil loss, known as a soil loss tolerance (or T factor), soil conservationists had a powerful tool for identifying fields that needed conservation practices, and even identifying a range of practices that would lead to acceptable levels of erosion. Erosion at a rate less than T, by definition, should lead to sustainable levels of crop production, at least as far as soil quantity is concerned.

To illustrate, on a field with a suspected soil erosion problem, annual soil loss would be calculated for the current management system. If T was exceeded, the RKLS factors would be held constant and smaller C and P factors corresponding to alternative management practices could be tried until annual erosion was less than T. Some practices, such as installing terraces, would affect the LS factors as well. As conservationists gained experience under local conditions with the USLE, it became the standard tool, in part because of the ease with which it could be explained to farmers to support voluntary efforts to reduce erosion.

Although simple and powerful, the USLE and RUSLE do not address all resource problems. In particular, the models estimate soil detachment but not deposition. Soil eroded from an agricultural field could be deposited within or along the field boundaries, and so the USLE is not in itself designed to address sediment delivery issues, though sediment delivery ratios can be used to get a rough idea of how much sediment enters watercourses. Further, the USLE does not address the movement of nutrients and pesticides from farm fields to water bodies. Such issues require a field scale simulation model.

The U.S. Department of Agriculture Soil Conservation Service had long recognized that a producer should have a conservation plan that addresses management impacts on all resources. To emphasize the fact that the agency considered all natural resources, the agency's name was changed to the Natural Resources Conservation Service, or NRCS. At roughly the same time, the NRCS introduced a method known as the Conservation Practices Physical Effects, or CPPE, matrix (NRCS, 2003a). The goal was to ensure that conservationists and producers looked broadly across all potential resource problems when formulating alternative management systems.

The CPPE is used as part of the conservation planning process. While performing a resource inventory on a farm, a conservationist would look for any of 66 potential resource problems. These problems are grouped under the headings of Soil, Water, Air, Plants, Animals, and Humans, and are known collectively as SWAPA+H. Each potential resource problem has a quality criterion to indicate when it should be considered a problem. Table 1 shows three potential resource problems related to soil erosion, together with their quality criteria and management practices that are likely to improve the resource problem.

A set of management systems that address all identified resource problems can be formulated by creating a table consisting of identified resource problems across the top. A management practice is added along the left side and a qualitative estimate (slight, moderate, or significant) of the effect of the management practice under the conditions in question is made for the first identified resource problem. Once the first resource problem has been adequately addressed, practices are added until the second, third, and all remaining problems have been adequately addressed.

Table 2 presents a management system designed for the Ida soils in the Loess Hills of western Iowa, taken from the Guidance Documents found in Section III of the Iowa NRCS State Field Office Technical Guide (NRCS 2003b). The first practices address soil

TABLE 1. Several Common Soil Resource Problems, Quality Criteria, and the Management Practices That Address Those Problems. Source: NRCS (2003c).

Resource Concern: Definition/ Assessment Method	Quality Criteria/Management Practices Used to Address the Resource Concern
Sheet and Rill: Removal of uniform layer of soil from the land surface caused by rainfall and surface water runoff. **Assessment Method:** RUSLE 2.	The average annual soil loss is at or below tolerance ("T") for the soil map unit. Conservation Cover; Conservation Crop Rotation; Contour Buffer Strips; Contour Farming; Contour Strip Cropping; Cover and Green Manure Crop; Diversion; Field Border; Filter Strip; Residue Management – No-Till and Strip Till, Mulch Till, Ridge Till, and Seasonal; Terrace.
Ephemeral Gully: Reoccurring gullies on cropland caused by concentrated flow of runoff water. They are obliterated by normal tillage operations. **Assessment Method:** Visual observation and Erosion and Sediment Delivery Equation.	Affected areas are stabilized. Conservation Cover; Conservation Crop Rotation; Contour Buffer Strips; Contour Farming; Contour Strip Cropping; Critical Area Planting; Diversion; Grade Stabilization Structure; Grassed Waterway; Field Border; Lined Waterway or Outlet; Mulching; Residue Management - No-Till and Strip Till, Mulch Till, Ridge Till, and Seasonal; Structure for Water Control; Subsurface Drain; Terrace; Water and Sediment Control Basin.
Classic Gully: Eroded channels that are too deep to be crossed with farm equipment. They may enlarge by head cutting and lateral widening. **Assessment Method:** Visual observation and Sediment and Gully Prediction Model.	Sheet and rill, ephemeral gully, and classic gully erosion are controlled and sediment leaving the site does not cause damage. Conservation Cover; Contour Buffer Strips; Contour Farming; Contour Strip Cropping; Critical Area Planting; Diversion; Grade Stabilization Structure; Grassed Waterway; Pond; Terrace; Water and Sediment Control Basin.

erosion issues, and the last address additional practices necessary for water quality. Typically, several alternative management systems are defined to give the producer a range of choices, for example, to resolve all problems soon, but requiring an immediate large investment, or to resolve the problems over a longer time frame with a smaller immediate investment. The NRCS Guidance Documents are the best description of how agricultural management can affect a range of resources for specific conditions that is available across the entire Midwest. Nevertheless, from a scientific point of view, there is much room for improvement, particularly in defining variables that could be measured or simulated to indicate the severity of the SWAPA+H resource problems, as well as defining thresholds indicating that there is a problem.

In the early 1990s, Leonard Lane, a hydrologist with the U.S. Department of Agriculture, Agricultural Research Service (USDA-ARS), saw the CPPE method as a significant advance toward a structured framework to integrate the effects of management across natural resources, and as a "smorgasbord" of research opportunities. He also recognized that there was a critical need to improve methods used to evaluate management alternatives and to help producers decide which management system to implement. The simple, effective approach of using the USLE and T to decide which management system to implement would not work if water quality, plant, and animal resource problems had to be considered at the same time. Thus, he led an initiative to address these issues by developing a Water Quality Decision Support System (WQDSS) consisting of an interface, a comprehensive field scale simulation model, and a multiobjective decision making component. In this paper the accomplishments that resulted from the WQDSS initiative are described, including a field test in the Harrison County NRCS Field Office in western Iowa, other applications, and current efforts to build on the same approach to improve decision making in agriculture for water quality.

MULTIOBJECTIVE DECISION MAKING APPROACH

Decision support systems (DSS) are an active area of research with seminal contributions by Keen and Morton (1978) and Bonczek *et al.* (1981). DSS applications for water resources are described in Loucks (1995), El-Swaify and Yakowitz (1998), Hays and McKee (2001), and Rizzoli and Jakeman (2002). Typically, a DSS will consist of an interface, database and links to models, knowledge bases, or geographic information systems (GIS) applications, with the intention of helping a decision maker reach a decision on an unstructured problem. Many land and water issues involve problems with multiple objectives. Multiobjective decision making theory is described in Keeney

TABLE 2. An Example of Formulating an Alternative Management System Using the Conservation Practices Physical Effects Approach From the NRCS (2003b).

Present Resource Condition
Location: MLRA 107
Soils: 1D3 Ida Silt Loam
Slope: 12
Slope Length: 150 feet
Land Use: Cropland (Corn-Corn-Soybeans)
Applied Practices: Cross Slope 5 Percent Residue Gradient
Tillage Operation: Fall Mulch Corn, 20 percent, Spring Mulch Beans 10 percent

Identified Problems
Sheet and rill erosion is 16 tons/acre. Ephemeral gullies are present. Pesticides and nutrients contaminate surface and ground water. Pheasant population is well below potential and habitat diversity is limited.

	RESOURCE CONCERNS									
	SOIL				WATER					ANIMALS
	Erosion		Condition			Quantity	Quality			Habitat
	Sheet and Rill	Ephemeral	Tilth	Compaction	Depos. Damage Off-Site	Excess Runoff	Nutrient	Pest.	Sediment	Cover/ Shelter
	Present Conditions									
Practices	SIG-	SIG-	SL-	MOD-	SIG-	MOD-	SIG-	MOD-	MOD-	SL-
Alternative #1										
600 Terraces	SIG+	SIG+	0	SL-	SIG+	SIG+	SL+	SL+	MOD+	SL+
330 Contour Farming	SIG+	SL+	0	0	MOD+	MOD+	SL+	SL+	SL+	0
328 Crop Rotation Continuous Corn	SIG+	0	0	0	SL+	0	SL-	SL-	0	0
329 Cons. Tillage No Till 50% Residue	SIG+	SL+	SL+	MOD+	MOD+	SIG+	SL+	SL+	MOD+	SL+
590 Nutr. Mgmt.	0	0	0	0	0	0	SIG+	0	0	0
595 Pest Mgmt.	0	0	0	0	0	NA	0	SIG+	0	SL-
Supplemental Practices (streams/rivers present)										
393 Filter Strip	0	0	0	0	SIG+	0	SIG+	SIG+	SIG+	MOD+
391 Riparian Forest Buffer	0	0	0	0	SIG+	0	SIG+	SIG+	SIG+	MOD+

and Raiffa (1993) and applications to land management are discussed in Beinat and Nijkamp (1998). General multiobjective decision support approaches include the Analytic Hierarchy Process of Saaty (1990) and DEFINITE by Janssen and van Herwijnen (1994).

The basic approach taken in the WQDSS was outlined in Lane *et al.* (1991). A decision maker defines the problem, then a conventional or baseline condition is determined and alternatives defined. The variables to be used in the decision are selected (decision variables), and the effects of the conventional and alternative systems are estimated using a simulation model together with all available observed data, expert opinion, databases, and knowledge bases. The decision variables are scored for each alternative, weights are selected for each decision variable, and an overall score determined for each alternative by summing the products of the weights and scores for all decision variables. Any alternatives scoring more than the current system are recommended for adoption.

Wymore (1988) proposed the multiobjective approach in the WQDSS. This method consists of two major steps: first, scoring each decision variable for each alternative; and second, assigning weights to each decision variable to calculate an overall score for the alternative. Decision variables are scored to eliminate the units and so make them comparable. By convention, scores range from 0 to 1.0, with 1.0 being as desirable as possible. The current, or conventional, management system by definition scores 0.5. Thus, all other systems are scored relative to the existing system to highlight the fact that the decision maker is comparing alternatives to the system currently in place. Score functions are selected for each decision variable from among the following choices: more is worse, more is better, desirable range, or undesirable range. The "more is worse" score function is used for a decision variable like the quantity of pollutants leaving a field. Net returns are scored using a "more is better" score function. The desirable and undesirable ranges were available for cases like soil water, where one would not want the soil to be too dry or too wet, although in practice few decision makers chose variables having desirable or undesirable ranges.

The second step in Wymore's approach assumes a simple additive value function of the form:

$$V(w,v) = \sum_i w_i v_i \tag{2}$$

to calculate an overall value, V, as the sum of the products of a weight, w, associated with each decision variable, or criterion, i, and the score, v, for that decision variable. Although conceptually simple, the approach can be difficult to apply in practice because decision makers find it difficult to directly assign weights. Yakowitz *et al.* (1993a) developed a method that eliminates the need for decision makers to specify a weight for each decision variable. Instead, decision makers rank the decision variables in order of importance. The cost of using the method is that a range of values representing the overall value for the alternative is calculated, rather than a scalar value that quantifies the overall value of a particular alternative.

The method developed by Yakowitz has an intuitive appeal to decision makers. Suppose there are n criteria, which the decision maker has ranked in importance. Let V_{ij} be the score of alternative j evaluated with respect to criterion i in the importance order. If w_i indicates the unknown weight factor associated with criterion i, the highest (lowest) or best (worst) additive composite score for alternative j, consistent with the importance order, is found by solving the following linear program described for the weights w_i.

$$maximize\ (minimize) \quad V_j = \sum_{i=1}^{n} w_i v_{ij} \tag{3}$$

$$s.t. \sum_{i=1}^{n} w_i = 1$$

$$w_1 \geq w_2 \geq \ldots \geq w_n \geq 0.$$

In both cases (maximizing or minimizing) the first constraint normalizes the sum of the weights to 1, while the second requires that the solution be consistent with the importance order and restricts the weights to be nonnegative. The solution to the two programs indicated above yields the full range of possible composite scores given the importance order. That is, any weight vector that is consistent with the importance order will produce a composite score that falls between the best and worst composite scores.

To enhance the intuitive appeal of this approach, Yakowitz *et al.* (1993a) also showed that the best and worst composite scores could be calculated in closed form, as the maximum or minimum composite score could be calculated by solving the following k problems:

$$v_{kj} = \frac{1}{k} \sum_{i=1}^{n} v_{ij} \tag{4}$$

The best or worst composite score for alternative j is then selected from the results as:

$$BestScore = BV_j = \max_k \{v_{kj}\}$$

$$WorstScore = WV_j = \min_k \{v_{kj}\} \tag{5}$$

Examples of this method applied to water quality problems in agriculture can be found in Yakowitz *et al.* (1992, 1993b). For clarity, the next section describes an example using the WQDSS across a county.

WQDSS TRIAL IN HARRISON COUNTY, IOWA

Overall Approach

The 1999 NRCS report "Field Level Evaluation of a Prototype Multiple Objective Decision Support System for Conservation Planning," describes a trial of the WQDSS in Harrison County, in western Iowa. The purpose of the trial was to determine if a DSS for water quality would be a useful tool for NRCS conservation planning. There were two parts to the trial. First, the NRCS State Office used the interface and simulation model inside the WQDSS to quantify the effects of management on a number of resource concerns. Second, a District Conservationist used the multiobjective decision making component with farmers to assess its potential role in conservation planning.

In Harrison County there are several very distinct areas, each with specific resource problems and typical management systems. Loess is windborn silt that is prone to movement by water, particularly rills and gullies (see Figure 1). The silt particles in loess can maintain steep slopes, often forming bluffs. In

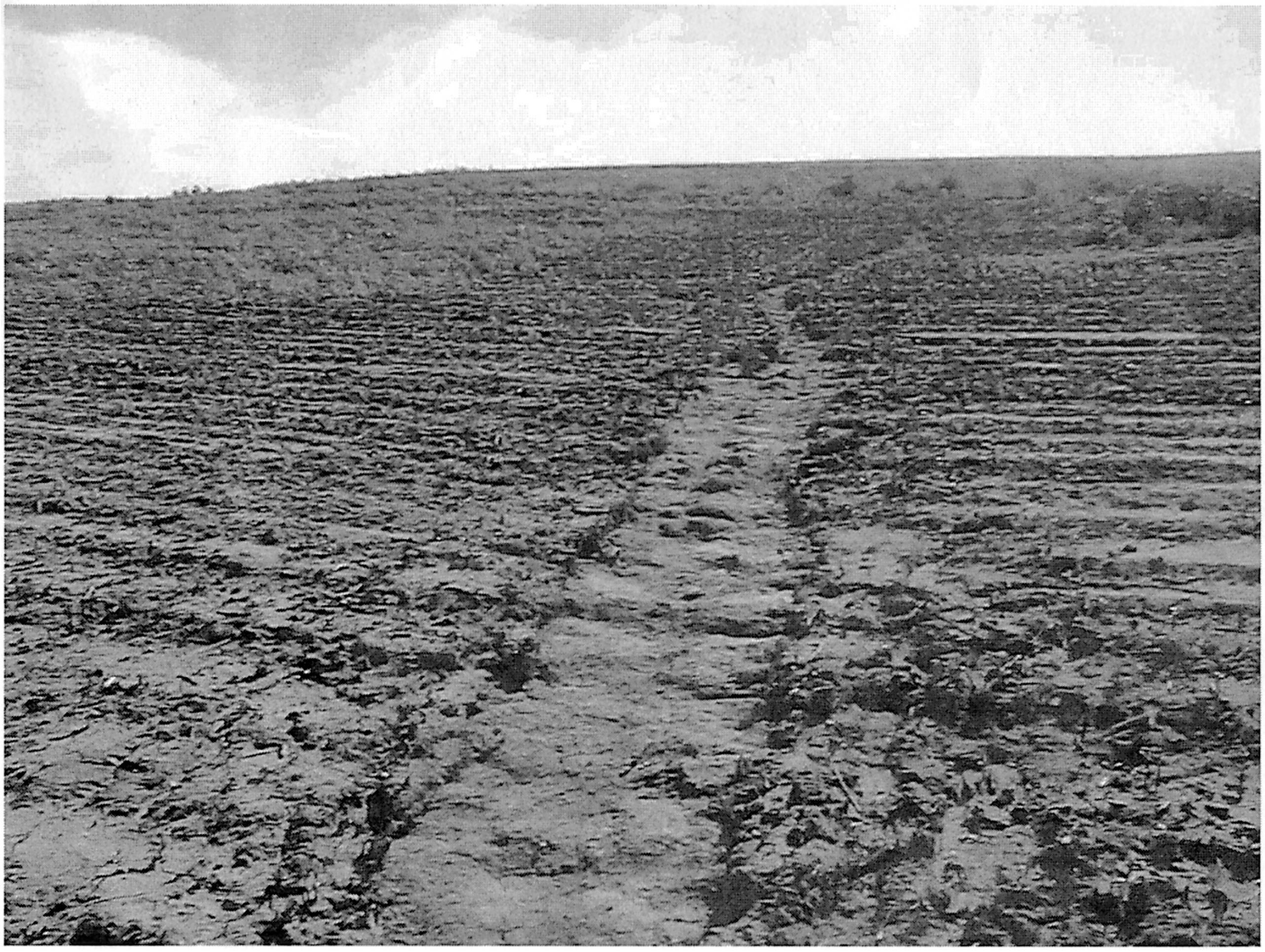

Figure 1. A Newly Formed Rill is Evident in This Field From the Loess Hills in Western Iowa.

western Iowa, loess has been deposited in layers up to 65 meters deep along the eastern side of the Missouri River Valley. Land that is not in the Loess Hills is primarily in the Missouri River Bottoms, which have heavier soils with very shallow slopes that need drainage rather than protection from erosion.

A total of 66 management systems were defined for six common soil field topography configurations. Of these, the 20 management systems simulated for Ida soils are listed in Table 3. Ida soils are common in the Loess Hills, and are deep, well drained, moderately permeable, and with medium to very rapid surface runoff. All management systems include a corn/soybean rotation, with the major management differences being timing and intensity of tillage, timing and quantity of herbicide applications, and timing of nitrogen applications.

Modeling and Scoring the Effects of Management on Resource Criteria

The simulation model in the WQDSS is a modified version of the Groundwater Loading Effects of Agricultural Management Systems (GLEAMS) model (Leonard *et al.,* 1987; Davis *et al.,* 1990). Modifications to GLEAMS include the addition of the nitrogen leaching component from CREAMS (Knisel, 1980), and the EPIC crop growth component (Williams *et al.,* 1989). A modified version of the economic accounting program based on the Cost And Returns Estimator by the Midwest Agricultural Research Associates (1988) was used to compute returns of the management systems based on simulated yields.

The model was calibrated to match runoff, baseflow as a proxy for percolation, sediment yield, and corn yields for several experimental watersheds on the Deep Loess Research Station near Treynor, Iowa, for

TABLE 3. The 20 Management Systems Simulated on Ida Soils. All nitrogen is applied on corn as anhydrous ammonia at the rate of 168 kg/ha, either preplanning or post-planting. The use of an additional herbicide application in June is indicated by "+ 2nd herb."

	Corn			Soybeans				
No.	Tillage	Nitrogen	Weed Control	Tillage	Weed Control	Watershed	Curve No.	Crop Residue
1	Fall Plow	Pre	Till Fall	Fall Plow	Till Fall	Overland Channel Hillslope	81	10
2	Fall Plow	Post	Till Fall	Fall Plow	Till Fall	Overland Channel Hillslope	81	10
3	Fall Disk	Pre	Till Fall	Fall Disk	Till Fall	Overland Channel Hillslope	80	35
4	Fall Disk	Post	Till Fall	Fall Disk	Till Fall	Overland Channel Hillslope	80	35
5	Spring Plow	Pre	Till Spring	Spring Plow	Till Spring	Overland Channel Hillslope	81	10
6	Spring Plow	Post	Till Spring	Spring Plow	Till Spring	Overland Channel Hillslope	81	10
7	Spring Disk	Pre	Till Spring	Spring Disk	Till Spring	Overland Channel Hillslope	80	35
8	Spring Disk	Post	Till Spring	Spring Disk	Till Spring	Overland Channel Hillslope	80	35
9	No-Till	Pre	Burndown	No-Till	Burndown	Overland Channel Hillslope	75	60
10	No-Till	Post	Burndown	No-Till	Burndown	Overland Channel Hillslope	75	60
11	No-Till	Pre	Burndown	No-Till	Burndown + 2nd Herb	Overland Channel Hillslope	75	60
12	No-Till	Post	Burndown	No-Till	Burndown + 2nd Herb	Overland Channel Hillslope	75	60
13	Spring Plow	Pre	Till Spring	Spring Plow	Till Spring	Terrace Hillslope	74	10
14	Spring Plow	Post	Till Spring	Spring Plow	Till Spring	Terrace Hillslope	74	10
15	Spring Disk	Pre	Till Spring	Spring Disk	Till Spring	Terrace Hillslope	73	35
16	Spring Disk	Post	Till Spring	Spring Disk	Till Spring	Terrace Hillslope	73	35
17	No-Till	Pre	Burndown	No-Till	No-Till	Terrace Hillslope	70	60
18	No-Till	Post	Burndown	No-Till	No-Till	Terrace Hillslope	70	60
19	No-Till	Pre	Burndown	No-Till	Burndown + 2nd Herb	Terrace Hillslope	70	60
20	No-Till	Post	Burndown	No-Till	Burndown + 2nd Herb	Terrace Hillslope	70	60

the period 1972 to1991. Figure 2 shows simulation means relative to observed means for the four variables over the 20-year period. The model had difficulty simulating runoff, percolation, and crop yield while maintaining parameters within their expected ranges, as this requires modeling the entire water budget. Evapotranspiration (ET) is such a large part of the water budget in western Iowa that a small overestimate or underestimate of ET can overwhelm runoff or percolation. Because a realistic crop yield is necessary to correctly estimate net returns, and runoff is needed to estimate sediment movement, those outputs were matched to observed amounts. As percolation was not directly measured and would be expected to diverge somewhat from baseflow, simulated percolation absorbed a significant portion of the error in the water budget, and simulated percolation remained much lower than the observed baseflow. Although there is a wide difference in tillage intensity between deep disking and ridge till with terraces, the ratios of simulated to observed means for the four variables are similar.

Average corn yields increased over the simulation period, so yields were calibrated to the ending, rather than the mean yields. Based on calibrated parameters for the observed management systems, other management systems were parameterized as described in Heilman (1995). These parameter sets were then extrapolated to quantify the 66 management system soil/slope combinations in Harrison County.

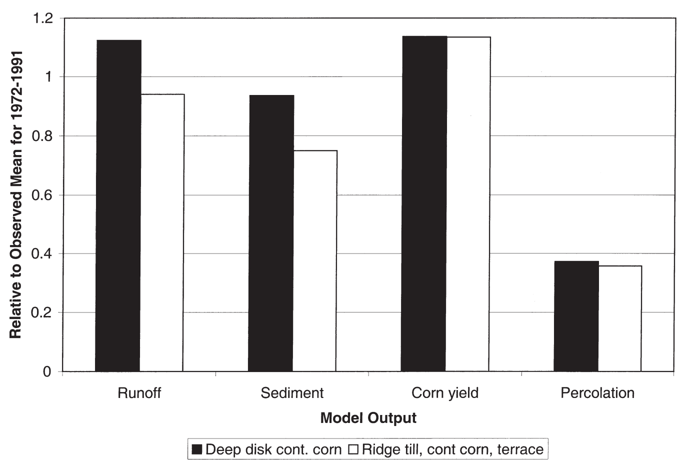

Figure 2. The Ratios of Simulation Results to Observed Values for Two Management Systems on Deep Loess Research Station Fields Are Generally Close to One.

The comprehensive field scale model provided estimates of many potential decision criteria. Table 4 shows six decision variables that a group of farmers and Soil Conservationists in the Deep Loess Hills considered important for five management systems on Ida soils. Some of the modeling assumptions are apparent. The net returns for the terrace systems are higher than the same tillage systems without terraces, as it is assumed that the cost of installing terraces was completely subsidized, although current programs do not cost share 100 percent of the terrace installation cost. Similarly, it is assumed that terraces are placed at the bottoms of all slopes to allow no surface runoff or sediment movement.

Net returns are lowest for the Fall Disk system both because of the cost of fall tillage in addition to spring disking and field cultivation and because of lower yields during dry years. Disking greatly increases erosion and sediment yield compared to No-Till, particularly when done in the fall because of the potential for heavy rains early in the season when there is little cover on the soil. The model does not simulate weed populations and thus implicitly assumes that chemical control of weeds is as effective as mechanical control. The different tillage systems do not affect nitrogen movement from the field as much as they do soil movement, although terraces increase the amount of nitrogen moved below the root zone. Additional management systems designed to conserve nitrogen could be considered if the farmstead has elevated levels of nitrogen in the ground water or the field is in a watershed with a recognized nitrogen problem. Phosphorus associated with sediment tracks the sediment movement closely. One potential weakness in approaching problems on a field by field basis is that one inherently assumes that all management systems are feasible. On a whole farm level, there may be time to disk in the spring for several, but not all, fields on the farm. Also, farmers may be averse to delays in planting during wet springs.

To make decision variables comparable, the next step is to score the model results (see Table 5). As an example, Figure 3 shows the function used to score the five management systems for their effect on nitrate in percolation. Although the simulation model underestimated the amount of percolation, if the relative amounts of nitrate in percolation for each management system are correct, the scored values should adequately express the relative gains possible by switching to the alternative management systems.

TABLE 4. Simulation Model Results for Five Management Systems and Six Decision Variables on Ida Soils.

	Net Returns ($/ha)	Soil Erosion (t/ha)	Sediment Yield (t/ha)	Nitrate in Percolation (kg/ha)	N in Runoff (kg/ha)	P in Sediment (kg/ha)
Fall Disk	55	37	38	7	4	21
Spring Disk (Terrace)	115	10	0	6	0	0
Spring Disk	104	18	18	4	4	11
No-Till (Terrace)	139	6	0	7	0	0
No-Till	135	5	6	6	2	4

TABLE 5. Scored Values for Five Management Systems and Six Decision Variables on Ida Soils.

	Net Returns	Soil Erosion	Sediment Yield	Nitrate in Percolation	N in Runoff	P in Sediment
Fall Disk	.5	.5	.5	.5	.5	.5
Spring Disk (Terrace)	.71	.98	1.0	.63	1.0	1.0
Spring Disk	.67	.92	.92	.85	.53	.91
No-Till (Terrace)	.78	.99	1.0	.59	1.0	1.0
No-Till	.77	.99	.99	.68	.93	.99

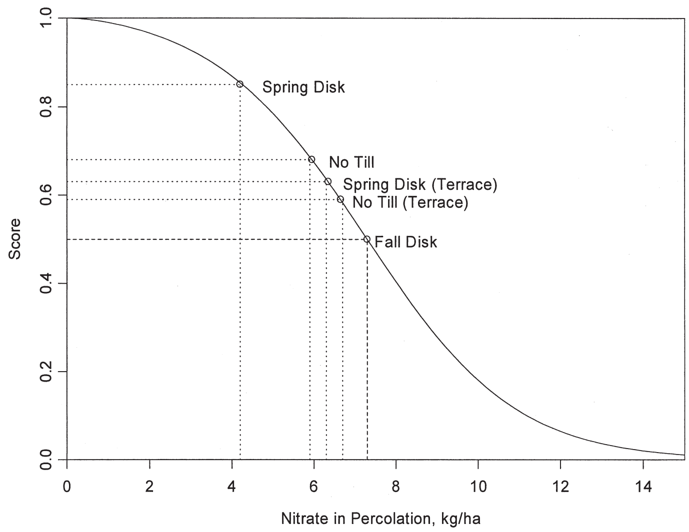

Figure 3. A Score Function for Nitrate in Percolation Shows How Model Results Are Converted to Scores.

Making a Decision

After scoring, the next step was the calculation of best and worst possible scores for each alternative. Individual farmers might have different importance orders for the decision criteria, or the nature of downstream water quality could influence the importance order. A typical ordering for a farmer in Harrison County might be: (1) net returns, (2) soil erosion, (3) sediment yield, (4) nitrate in percolation, (5) nitrogen in runoff, and (6) phosphorus in sediment.

The best and worst possible scores for the conventional system, Fall Disk, are both 0.5, since the score for each decision variable was defined to be 0.5 for the conventional system. Calculating best and worst scores for other systems requires the importance order and the calculation from Equation (5). For example, best and worst scores for the Spring Disk (Terrace) management system could be calculated as

Maximum {.71, .85, .90, .83, .86, .89} = .90

Minimum {.71, .85, .90, .83, .86, .89} = .71

Figure 4 shows the ranges of possible scores for the management systems in the example. The worst scores of all of the alternatives score higher than the conventional system. Given those decision variables, alternatives, scores, and the importance order, one of the alternatives should be implemented, although the overlap in ranges between the best and the worst scores makes it difficult to discriminate between four alternative management systems. The No Till systems appear to score higher than the Spring Disk systems, but when the bars overlap, the decision maker's exact weights could cause the overall highest score to vary. In this case, a farmer could select any one of the alternatives depending on his knowledge and equipment and do better than continue with the existing management system.

Report on the WQDSS Trial

The NRCS wanted to assess a multiple objective decision support system because they had many tools capable of assessing individual resource problems, but no tool capable of prioritizing goals or simulating the interaction of conservation practices on multiple resource concerns simultaneously. There was a recognized need for a repeatable, defensible way of estimating the interrelated effects of conservation management systems for site specific conditions. Further, there was no systematic method to help producers sort out the conflicting effects of alternative management systems on income and the environment.

The trial of the WQDSS assessed the use of a multiple objective decision support system from a number of vantage points. The WQDSS was compared against a list of 14 desirable characteristics for decision support systems drawn from similar assessments:

- use readily accessible and affordable hardware and software,
- intuitive and adaptable user interfaces,
- modularity to allow incremental development,
- internet connectivity,
- ability to use distributed databases and models,
- interoperability to allow use of components regardless of where they are developed,
- logging and tracking to document decision processes and produce records of decisions,
- GIS capability,
- visualization displays of data, relationships and anticipated results,
- mechanism to allow stakeholder involvement and self assessment,
- ability to facilitate adaptive management and monitoring,
- depiction of uncertainty in data, relationships or results,
- treatment of multiple goals, objectives and measures, and
- ability to create and store scenarios.

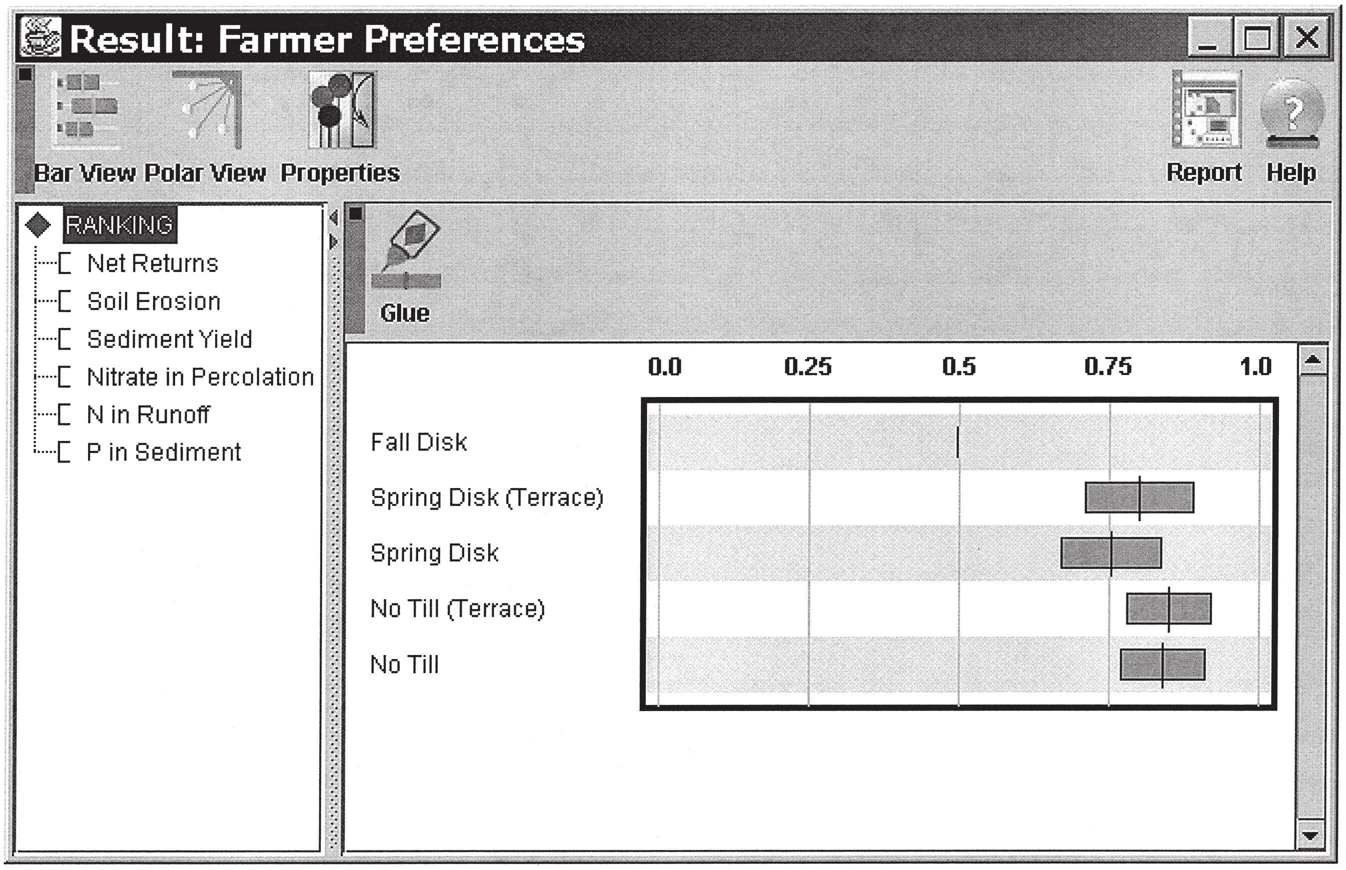

Figure 4. A Graphical Display From the Facilitator Shows the Desirability of Alternatives Given a Typical Farmer's Ranking of Decision Variables.

The report (NRCS, 1999) lists the findings and recommendations for each of the desirable characteristics. To summarize the findings, the report concluded that a multiple objective DSS could be used to address both soil erosion and water quality issues. Demonstrations of the WQDSS consistently encouraged farmers to discuss and consider multiple natural resource problems, including sediment, and losses of nutrients and pesticides. Younger farmers tended to be much more comfortable with a DSS approach than older farmers. All farmers wanted to ensure that the conditions of their particular farm were taken into account and that the economic estimates were realistic. A key issue was that the system could not take too much time for the conservationists, nor require a long and complicated interaction with the producers. The implication is that the simulation modeling should be done somewhere other than the Field Office.

The WQDSS was not recommended for widespread adoption because the necessary databases had not been developed and the WQDSS required the Unix operating system. The NRCS report did recommend a long term, multiagency effort to develop and implement an operational tool to support conservation planning. Such a tool would facilitate the quantification of management effects on natural resources, help address water quality issues, manage change and increase the effectiveness of Conservationists in the field. According to the report, such a tool should have the following key characteristics:

- a user friendly interface,
- the ability to pull information from both GIS data and the interface,
- the use of models to provide for more precise information than can be gleaned from the conservation practices physical effects information,
- a modular design to allow for use of different models in different parts of the country,
- the incorporation of a DSS to provide for simultaneous evaluation of conservation system options relative to multiple resource and business objectives, and
- the ability to easily export information into farmer friendly conservation plan maps and documents.

Building an operational DSS for conservation planning that meets those requirements is no small undertaking. Identifying the major resource problems, management systems that address the problems, models that simulate key processes, and then simulating those management system effects across large areas will require significant effort and coordination across a number of institutions.

OTHER APPLICATIONS OF THE WQDSS MULTIOBJECTIVE APPROACH

The WQDSS has been used for a number of other applications including shallow land burial systems for low level nuclear waste (Paige *et al.,* 1996), targeting farms for planning (Heilman *et al.,* 1997), and rangeland planning (Lawrence *et al.,* 1997). Imam (1994) addressed modeling and DSS uncertainty issues.

The institution with the most experience in resource decision making with the WQDSS multiobjective approach is the Queensland Department of Natural Resources and Mines in Australia. The Queensland DNRM contracted to have the decision-making component of the WQDSS implemented in the Java computer language as a generic multiobjective decision making tool called the Facilitator. There were some changes to the approach in the Facilitator, namely the score functions do not assume that there is a current management practice that scores 0.5 by definition. Also, there is support for a hierarchical importance ordering, so objectives can be grouped under categories such as “water pollutants” or “sustainability” as described in Yakowitz and Weltz (1998). The Facilitator has some added features to document the process of reaching a land use decision involving watersheds or other large areas, in which a number of stakeholders are involved. The Facilitator is being used for watershed planning in the United States, Mexico, India, and Zimbabwe.

Because there is no embedded simulation model, expert opinion has been the primary means of estimating the effects of management. Watershed planning has been the primary application of the Facilitator, but it has also been used for water development, floodplain management, forestry, animal production, project evaluation, and regional strategy prioritization. The Facilitator is available for free downloading, as is its source code (SOURCEFORGE.net, 2000). To promote the application of multiobjective decision support for environmental management, a series of conferences under the name MODSS was initiated by Leonard Lane and others, as documented in El-Swaify and Yakowitz (1998), Lawrence and Robinson (2002), and as part of Rizzoli and Jakeman (2002).

FUTURE PLANS AND IMPROVEMENTS

The fundamental problem in natural resource management in agriculture is the difficulty in quantifying the effects of management given a wide range of resource concerns and the inherent variability of climate, soils, topography, and management that affect farm productivity, sustainability, and offsite effects. Simplifying assumptions that worked in the past, such as using estimates of annual erosion as a first-cut indicator for many other resource concerns, will not work, as society puts more emphasis on the importance of clean water and other resources.

On the other hand, there are opportunities to work more efficiently. Great progress has been made in developing databases from field experiments, improving simulation models, and furthering our understanding of the processes that affect water quality from agriculture. The challenge is to develop tools, call them decision support systems, which harness the information available to improve decision making. Newman *et al.* (2000) and Matthews and Stephens (2002) describe a number of the difficulties encountered in getting DSS technology adopted in agriculture and suggest greater user involvement with less research emphasis and iterative prototyping are approaches more likely to lead to adoption. Information technology will allow a restructuring of our approach to delivering the science used for water quality decision making. Currently, there is too large a burden on those working directly with the farmer to integrate the available science. Specialists are needed to create the databases and run simulation models for particular problems over large areas.

One simplification that can help make the shift towards increased specialization (shown in the Harrison County example) is the use of representative fields. By assuming away some of the complexity in individual fields, it is possible to develop a finite number of representative field management system combinations. A modeling specialist can then collect available data and simulate effects of management systems on those fields. Expert review of results could confirm the realism of simulation efforts. Once the information is in a database, the NRCS conservationists can learn the effects of management on the representative fields found locally, and “tell the story” to interested producers (Heilman *et al.,* 2002). Of course, decisions will only be as good as the link between the representative field and the actual field.

If, on the other hand, each individual field always had to be treated as a special case, there would never be enough manpower to simulate effects of alternative management systems, review results, and communicate results to producers across wide areas of the Midwest given current technology. In fact, there is an effort underway to link observed data from the MSEA, or Management System Evaluation Areas (Hatfield *et al.,* 1993), the Root Zone Water Quality Model (Ahuja *et al.,* 2000), and the Facilitator to build and apply an expert reviewed database/DSS for conservation planning by the ARS and the NRCS in Iowa.

CONCLUSION

Natural resource management in agriculture will be much more complex in the 21st Century than in the past. Society wants agriculture to contribute to the reduction of a range of water quality problems in addition to reducing erosion. Producers over very large areas will need a way to assess how alternative management systems can address water quality problems while maintaining or enhancing their lifestyle and income.

A trial of the WQDSS multiobjective decision support system for water quality in the Harrison County Field Office in western Iowa led to the specification of requirements for an operational system and the recommendation that such a DSS be built to support conservation planning. A DSS could meet the NRCS need for a systematic approach to conservation planning with quantified effects of management on a range of resource concerns, help address water quality issues and manage change. It would be critically important that such a DSS be easy to use and not require substantial additional time of either the conservationist or producer. An example from the Deep Loess Hills of western Iowa illustrated the DSS used in the trial for fields with Ida soils. The example indicated that several management systems using conservation measures such as terraces or No-Till would have water quality as well as economic benefits over Fall Tillage, although some of the systems could increase nitrogen movement towards ground water. A graphical multiobjective component identified several options that would be more desirable than Fall Tillage, but was unable to identify a clearly superior alternative.

Implementing an operational DSS for conservation planning across the Midwest will require significant effort. The Conservation Practice Physical Effects matrix should be reviewed to identify variables and quality criteria representative of each of the resource concerns. Also needed are methods to quantify the effect of current and alternative management systems over large areas. These methods include simulation models, but would also require built-in support for defining many management systems on a number of representative fields, compare simulated data to be observed, facilitate expert review, and display results in a meaningful way to producers. Implementation of these tools will require modeling specialists to be responsible for quantifying the effects of management to reduce the burden on Field Office personnel. There should also be a link between the information provided and society's incentives to encourage adoption of management systems with environmental benefits if those systems produce lower economic returns.

The WQDSS and follow-on DSS efforts presented here are just one example of the impact that Leonard Lane has had on water resource management. In this case, Leonard's contribution was to recognize a long term strategic need, develop a strategy to address the need, assemble resources and a team to implement the strategy, and then help the team deliver a product. Any improvement in the management of our natural resources to come out of these efforts will be the result of his initiative and leadership.

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