Global Livestock CRSP

Exploring Uncertainty in Decision Support Systems for Land-Use Management

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Research Brief 09-01-SUMAWA April 2009

Underlying all decision support systems are criteria scoring and decision rules. A multi-objective decision support tool known as the Spatial Environment and Agricultural Decision Support (SEADS) tool was developed by SUMAWA team members to be used by land managers and scientists in the identification of appropriate and desirable decisions for landscape management in settings where a variety of multiple competing interests exist. The SEADS toolkit passes observational and model data through mathematical equations termed "scoring functions" that establish a score for various potential land use options; these scores can be used to support decisions made on the ground. As part of the SEADS development, an uncertainty analysis was carried out to determine the degree to which these scoring functions affect the final score, therefore analyzing the extent to which SEADS outcomes may be improperly influenced by functions. Seven methods were used to parameterize three scoring functions that are part of SEADS. Results indicate that parameterization (the programming of the model) disproportionately influenced model outcomes when utilizing the SEADS scoring method. Further research is currently underway to assess the extent to which the model is sensitive to this parameterization. It is therefore important to understand that models like SEADS are intended to be tools that provide decision makers with an additional layer of information for land-use management. Using modeled data must be tempered with rigorous scientific research. In the end, it is the people and not the models that have to make the decisions.

Background

This research analyzes the impact of uncertainty in parameterizing the decision rules for a spatially explicit multi-objective decision support system recently developed for use in Kenya. This system is designed to work as a mechanism to facilitate non-governmental entity participation in water resources decision-making. The Spatial Environment and Agricultural Decision Support tool (SEADS) was developed to assist land use managers in watershed-scale decision-making by integrating biophysical, economic, and social factors in a spatial decision-making space (Baldyga, 2008; Baldyga and Holley, 2008). SEADS incorporates decision rules from the Facilitator decision support system (Heilman et al., 2002) and capitalizes on readily available data sets and models, with the Soil and Water Assessment Tool (SWAT) (Arnold and Allen, 1996), embedded within the Automated Geospatial Watershed Assessment tool (Miller et al., 2007), being the principal hydrologic model.

SEADS is designed as a multi-criteria decision support tool tailored to address a class of problems with inherent conflicting objectives involving a set of evaluated alternatives. The tool identifies the highest score relative to the stated objectives in the management process, which are statements that describe a landscape system's desired end state, such as sustainable ecosystem services and productive agriculture. Criteria are used as measures of a given alternative's outcomes in meeting objectives. Erosion rates, for example, are measures of both long-term sustainability and productive agricultural systems. Users identify alternatives, which are options that deviate from the baseline condition, such as land use changes, different crop choices, or land management changes. A properly functioning decision support system ranks the relative suitability of alternatives for the desired outcome by measuring and scoring various criteria. Throughout the decision making process, there may be one or many stakeholders, and they may be comprised of groups or individuals who are considered to be affected by the decision making outcomes.

Decision support systems must employ some function for ranking alternatives, and these functions often require users to assign importance weights to criteria. SEADS uses a modified Analytical Hierarchy Process that does not require decision makers to specify numerical weights to determine criteria importance, but is instead based on how the users rank relative the importance of the criteria. This approach does not seek to find the "best" solution to a problem, but rather to determine one that is most acceptable to decision makers based on their

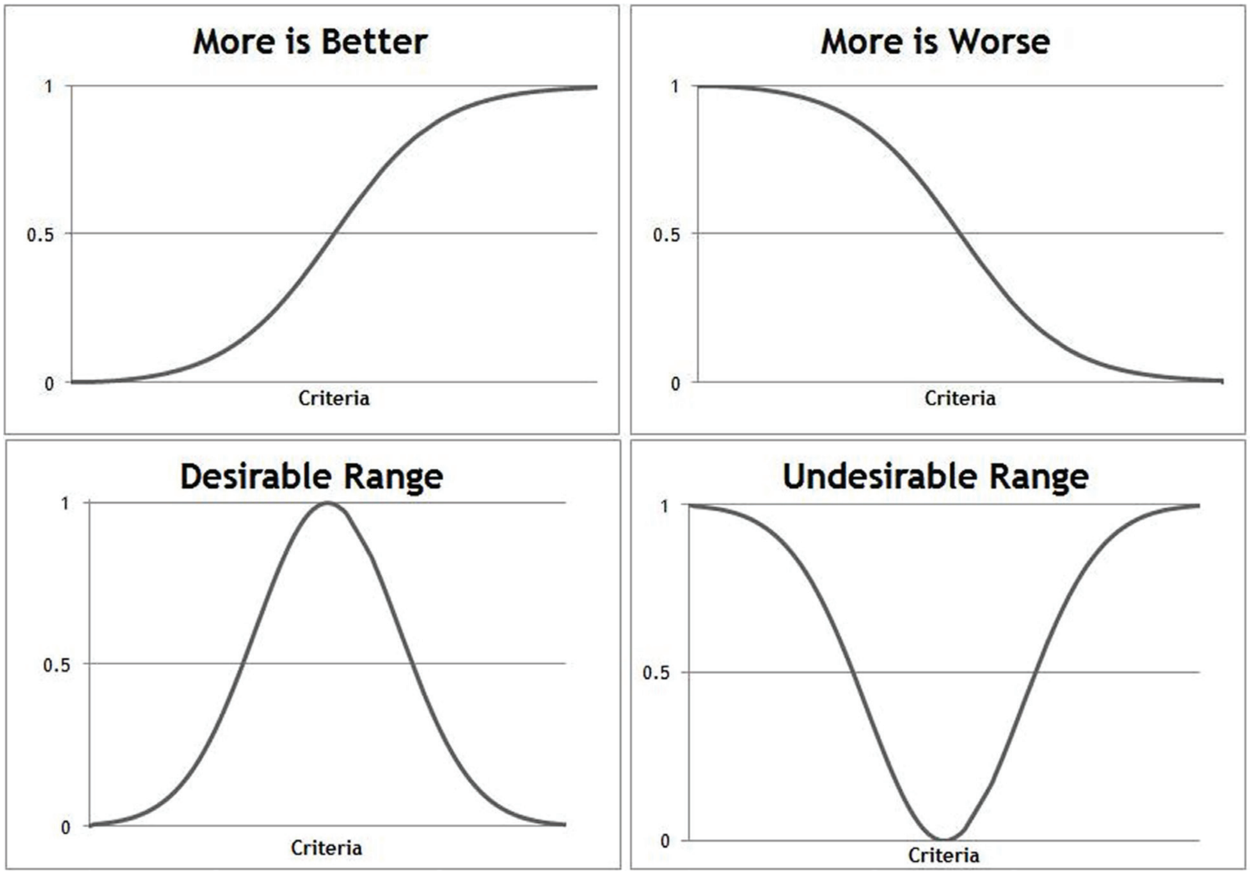

Figure 1. Four scoring functions used in the SEADS tool that transform observed or model data into scores for use in decision-making.

interpretation of the most critical factors leading to their desired outcome. Each data set that is used to determine an alternative's score must pass through a scoring function that transforms the data from its original value into a unitless score from 0-1. This allows criterion with differing measurement scales to be directly compared.

Developing scoring functions used in SEADS (Figure 1) requires that the user set minimum and maximum allowable values for each criterion. This may be in several ways: expert opinion of a system, historical data, legal regulations, or simulated data. The minimum and maximum values impact how the transformed score is calculated, which can ultimately propagate through the entire decision making process. Scant attention has been paid to the uncertainty introduced into the decision making process resulting from the use of these scoring functions. This project addressed this research gap to identify and then limit the uncertainty that is built into SEADS in the decision making process.

Preliminary Findings

Five alternative land use scenarios for the River Njoro watershed uplands were generated in ArcGIS 9.2 using land cover maps developed by the SUMAWA project and presented in Baldyga et al. (2007) (Table 1). These alternatives were created to broadly assess the relative impact of management decisions and do not necessarily reflect actual land use alternatives for consideration by stakeholders in the region. Current land use is based on a 2003 land cover map developed for the watershed. Alternative 1 represents small-scale agriculture incursions into the upland forest from the southwest based on trends noted since 1995. Alternatives 2 and 4 characterize drastic land use changes to 100% maize and small-scale agriculture and pasture, respectively. Alternative 3 is the current land use, but with contour cropping implemented in small-scale agricultural areas as a soil conservation measure.

Table 1. Descriptions for alternative land use management options tested for this study.

Land Use Alternative	Description
Current	Current land use based on 2003 land cover map (Baldyga et al., 2007).
Alternative 1	Forest incursions into the uplands.
Alternative 2	All small-scale agriculture is converted to 100% maize.
Alternative 3	Current land use with agricultural areas employing contour farming.
Alternative 4	Densely vegetated areas converted to small-scale maize-bean intercropping and pasture.

*Table 2. Alternative rankings for five land use scenarios based on the preference order: 1) Water Yield, 2) Groundwater yield, and 3) Sediment Yield. These rankings change depending on which of the seven methods used to parameterize the scoring functions was selected; * and ** denote equally ranked alternatives.*

Ranking	Method 1	Method 2	Method 3	Method 4	Method 5	Method 6	Method 7
1	Current*	Alternative 4	Current*	Alternative 1	Alternative 3	Alternative 1*	Alternative 2*
2	Alternative 2*	Current*	Alternative 1*	Alternative 2	Current	Alternative 3*	Alternative 3*
3	Alternative 3*	Alternative 3*	Alternative 2*	Current	Alternative 2	Current	Current**
4	Alternative 4*	Alternative 2	Alternative 3*	Alternative 3	Alternative 4	Alternative 2**	Alternative 1**
5	Alternative 1	Alternative 1	Alternative 4	Alternative 4	Alternative 1	Alternative 4**	Alternative 4

SEADS allows users to define each criterion based on four scoring functions, or decision rules, in the form of curves: more is better, more is worse, desirable range, and undesirable range (Figure 1; Yakowitz et al., 1992). Scoring functions normalize quantitative or qualitative raw data for individual decision criteria into dimensionless scores on a 0 to 1 scale, relative to the minimum and maximum allowable values selected for each criterion. By expressing decision variables in this common dimensionless scale, comparisons among variables with varying scales are possible.

For this research, three criteria from the SEADS tool are analyzed: groundwater yield, sediment yield, and water yield. These criteria reflect important issues in the watershed and use default scoring functions in SEADS. All three criteria are SWAT outputs and for the purpose of this analysis are considered on an annual basis. These criteria reflect three separate concerns that have been reported by stakeholders within the River Njoro watershed.

Parameterizing the SEADS scoring functions requires setting minimum and maximum values for the appropriate curve. Aside from legal constraints that define guidelines for setting minimum or maximum allowable values, there are no steadfast rules for how these are set. In this analysis, SWAT outputs are used to set these values. The goal in analyzing the potential impact of uncertainty on SEADS scoring functions was to capture hydrologic model output variation within a typical 20-year land use management window.

Many hydrologic model simulations were run to define the expected range of values using a Monte Carlo simulation method, and researchers used seven different strategies to define the shapes of the scoring functions from these data. All of these scoring functions would be acceptable strategies for the use in SEADS based on decision support literature. If the shape of the scoring function were unimportant, one would expect to see no variability in the rankings of the different alternatives after being passed through the different simulations.

Once the assortment of potential scoring functions were set, the SWAT model was run using the alternative land use options outlined in Table 1. Results from the model were fed into the scoring functions, and the resultant scores were compared with one another. Identical weather characteristics were fed into all model runs to isolate their outputs to reflect the magnitude and direction of change under different land uses independent of weather variability. Table 2 shows how the ranking order changed significantly as a function of the method used to create the scoring functions. This table illustrates that the way in which the scoring functions are set has the potential to significantly alter the selection of a land use alternative for a given objective. Comparing Methods 2 and 4, for example, shows that the relative rankings of all the various land use options were different. In this case, the highest ranked land use alternative for Method 2 became the lowest ranked, while the lowest ranked became the highest. This finding is particularly troublesome because the data that were fed into the scoring functions were exactly the same for each method, with the only change being how the minimum and maximum values for these scoring functions were set.

Practical Implications

Uncertainty in scoring functions used in the SEADS tool was addressed by this research. SEADS allows for analyzing trade-offs between land use alternatives, potential impacts on the natural environment, and differing land management preferences among decision makers. Five alternative land use scenarios were developed, and three decision criteria in SEADS were analyzed: groundwater recharge, water yield, sediment yield. The purpose of this study was to quantify the uncertainty in decision making resulting from the way in which scoring functions are set within the SEADS tool.

Although this study only analyzed five land use alternatives and three criteria ranked using a single preference order, any number of objectives and land use alternatives can be proposed and compared. Given the impact of uncertainty on the total scores presented in this analysis, it is pertinent to consider uncertainty with all scoring functions selected in the SEADS tool, or any similar decision support strategies, to assure that decision makers are being given the best available knowledge.

Further research is currently underway to assess the extent to which the model is sensitive to this parameterization. It is therefore important to understand that models like SEADS are intended to be tools that provide decision makers with an additional layer of information for land use management. Using modeled data must be tempered with rigorous scientific research. In the end, it is the people and not the models that have to make the decisions.

Further Reading

Arnold, J.G. and P.M. Allen. 1996. "Estimating hydrologic budgets for three Illinois watersheds." *Journal of Hydrology* 176: 57-77.

Baldyga, T. 2008. "Spatial Decision Support System: An Integrated Approach to Assessing and Managing Natural Resources." *Research Brief 08-05-SUMAWA*. Global Livestock Collaborative Research Support Program (GL-CRSP), University of California, Davis.

Baldyga, T. and F. Holley. 2008. "The SUMAWA Prototype Spatial Decision Support System and Its Tools: An Overview." *Research Brief 08-03-SUMAWA*. Global Livestock Collaborative Research Support Program (GL-CRSP), University of California, Davis.

Baldyga, T.J., S.N. Miller, K.L. Driese, and C.M. Gichaba. 2007. "Assessing land cover change in Kenya's Mau Forest region using remotely sensed data." *African Journal of Ecology* 46(1): 46-54.

Heilman, P., G. Davis, P. Lawrence, J.L. Hatfield, J. Huddleston. 2002. "The Facilitator: An open source effort to support multi-objective decision making." *Proceedings of the 1st Biennial Meeting of the International Environmental Modelling and Software Society*. 3: 253-258.

Miller, S.N., D.J. Semmens, D.C. Goodrich, M. Hernandez, R.C. Miller, W.G. Kepner, and D.P. Guertin. 2007. "The Automated Geospatial Assessment Tool." *Environmental Modelling and Software* 22:365–367.

Yakowitz, D.S., L.J. Lane, J.J. Stone, P. Heilman, and R. Reddy. 1992a. "A decision support systems for water quality modeling." *Proceedings of the Water Resources Sessions/Water Forum*, August 1992, Baltimore, MD: ASCE Water Resources Planning & Management, 188-193.

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The GL-CRSP Sustainable Management of Rural Watersheds (SUMAWA) project was established in 2003 and is a multidisciplinary research effort focusing on biophysical and human-related factors governing health in the River Njoro watershed in Kenya. The Principal Investigator for SUMAWA is Dr. Patterson Semenye. Email: semenye@sumawa.or.ke.

The Global Livestock CRSP is comprised of multidisciplinary, collaborative projects focused on human nutrition, economic growth, environment and policy related to animal agriculture and linked by a global theme of risk in a changing environment. The program is active in East and West Africa, Central Asia and Latin America.

This publication was made possible through support provided by the Office of Agriculture, Bureau of Economic Growth, Agriculture and Trade, under Grant No. PCE-G-00-98-00036-00 to University of California, Davis. The opinions expressed herein are those of the authors and do not necessarily reflect the views of USAID.

Edited by Franklin Holley & Susan L. Johnson