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Abstract: LENNART is a net-based decision support system (DSS) that has been designed to evaluate the costs of various agronomic measures for reducing leaching of nitrogen from arable land. Both the calculated cost and the reduced leaching in kg ha^{-1} are presented, as well as the cost per kg reduced N leached per hectar. The model can be adjusted by the user to reflect local conditions. The base unit of this model is the field level (hectare). Farms, sub-catchments, catchments or other regions of interest are built up from a field level.

The system (LENNART) has been designed to serve as decision support under several different decision environments. While these uses are not exclusive they give some idea of the flexibility and utility of the model for different types of decision makers. This paper describes how the system may be used for support in three types of decision environments associated with the implementation of agro-environmental policy. The three environments are defined through characterization of the users in that environment. In the problem, defined here, the implementation of measures to reduce the leaching of nitrogen from cultivated land, the users identified are farmers, authorities and researchers. The paper begins with a description of the background to the problem, the next section describes the methodology used to develop the DSS. This is followed by a description of the decision environments, the structure of the model LENNART and ends with conclusions and further development plans for the model.

Keywords: Decision Support Systems (DSS), net-based DSS, agricultural land management, nitrogen leaching, LENNART, BAK, SOILN-DB.

1. INTRODUCTION

Environmental problems such as pollution can be described as arenas where public values take precedence over the activities of private actors. Arenas where in order to achieve the desired social benefits behavior patterns, i.e. decisions, must be altered. Decisions are responses to flows of information and are thus rarely singular or linear but rather as a rule multiple and non-linear. The subject of this paper is how information flows, a decision support system (DSS), can be designed which takes into account multiple decision environments.

The DSS described in this paper, LENNART, is a net-based system designed to evaluate the costs of various agronomic measures for reducing leaching of nitrogen from arable land. The first section of the paper describes the background for development of the model; the contribution of agriculture to the problem of eutrophication and the initiation of agro-environmental policies to redress the problem. The second section describes the systems analysis used in the design of the DSS: problem identification, the development methodology and the decision environments. The following section describes the structure of a DSS designed to serve in multiple environments, LENNART. The paper ends with conclusions and a description of the planned extensions of the prototype model. Throughout the paper, the contribution of Swedish agriculture to eutrophication of the Baltic Sea and the catch crop cultivation program as an abatement measure, are used to illustrate development of the DSS.

2. BACKGROUND

The problem of eutrophication is often considered as one that involves non-point source (NPS) pollution as a primary problem. However, sectorally defined discharge sources that are sufficiently concentrated may be identified and abatement measures suggested which decrease discharge from that particular sectoral source, for example, the contribution of agriculture to surplus levels of nitrogen in catchment basins.

There are three ways that nitrogen is transferred from the agricultural sector; through agricultural end products, and by release to either the air or water. Agronomic practices which contribute to nitrogen leaching/runoff are varied but those which directly contribute (rather than indirectly through atmospheric deposition) to release into water are primarily connected with field cultivation practices. For example, a national study of the US agricultural sector based on survey data from the USDA [Trachtenberg and Ogg, 1994] suggests "that farmers use more fertilizer than necessary because of insufficient crediting for nutrients coming from manure and legumes". Changes in agronomic practices, best management practices (BMPs), have been identified which could substantially reduce the level of nitrogen leaching/runoff [Gustafson et al., 1998] Implementation of BMPs by farmers is generally assumed to be voluntary, encourged by support from extension services or other government programs. However, these programs have not achieved expected results.

An evaluation of the Wisconsin Nonpoint Source Water Pollution Abatement program concluded that "despite the size and sophistication of Wisconsin's NPS program, there is little if any improvement in ambient water quality in these watersheds, probably because of a general lack of adequate participation in the voluntary program" [Wolf, 1995]. In a recent Swedish regional study, Gustafson et al. [1998] conclude that with regard to the lack of participation in voluntary measures "there seems to be an urgent need for an intensive programme for information, education and advisory services to farmers if the goals on water quality set by the government for the Laholm Bay area [Sweden] should be achieved within a reasonable time period. But also implementation of new more effective tools seem to be necessary."

Cultivation practices which can reduce nitrogen leaching have been supported in Sweden through a program of subsidies directed at specific regions. Several measures have been promoted in this way; creation of wetland areas, extensive pasture and buffer zones along watercourses, the use of catch crops, and long term pasture. The original goal of the catch crop program when it was initiated in 1995 was that 39,000 hectares would eventually be signed up with the program. The level of compensation was set at 500 SEK/ha. During 1996, a little over 4,800 acres, representing around 12% of the goal, were included in the program. Due to this low interest the compensation level was almost doubled in 1998 to 900 SEK/ha after a recommendation by the Swedish Ministry of Agriculture. This increase led to a somewhat higher participation rate, an enrollment of 7,900 hectares or about 20% of the target level but the low level of participation led to a new set of recommendations from the Ministry of Agriculture. Participation rules were relaxed with respect to dates for sowing and plowing in the catch crop, in addition, complementary payments could be received for delayed cultivation [SOU, 1999]. While the new rules have led to oversubscription in the program [Swedish Board of Agriculture, 2001] the question of which factors led first to the lower than expected participation rate and then to the greater than expected participation rate have yet to be understood [Collentine, in press].

The policy goal of achieving a 50% reduction in the 1985 rate of nitrogen discharge into the Laholm Bay catchment, will to a great extent be determined by the rate of implementation of BMPs [Shepard, 2000]. The success of agro-environmental policy, and thus the cost effectiveness of these policies, will be enhanced through an understanding of the factors which determine how producers make choices with regard to BMP implementation (i.e. which measures to adopt). If these factors are better understood then information flows may be developed which support the decision of farmers to adopt specific measures as well as support authorities in the design, implementation and evaluation of agro-environmental policy. Researchers have an important role to play in the development of DSSs that can fill both of these needs through exploitation of available technology to support user driven decision environments.

3. SYSTEMS ANALYSIS

3. 1 Problem identification

The problem initially defined for analysis was the lack of enrollment in a voluntary agro-environmental program targeted at the reduction of nitrogen leaching from cultivated land. In particular the Swedish program which offered subsidies for the cultivation of catch crops. The development team analyzing the problem (an economist, a soil scientist and a systems analyst) identified two primary goals of the program; the reduction of nitrogen loads and the effect on farm income of program supported agronomic practices (BMPs). The first step taken after problem identification was to study how information flows to support actors making decisions with respect to these two goals could be incorporated into a DSS. To perform this study the systems analysis methodology described below was used.

3.2 Development methodology

The methodology used by the DSS development team is illustrated in Figure 1. There are two phases in the development process. In the first stage the focus is on the actors that are associated with the problem. In this phase the potential users of a DSS and their task related roles are analyzed. This actor decision analysis in turn is the starting point for the second stage in the development process; the DSS design phase. As can be seen in Figure 1 the flow is linear from identification to design, however, both a non-singular and non-linear approach are incorporated into the development process.

In the identification phase there is a parallel process which follows problem definition. This refers to the parallel development of each actor type associated with the problem. The identification, categorization and workflow description of each actor is followed through on into the design phase. It isn't until the design phase that the model incorporates the need for support in each decision environment into a single model.

During the design phase of development in Figure 1 the model evolves in a non-linear fashion. The structure of the model is developed over this phase following the iterative loop described in Figure 2. Starting with development of a prototype, followed by assessment and then a redesign plan for a new prototype, the loop is repeated until a DSS is determined to be ready for wide based introduction. The decision environments described by the problem are the basis of this user driven development process.

It is very important to use the right method of system development in the construction of decision support systems. Therefore, the development team dedicated a large amount of the analysis period to the formulation of the most appropriate method of model development. The method used is based on among others, discussions and suggestions in Turban and Aronson [2001]. Their methods for DSS construction and strategies for implementation have been adapted to fit the specific problem area of regional water management. In addition, adaptation is supported by: (i) Lam and Swayne [2001], who emphasize that environmental information system must meet the requirement of the user to be successful and common problems in EIS history; (ii) Parker [1999] who points to important factors such as user interface, system updates and user centered design in her review of why DSS within agriculture often have problems with rates of adoption; (iii) McClean et al [1995] in their evaluation of their experience from working with prototyping within the NELUP project. These sources all document valuable experiences which were considered in the methodology used for DSS development. The development methodology described above was chosen to avoid common difficulties arising from development with a model-focus rather than a user-focus.

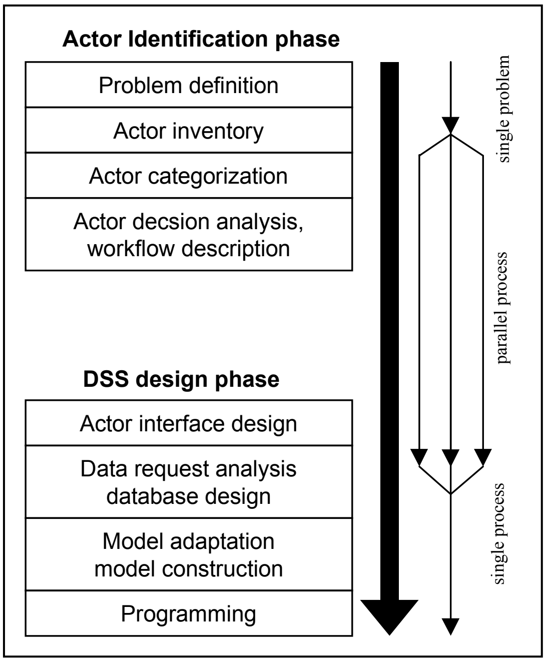

Figure 1. Development phases.

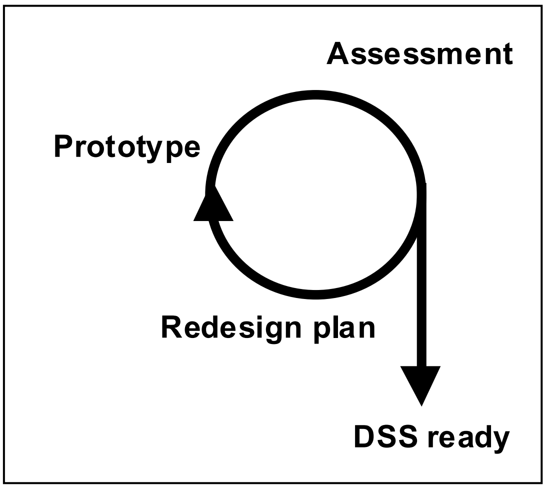

Figure 2. Iterative development loop.

3.3 Decision environments

An inventory of actors involved focused on three groups of actors with an interest in the problem; farmers, regional managers (authorities) and researchers. The primary decision environment is the choice of farmers to enroll or not enroll in the program managed by regional authorities. Information flows in the primary decision environment are generated by researchers in support of the decisions of both types of actors. However, the needs of these actors for information are not the same.

Regional managers need information on a regional scale. They have a need of aggregated information, and have a particular interest in the primary goal of the program, a reduction of leached nitrogen at least cost. Farmers, however, need local site specific information, and have a particular interest in the effect of the program measures on farm income. To determine the effect on farm income, there is a need for access to data on costs, field management and location of the field (see Figure 3 for a list of catch crop cultivation decision factors).

Researchers are relied on to provide information on nitrogen leaching and economic effects at both aggregated and site specific scales. The first two groups need information processed in a way that can be directly used as support in decision making. The third group needs to be able to provide reliable information for this purpose. Initial analysis by the development team pointed to the need for several different DSS, a costly alternative. The question then raised was whether it would be possible to construct a DSS that met several objectives in multiple decision environments. The need for data would be similar, but there was a need to be able to work on different scales and with different goals.

- Field specific qualities; soil type, previous crop, drainage.
- Farm specific qualities; crop rotation, agronomic practices, access to capital, access to information.
- Regional specific qualities; local weather.
- The producer's perception of the costs and benefits of the alternatives.
- The individual risk profile of the producer and sectoral risk.
- The rate of adoption by other producers.

Figure 3. Farm decision factors.

4. LENNART

LENNART is a net-based system designed to evaluate the costs of various agronomic measures for reducing leaching of nitrogen from arable land. Some examples of these types of measures are catch crops, cultivation timing and manure application timing. The model can be adjusted by the user to reflect local conditions. The base unit of this model is the field level (hectare). Farms, sub-catchments, catchments or other regions of interest are built up from a field level.

The model is built on a relational database that is located on a web-server. Access to the system is performed via normal Internet browsers using plain HTML-code. The HTML-code is dynamically generated through server-side scripts. Both the system and sub-models of LENNART are maintained inside these scripts. When using the system the user sends a request to the web-server which processes the request and sends the result back as an HTML-page to the browser of the user.

On the server, LENNART computes the economic costs for adopting catch crops on each field and generates the resulting nitrogen loss reduction on that particular field. The economic model driving these cost estimations does not need any substantial amount of computational power. Therefore, the model is able to be run directly on the server when the user sends her request. Model responses are produced within seconds. This short response time is, however, not the case for calculation of nitrogen reduction.

The basis for calulation of reductions in leaching losses of nitrogen is the physically based SOILN-DB model, [Johnsson et al, 2002]. Since rather extended demands are placed on the amount of data needed to run the model, the development team decided that these demands would be too cumbersome for for LENNART. Instead, an extensive number of standardized runs were stored in a separate database. Nitrogen leaching for different soils, crop combinations and areas (climates) are kept in the database. Thereby nitrogen leaching data can be sent back to the LENNART user within seconds.

There are three primary factors which led to the choice of a server based web site accessed through the internet for LENNART; access factors, development factors and data base factors. A server based program promotes access for a wide group of intended users. The site can be accessed by multiple users from individual computers, with the only personal computer software requirement being a standard web navigating program (Netscape or Explorer). Enabling access to the program through individual computer connections also allows the program to be demonstrated in a variety of environments. Farm advisers can demonstrate use of the program in consultations with farmers during farm visits. The program can also be demonstrated and used by groups in seminars. In addition to being used pedagogically, the web site address can also be linked to other sites or promoted through campaigns in other media as well as passed on from user to user.

Development of the model can be continuous over time as control over the version being used is determined through the server. This quality also means that no problems arise with versions being used which are out of date. Each time a user logs on, the version which becomes available is determined through commands on the server. This also allows for partitioning over time to test development of model components, part of the iterative development loop depicted in Figure 2. For example, inclusion of a wizard format or tutorial can be tested by incorporating that component into the model made available to users on the server over for a specific period of time or a specified number of runs. Results from this partitioned model can be compared and choices made by model developers with respect to incorporation or development of the most favorable components.

The net-based format also allows for incorporation of changes in development of the independent natural science process based sub-model, SOILN-DB. The server platform of LENNART allows changes to be made in the user available model as soon as new information becomes available which affects the results of the sub-model. The entire model doesn't need to be replaced, only those changes which are made to the model. This ensures that LENNART is able to make use of the best information available.

The location of the model on a server also means that the data base which is developed as the model is used, is also located in one place and can be accessed from anywhere by designated users. As new data becomes available, i.e. every time the model is used, this data is directly available on the server. The immediacy of availability supports both users that are interested in comparative data and users that are interested in aggregate data for policy evaluation and design. Figure 4 illustrates one of the comparative summary pages in the second prototype of LENNART. This page compares the farm user's inputed cost estimates with the cost estimates used by the Swedish Agicultural Board for calculating the effect of cultivation of catch crops.

It is also possible to use partitioning with respect to the database. Open access to the entire database through the Internet makes it possible for those users that are interested in the model to actively work with the database for this purpose. User behavior data are stored in the database together with submitted data to the system. These data are easily analyzed by regional managers and researchers. Figure 5 reproduces a diagram of LENNART user estimates of labor costs per hour. Statistical analysis of this kind of data is of interest for policy analysis and program evaluation.

The technical platform for LENNART is a Windows environment using an Access 2000 database, Active Server Pages (ASP) with server-side Visual Basic Script and a few client-side Java Scripts. The second prototype of the model (in Swedish) is available in the public domain at: http://neptunus.md.slu.se/VASTRA/BAK/index.html.

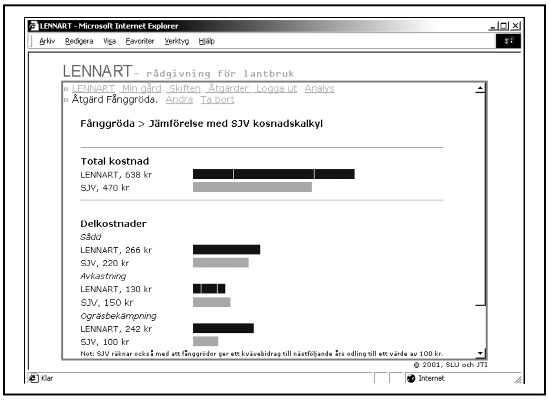

Figure 4. Comparative summary page in LENNART for farm users (in Swedish).

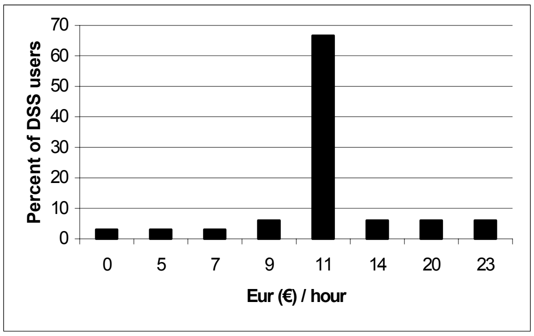

Figure 5. Farm user estimation of labor cost per hour based on data from test-runs of LENNART.

5. CONCLUSIONS AND FURTHER DEVELOPMENT

"Making adequate decisions over long time periods in a changing environment and subject to incomplete information, misinformation, uncertainty, and changing preferences is one of the central and most sophisticated human activities.", Rademacher [1994] quoted in Parker [1999].

The design and construction of a DSS involves making many hard decisions. One of the most difficult decisions to make is to find the right level for weighing demand of data by modellers against users' interest in quick and easy to use systems. Another one is determining the right moment to stop development of a prototype and to begin construction of a new one, a cycle of the iterative development loop. The flexibility designed into LENNART, particularly the server based platform, make both of these decisions a bit easier.

LENNART, as presented in this paper, represents the second prototype. Each round in the system development cycle has taken approximately one year. The key to further development is continued testing and evaluation. After positive response from the Swedish Board of Agriculture at a demonstration of the model, in the near future test evalutation will be made possible through a link on the department web site. Other planned development of LENNART includes construction of user help-systems, an on-line tutorial for first time users, directed user tests and extensions for the evaluation of additional measures.

6. ACKNOWLEDGEMENTS

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