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A spatial decision support system for the analysis of environmental impacts of integrated crop-livestock production system

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A spatial decision support system for the analysis of environmental impacts of integrated crop-livestock production system

by

Dharmesh Kumar Jain

A Dissertation Submitted to the Graduate Faculty in Partial Fulfillment of the Requirements for the Degree of DOCTOR OF PHILOSOPHY

Department: Agricultural and Biosystems Engineering
Major: Agricultural Engineering (Soil and Water Resources)

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1995

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GENERAL INTRODUCTION

Livestock production in Iowa is an important economic component for many rural communities, and is gradually emerging as a value-added industry. In 1992, Iowa leads the nation in total number of hogs on farm, hogs produced for market, and hogs slaughtered. Iowa also ranked third in cattle and calves on land, ranked eight in total number of dairy cows and milk production, and was seventh in poultry production (USDA, 1993). The total hogs and pigs on land in 1993 totaled 14.6 million, or 26% of the Nation's hog population in the United States. Revenue from livestock and dairy operations for 1992 was estimated at 58.3% of the total cash receipt for all farm products. Cash receipt from hog marketing was $2.82 billion. More than 24.4 percent of the nation's pork supply and 8.2% of the grain-fed cattle are marketed from Iowa farms (Iowa Agricultural Statistics, 1994).

The Iowa hog population of about 14 million heads generates an estimated 15 to 18 million metric tons of manure annually. This manure contains about 250.8 million lb of nitrogen, 74.8 to 88 million lb of phosphorus, and 149.6 to 176 million lb of potassium (Midwest Plan Service, 1976). When properly applied to the cropland, the manure generated from livestock is sufficient to supply about one-fourth of Iowa's crop nutrient needs. However, improper utilization of animal manure can cause environmental pollution, thereby raising concerns for water quality and public health.
Growing awareness and concern about the relationship between livestock production and environmental quality have focused attention on developing and implementing sustainable agricultural production systems through development of farming systems that are productive and profitable, conserve the natural resource base, and protect the natural environment. In spite of this, agricultural practices, including crop and animal production, continue to be cited as the major source of nonpoint pollution (Shuler, 1979). The excessive application of synthetic chemicals and the inefficient handling, storage, and utilization of animal manure can cause serious environmental damage (Jansson, 1983). Given these water quality concerns, an integrated crop-livestock system that minimizes environmental pollution and maximizes the utilization of nutrients is needed. However, very little research has been undertaken to examine the scale of the technology and the optimal level of crop-livestock production that are consistent with expected environmental protection goals. Integration of crop and livestock production systems and the development of sustainable production system involve critical decision making by farmers and farm managers as well as resource managers and planners. The overall goal of this research is to develop a prototype decision support system to facilitate analysis management of environmental pollution problems associated with integrated crop-livestock production.
Objectives

As stated earlier, the major goal of this research is to develop a spatial decision support system to facilitate analysis of environmental pollution problems (e.g., water quality degradation) associated with integrated crop-livestock production. The specific objectives of the research are:

1. Determine inputs and outputs (material balance) of nutrient in a typical integrated crop-livestock production unit at several spatial scales.

2. Delineate, using spatial analysis techniques of geographic information system, optimal land areas of a watershed for siting livestock production systems and for land application of manure, given landscape and environmental protection constraints.

3. Evaluate the impacts of alternative manure management practices in crop-livestock production on groundwater quality.

4. Examine the surface water pollution potentials of integrated crop-livestock production practices through the use of an interactive biophysical modeling environment.
A Review of Literature

This section will elaborate on the stated objectives, reviewing pertinent literature and reporting related past research findings. The general intent of the literature review is to summarize relevant previous studies and findings, and to discuss theories, concepts and computer models that will be used in achieving the research objectives.

Stenhouse and Narayanan (1984) reported a significant increase in Canadian Agriculture's reliance on non-farm sources of plant nutrients, and there has been an attendant decline in the use of and value placed on livestock manures. One of the various explanations for this increasing trend is the present status of manure as imprecise means of supplying plant nutrients. Also, land application of manure is often perceived as potentially damaging to the environment as in the case of soil and water pollution and odor nuisance.

There is, however, an important role to be played by livestock manure on integrated livestock-crop farms or on specialized cropping operations adjacent to intensive livestock farms that have surplus manure for off-farm disposal. Ngambeki et al. (1992) observed that farmers in semi-arid zone of West Africa were slow to integrate crops with livestock and to utilize intermediate farm products of crop residues, draft power, and animal manure to tackle production constraints. They used a linear programming model to demonstrate that, apart from the adoption of cropping techniques and by integrating crops with livestock, farmers can make more efficient use of their
marginal land with less chemical fertilizers, thereby substantially improving their
economic gains and achieving a more sustainable agricultural production.

Pearson and Levin (1992) found that an increasing number of farmers are, for
economic and environmental reasons, using animal manure more efficiently on their
farms. Their study was conducted to determine the options available to a farmer who is
interested in eliminating off-farm nitrogen sources and using only on-farm manure.
Fertilizer, crop residue, and animal manure are three possible sources of nutrients for
plant growth. Fertilizer is a purchased input, while crop residue and animal manure are
two potential source of crop nutrient produced locally. From crop nutrient requirements
for the area under cultivation coupled with nutrients supplied from local products, the
total nutrients derived from off-farm sources (fertilizer) were estimated. A negative
supply indicated a surplus of nutrient and self sufficiency in meeting crop nutrient
requirement of a respective production technology.

Except when considered on a global scale, the nutrient cycle is generally not
closed; that is, there are inputs and losses from regional, farm, or field level. Nitrogen is
described as the most perplexing of all the nutrients. It moves through a variety of
pathways both biological and chemical; has several oxidation states; and can exist in
various forms such as a dissolved cation or anion, and precipitated salt. Nitrogen has
negative environmental consequences on surface and groundwater and on the quality of
air.
A given amount of animal wastes spread on land can have different impact on water quality depending on a number of factors such as soil, topography, climate, hydrogeology, proximity to roads, and nearness to surface water bodies. Some of these parameters, which are spatial in nature, can be efficiently handled by a GIS. GIS-assisted site selection narrows down the large areas under consideration to a set of optimal sites that meet several criteria. This approach to selecting optimal animal production sites takes care of spatial attributes which alone can make a site highly vulnerable to both surface and groundwater pollution.

Hamlett et al. (1990) reviewed the use of GIS in assessing various resource-related activities. These activities occur at various scales, ranging from analysis of multiple benefits of the 1985 Farm Bill at the national level (Maizel, 1990) to detailed county-specific assessment of conservation programs (Shanholtz et al., 1990). Other GIS applications in resources management have been undertaken, as evidenced by programs such as the development of a natural resource database (RIGIS) in Rhode Island (Baker and Panciera, 1990), the management of agriculture and urban development in Hawaii (Khan and Liang, 1990), and the regional mapping of groundwater contamination in northeastern U.S. (Bleecker et al., 1990). In a typical application discussed by Hamlett et al. (1990), the GIS was used to rank the nonpoint pollution potentials of watersheds in Pennsylvania on the basis of data on animal population and landscape. The distributions of different types of animals within the 104 watersheds considered in the study were calculated and appropriate nutrient loading
functions for each animal type were developed. The nitrogen and phosphorus production from the livestock per acre of cropland and pasture were determined for each watershed and stored as a separate GIS data layer. These data layers were coupled with simplified pollution models to determine the pollution potential, and hence, the ranking of each watershed.

Wolfe et al. (1990) used a GIS to determined locations of dairies as well as areas for agricultural waste disposal. Locating optimal sites for dairies required the consideration of many factors that are spatially distributed across the landscape, including topography, soil, geology, and wind characteristics. The results of this study indicated that, with appropriate data, GIS can form the basis for a decision support system dairy waste management.

Hendrix et al. (1992) utilized a GIS to delineate environmentally-sound sites for the land application of municipal wastes. Land suitability for several waste treatment techniques was evaluated using factors representing soils, topography, and land use, which were integrated with information about the biological, chemical, and physical properties of the waste. Results of the analysis were combined with a set of factors that reflect the social and political constraints of applying wastes on land.

Younos et al. (1989) developed a site selection system to identify potential land parcels for application of sludge from a wastewater treatment facility using the Virginia Geographic Information System (VirGIS) database (Shanholtz et al., 1986). The procedure for site selection was based on sludge management recommendations of the
U.S. Environmental Protection Agency and on factors such as land use, soil type, topography, and proximity to surface water bodies. The study concluded that, if a spatial database exists, GIS appears to be a flexible and cost-effective tool for selection of sites for land application of wastes.

Mathematical modeling of nutrient flows in the environment is useful for the selection and optimum design of management strategies. For example, incorporating manure into the soil might be selected over surface spreading if the probability of exceeding a given water quality standard was smaller for the former practice than the latter. Models do not only simulate the mechanism of a well-defined process but also incorporate the effects of alternative nutrient and different levels of land management practices on environmental quality. In particular, a model can simulate the effect of methods and rates of manure application, tillage practices, and manure handling.

Modeling of plant nutrient flows to, from, and within an integrated crop-livestock farm forms the basis of understanding the spatial and temporal dynamics of farm practices and the consequences of farm management decisions. Numerous models have been developed to simulate nutrient dynamics in agricultural systems. These models provide the framework for interpreting results from several experiments and for integrating basic knowledge of biophysical processes at appropriate scales and field conditions. Some of these models are not easy to use and were not developed to examine intricacies and spatial dynamics of integrated crop-livestock farms. It is, therefore, incumbent that nutrient management models incorporate the interrelated
processes at both the whole-farm and watershed level, be easy to use, and assist planners and farm manager in understanding the effectiveness of nutrient management strategies. It is the purpose of this research to provide a tool by which resource managers can utilize to evaluate the effectiveness of and plan nutrient (manure and fertilizer) management practices in an agricultural watershed.

Several mathematical models, including NTRM (Shaffer et al., 1987), SOILN (Johnsson et al., 1987), NLEAP (Shaffer et al., 1990), and LEACHN (Hutson et al., 1991) have been developed to evaluate nutrient dynamics in agricultural soils. In a nitrogen model developed by Johnsson et al. (1987), respiration, manure and fertilizer utilization, harvesting, and deposition were included as major processes that determine inputs, transformation, and outputs of nitrogen. Inputs of nitrogen to the soil can be in the form of commercial fertilizer and manure or atmospheric inputs from rainfall. Output can include losses from runoff, harvest, leaching, and denitrification. An agricultural nitrogen mass balance model described by Messer et al. (1983) uses two submodels: an animal industries submodel to estimate livestock and feed fluxes, and a plant industries submodel to account for fluxes of citrus, vegetables, field crops, and timber products. Inputs for livestock industries submodel include feed, breeding stock, and meat products, while outputs include animal and meat exports, manure and urine, and in-state consumption.

Decision support system that integrate knowledgesystems, GIS, and mathematical models have been used to examine ill-posed problems associated with
environmental pollution. The need for a decision support system (DSS) arises from the fact that not all the problems are either tractable or can be transformed into mathematical models using traditional algorithms. In such cases, a solution methodology that involves heuristics and rules can be employed. Consequently, knowledge-based systems, a branch of Artificial Intelligence (AI) technology, have been employed as a problem solving paradigm for many management problems. Knowledge-based systems are intelligent computer programs which uses knowledge and inference procedures to solve ill-structured or ill-posed problems (Stone et al., 1986).

Lam et al. (1993) described an expert or knowledge-based system approach as the storage, retrieval and manipulation of knowledge. Such a system includes GIS maps, numerical data from models, expert rules, regulatory guidelines, model choices, parameter selection, logical algorithms, statistical methods, and other forms of information. With the advent of computers (microcomputers and workstations), information technologies now exist that can store, retrieve and manipulate various forms of knowledge under a single intelligent system. The intelligent interface can consist of logical units, or so-called inference engines (Lam and Swayne, 1993), as well as menus that enable one form of knowledge (e.g. GIS) to interact with another (e.g. model parameter selection). For example, Lam et al. (1993) developed RAISON or Regional Analysis by Intelligent Systems ON microcomputers, that incorporates GIS, an expert system, and models of water quality (Lam and Swayne, 1993).
Several different types of knowledge-based systems that incorporate GIS, heuristics of expert systems, databases, and biophysical models have been developed to facilitate environmental management. He et al. (1992) incorporated GIS database and expert systems for modeling impacts of spatially variable fertilizer application rate. A qualitative physical land evaluation system (ALES) was used by Lanen et al. (1992) to explore the possibilities for slurry injection. Expert knowledge was captured into the ALES and successfully linked to a GIS in which a small-scale soil map was stored. Decision trees to assess physical suitability for slurry injection were within ALES. The combined use of computer-captured knowledge and GIS proved very useful in preliminary exploration of several land use options. Other knowledge-based systems developed for agricultural management, include COMAX/GOSSYM (Lemmon, 1986), CALEX (Plant, 1989), SMARTSOY (Batchelor et al., 1989), and EWEES (Cumby et al., 1992). The COMAX knowledge-based provides expert advice on when to irrigate and fertilize a field to achieve optimal crop yield goals. CALEX is an another integrated cotton expert system that assists farmers in crop production decisions, while SMARTSOY is a prototype expert simulation system that combines crop growth model with expertise on insect damage to evaluate the effects of multiple insect population damage on soybean yield. EWEES or European Waste Engineering Expert System was developed for waste management in animal production systems.
Dissertation Organization

The dissertation contains four papers which represent the four specific objectives mentioned earlier. Each paper was written by the author in a format suitable for publication in refereed journals. The first paper entitled "Evaluating Nutrient Balances in Crop-Livestock Production" will be submitted to the American Journal of Alternative Agriculture. The second paper was published recently in the Journal of Computers, Environment, and Urban Systems, volume 19 (issue 1), page 57-75, under the title "Spatial Decision Support System for Planning Sustainable Livestock Production" (Jain, D.K., U.S. Tim, and R. Jolly). The third paper entitled "Spatial Decision Support System for Livestock Production Planning and Environmental Management" has also been accepted for publication in the Journal of Applied Engineering in Agriculture. The fourth paper which represents the fourth objective has the title "Evaluating Impacts Of Crop-Livestock Production On Surface Water Quality" is written for submission to the International Journal of GIS. Each paper contains an abstract, introduction, background, material and methods, results and discussion, conclusions, and references. A general conclusion of the study follows these papers.
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EVALUATING NUTRIENT BALANCES IN CROP-LIVESTOCK PRODUCTION

A paper to be submitted to the American Journal of Alternative Agriculture

Jain, D.K. and U.S. Tim

ABSTRACT

Sustainable agriculture requires an holistic approach to farm resources management coupled with comprehensive assessment of nutrient balances at the field, farm, watershed, and regional scales. A nutrient balance gives a good estimate of the difference between nutrient input and nutrient output. A nutrient imbalance is a potential source of loss of environmental degradation, particularly surface and groundwater contamination. This paper presents a typical assessment of nutrient balance in integrated crop-livestock production systems at the state and county levels. The study indicates that a reduction in fertilizer inputs can be easily met by utilizing nutrient value of animal manure, thus providing a safe disposal of manure and substantial economic gains.
INTRODUCTION

Crop and livestock production are important components of Iowa economy. Swine production, for example, generates about $2 to $3 billion annually to Iowa's agricultural revenue and employs about 4% of the work force (Kliebenstein and Ryan, 1991). In a recent review of the role of animal production in sustainable agriculture, Duffy (1992) stated that animals add to the income stream, provide crop fertilizer through manure, and help add diversification. On the role of swine production in sustainable agriculture, Honeyman (1991) reported that swine are versatile enough to adapt to sustainable concepts, and swine production provides several opportunities to enhance economic development. However, the expansion of livestock production requires exploitation of land resources, and inevitably can lead to potentially serious environmental quality problems. Under these circumstances, animal production integrated with cropping systems can play a significant role in sustainable agriculture.

Historically, organic manure from animal production has been important for maintaining soil fertility and improving soil microbial activity. However, in recent decades, because of availability of cheap inorganic fertilizers, farmers have considered animal manure as "waste". Increased intensification of livestock production has encouraged farmers to regard application of organic manure as a disposal process. Consequently, large quantities have been applied to limited land areas without proper consideration of their nutrient value and the potential pollution hazards.
Estimates of animal production on farms across Iowa suggest a total annual output of about 20 million tons, based on 1992 Agricultural Census data. The plant-available nitrogen (N) of these manure has a potential annual value of about $38 million, based on a fertilizer price of $0.15 per lb nitrogen. However, utilization of manure on cropland is poor because management practices lead to nitrate leaching, runoff losses, ammonia volatilization, and denitrification losses.

In addition to poor management of nutrients on farms, recent statistics by Duffy and Thompson (1991) suggest that farmer's perception of nutrient value of animal manure is also poor. In a survey of Iowa farms with livestock, only 49% of the farmers reported taking credit for manure applied to their fields. In general, the survey showed that farmers make small and inconsistent decreases in inorganic fertilizers following application of animal manure. Even a modest improvement in allowances for nutrient supplied from manure could result in major saving in fertilizer costs without loss of yields and with less environmental pollution. Because of this, characterizing nutrient balances--inputs and output--at the state and county level can provide information necessary to plan sustainable agricultural production systems, where crops and livestock are major components. Furthermore, the evaluation of nutrient flows to, from, and within crop-livestock farms forms the basis for understanding the spatial and temporal dynamics of farms practices and for assessing the consequences of nutrient management decisions on air, soil, and water quality.
This paper assesses the nutrient balance in an integrated crop-livestock production at various spatial scales. Nutrient balance at state and county scales were performed on the basis of nutrient requirement by crops, nutrient availability, plant uptake, and nutrient losses through a number of pathways. Emphasis is placed on nitrogen and phosphorus cycling, because deficiencies or surpluses of these two elements are important from the water quality perspective. Both of these elements have been associated with eutrophication of surface water.

**SOURCES AND CYCLING OF NUTRIENTS IN CROP-LIVESTOCK FARMS**

Pearson and Levin (1992) found that an increasing number of farmers are, for economic and environmental reasons, using livestock manure more efficiently on their farms. Their study was conducted to determine the options available to a farmer who wants to eliminate off-farm N sources and use only on-farm manure. Fertilizer, crop residue, and animal manure are three possible sources of nutrients for plant growth. Fertilizer is a purchased input, while crop residue and animal manure are two potential sources of crop nutrient produced locally. Young et al. (1992) evaluated manure nutrient production versus cropland and crops available for recycling the nutrients in Millcreek Township, Lebanon County, Pennsylvania. Development of such a procedure for evaluating animal manure was important for another reason too. As nutrient management plans were developed it became apparent that many animal farms
had inadequate land available under their ownership for environmentally-sound manure recycling through crops. A nutrient balance provides a good estimate of the differences between nutrient inputs and outputs. The difference between these inputs and outputs may be a potential indicator of environmental losses (Korevaar, 1992).

Figure 1 describes the various components of an integrated crop-livestock production system and the cycling of nutrients among different pools in the system. There are also significant losses of these nutrients through various pathways including runoff, leaching, volatilization, and denitrification. A brief discussion of the various on-and off-farm sources of nutrients is presented in the following section.

**On-Farm Sources Of Nutrients**

Animal manure is a major source of organic matter and plant nutrients. Incorporating animal manure into soil not only adds valuable plant nutrients but also provide better soil structure. The nutrient content of the manure depends on the type of animal, animal age, and production level of animal (Meisinger and Randall, 1991). The availability of manure nitrogen to plant depends upon the form of nutrient is present in manure. For example, nitrogen in manure is usually found in three forms: (a) inorganic nitrogen, which is rapidly mineralizable nitrogen; (b) easily decomposable organic nitrogen compounds with a low carbon-to-nitrogen ratio; and (c) resistant and slowly mineralizable organic matter with a high carbon-to-nitrogen ratio. Effectiveness of nitrogen from manure depends on the time of application (autumn or spring) and
method of application. For spring application the effectiveness of nitrogen for the whole growing season is estimated at between 30 and 60%.

Most of the phosphorus in manure is in inorganic form. Phosphorus has very low mobility in soil. Any excess of phosphorus beyond the crop need will remain attached to the soil and available for surface movement with sediment. Potassium is another nutrient present in manure and required by plants. In contrast to nitrogen, potassium in animal manure is freely available to crops and excessive application rates will increase uptake causing a possible nutrient imbalance.

Symbiotic fixation of nitrogen, a process of converting atmospheric nitrogen sources into plant nitrogen by symbiotic bacteria living in root nodules of certain plants, also contributes to on-farm nitrogen inputs. A recent regional assessment of the nitrogen input in the U.S. corn belt indicated that over $1 \times 10^6$ million tons of nitrogen enter the soil annually through symbiotic fixation of nitrogen (Peterson and Russelle, 1991). The amount of symbiotically-fixed nitrogen, however, is influenced by both genetic and environmental factors, including the type of crop grown, available soil nitrogen, crop management, available soil water, and bacteriological and chemical characteristics of the soil medium (Leggs and Meisinger, 1982; Philips and Dejong, 1984; Heichel and Barnes, 1984).

The nitrogen in irrigation water contributes to on-farm nitrogen for plants. The nitrogen added in irrigation water can vary greatly from site to site with ranges of 9 to 130 lb/acre (or 10-145 kg of N/ha) being quite common (Legg and Meinsinger, 1982).
Irrigation inputs of nitrogen can be calculated by using the quantity of water applied and the concentration of nitrogen in the applied water. Rainfall also adds nitrogen to the soil. Nitrogen primarily from precipitation inputs can be calculated in the same way as irrigation inputs by multiplying the average annual precipitation amount by the total nitrogen concentration (NO₃ plus NH₄ plus organic N in ppm) in the rainfall. Here, total rainfall amount can be estimated from state and regional maps or databases, while the concentration of nitrogen in the rainfall can be estimated from regional maps and can vary between 1 and 4 mg/L, with 2 to 3 mg/L being a common range. In many areas of the U.S., precipitation contributes about 2 to 13 lb/acre of nitrogen annually, although somewhat higher values of between 9 and 18 lb/acre of nitrogen have also been reported (Brezonic, 1976).

Dry deposition in terms of absorption of nitrogen from the atmosphere as ammonia and other similar compounds is another potential source of nitrogen input to the soil. Some studies have found dry deposition to be comparable to rainfall inputs of nitrogen, while others have considered them of minor significance. Due to lack of information, dry deposition of nitrogen has been estimated to be roughly equal to the value for wet depositions. Schepers et al. (1991), for example, gave an approximate annual range of 2-13 lb/acre nitrogen.

Annual addition of nitrogen through non-symbiotic fixation is generally less than 15 lb/acre, and is influenced by range of environmental factors. Free-living bacteria in the soil are main promoters for the non-symbiotic fixation of nitrogen. High levels of
nitrogen fixation require an abundant supply of readily available organic matter, high soil moisture level, low soil nitrogen levels, near-neutral pH, and adequate supply of phosphorus (Stevenson, 1982). Non-symbiotic nitrogen fixation are generally higher in the region of low intensity like forests, grassland, or non fertilized cropland where nitrogen fixation ranges from 30 to 70 lb/acre (34 to 78 kg/ha). However, in modern agriculture with medium to high supply of nitrogen, nonsymbiotic fixation is restricted, and ranges as low as 2 to 6 lb of N/acre per year.

**Off-Farm Sources Of Nutrient**

Nitrogen is the leading fertilizer nutrient applied to agricultural lands, with an estimated $1 \times 10^6$ tons applied in the U.S. in 1984 (Hargett and Berry, 1985). Fertilizer needs are primarily based on crop removal rates and yield goals. Therefore, given the crop nutrient requirement and yield goals, the total nutrient supply from off-farm source (fertilizer) can be estimated. In nitrogen application to crops, the primary goal is to apply just the right amount that meets crop needs. To do otherwise may enhance the potential for nitrate leaching and phosphorus build-up in the soil. In general nitrogen losses in soil can be minimized by judicious application of commercial fertilizer materials.

Nitrogen additions through seed is another potential secondary input source of on-farm nutrients. The amount added, however, is generally negligible and depends upon the type of crop grown. For example, for corn a seed application rate of 20 lb/acre
would add less than 0.3 lb/acre. Similar calculations for soybeans, wheat, and potato
yield addition of nitrogen of 4 lb/acre, 1.6 lb/acre, and 5 to 10 lb/acre, respectively.

ENVIRONMENTAL ISSUES IN INTEGRATING CROP AND LIVESTOCK
PRODUCTION SYSTEM

Potential environmental pollution problems resulting from integrating crop with
livestock production system can be grouped into following three major impact areas:

Surface Water Pollution

Nutrients, especially nitrates, have entered surface and ground water in some
areas. The major macro-nutrients removed from fields as runoff carried waste material
are nitrogen and phosphorus: the basic elemental nutrients needed to sustain aquatic life.
Nitrogen, in the form of ammonia and nitrate, is the major form of nitrogen nutrient
available to eutrophic organisms. Organic nitrogen becomes available only after
conversion to inorganic forms by bacterial action.

Various forms of inorganic phosphorus are also implicated as contributors to
eutrophication. Phosphates, and to a lesser extent nitrogen, can cause excessive growth
of aquatic plants in rivers and lakes. This can reduce water clarity. The water body can
actually shrink in size as shoreline areas accumulate live and decaying plants. As these
plants die and decompose, oxygen is consumed. This can cause serious decline in the
dissolved oxygen levels in a lake or in slow-moving areas in a river. Fish kills or
changes in aquatic species may occur. The concentration of inorganic phosphorus that will produce problems varies from: below 0.005 mg/l is a nutrient deficient region; between 0.005 and 0.02 mg/l is a region of potential algae bloom; and above 0.1 mg/l as phosphorus, is an excessively enriched region.

In addition to excess of nutrient application, loss of nutrient from land application and from animal feedlot reaching the surface water is also dependent on spatial factors such as topography, location of feedlot and field with respect to water course, feedlot size, and soil type and structure. Butchbaker et al. (1971) has described these factors in relation to beef cattle feedlot design, and waste management.

**Groundwater Pollution**

The goal of any nutrient management plan must include minimizing nitrate leaching from agricultural activities into groundwater. Nitrate, is a highly mobile nitrogen form that can be leached through the crop root zone. Management of nitrogen to minimize nitrate losses in farming is based on a simple concept of nutrient budgeting. Ideally all sources of plant-available nitrogen should be taken into account to calculate available nutrients and to make an estimation for net nutrient supply just sufficient to maximize crop yield.

Groundwater pollution in an integrated crop-livestock production system is affected primarily by the feedlot's design and by the waste management practices used. Waste management practices that are major sources of groundwater pollution are heavy
land application of animal wastes and the improper method of application. Proper selection of site with impervious soils, low groundwater table and low drainage soils is the most essential step in designing a feedlot so as to prevent groundwater pollution.

**Air Pollution**

The atmosphere has long been used as a sink for waste disposal by many industrial and agricultural processes. Of the agricultural processes, large livestock operations are among the greatest air polluters. They seriously alter the quality of the air in the immediate surroundings. Main indicator of air pollution associated with feedlot operations are odor and suspended matter. Odor pollution, though less directly harmful to health than other environmental annoyances, can seriously affect mental attitudes and adversely influence ability to work effectively and to relax comfortably. Because of the odor problems, numerous lawsuits have been filed against livestock producers (Hamilton, 1992). Location of livestock units, and manure application sites are causes of odor nuisances.

**EXAMPLE CALCULATION OF NUTRIENT CYCLING**

Nutrient cycling and balances were calculated for crop and livestock farms in the entire state of Iowa and for Adams county, Iowa. Nutrient balances were performed on the basis of different types of crops grown (e.g., corn, soybean, wheat, oats, and alfalfa)
and livestock species (e.g., hogs, beef cattle, dairy). The primary inputs of nitrogen considered were fertilizer, manure, symbiotic nitrogen fixation, and atmospheric deposition. Other minor inputs were not considered due to their small contribution to the overall nutrient balance. It was also assumed that crop residues are incorporated into soil and all manures were assumed to be spring applied, and the nitrogen, phosphorus, and potassium credits are taken into account in calculating crop nutrient requirements. The amount of manure nutrient available for application was that obtained from livestock farms less losses due to runoff and leaching. If manure nutrients available for application were found to be lower than the amount required for corn, wheat, and oats production, then the deficit was assumed to be supplied by commercial fertilizer. Soybean and alfalfa crops were assumed to received no fertilizer or manure nutrient. The results of the nutrient cycling or nutrient balances are summarized at the state and county levels.

State-Level Analysis

A simplified nitrogen budgeting was devised given the agricultural activities in Iowa. To accomplish this, nutrient input and output data available from Iowa Agricultural Statistics were used in this analysis (Facts of Agriculture, 1994). Figure 2 shows an example distribution of hog by county in 1992 as used in the analysis.

In performing statewide nutrient balances for state, it was assumed that all cropping enterprise are integrated with some form of livestock production unit. Given
the hog, beef, and milk cow population of $1.49 \times 10^6$, $1.12 \times 10^6$, and $0.3 \times 10^6$ heads, respectively, and the total corn and soybean yield of 147 and 44 bushels/acre respectively, a deficit of 68.64% of nitrogen and 82.19% of phosphorous was determined. Two major sources of nitrogen losses—leaching and losses during land application, were taken into account while performing the nutrient balance. The detailed results of the analysis are tabulated in Tables 1a through 1e. Aggregating the use of fertilizer and availability of crop nutrient from animal manure at the state level eliminates those areas with input/output imbalance.

**County-Level Analysis**

Analysis of nutrient cycling in integrated crop-livestock production system was performed using crop and livestock data for Adams County of southern Iowa. Adams county was chosen primarily because it has large acreage of crops and concentrated livestock production enterprises, a large value of agricultural output, and a history of environmental problems in most of major watershed. Hog population, based on inventory, in this county for the year 1993 totals to 51,000 head. Total yields of corn, soybean, oats, and wheat crops are reported as $9 \times 10^6$, $1.9 \times 10^6$, $0.31 \times 10^6$, and $0.02 \times 10^6$ lbs, respectively. Based on these values, a 67.67% deficit in nitrogen requirement and 82.31% deficit in phosphorus requirement was estimated (Tables 2a through 2e).
SUMMARY AND CONCLUSION

Growing awareness and concern about the linkages between crop and livestock production systems and degradation of the environment have focused attention on the modification of agricultural systems to enhance productive efficiency, and economic and environmental sustainability. Recently, livestock production units in Iowa have increased in size and production has become more confined, concentrated and intense. This increase has significantly altered the complimentary relationship between crop and livestock production in which the grain and roughage produced on land went back into livestock product and the manure from livestock went back on the land.

In this study, a simplified nutrient balance analysis was performed at state and county level. On the county level, 32.33%, 17.69%, and 6.47% of nitrogen, phosphorus, and potassium, respectively, was recovered as plant available nutrients from livestock units integrated with crop farms. Similar results for state level were 31.36%, 17.88% and 6.22%. Although manure does not supply the overall crop nutrient requirement, it partially meets the crop nutrient need. A mixed application of manure and chemical fertilizer reduces the cost of fertilizer input and also provides a better structure to soil.
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Figure 1. Components of integrated crop-livestock production system
Figure 2. Spatial distribution of hog population on Iowa farms in 1993.
Table 1(a). Manure nutrient production in Iowa.

<table>
<thead>
<tr>
<th>Animal Type</th>
<th>Population*</th>
<th>N, P, K produced per head per year</th>
<th>Total N, P, K produced (x1000 lb)</th>
<th>Runoff &amp; Leaching Losses** (x1000 lb)</th>
<th>Net Production (x1000 lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hogs (inventory)</td>
<td>14900000</td>
<td>25  19  19</td>
<td>372000 283000</td>
<td>186000 84000</td>
<td>113000</td>
</tr>
<tr>
<td>Beef Cattle</td>
<td>1115000</td>
<td>62  45  53</td>
<td>69150 30150</td>
<td>34565 15052.5</td>
<td>23638</td>
</tr>
<tr>
<td>Milk Cow</td>
<td>300000</td>
<td>131 100 114</td>
<td>39300 30000</td>
<td>19600 9000</td>
<td>13600</td>
</tr>
</tbody>
</table>


Table 1(b). Crop nutrient utilization in Iowa.

<table>
<thead>
<tr>
<th>Land Use</th>
<th>Area** (x1000 ac)</th>
<th>Yield (lb/ac)***</th>
<th>Nitrogen (N) - lb</th>
<th>Phosphorus (P,0,0 - lb</th>
<th>Potassium (K,0,0 - lb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crop</td>
<td></td>
<td>(lb/ac)***</td>
<td>Total (x1000)</td>
<td>lb/ac***</td>
<td>Total (x1000)</td>
</tr>
<tr>
<td>Corn</td>
<td>12950</td>
<td>140.0</td>
<td>185</td>
<td>2395750</td>
<td>80</td>
</tr>
<tr>
<td>*Soybean</td>
<td>8120</td>
<td>44.0</td>
<td>-</td>
<td>-</td>
<td>46.5</td>
</tr>
<tr>
<td>Oats</td>
<td>375</td>
<td>67.0</td>
<td>75</td>
<td>28125</td>
<td>35</td>
</tr>
<tr>
<td>Wheat</td>
<td>40</td>
<td>39.0</td>
<td>70</td>
<td>2800</td>
<td>30</td>
</tr>
<tr>
<td>*Alfalfa</td>
<td>1550</td>
<td>3.70t</td>
<td>-</td>
<td>-</td>
<td>40</td>
</tr>
</tbody>
</table>

*No additional nitrogen was considered for soybean and alfalfa
Table 1(c). Nutrient addition from secondary sources.

<table>
<thead>
<tr>
<th>Source*</th>
<th>Area (x1000 ac)</th>
<th>Nitrogen (N) x1000 lb @lb/ac</th>
<th>Total</th>
<th>Phosphorus (P₂O₅) 1000xlb @lb/ac</th>
<th>Total</th>
<th>Potassium (K₂O) 1000xlb @lb/ac</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Legume</td>
<td>9670</td>
<td>30</td>
<td>290100</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Wet Deposition</td>
<td>23035</td>
<td>10</td>
<td>230350</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>


Table 1(d). Complete nutrient input/output for the Iowa.

<table>
<thead>
<tr>
<th>Source</th>
<th>Total Input (x1000 lb)</th>
<th>Total Output (x1000 lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>P</td>
</tr>
<tr>
<td>Corn</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soybean</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oats</td>
<td>28125</td>
<td>13125</td>
</tr>
<tr>
<td>Wheat</td>
<td>2800</td>
<td>1200</td>
</tr>
<tr>
<td>Hogs (inventory)</td>
<td>186250</td>
<td>198170</td>
</tr>
<tr>
<td>Beef Cattle</td>
<td>34565</td>
<td>35122.5</td>
</tr>
<tr>
<td>Milk Cow</td>
<td>19650</td>
<td>21000</td>
</tr>
<tr>
<td>Legume</td>
<td>290100</td>
<td>-</td>
</tr>
<tr>
<td>Wet Deposition</td>
<td>230350</td>
<td>-</td>
</tr>
<tr>
<td>Nutrient</td>
<td>Nutrient available (x1000 lb)</td>
<td>Nutrient required (x1000 lb)</td>
</tr>
<tr>
<td>----------</td>
<td>-------------------------------</td>
<td>-------------------------------</td>
</tr>
<tr>
<td>N</td>
<td>760915</td>
<td>2426675</td>
</tr>
<tr>
<td>P</td>
<td>254292.5</td>
<td>1427905</td>
</tr>
<tr>
<td>K</td>
<td>225837</td>
<td>3632075</td>
</tr>
</tbody>
</table>
Table 2(a). Manure nutrient production in Adams County, Iowa.

<table>
<thead>
<tr>
<th>Animal Type</th>
<th>Population*</th>
<th>N, P, K produced per head per year</th>
<th>Total N, P, K produced (x1000 lb)</th>
<th>Runoff &amp; Leaching Losses**</th>
<th>Net Production (x1000 lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>N</td>
<td>P</td>
<td>K</td>
<td>N</td>
</tr>
<tr>
<td>Hogs (inventory)</td>
<td>51000</td>
<td>25</td>
<td>19</td>
<td>19</td>
<td>1275</td>
</tr>
<tr>
<td>Beef Cattle</td>
<td>19100</td>
<td>62</td>
<td>45</td>
<td>53</td>
<td>1184</td>
</tr>
<tr>
<td>Milk Cow</td>
<td>200</td>
<td>131</td>
<td>100</td>
<td>114</td>
<td>26</td>
</tr>
</tbody>
</table>


Table 2(b). Crop nutrient utilization in Adams County, Iowa.

<table>
<thead>
<tr>
<th>Land Use</th>
<th>Nitrogen (N) - lb</th>
<th>Phosphorus (P₂O₅) - lb</th>
<th>Potassium (K₂O) - lb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crop</td>
<td>Area** (1000xac)</td>
<td>Yield (lb/ac)**</td>
<td>Total (x1000)</td>
</tr>
<tr>
<td>Corn</td>
<td>64</td>
<td>140.7</td>
<td>185</td>
</tr>
<tr>
<td>*Soybean</td>
<td>43</td>
<td>43.9</td>
<td></td>
</tr>
<tr>
<td>Oats</td>
<td>5</td>
<td>61.6</td>
<td>75</td>
</tr>
<tr>
<td>Wheat</td>
<td>0.6</td>
<td>36.0</td>
<td>70</td>
</tr>
<tr>
<td>*Alfalfa</td>
<td>15.4</td>
<td>4t</td>
<td>180</td>
</tr>
</tbody>
</table>

*No additional nitrogen was considered for soybean and alfalfa
Table 2(c). Nutrient addition from secondary sources.

<table>
<thead>
<tr>
<th>Source*</th>
<th>Area (x1000 ac)</th>
<th>Nitrogen (N) x1000 lb (lb/ac)</th>
<th>Total (lb/ac)</th>
<th>Phosphorus (P₂O₅) x1000 lb</th>
<th>Total (lb/ac)</th>
<th>Potassium (K₂O) x1000 lb</th>
<th>Total (lb/ac)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Legume</td>
<td>48</td>
<td>30</td>
<td>1440</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Wet Deposition</td>
<td>128</td>
<td>10</td>
<td>1280</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>


Table 2(d). Complete nutrient input/output for the Adams County, Iowa.

<table>
<thead>
<tr>
<th>Source</th>
<th>Total Input (x1000 lb)</th>
<th>Total Output (x1000 lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>P</td>
</tr>
<tr>
<td>Corn</td>
<td>11840</td>
<td>5120</td>
</tr>
<tr>
<td>Soybean</td>
<td>-</td>
<td>1999.5</td>
</tr>
<tr>
<td>Oats</td>
<td>375</td>
<td>175</td>
</tr>
<tr>
<td>Wheat</td>
<td>42</td>
<td>18</td>
</tr>
<tr>
<td>Hogs (inventory)</td>
<td>638</td>
<td>678</td>
</tr>
<tr>
<td>Beef Cattle</td>
<td>592</td>
<td>602</td>
</tr>
<tr>
<td>Milk Cow</td>
<td>13</td>
<td>14</td>
</tr>
<tr>
<td>Legume</td>
<td>1440</td>
<td>-</td>
</tr>
<tr>
<td>Wet Deposition</td>
<td>1280</td>
<td>-</td>
</tr>
</tbody>
</table>
### Table 2(e). Nutrient balance for the Adams County, Iowa.

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Nutrient available (x1000 lb)</th>
<th>Nutrient required (x1000 lb)</th>
<th>Balance (x1000 lb)</th>
<th>%Nutrient available from on-farm sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>3963</td>
<td>12257</td>
<td>-8294</td>
<td>32.33</td>
</tr>
<tr>
<td>P</td>
<td>1294</td>
<td>7312.5</td>
<td>-6018.5</td>
<td>17.69</td>
</tr>
<tr>
<td>K</td>
<td>1202</td>
<td>18568</td>
<td>-17366</td>
<td>6.47</td>
</tr>
</tbody>
</table>
SPATIAL DECISION SUPPORT SYSTEM FOR PLANNING SUSTAINABLE LIVESTOCK PRODUCTION


Jain, D.K., U.S. Tim and R. Jolly

ABSTRACT

Recent shifts toward intensive and large confined livestock production units to enhance economic growth coupled with increased concerns for air, soil, and water quality have necessitated the development of computer-based management decision support systems for selecting environmentally sound production sites and for planning sustainable production systems. An integral part of a sustainable livestock production system is the selection of appropriate land areas that meet several environmental, socio-economic, and aesthetic constraints. Traditionally, regulatory and zoning criteria in conjunction with manual review and overlay of land cover, soils, and topographic maps have been used to select sites for livestock production. This approach can be both time-consuming and expensive, and the land areas delineated by this method have been shown to be problematic from the odor nuisance and water pollution standpoint. A more rational approach that narrows down large areas under consideration to a finite set of optimal sites that satisfy the environmental protection goals is needed. This paper
describes the development and application of an interactive spatial decision support system to delineate optimal land areas for locating a number of livestock production strategies. The spatial decision support system is based on the ARC/INFO geographic information system and incorporates the effects of land use, soil type, topography, proximity to roads and surface water bodies, and other aesthetic and political considerations as well as multicriteria analysis techniques. The design and implementation of the system as well as an example application involving several alternative livestock production strategies are presented.

INTRODUCTION

In the United States, livestock production represents a major economic force for many rural communities. It is the basic industry for a number of states, providing jobs and generating cash revenue. In Iowa, for example, the livestock industry is a major source of jobs for both rural and urban populations. It is estimated that approximately 166,000 jobs in Iowa, which represents about 12% of the 1989 workforce, are directly or indirectly linked to the livestock production industry (Iowa Business Council, 1990). In 1992, revenue from livestock activities accounted for about 55% of Iowa's cash receipt from all farming activities (Figure 1) (Iowa Farm Bureau Federation, 1994). In addition, for many rural communities, livestock production represents an important value-added
industry by taking into account new materials such as forage and grains and transforming them into other products.

Although economically viable, the livestock industry is currently facing a number of challenging environmental problems and highly complex social issues, many of which are related to its size and geographically concentrated nature. From an agricultural perspective, the role of livestock waste in the nitrate contamination of groundwater, the nitrogen and phosphorus eutrophication of surface water, and the fate of heavy metals and pathogens in livestock wastes applied to soils are the central environmental issues. Other related social and public health issues, including odor nuisances, disposal or composting of dead animals, food safety, and animal health and welfare, also confront the livestock industry. Furthermore, the polluting effect of ammonia volatilization from livestock production systems and the contributions of nitrogen oxide and methane to global warming and of sulphur dioxide to acid rain are now receiving increased attention.

Increased emphasis on environmental quality has also placed new demands on livestock producers to ensure that their production practices are in harmony with the natural environment. Citizens are urging their local and state governments to pass land use ordinances that control the location of new livestock facilities and to increase the level of regulations. Furthermore, as nonfarm people move into rural areas, the potential for lawsuits about the effects of livestock production has increased. For example, in 1990 an Iowa District Court in Boone County issued an injunction against
Iowa State University's state-of-the-art Swine Research Facility because of odor complaints. Also in 1990, the Iowa Court of Appeals heard a case in which a sweet corn producer alleged that a hog producer spilled substantial amount of livestock waste on the road near his farm, rendering over 30 acres of sweet corn unmarketable (Hamilton, 1992). Similar cases against livestock producers and related to odor and environmental degradation from livestock production have been documented in other regions of the United States. The cases exemplify some of the legal issues and environmental quality problems associated with livestock production.

Since the farm crisis, farmers have attempted to identify opportunities for expanding their economic outlook, thereby increasing individual farm profitability. In Iowa for example, a task force composed of agricultural and business leaders has suggested that expansion of the state's livestock production industry offers some potential for taking advantage of the natural and human resources, adding value to the farm commodities that are produced so well. They also argue that expansion and intensification of livestock production are needed to maintain and enhance economic development goals. However, expansion of livestock production requires exploitation of land resources and could lead to potentially deleterious effects on environmental quality. Through proper planning and siting of the livestock production units, most of the associated environmental problems can be minimized. One approach to minimizing potential environmental impact of livestock production and odor complaints from rural
residents is to provide a buffer between them. Spatial decision support systems, developed on the basis of geographic information systems (GIS), play a major role. Recently, the development and application of GIS for efficient handling, manipulation, and analysis of spatial information have substantially improved the identification of land areas suitable for siting and developing livestock production enterprises. The integration of Boolean and logical analysis, fuzzy knowledge, and multicriteria evaluation techniques with GIS provides the decision-maker with an advanced tool to assess the various alternatives on the basis of conflicting criteria and multiple objectives. In traditional site selection procedures, identification of potentially suitable land areas, because of restrictions on time and capital resources, was based solely on regulatory limits, municipal bylaws, and manual overlay of topographic, soil, and land use maps. By using GIS, associated time and capital expense can be drastically reduced and economic development and environmental protection goals can be incorporated into the site selection process.

In the study reported here, an ARC/INFO GIS-based spatial decision support system was developed to facilitate delineation of land areas that are suitable for the location of various livestock production strategies. This study is part of a comprehensive project that attempts to evaluate the environmental, social, and economic impacts of livestock production expansion in Iowa. This paper is intended to demonstrate the use of GIS in identifying optimal land areas for livestock production, taking into account several environmental, aesthetic, and economic constraints. An
example application of the spatial decision support system to the Lake Icaria watershed in southern Iowa is presented.

Southern Iowa was chosen for the study because its landscape is representative of the western Corn Belt and Great Plains—the so-called middle border. Also this region is agriculturally dependent, and livestock production, grain, and livestock processing industries are frequently identified as potential expansion targets. Concomitantly, southern Iowa has become increasingly dependent upon surface water for domestic water supply and recreation. Hence, the expansion of value-added livestock production, with its large by-products and waste stream, in conjunction with the region's growing rural population, have placed economic development and environmental quality on a collision course.

The rest of this paper is structured in several sections as follows. First, an overview of the GIS and spatial decision support system is presented. Then, some of the multicriteria site selection techniques and the hierarchical optimization/spatial weighting technique used in the livestock production and site selection spatial decision support system are briefly discussed. The spatial decision support system is described primarily from the user's point of view. Finally, the remaining part of the paper, except for the summary and conclusions, is devoted to describing an example application of the spatial decision support system for livestock production planning.
METHODOLOGY

An Overview of GIS

The GIS technology has come a long way in the past decade and continues to evolve. New application areas have been found, including agriculture, forestry, hydrology, resource management, and coastal resource management; new products have appeared in the marketplace; dramatic improvements continue in the capability of hardware and software operating platforms; and large volumes of data sets have become available. In fact since its initial development in the early 1960s, the GIS technology has grown rapidly to become a valuable tool in the analysis and management of spatial ecological problems. Defined by Burrough (1986) as “an organized collection of hardware and software to capture, store, analyze, and display all forms of geographically referenced information,” the GIS technology supports a wide range of spatial analysis that includes processes to create new classes of spatial objects, analyze the locations and attributes of objects, and perform spatial modeling using multiple classes of objects and the relationship between them.

A GIS also includes primitive operations for (a) calculating the centroid of polygons; (b) performing geometric operations on lines, points, and polygons; (c) building buffers around spatial objects; and (d) determining the shortest path through a spatial network. The functionality of leading GIS products and software as well as the potential application areas continue to grow, with no obvious end in sight. Thus, the
GIS technology has been widely adopted in local, state, and federal resource planning agencies as well as in the utilities and transportation industry.

In resource management and planning, several advantages of a GIS have been identified (Tim and Jolly, 1994). It provides resource planners and decision-makers with a set of tools to analyze spatial data effectively, and when combined with other information (e.g., economic, demographic) and with computer-based systems (e.g., spatial and process modeling, expert systems), can provide a flexible management decision support system. Typical examples of recent GIS applications in natural resource management and site planning include characterization and prioritization of hazardous waste sites (Soby, Connolly and Folsom, 1992); selection of optimal sites for land application of sewage sludge (Younos and Metz, 1988); modeling changes in water quality from land use activities (Joao and Walsh, 1992; Johnston, 1989); delineation of critical areas of nonpoint pollution and planning of pollution control strategies (Tim, Mostaghimi and Shanholzt, 1992; Tim and Jolly, 1994); and delineation of wetland protection zones (Zimmont, 1993). In these applications, GIS not only provide the ability to integrate and examine disparate spatial data but allow large-scale ecological models to be constructed and tested. As the diversity of users and uses of GIS increase, more and more application areas of GIS are likely to emerge.
Spatial Decision Support System

In recent years, the livestock production industry in the United States has undergone considerable changes. The number of animals in a given production unit has increased enormously, while the production system has become more concentrated, with a general trend toward larger units. With these changes, the following environmental quality issues emerge: (a) Given a finite land base (e.g., a watershed constrained by landscape characteristics, including soils, land use and land cover, and topography), what type and size of livestock production facilities (or units) can be located to maintain the complementary relationship between crop and livestock production? (b) Where should these facilities be located within the landscape to minimize environmental problems, including odor and water pollution? Answers to these questions require the use of spatial decision support systems that (a) provide geoprocessing capability for evaluating a large number of alternative and competing land areas to obtain an optimal site; (b) facilitate the introduction of multiple criteria into the site selection process; (c) enable the decision-maker to change the relative importance of a criterion to reflect the different objectives and opinions of the "players" involved in the site selection process; and (d) present, in an interactive mode, the results of the analyses in a variety of media that help the decision-maker understand them.

Depending on the application area, the definition of a spatial decision support system can take many forms. In the simplest and most general form, a spatial decision support system is defined as a computer-based system that integrates spatial database
management, spatial (or process) modeling, and map display capabilities to help
decision-makers analyze semi- or ill-structured problems (Densham, 1991; Armstrong,
Rushton, Honey, Dalzeil, Lolonis, De, and Densham, 1991). The system helps
decision-makers generate solutions that are optimal with respect to a set of criteria and
analyze trade-offs between those criteria. Its primary functions are to (a) provide the
mechanisms for interactive input and manipulation of large volumes of spatial data; (b)
allow representation of the complex spatial relationships and structures that are common
in spatial data, including analytical techniques that are unique to both spatial analysis
and modeling; (c) provide output in a variety of spatial forms; and (d) facilitate
decision-making and improve the effectiveness of the decision made (Turban, 1988).

Spatial decision support systems are explicitly designed to provide the user with
an interactive decision-making environment that enables geographic data analysis and
spatial modeling to be performed in an efficient and flexible manner. Generally, these
systems have evolved in parallel with management decision support systems developed
for the business community. Here, the management decision support systems are used
for such activities as strategic planning, scheduling of business operations, and
investment appraisals. Spatial decision support systems extend these capabilities to
provide a rational and objective approach to spatial decision analysis and enable the
decision-maker to assess the implications of the trade-offs between alternatives. In
livestock production, which is the central theme of this paper, a spatial decision support
system assists the decision-maker in planning sustainable (economically profitable, environmentally sound, socially acceptable) production systems.

A number of prototype spatial decision support systems have been developed for site planning and to facilitate analysis of ill-structured (environmental) problems. Openshaw, Carver and Fernie (1989) described a spatial decision support system, developed with ARC/INFO GIS, to delineate feasible sites for the disposal of radioactive waste. Carver (1991) incorporated multicriteria evaluation techniques with GIS to obtain a spatial decision support system that identifies suitable sites for the disposal of radioactive waste. Diamond and Wright (1989) described the development of a spatial decision support system that enables planners to address the multi-objective nature of a site-screening process. In their study, a rule-based "expert" system and a multi-objective integer programming model were linked to the GRASS GIS (USACERL, 1988) to obtain an interactive spatial decision support system for environmental planning and management. Tomlin and Johnston (1988) described ORPHEUS, a prototype spatial decision support system for environmental planning and land use allocation. In the following section, details of the livestock production site selection spatial decision support system are presented.
Livestock Production Site Selection

Overview of site selection techniques

The techniques for evaluating alternative choices in land suitability assessment are many and varied. Generally, they range from manual review of land use/land cover records in conjunction with municipal bylaws to the map overlay technique pioneered by McHarg (1969) and to more complex multicriteria optimization techniques described in Cochrane and Zeleny (1973). The multicriteria optimization techniques include such methods as ideal point analysis, concordance-discordance analysis (otherwise known as the conjunctive-disjunctive constraint procedure), and hierarchical optimization (Jankowski and Richard, 1994). These techniques have been described in detail in McRimmon (1977) and Wright, ReVelle and Cohon (1983); therefore, an exhaustive treatment is unnecessary in this paper.

Briefly, however, the ideal point analysis technique is based on the deviation of a set of ideal solutions (or feasible regions) from a set of efficient solutions that are weighted according to specified criteria governing the site selection process. Since the ideal solution rarely exists, this technique involves the use of a best compromise solution that minimizes the distance from the "theoretical" ideal solution. Carver (1991) expressed this minimum distance, $d_{min}$, as follows:
\[ d_{\text{min}} = \sum_{j} (1 - e_{ij}) w_j \]  

where \( w_j \) is the \( j \)th criterion weight, and \( e_{ij} \) is the standardized score defined by

\[ e_i = \frac{\max S_{ij} - S_{ij}}{\max S_{ij} - \min S_{ij}} \]

where \( S_{ij} \) is the raw score of alternative \( i \) according to criterion \( j \) derived from an evaluation matrix \( S \); and \( \max S_{ij} \) and \( \min S_{ij} \) are, respectively, the maximum and minimum values of the raw score. To evaluate the attractiveness of an alternative \( i \), the decision-maker weights the distances from the ideal solution with respect to individual criterion considered in the analysis.

The concordance-discordance analysis technique is based on pair-wise comparison of alternative choices (a real choice and a hypothetical alternative choice) in which the feasible region is characterized by increasing high dominance indices (Voogd, 1983). For an alternative to dominate, its cumulative score for all the attributes must be at least as good as or better than that of another alternative. By using a predefined minimum concordance index (characterized by the AND logical operation) and a maximum discordance index (characterized by the OR logical operation), a dominance matrix can be generated that shows the outranking relationship of an alternative \( a \). The
concordance index of an alternative \( a \) with respect to competing alternative \( a' \) can be represented (Carver, 1991) as follows:

\[
C_{aa'} = \frac{\sum w_j}{\sum \frac{w_j}{\sum w_j}}
\]  

(3)

where \( \Sigma w_j \) is the sum of weights of the criterion for which \( a \geq a' \), and \( \Sigma w_j \) is the sum of weights for all criteria \( a \geq a' \). The discordance index of alternative \( a \) with respect to \( a' \) is the ratio of maximum difference between weighted scores when \( a < a' \) and maximum difference between weighted scores for the criterion yielding the maximum difference between the weighted scores when \( a < a' \) for all alternatives. In this technique, a score of 1 is accumulated each time an alternative solution set outranks the other. By direct summation of the dominance score, the index of preferability of an alternative solution can be determined and the site ranked accordingly.

The hierarchical optimization technique attempts to rank all criteria according to their respective priorities. Subsequent optimization of the process is carried out in a stepwise manner such that higher-order ranking criteria are maximized before low ranking criteria. The resulting evaluation matrix can be truncated according to the goals of the decision-maker. In this technique, the decision-maker assigns preferences to the high-level objectives and then assesses the instrumentality of each criteria in attaining
those objectives. In so doing, direct assessment of the high-level objectives results in inferences being drawn about intercriteria weightings.

The multicriteria site analysis techniques briefly described above are by no means exhaustive. Other approaches based on fuzzy knowledge and neural networks have been proposed (Hall and Wang, 1992). Diamond and Wright (1989) used a rule-based expert system with GIS to develop a spatial information system for land use planning. Wang (1994) used artificial neural networks and GIS to develop a land suitability assessment tool for agricultural production planning.

Overview of our model

The livestock production planning and site selection spatial decision support system described in this paper combines the hierarchical optimization technique and spatial weighting scheme, spatial databases, and ARC/INFO GIS (ESRI, 1992) to facilitate evaluation of trade-offs between livestock production expansion (and economic development) and environmental quality. The spatial weighting scheme adopted in this study has the following characteristics: (a) a set of available alternatives with specified criteria and criteria ratings; (b) a process for comparing criteria by obtaining numerical scaling of criteria ratings (intracriteria preferences) and numerical weights across criteria (intercriteria preferences); (c) a well-specified objective function for aggregating the preferences into a single number for each criterion; and (d) a rule for choosing the alternative (or ranking of alternatives) on the basis of the highest
cumulative weight. Using this scheme, the desirability or suitability of a given land area $A$ (represented in ARC/INFO as a grid cell) is expressed as follows:

$$S_{Aj} = \sum_{i=1}^{N} f_i w_i$$

where $S_{Aj}$ is the cumulative suitability score of the land area $A$ for a given criterion $j$; $f_i$ is the rating (or numeric score) of a criterion and represents a unique spatial attribute (e.g., slope, aspect, proximity to blueline stream); $w_j$ is the corresponding weight of the criterion; and $N$ is the total number of discrete land areas (grid cells) in, for example, a watershed. The rating $f_i$ (range from 0 to 10) of a particular criterion reflects its relative importance, while the weight, $w_j$ (range from 0 to 100), allows the decision-maker to specify the importance of a particular criterion relative to other criteria.

In evaluating the suitability of a land area $A$, the spatial modeling capabilities of the ARCGRID module of ARC/INFO were used. Figure 2 illustrates the criteria and criteria ratings used in the analysis. Table 1 summarizes the steps involved in the analysis. The first step in obtaining a composite suitability map of a potential land area $A$ involved the generation of map coverages, the assignment of criteria ratings ($f_i$) to individual criteria through the remap table, and the assembly of criteria and weight grids. Once these grid coverages have been assembled, a composite cumulative
suitability_grid can be created by using the spatial modeling tools in ARCGRID. Thus the composite suitability_grid was calculated by using:

\[
\text{Suitability\_Grid} = [\text{Criteria\_grid} \times \text{Criteria\_weight}] + \ldots + [\text{CriteriaN\_grid} \times \text{CriteriaN\_weight}]
\] (5)

in which \textbf{Criteria 1} can represent aspect, slope, permeability, road proximity, or land-use class. Numeric scores that correspond to suitability classes are assigned to each grid. The values in the suitability_grid, which can exceed 100, are then rescaled to a value ranging from 0 to 100, with 100 representing very high suitability. In ARCGRID, rescaling of the composite suitability_grid was performed by using the expression:

\[
\text{Scaled Suitability\_Grid} = \frac{\text{Suitability\_Grid} \times 100}{\text{Max. value of Suitability\_Grid}}
\] (6)

The suitable land areas in the scaled suitability_grid can be identified either on the basis of their relative or absolute suitability. In the relative suitability classification, the land grid cells in the scaled suitability_grid were categorized as not suitable, marginally suitable, moderately suitable, and highly suitable, depending on their respective cumulative scores. In the absolute suitability assessment, only one suitability classification can be obtained and no intracriteria preferences were considered (e.g., if a
slope range of 0% - 2% is preferred, a score of 10 is assigned and other slope ranges are scored zero).

SYSTEM IMPLEMENTATION

The GIS

Two GIS software programs--ARC/INFO developed by the Environmental Systems Research Institute in Redlands, California, and ERDAS developed by Earth Resources Data Analysis Systems, Inc. of Atlanta, Georgia--were used extensively in the development of the spatial decision support system for livestock production planning and site selection. The ARC/INFO software, primarily the ARCGRID module, was used in the manipulation, analysis, and modeling of spatial and nonspatial data. ERDAS was used primarily in the classification and processing of land use and land cover data. Morehouse (1992) and Maguire (1992) present comprehensive overviews and profiles of ARC/INFO and ERDAS GIS software, respectively.

Summarily, the ARC/INFO software uses a hybrid vector data model to manage both locational and thematic data. Locational data are represented in ARC using a topological data model, while thematic data in INFO are represented by a relational data model. The data model consists of a georelational model that combines a specialized geographic view of the data with a conventional relational database model structure. Within ARC, a set of unique spatial operators facilitate data analysis. These operators include coverage operators for point, line, and polygon overlays; spatial interpolation
using conventional techniques and geostatistics; map projection and coordinate transformation; and Boolean operations and logical combinations of attribute data (Morehouse, 1992).

The ERDAS software is an image processing and geographic data analysis program that supports some basic GIS functions such as data capture, data manipulation and analysis, and data display (Maguire, 1992). The software program is based on the raster data structure that tessellates geographic space into regular square cells or pixels. Generally, ERDAS is organized into several modules that support basic functions such as input/output processing, multivariate image processing and analysis, raster-based modeling (using GISMO), 2.5-D and 3-D topographic modeling, and other specialized modules for software development and analysis of attribute databases (Maguire, 1992). The ERDAS-ARC/INFO Live Link also provides users with advanced raster-vector data integration and conversion.

The User Interface

The livestock production planning and site selection spatial decision support system is designed to run on a DEC workstation under the UNIX operating environment. The main component of the system design is the user-friendly graphical interface, which allows the user to control most of the system by direct interaction using a mouse. The graphical user interface (GUI) allows the user immediate access to, and direct manipulation of, all relevant elements of the spatial decision support system.
Figure 3 shows the main interaction screen of the system. The screen follows the standard established for modern GUIs.

In operating the system, the user inputs the various GRID coverages for all the criteria involved in the analysis (e.g., aspect, land slope, soil drainage class, hydrography, etc). Then the user assigns the corresponding weights. Upon specification of the criteria and weight grid coverages, the user may opt to edit the remap table or view the input grids (Figure 3). These options are provided as icons on the right side of the screen. Clicking on the "Process Selection" icon initiates spatial modeling using ARC/INFO GRID. At this point, the system opens ARCGRID and performs the modeling using the hierarchical optimization/spatial weighting procedures described earlier. The user can display the results showing suitable land areas in ARCPLOT and ARCVIEW. Hardcopy of the selected sites can also be obtained from a sequence of arc macro languages developed to facilitate spatial modeling. In general, the spatial decision support system provides immediate response to changes in the criteria; whenever criteria are directly changed, the graphical screen display is updated to reflect the new ranking of suitable sites.
EXAMPLE APPLICATION

Description of Study Area

The spatial decision support system described in this paper was applied to the Lake Icaria watershed to delineate suitable land areas for implementing a number of livestock production strategies. The 7,075-ha (17,280-acre) Lake Icaria watershed is located in Adams County about 8 km (5 miles) from Corning, Iowa, and approximately 112 km (70 miles) southwest of Des Moines. Drainage from the watershed empties into Lake Icaria, which is the major source of rural drinking water for the region. Lake Icaria has a surface area of about 280 ha (700 acres) and is part of the 760 ha (1900 acres) Lake Icaria Recreational Area, which provides facilities for boating, fishing, swimming, camping, and other recreational activities. Lake Icaria also provides water for domestic and industrial use within Corning and surrounding towns. A creamery, the second largest in Iowa, is located at Corning and produces about 4 million kilograms of butter annually. Much of the water for food processing at this industry is obtained from Lake Icaria.

Soils in the Lake Icaria watershed are prairie-derived and include the Macksburg-Winterset (nearly level to gently sloping), Sharpsburg-Adair (nearly level to moderately steep), and Shelby-Sharpsburg (moderately sloping to steep) soil associations. Agricultural land use and land cover in the Lake Icaria watershed consist primarily of row crops integrated with livestock (hog, beef cattle, poultry, sheep)
production enterprises (Figure 4). Cropped areas compose about 49% of the watershed, while 4.6% of the watershed area is identified as idle land. Pasture covers 22.4% of the watershed area, while 11.6% of the watershed is placed under the cropland reserve program. The remaining 12.5% of the Lake Icaria watershed consists of water bodies, farmsteads, roads, and parkland.

Raising livestock, primarily hogs and cow-calf herds, is an important enterprise for farmers in the watershed. A recent field survey identified 580 cattle and several medium-scale hog confinement operations in the watershed. The cattle herds are divided between 14 pasture operations distributed throughout the watershed. The hog confinement operations are located adjacent to parkland on the north side of the watershed. In general, the livestock operations in the Lake Icaria watershed show significant overgrazing with about 50 ha (125 acres) of pasture land showing, severe soil erosion problems. A recent preliminary soil erosion study of the watershed also indicates that about 2,600 ha (6,500 acres) of cropland have soil erosion rates that exceed established tolerable limits. Almost all of the soil eroding from the watershed ends up as siltation within the lake, causing an annual loss in storage capacity of 17,500 m³.

Livestock Expansion Strategies

Table 2 summarizes the various livestock expansion strategies for the Lake Icaria watershed example application of the spatial decision support system. These
expansion strategies were designed with the objective of demonstrating the applicability and utility of the site selection spatial decision support system and were chosen to represent the production strategies currently being promoted in southern Iowa. Associated with each production strategy are landscape characteristics (e.g., contiguous land area requirement), production size, nature and amount of manure (liquid or solid) generated, and acceptable manure management practices.

**Results of Example Application**

The spatial decision support system described in this paper was used to delineate suitable land areas in the Lake Icaria watershed for the siting of several livestock production strategies listed in Table 2. This paper presents only the delineated land areas that are suitable for large- and small-scale livestock production strategies. Figures 5 and 6 show the optimal land areas, aggregated on a land tract level, for siting the indicated livestock production strategies, given the various social (e.g., aspect, distance to roads), economic (e.g., profitability of the strategy represented by size of production), and environmental (proximity to surface water, soil permeability, slope) constraints. Figures 7 and 8 show the corresponding suitable land areas for the location of small-scale livestock production units. In general, for the 7075-ha Lake Icaria watershed, about 10, 57, 14, and 22 ha of land area were suitable for siting large-scale deep-bedded hog, large-scale hog confinement, large-scale hog pasture, and large-scale beef grazing systems, respectively. For the small-scale livestock production strategies
(Table 2), about 125, 116, 183, and 208 ha of the watershed land areas were found to be suitable. These differences in the suitable land areas for large- and small-scale production systems reflect contiguous land area requirement as well as the nature of each production system. The location of existing livestock production units in the Lake Icaria watershed matched closely with the sites selected by the spatial decision support system developed in this study. This agreement provides some level of confidence with the capability and applicability of the spatial decision support system for site selection and planning livestock production systems.

**SUMMARY AND CONCLUSIONS**

To address the environmental pollution problems associated with livestock production, local, state, and federal governments have passed a number of enabling and far-reaching regulations. Also, lawsuits seeking to reduce odors and other nuisances are emerging, with the majority in the swine/hog production sector. The general public is becoming more conscious of the impact that livestock production can have on the quality of air, soil, and water. Consequently, there is tremendous pressure on livestock producers to ensure that all forms of pollution resulting from their production practices are controlled. However, the potentially adverse environmental impacts of livestock production can only be minimized if resource managers, farm planners, and decision-makers are equipped with decision support systems for adequate planning of the
sustainable production systems. An integral part of sustainable livestock production planning is the delineation of optimal production sites.

The selection of suitable sites for locating any facility is a complex process. The decision-maker must be able to manipulate large amounts of geographic data and address multiple planning objectives in an efficient and systematic manner. Traditional site selection techniques have proved inefficient because of the large amounts of data required and the multicriteria nature of the process. Therefore, the use of spatial decision support systems for livestock production planning and site selection is a cost-effective alternative that allows incorporation of numerous variables as well as efficient handling of large amounts of data. These computer-based systems facilitate delineation of alternative siting strategies that are consistent with specified planning objectives.

This paper described a spatial decision support system for planning livestock production, specifically for delineating suitable land areas for locating the facility. The spatial decision support system, which uses hierarchical optimization, spatial weighting techniques, and ARC/INFO GIS, can improve decision-making when several criteria are involved and a large number of alternative sites are to be evaluated. When applied to the Lake Icaria watershed, the spatial decision support system shows great promise as an efficient and cost-effective tool for addressing some of the environmental problems associated with livestock production. Compared to traditional site selection techniques, the spatial decision support system enables disproportionate allocation of weights, which gives the decision-maker added flexibility to assess the relative importance of a
criterion. It also provides an interactive framework and user-friendly spatial modeling environment that the planner or decision-maker can use to incorporate physical, economic, and environmental constraints into the site selection process and to compare the attractiveness of several competing alternative sites.

Although the spatial decision support system described in this paper is an advancement in decision analysis for planning sustainable livestock production systems, the system clearly needs continued refinement. First, application of the spatial decision support system to more complex decision-making is required to further verify its feasibility and capability. Second, integration of other multicriteria decision-making techniques into the existing system is needed to increase the applicability of the system and extend the usefulness of GIS for spatial decision-making. Finally, incorporation of "expert" systems and process models into the existing system would extend its usefulness.

REFERENCES


Hamilton, N. D. (1992). *A livestock producer's legal guide to nuisance, land use control, and environmental law*. Drake University Agricultural Law Center, Drake University, Des Moines, IA.


Iowa Farm Bureau Federation. (1994). *Iowa Farm Facts*. Iowa Farm Bureau Federation, Des Moines, IA.


Table 1. Summary of criteria and criteria ratings important to siting a livestock production facility.

<table>
<thead>
<tr>
<th>Categories</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Well drained</td>
<td>0</td>
</tr>
<tr>
<td>Somewhat moderately well drained</td>
<td>2</td>
</tr>
<tr>
<td>Moderately well drained</td>
<td>4</td>
</tr>
<tr>
<td>Somewhat poorly drained</td>
<td>7</td>
</tr>
<tr>
<td>Poorly drained</td>
<td>10</td>
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</table>

<table>
<thead>
<tr>
<th>Categories (cm/hr)</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 0.15</td>
<td>0</td>
</tr>
<tr>
<td>0.15 - 0.51</td>
<td>2</td>
</tr>
<tr>
<td>0.51 - 1.52</td>
<td>4</td>
</tr>
<tr>
<td>1.52 - 5.10</td>
<td>6</td>
</tr>
<tr>
<td>5.10 - 15.2</td>
<td>8</td>
</tr>
<tr>
<td>Greater than 15.2</td>
<td>10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Categories (%)</th>
<th>Rating</th>
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</thead>
<tbody>
<tr>
<td>0 - 2</td>
<td>10</td>
</tr>
<tr>
<td>2 - 5</td>
<td>8</td>
</tr>
<tr>
<td>5 - 14</td>
<td>6</td>
</tr>
<tr>
<td>14 - 35</td>
<td>4</td>
</tr>
<tr>
<td>&gt; 35</td>
<td>0</td>
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* these factor values represent concern for groundwater quality.
Table 1. Continued.

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<th><strong>Criterion: Stream Proximity</strong></th>
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<tr>
<td>50 - 100</td>
<td>2</td>
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<td>100 - 200</td>
<td>6</td>
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<tr>
<td>200 - 300</td>
<td>8</td>
</tr>
<tr>
<td>300 - 400</td>
<td>9</td>
</tr>
<tr>
<td>Greater than 400</td>
<td>10</td>
</tr>
</tbody>
</table>

<table>
<thead>
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<th><strong>Criterion: Road Proximity</strong></th>
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<tr>
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<td>300 - 400</td>
<td>4</td>
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<tr>
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<table>
<thead>
<tr>
<th><strong>Criterion: Aspect</strong></th>
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<td>10</td>
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<tr>
<td>270 - 315</td>
<td>9</td>
</tr>
<tr>
<td>315 - 360</td>
<td>1</td>
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</table>
Table 2. Livestock production expansion strategies.

<table>
<thead>
<tr>
<th>Production Strategy</th>
<th>Small</th>
<th>Medium</th>
<th>Large</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hog (Confinement)</td>
<td>100 sows 0.8 ha, 2,080,236 litres&lt;sup&gt;b&lt;/sup&gt;</td>
<td>250 sows 1.2 ha, 5,319,818 litres</td>
<td>1,000 sows 4 ha, 21,279,270 litres</td>
</tr>
<tr>
<td>Hog (Deep Bedded)</td>
<td>100 sows 1 ha, 812.9 tonnes&lt;sup&gt;c&lt;/sup&gt;</td>
<td>250 sows 1.2 ha, 2,030.3 tonnes</td>
<td>500 sows 2 ha, 4,631.3 tonnes, 3,666,530 litres</td>
</tr>
<tr>
<td>Hog (Pasture)</td>
<td>50 sows 0.8 ha, 3.6 ha of pasture 193.2 tonnes</td>
<td>100 sows 1.2 ha, 7.1 ha of pasture 387.4 tonnes</td>
<td>250 sows 1.6 ha, 19 ha of pasture 967.1 tonnes</td>
</tr>
<tr>
<td>Beef (Rotational Grazing)</td>
<td>40 cows 0.8 ha, 25.9 ha of pasture 54.4 tonnes</td>
<td>100 cows 1.2 ha, 64.8 ha of pasture 136.1 tonnes</td>
<td>250 cows 1.6 ha, 161.9 ha of pasture 340.2 tonnes</td>
</tr>
<tr>
<td>Beef (Conventional Grazing)</td>
<td>40 cows 0.8 ha, 40.5 ha of pasture 54.4 tonnes</td>
<td>100 cows 1.2 ha, 101.2 ha of pasture 136.1 tonnes</td>
<td>250 cows 1.6 ha, 253 ha of pasture 340.2 tonnes</td>
</tr>
</tbody>
</table>

<sup>a</sup> minimum contiguous area required for facility
<sup>b</sup> manure (waste) generated by production strategy
<sup>c</sup> metric tonnes (1 metric tonne = 1.094 tons)
Figure 1. Revenue and Cash Receipts Generated from Iowa Agriculture (Iowa Agricultural Statistics, 1994)
Figure 2. Procedure flowchart for delineating suitable sites for sustainable livestock production.
Figure 3. Primary interaction screen for the spatial decision support system for site selection and planning of sustainable livestock production.
Figure 4. Spatial distribution of land use in Lake Icaria watershed
Figure 5. Suitable land areas (aggregated at the tract level) for siting large-scale: (a) hog-confinement, and (b) hog-pasture systems. Location: Lake Icaria Watershed, Adams County, IA.
Figure 6. Suitable land areas (aggregated at the tract level) for siting large-scale: (a) conventional beef-grazing, and (b) hog deep-bedded system. Location: Lake Icaria Watershed, Adams County, IA.
Figure 7. Suitable land areas (aggregated at the tract level) for siting small-scale: (a) hog-confinement, and (b) hog-pasture systems. Location: Lake Icaria Watershed, Adams County, IA.
Figure 8. Suitable land areas (aggregated at the tract level) for siting small-scale: (a) conventional beef-grazing, and (b) hog deep-bedded system. Location: Lake Icaria Watershed, Adams County, IA.
ABSTRACT

Spatial decision support systems are used to plan production systems and direct the implementation management strategies that are compatible with environmental protection goals. They enable resource managers select appropriate production technologies that minimize environmental damage, and evaluate alternative management practices. This paper describes a spatial decision support system (SDSS) developed to facilitate planning and management of environmentally-sound livestock production. The spatial decision support system integrates a geographic information system, spatial and biophysical modeling, and a knowledge-based system into an interactive tool to select suitable watershed land areas for siting livestock production, to select fields for manure application, and to determine the potential impacts of livestock production practices on groundwater quality.
INTRODUCTION

The livestock industry faces a number of challenging environmental and social issues, many of which are related to the number of animals in a production unit and fears over water quality. Central environmental issues include, the role of animal manure in the contamination of groundwater by nitrates, the eutrophication of surface water by excess nitrogen and phosphorus applications, and the accumulation of heavy metals and pathogens in soils. Also, the polluting effect of ammonia volatization from manure and the contributions of nitrogen oxide and methane to global warming are receiving increased attention. Social issues include odor nuisances (Hamilton, 1992), animal welfare, and food safety.

During the last decade, the livestock industry in the United States has undergone considerable changes. The number of animals in a production unit has increased enormously, while the production system has become more concentrated and intense. With these changes, the following environmental quality issues have emerged. 1. For a given piece of land (e.g., a watershed constrained by landscape characteristics such as soils, land use and land cover, and topography) what type and size of livestock production can maintain the complimentary relationship between cropping systems and livestock? 2. Where can livestock units be located in the watershed to minimize potential pollution with odors and nutrients? 3. Where can livestock manure be applied in the watershed to minimize soil and water quality problems? Answers to these
questions require tools to: (1) manage large volumes of spatially-variable data, (2) incorporate multiple objectives and competing criteria into the site delineation and planning process, (3) estimate potential water quality impact of the livestock production system, and (4) present the results of the analysis in a variety of ways that enhance decision-making. This paper describes a spatial decision support system to facilitate design and analysis of environmentally-sound livestock production systems. It includes a brief overview of the spatial decision support system and its various component and an example application that demonstrates the use of the system.

METHODS AND MATERIAL

Spatial decision support systems are tools that integrate spatial data and models with expert or knowledge-based systems to analyze semi-structured or ill-posed problems (Densham, 1991; Harsh, 1987; Armstrong et al., 1991). For planning the livestock production and environmental management, a spatial decision support system evaluates alternative production practices to select those that are commensurate with environment protection goals. In the following section, details of a spatial decision support system developed for livestock production planning are presented. Figure 1 shows the components of the spatial decision support system developed in this study.
GIS

A geographic information system (GIS) can be broadly defined as "an information systems technology for collecting, storing, retrieving at will, transforming, and displaying spatial and non-spatial data from the real world" (Burrough, 1986). As a technology, a GIS has several components which can be used to perform the following tasks: (1) to store, manage and integrate large amounts of spatially-referenced data; (2) to enable spatial retrievals; (3) to provide methods of analysis which relate specifically to the geographic component of the data; and (4) to display the data or results of analyses in the form of maps, tables, or graphs. Given these functional components, it is not surprising that GIS has been widely used in fields such as natural resource conservation, environmental planning, forestry and agriculture, and transportation and utilities management, amongst many others (Antenucci et al., 1991).

A number of GIS software have been developed for spatial data management and modeling, the choice of which depends on the experience of the user and the nature of the application. In this study, the ARC/INFO GIS software (ESRI, 1992) developed and marketed by Environmental Systems Research Institute, was used to develop the spatial decision support system. The ARC/INFO software can be envisioned as a collection of tools that operate on points, lines, and polygons, and performs data capture, error refinement and verification, coordinate transformation, database construction and manipulation, spatial analysis and modeling, and data query and display (Morehouse, 1992).
In ARC/INFO, the basic storage unit is the "coverage", which is a single layer of a map containing information about the spatial feature. Each coverage has a topology that defines the relationship between the spatial objects in the coverage. The topology allows performing operations such as contiguity analysis without accessing the spatial features' tables or coordinate. ARC/INFO also has a command sequencing and interpreting control language called arc macro language (AML), that permits structuring the command programs. AML provides string operations, loops, if-then-else blocks, and external file access protocols. Several program modules including ARCEDIT, ARCGRID, and ARCPLOT provide a wide range of functions, including data acquisition, spatial modeling, and interactive visualization and display of spatial data.

Modeling

Two modeling techniques were used in the spatial decision support system: spatial modeling and biophysical modeling. Spatial modeling used multi-criteria evaluation technique (MCE) for: (1) determining optimal land areas for siting livestock production systems, and (2) delineating suitable areas for manure application. The second modeling technique involves the use of a biophysical model to evaluate the groundwater quality impacts of land application of manure, given the agricultural land use, type and size of livestock production enterprises, and the amount of manure produced. Each modeling technique is briefly described below.
Spatial Modeling

The MCE technique, described in detail elsewhere (Carver, 1991; Jankowski and Richard, 1994), was incorporated with ARC/INFO GIS to determine suitable land areas for the planning of livestock production systems and for selecting suitable land areas for manure application. This technique is highly-suited for this study because of its simplicity, its efficient treatment of multiple criteria and conflicting objectives, and its capability to handle many different factors that may be involved in livestock production planning and decision-making. In addition, the MCE technique can reflect the preferences of decision-makers, and facilitates analysis of sensitivity of factors. Through analysis of sensitivity, the decision-maker can either assess the validity of the factors used in ranking the various alternatives or examine inter- and intra-criteria preferences.

The MCE technique, as used here, involved two basic steps: formulating an effectiveness matrix of factor and factor scores for each physical landscape attribute, and assigning a weight vector of priorities reflecting the importance of each factor. Factors used in the analysis included: land slope, aspect, soil permeability, distance to roads, and proximity to stream, to mention a few. The suitability of land area $i$ given a factor $j$ was determined using the following equation:

$$ S_{ij} = \sum_{i=1}^{N} f_{ij} w_j $$

(1)
where \( S_{ij} \) is the suitability score, \( f_{ij} \) is the effectiveness score, and \( w_j \) is the weight vector. The effectiveness score of a factor, \( f_{ij} \) (which may range from 1 to 10), and the corresponding weight of the factor, \( w_j \) (which may range from 0 to 100 with total not to exceed 100) can take the following form:

\[
\begin{align*}
    f_{ij} & = \begin{bmatrix}
    f_{i1} & \cdots & f_{ii} \\
    \cdots & \cdots & \cdots \\
    f_{ij} & \cdots & f_{ij}
\end{bmatrix} \\
    w_j & = (w_1, w_2, w_3, \ldots, w_J)
\end{align*}
\] (2a)

In calculating \( S_{ij} \), spatial modeling capabilities of the ARCGRID program module of ARC/INFO was used. The factors and factor scores used in the analysis are summarized in Table 1. The scores assigned to each factor were obtained from an extensive review of the literature, together with information obtained from several state agencies and extension field offices. Implementing the MCE technique within ARC/INFO involved: (a) obtaining a composite suitability map by generating map coverages of the factors listed in Table 1, (b) assigning factor scores \( f_{ij} \) by using a remap table, and (c) spatially-organizing the factors and weights at the grid-cell level. Once
the grid coverages had been assembled, a cumulative suitability grid was generated by using Equation 1 and ARCGRID modeling tools. Several AMLs were written to facilitate calculation of the values in the cumulative suitability grid. These values were then re-scaled to range from 0 to 100, with high values for high suitability and low values for low suitability. Re-scaling was performed in ARCGRID with:

\[
\text{Suitability.grid} = \frac{\text{Suitability.grid} \times 100}{\text{Max. value of Suitability.grid}}
\]  

(3)

Biophysical Modeling

The potential impact of manure applications on groundwater quality was evaluated with the Nitrate Leaching and Economic Analysis Package (NLEAP) model. Details of the model can be found in Shaffer (1991). NLEAP was developed to: accurately estimate nitrate leaching to groundwater beneath agricultural areas, determine nitrate leaching "hot-spots", and determine effectiveness of management strategies on farm-fields to reduce pollution of groundwater by nitrate. Originally, the model was developed for field-scale nitrate leaching assessment but has recently been extended to the watershed-scale by using GIS (Shaffer and Wylie 1993; Pierce et al., 1991).
Knowledge-based System

The use of knowledge-based systems or expert systems in agricultural management and environmental decision-making has increased tremendously during the past decade. Plant and Stone (1991) described the various knowledge-based systems used in agriculture. Buick et al. (1992) described a knowledge-based crop rotation and production advisory system for developing farm-level management plans that meet yield targets, economic return goals, and environmental quality objectives. Lam and Swayne (1993) described RAISON, an expert system that integrates hydrological database, modeling, and GIS. Lanen and Wopereis (1992) evaluated optimal land areas for injecting manure slurry from intensive animal production. He et al. (1992) developed a knowledge-based system for site-specific fertilizer application.

The knowledge-based component of the spatial decision support system discussed here was written in LISP language and was based on the Induction Dichotomy (specifically ID3) decision tree algorithm. Details of Induction Dichotomy were described by Quinlan (1986). In the spatial decision support system, the knowledge-base for nitrate leaching was developed by using simulations results from the NLEAP model for various combinations of climate, soils, and management practices. These results represented the training sets for inducing classification rules of nitrate leaching potential.

In developing the knowledge-base using ID3 decision tree algorithm, an associational rather than positional representation was used. The primary difference
between these representations has been discussed in detail in Quinlan (1986). Although associational representation requires more data storage, the input parameters (training sets) can be uniquely specified to facilitate user-initiated query. In building the decision tree, the user can specify the rules for choosing an attribute to use in partitioning the instances at the root node. These rules may include the choice of an attribute with the lowest or highest value, or a random selection of an attribute. In this study, the random selection of an attribute was kept as a default choice.

**SYSTEM IMPLEMENTATION**

The spatial decision support system was developed to run on a DEC workstation under the UNIX operating environment. However, with some modifications to the control files, it can be readily adapted to other workstations and microcomputers. The main design component of the system is a graphical user interface that lets the user interact with the modeling components through a mouse, and pop-up menus. Figure 2 shows the main interaction screen for the spatial decision support system.

To demonstrate the spatial decision support system, a visual trace of the screen display will be used to illustrate each stage of the user's progress through the system. In operating the spatial decision support system, the user generates the various grid coverages for all the factors summarized in Table 1 (e.g., aspect, land slope, soil drainage class, proximity to streams, etc.). The grid coverages can be generated by
using the POLYGRID command in ARC/INFO or by generating a FISHNET grid that covers the entire study area. Then, the corresponding scores and weights are assigned to each factor grid coverage and criterion, respectively. Upon specifying the factor grid and weight grid coverages, the user begins spatial modeling in ARCGRID by selecting the "Process Selection" button (or icon). The system begins spatial modeling with the equations described earlier. The suitable land areas for each activity such as siting livestock units and manure application can be displayed in ARCPLOT or visualized in ARCVIEW version 2.0.

After delineation of suitable land areas the system prompts the user to define the region for which assessment of water quality impacts (e.g., nitrate leaching) is desired. This may be necessary if the objective of the user is to perform field-by-field assessment of nitrate leaching or to identify "hot-spots" of groundwater contamination. Using the mouse, the user can define this region by creating a "window" on the screen display (Figure 3) or by selecting the entire watershed. An interface program written in C language then converts spatial attributes of the selected region into the ID3 structured query format. After this, the user is prompted for additional information on fertilizer and manure application rates and tillage practices for the selected land areas.

Upon completion of all the inputs, the system interacts with the knowledge-base to generate values of nitrate leaching potential. Here, the nitrate leaching rules induced from the NLEAP training sets and stored in the hierarchical format using ID3 decision tree algorithm, provide outputs of nitrate leaching for grid cells in the region defined.
The computed values of nitrate leaching, expressed in terms of low, medium, and high leaching potentials can be analyzed and visualized within the GIS software package. The spatial decision system is uniquely structured such that whenever a factor score or weight is changed, the output screen is refreshed to reflect such a change.

**EXAMPLE APPLICATION**

**Description of Study Area**

The spatial decision support system described in this paper was applied to the Lake Icaria watershed to delineate suitable land areas for planning small, medium, and large hog confinement units. The 7075-ha Lake Icaria watershed is located in Adams County and is approximately 112 km southwest of Des Moines, Iowa. Topography of the watershed varies from gently sloping to moderately steep. Soils were developed primarily from loess, pre-Wisconsin till, or pre-Wisconsin till-derived paleosols. The predominant soil associations include: Sharpsburg-Adair (nearly level to moderately steep), Macksburg-Winterset (nearly level to gently sloping), and Shelby-Sharpsburg (moderately sloping to steep).

Land use in the Lake Icaria watershed consists primarily of row crops (corn and soybean) integrated with a few livestock production units. In 1991, about 49% of the watershed was under corn and soybean production, while 22.4% and 11.6% of the watershed, respectively, was under pasture and the conservation reserve program
(Figure 4). About 12.5% of the watershed consisted of farmsteads, roads, parkland, and water. The remaining 4.5% of the watershed, which include irregular shaped tracts of land and parts of cropland fields that are non-farmable, was idle land. Livestock production is a small, but important, component of the Lake Icaria watershed land use. A 1991 survey identified 580 cattle and several medium-size hog confinement operations in the watershed. The cattle herds are divided between 14 pasture operations distributed throughout the watershed. The hog confinement operations are located on the north side of the watershed.

Results of Example Application

A number of livestock production strategies were analyzed using the spatial decision support system developed in this study. For brevity and to minimize repetition, only the results related to the implementation of large hog confinement systems (1000 sows with 4-ha contiguous land area requirement) in the watershed are described in this paper. A detailed description of results for other livestock production strategies that were evaluated using the spatial decision support system can be found in a recent report (Leopold Center for Sustainable Agriculture, 1995).

For the Lake Icaria watershed, Figure 5 shows the spatial distribution of the land areas suitable for siting large hog confinement units. In examining the result shown in Figure 5, it is important to note that the suitable land areas were aggregated at the tract level. Nevertheless, for the 7075-ha Lake Icaria watershed, about 57 ha (or 0.8% of
watershed area) was determined to be suitable for siting only two large hog confinement units. The land areas suitable for application of manure, as delineated by the spatial decision support system, are shown in Figure 6. Here, the suitable land areas, which total about 1277 ha (or 18% of watershed area), were aggregated at the grid cell level and this should be kept in mind when examining the results shown in Figure 6. The cell size used in distributing watershed parameters was fixed at 100 m by 100 m or 1 ha.

The groundwater quality impact of manure applied on the Lake Icaria watershed was evaluated. The two large hog confinement units determined previously generate about 42.6 million liters of manure. When applied uniformly on the cropland areas of the watershed, this manure provides approximately 168 kg/ha of nitrogen. For a total nitrogen application rate of 207 kg/ha (based on yield goals), Figure 7 shows the spatial distribution of nitrate leaching potential. Here again, the nitrate leaching losses, predicted by NLEAP and organized in the knowledge-based component of the spatial decision support system, were aggregated at the grid cell level. Overall, the results obtained from this example application demonstrate the utility and potentials of the spatial decision support system. The spatial decision support system is being extended to include the socio-economic impacts of the livestock production system.
SUMMARY AND CONCLUSIONS

To address the environmental pollution problems associated with livestock production, local governments have passed new ordinances controlling the location of concentrated production systems, while the federal government has passed a number of environmental regulations. In addition, law suits seeking to reduce odor nuisances from livestock production are emerging. The general public is becoming more conscious of the impact livestock production can have on the quality of air, soil, and water. Livestock producers are under tremendous pressure to ensure that all forms of pollution from their production practices are controlled, or even eliminated. However, these pollution problems can only be minimized if resource managers, farm planners, and decision-makers are equipped with decision support systems for planning environmentally-sound production systems.

In this paper a spatial decision support system, developed by coupling ARC/INFO GIS, spatial and biophysical modeling, and knowledge-based system was described. The spatial decision support system is uniquely structured to facilitate the planning and management of livestock production systems, and includes components for: (a) delineating suitable land areas for siting livestock production systems, given site-specific landscape characteristics; (b) determining suitable land areas for manure application; and (c) assessing the potential impact of manure application on groundwater quality. An example application to the Lake Icaria watershed showed the
spatial decision support system to hold great promise as an interactive and flexible tool for addressing some of the environmental problems associated with livestock production. Overall system also provides an integrated framework and user-friendly modeling environment for evaluating and comparing the attractiveness of several livestock production strategies. Finally, the evaluation of nitrate leaching potential, using the spatial decision support system, provides decision-makers with yet another useful tool for environmentally-sound livestock production planning.

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Table 1. Some criteria, factors, and factor scores used in the spatial decision support system.

(a) **Criterion**: Stream Proximity (m)

<table>
<thead>
<tr>
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<tr>
<td>50 - 100</td>
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<tr>
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<tr>
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(b) **Criterion**: Soil Permeability (cm/hr)

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<td>0.51 - 1.52</td>
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(c) **Criterion**: Road Proximity (m)

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<td>9</td>
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(d) **Criterion**: Slope (%)

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</table>

(e) **Criterion**: Aspect (degrees)

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Figure 1. Architecture and Conceptual Framework of the Spatial Decision Support System.
Figure 2. Major interaction screen for the spatial decision support system.
Figure 3. Sample interaction screen for defining areas for evaluating nitrate leaching potential.
Figure 4. Spatial distribution of land use in Lake Icaria watershed
Figure 5. Spatial distribution of suitable land areas for siting large hog confinement units (suitable land areas aggregated at the tract level).
Figure 6. Spatial distribution of suitable land areas for manure application (suitable land areas aggregated at the tract level).
Figure 7. Spatial distribution of nitrate leaching potential (suitable land areas aggregated at the tract level).
EVALUATING IMPACTS OF CROP-LIVESTOCK PRODUCTION ON SURFACE WATER QUALITY

A paper to be submitted to the Journal of International Geographic Information System

Jain, D.K., U.S. Tim, and Hsiu-Hua Liao

ABSTRACT

A generic interactive and integrated (GIS/surface water quality) system was developed as a tool for parameter determination, creating alternative nutrient management practices, evaluating the effects of such practices on surface water quality degradation, and assist user in applying the results through a visual interpretation. In order to evaluate nutrient loading on surface water from integrated crop-livestock production a surface water quality model capable of incorporating the spatial dynamics of watershed was needed. The AGNPS distributed-parameter model was used for this purpose. Being a distributed model, AGNPS requires very detailed inputs for a large extent. Although the AGNPS model has greatly enhanced predictive capability in conserving surface water quality, implementation of the model is highly dependent upon availability of input data. One alternative to this problem is to combine different and various sources of geographic-hydrologic data into one database to allow rapid retrieval of information as well as to develop new relationship through relational database capabilities and GIS functions. Thus, the AGNPS model was integrated with
ARC/INFO GIS to form a user-friendly modeling interface for surface water quality analysis. The interface automates extraction of the input parameters from GIS data layers and allows the user to interactively generate scenarios of nutrient management practices in crop- livestock production.

In order to demonstrate utility of the integrated system, an example application was performed on 7075-ha Lake Icaria watershed in southern Iowa. In one of the scenarios of integrating large hog confinement units with crops yield a 4% and 2.1% reduction in nitrogen and phosphorus loading, respectively.

**INTRODUCTION**

The degradation of the nation’s water resources is an issue important to all Americans. Agriculture has been identified as the largest contributor of nonpoint-source pollution of surface and groundwater systems. In a 1986 Report to Congress, the USEPA noted that routine agricultural activities were responsible for more than 60% of the surface water pollution problems (USEPA, 1990). Siltation of streambeds due to accelerated soil erosion, nutrients (primarily nitrogen and phosphorus) and pesticides in agricultural runoff, and pathogens from feedlots, urban runoff, and sewage were the major causes cited for surface water quality impairments. The off-site impacts of these pollutants include: loss of recreational use of streams, lakes, and estuaries; loss of fish and wildlife habitat; and reduction in the aesthetical qualities of the aquatic environment.
(Halcrow et al., 1982). In additions, monetary damages from nonpoint-source pollution are estimated to be about $9 billion annually (Ribaudo, 1992). Thus, nonpoint-source pollution has become an important issue from both environmental and economic perspective.

During the past several decades, federal and state agencies charged with water quality protection have attempted to address the problem of nonpoint-source pollution by establishing the relationship between land management practices and environmental and water quality degradation. Efforts have been directed at mitigating adverse agricultural impacts by (i) expanding the understanding of the processes that influence surface hydrology and the fate of chemicals in the environment, (ii) establishing methods and developing tools for evaluating the extent and nature of agricultural pollution of water resources, and (iii) translating the knowledge into improved land management practices and sustainable agricultural production systems. However, some of these efforts require long-term demonstration projects and expensive on-site measurement and monitoring. Because of these issues, computer models for nonpoint-source pollution control are being relied on more frequently to provide guidelines in developing strategies for alternative agricultural management.

In recent years, computer modeling has gained wide spread acceptance as a cost effective tool for developing agricultural management practices that protect water quality. Numerous lumped and distributed parameter hydrologic/water quality (H/WQ) models, including CREAMS (Knisel, 1980), ANSWERS (Beasley and Huggins, 1982),
AGNPS (Youngs et al., 1987) and SWRRB-WQ (Arnold et al., 1990), have been developed to predict the impacts of agriculture on the quality of surface water. Several journal articles and review papers provide excellent overviews of the state-of-the-science in H/WQ modeling (Rose et al., 1990; Oliver and Solomone, 1990). Models are powerful tools in determining the probable impacts of alternative management strategies and farming systems on water quality. However, several limitations in their use and the potential for misuse must be recognized.

A major limitation in the use of H/WQ models have been their inability to handle the large amounts of input data that describe the heterogeneities of the natural system. For a long time, researchers have recognized that the spatio-temporal variability in landscape characteristics including soil, land use, topography, and climate, affects the hydrologic response of the physical system and severely limits the applicability of models. The extreme complexity of manipulating large volumes of spatial and nonspatial (or attribute) input data, for example, severely limits the use of distributed H/WQ models. A recent and emerging technology represented by geographic information systems (GIS) provides the tools to generate, manipulate, and spatially organize disparate data for distributed modeling. In GIS, the successive analysis of spatial data can partition large heterogeneous areas into small hydrologically homogeneous units upon which a model can be applied.

During the last decade, interest in modeling the movement of nonpoint-source pollutants in complex landscapes, and the potential that GIS offer for managing spatially
disparate environmental data have been growing. Applications of GIS include work on soil erosion modeling (De Roo et al., 1989; Sivertun et al., 1988); evaluation of changes in water quality from land use management activities (Hopkins and Clause, 1985; Wlash, 1985); surface runoff modeling (Vieux, 1988; Stube and Johnson, 1990); and groundwater flow modeling (Hammock and Lorenz, 1992). However, in most of these applications, the GIS was utilized to estimate model input parameters. Needham and Vieux (1989) examined the application of ARC/INFO to generate spatial input data for the AGNPS model. Using a GIS, VanBlargan et al. (1990) generated data for a hydrologic model. Moore et al. (1988) utilized ARC/INFO to provide topographic attributes for modeling hydrology and water quality in a watershed. Wolfe and Neale (1988) used a raster GIS (GRASS) to provide limited data input to a finite-element hydrologic model. Using the analytical capabilities of GRASS, they overlaid map layers for soils and land use to delineate hydrologically homogeneous areas having unique parameters. Olivieri et al. (1991) developed a method for automated generation of input data for the AGNPS model by using the ERDAS GIS software.

Geographic information systems have been interfaced or integrated with simulation models in several recent studies. Srinivasan and Engel (1991) developed an interface between GRASS GIS and ANSWERS to assist with inputting and interpreting model output. Blaszczynski (1992) integrated the revised universal soil loss equation (RUSLE) with GIS to evaluate the environmental impacts of soil erosion. De Barry (1991) linked a rainfall-runoff model with ARC/INFO to determine runoff volumes in a
watershed. Hession et al. (1989) linked the Virginia GIS (VirGIS) with AGNPS model to evaluate the effectiveness of alternative cropland management strategies in reducing nonpoint-source pollution to the Chesapeake Bay. Tim et al. (1992a,b) integrated two simplified pollutant export models with VirGIS to estimate soil erosion, sediment yield, and phosphorus loading from the Nomini Creek watershed in Westmoreland County, Virginia. Several other investigators (Gilliland and Baxter-Porter, 1987; Halliday and Wolfe, 1991; Vieux, 1991) have either developed interfaces between a GIS and simulation model or attempted to integrate these two independent computer-based technologies. In spite of these example applications, the development of integrated modeling system (e.g., linking simulation models with GIS) to resolve nonpoint-source pollution problems has not kept pace with the emergence of new computer-based technologies or complex, multifaceted environmental problems. In fact, a major problem in environmental modeling is that for the most part, the GIS and the H/WQ model are used in isolation. Although the model or the GIS may be a powerful tool for itself, realistic and cost-effective solutions to some environmental problems can only arise by integrating them at the appropriate spatial and temporal scale.

This study was aimed at developing an integrated modeling system for evaluating surface water quality impacts of nutrients management practices in livestock production systems. The uniqueness of the integrated system is the provision of menus for on-screen definition of alternative manure management strategies. The overall objective was to interface an existing H/WQ model with ARC/INFO to upgrade process
modeling tool to fully interactive and spatial modeling tool with a graphical user interface. This interface not only completes an existing spatial decision support system but also almost completely relieves user from extraneous data input, manipulation of output data, and graphical display of model results.

MATERIAL AND METHODS

AGNPS Model

The AGNPS model is an event-based, distributed parameter model developed by Young et al. (1987) as a means of objectively evaluating NPS pollution from agricultural watersheds. The AGNPS model works on a grid cell basis, and requires discretization of the watershed into uniform grids to capture the spatial variability of processes and parameters within the watershed. The basic components of model include: hydrology, sediment delivery, transport of nitrogen, phosphorous and chemical oxygen demands. The AGNPS model also simulates point source inputs of sediments from gullies as well as the contribution to surface water of nutrients from animal production. Nutrient export from cropland areas are predicted by using relationships developed in the CREAMS (Knisel, 1980).

In this study the latest version of the AGNPS model (version 4.0.3) that runs on UNIX operating system was used. In AGNPS 4.0.3 there is no limit on number of cells from the model side, however it is controlled by the hardware. For each grid in
watershed, fundamental relationships exist between the dependent hydrologic processes and landscape characteristics. A description of different parameters required by the model is summarized in Table 1. Many of these parameters are obtainable either from published data, available watershed records, or from farm surveys. The model’s user guide also contains tables listing standard variables for some of the model parameters (Tables 2 and 3). When all the parameters are specified, the model provides estimate of several parameters including: total runoff volume; soil erosion rate per cell; sediment delivery (detachment, deposition); total nitrogen and total phosphorus concentrations and loading; and chemical oxygen demands. A more detailed description of model can be found in Young et al. (1989).

GIS Database

A number of GIS software have been developed for spatial data management and to assist water quality modeling efforts. The choice of software depends on the experience of the user and the nature of the application. In this study, the ARC/INFO GIS software (ESRI, 1992) was used to generate, organize, and store both spatial and nonspatial data for the decision support system. The spatial database was generated through information derived from maps. For example, roads, watershed boundary, and hydrography coverage were generated by manually digitizing the U.S. Geological Survey topographic 7.5 minute quadrangle map. Soil information was initially captured from Adams County soil survey map produced by the U.S. Department of Agriculture.
Spatial and nonspatial soil information for the watershed was obtained from ICSS Resource Facility, Iowa State University. Land use and land cover information was secured through interpretation of aerial photographs. Classifications of the land use types were carried out using the ERDAS GIS software and the digital information was formatted in the ARC/INFO export format. Using the Triangulated Irregular Network (TIN) model of ARC/INFO and the LATTICEPOLY utility, elevation, slope and aspect coverage were derived from the digital elevation model (DEM) of the study area. The terrain coverage, along with the land use/land cover, soils, hydrography, and road were clipped to the watershed boundaries. Spatial information required to run the AGNPS model was extracted from ARC/INFO and converted into a fishnet coverage with every cell containing values for all required parameters. For secondary information on these basic parameters, look up tables were also created using the INFO relational database of ARC/INFO.

Model Integration

The AGNPS model was integrated with ARC/INFO GIS to provide a framework for assessing impacts of agricultural practices on surface water quality. The primary objective of integrating AGNPS and ARC/INFO was to provide users with a seamless modeling environment that reduces the time-consuming data input. By doing so, all operations from parameter determination to display of results were performed within the ARC/INFO GIS environment.
This integration was designed such that the AGNPS model becomes one of the analytical functions of ARC/INFO GIS to simulate processes, GIS generates and manipulates input parameters, and GIS allows for interactive management of animal feedlots. Files between AGNPS model and GIS were instantly exchanged through the in-built INFO relational database. A separate interface for converting GIS data to and from the model was written in C language.

User Interface

The primary design component of the integrated system is a graphical user interface that enables the user to run the model and graphically display the results. The complete architecture of the integration is shown in Figure 1. The system starts with a primary interaction screen where the user selects an option of executing AGNPS from ARC/INFO (Figure 2). The three options of generating input file and running AGNPS are: (a) AGNPS will be run on an existing data file, which will be chosen by the user from a list of files residing in the current directory, and results will be displayed and printed; (b) an existing file will be edited to incorporate new data such as management practices on certain farms; (c) a new input file will be generated in ARC/INFO before executing AGNPS. If option (c) is chosen, user starts with specifying the names of fishnet coverages. Through a pop-up menu system, user selects appropriate item in the fishnet coverage for every input parameter. This interactive determination of AGNPS model through extraction of data in the fishnet coverage is demonstrated in Figure 3.
The user interface for AGNPS modeling in ARC/INFO allows the user to interact with more than one window (menu) at a time. The system displays and manages multiple menus using AML thread utility in ARC/INFO. Threads are the mechanism that delivers input to the AML processor. Having more than one thread allows user to have more than one active window with which to interact. This enables design of a full-screen application instead of the hide-and-go-seek interfaces (i.e., the menu appears, disappears, reappears, etc.).

As shown in Figure 4, the user can, in the first window, select input/output options, specify watershed level information on cell resolution, rainfall data and storm characteristics. In order to ensure data entry in a sequence, without missing any required input, the modeling environment was designed such that, at a time, only one window will accept data from the user. When data entry in one window is completed, the AML passes control to the next window until all the required data are supplied. Menus are reactivated in the sequence provided in AML code.

In the second window, the user chooses items from the fishnet coverage to extract parameters related to watershed topography, land use, land management practices, and erosion sources (Figure 5). From this window, request is send to activate soil and channel menu for specifying items for soil and channel properties by selecting the soil or channel button (Figure 6 and 7). Information specified so far can be stored in an ASCII file for future use. This file, if required, can be edited before running the model.
After data extraction is completed in first and second window in addition to other supplemental windows for input of soil and channel properties, the system prompts user for an interactive specification of animal feedlot parameters (Figures 8a and 8b). If user chooses “YES”, (see query insert Figure 8a) the animal feedlot window will be activated for specification of feedlot data required by the AGNPS model. Before user specifies the animal feedlot location as required by the model, a user input is required for displaying the watershed properties for an interactive selection of point sources of pollution. Here, the user may specify the grid of previously selected animal feedlot sites or the grid of existing feedlots. After completing this window, a new menu pops up for interactive data entry on feedlot topography, feedlot characteristics, animal type, animal density, and buffer area (Figures 9a and 9b). User can enter new values or keep default values which were loaded from a system file. On completing data input in the feedlot interacting windows and menus, the integrated modeling system displays watershed properties overlaid on existing or previously selected location of livestock units. Using a mouse, the user then selects animal feedlot locations to be included in the AGNPS model simulation. A program written in the C language then inserts animal feedlot locations into the basic data file created from first two windows. The program reads each row into a large string variable, which, in turn, is read to extract a cell number associated with the record number and stored in a variable. The value stored in this variable is matched with user selected feedlot cell-id, and the required feedlot data is written to a basic data file to generate a new input file.
Upon completion of all the inputs, the interactive modeling system interacts with the executable code of the AGNPS model. Once the simulation is completed, a new window (Figure 10) appears for the user to select the output results to be analyzed and visualized within the ARC/INFO GIS.

AN EXAMPLE APPLICATION

The integrated modeling system developed by the use of AGNPS and ARC/INFO was applied to the Lake Icaria watershed in order to examine the environmental impacts of alternative management practices in crop and livestock production system. The 7075-ha Lake Icaria watershed, as described previously, is located in Adams County, Iowa. Topography of the watershed varies from gently sloping to moderately steep. Soils were developed primarily from loess, pre-Wisconsin till, or pre-Wisconsin till-derived paleosols. Predominant soil associations include: Sharpsburg-Adair (nearly level to moderately steep), Macksburg-Winterset (nearly level to gently sloping), and Shelby-Sharpsburg (moderately sloping to steep). Land use in the Lake Icaria watershed consists primarily of row crops (corn and soybean) integrated with a few livestock production units. In 1991, about 49% of the watershed was under corn and soybean production, while 22.4% and 11.6% of the watershed, respectively, was under pasture and the conservation reserve program (Figure 11). Livestock
production, in 1991, consisted of 580 cattle and some medium-size hog confinement operations.

Four alternative management practices were evaluated in order to demonstrate the applicability of the integrated AGNPS-ARC/INFO modeling system in predicting surface water pollution impacts of crop-livestock production. The primary objective in designing the four management practices was to illustrate the advantages of interactive modeling of nutrient loading to watershed streams using a GIS-based framework. The first management practice may be treated as a baseline case, where it was assumed that there is no animal feedlot located in the watershed. In this case, the only source of nutrient loading to the watershed stream was from agricultural practices. In second strategy, surface water quality evaluation was performed after including environmentally-sound locations of large hog units of 1000 sows (Figure 12). Here, grids containing feedlot locations were modified to represent feedlot units with required input parameters. No nutrient produced by the hog confinement units was applied to crop land and commercial fertilizer was assumed to be the only nutrient source. In third strategy, however, all the manure produced by the hog units were applied to cropland on top of commercial fertilizer application. In this strategy, the aim was to compare the pollution potential of excess application of manure nutrients. In fourth strategy, the fertilizer requirement of crops grown in the watershed was estimated after determining the nutrient availability from manure produced on the hog units. System allows to include animal feedlot sequentially through mouse selection or all at once. This enables
planner to identify the most potential source of pollution. The nitrate leaching to surface water from the four strategies are discussed in next section.

RESULTS AND DISCUSSION

The integrated AGNPS-ARC/INFO system was run for the four different management scenarios described previously. Nitrogen and phosphorus loadings were the primary output analyzed. By comparing the predicted values for four alternative management practices, recommendations regarding the effectiveness of individual practice can be made. The study of four distinct practices also allows decision makers to investigate the watershed hydrologic response to nutrient management practices. Results for all four scenarios are discussed below.

Figures 13-20 show the spatial distribution of total nitrogen and total phosphorus loading for the Lake Icaria watershed. In all four scenario simulated, total nitrogen and total phosphorus loading to streams range from 0-5.2 lb/acre and 0-3.0 lb/acre respectively. However, this value changes with changes in management practices or with the management scenarios. In scenario I, crop production was the only agricultural practice simulated. It was assumed that there is no animal feedlot unit in the watershed. The nitrogen and phosphorus requirements for the grid cells under corn were estimated as 185 lb/acre and 80 lb/acre, respectively, for a yield goal of 150 bu/acre. As shown in Figure 13 and 14, about 7% and 1.75% of the watershed had total nitrogen and total
phosphorus loadings exceeding 5.2 and 3.0 lb/acre, respectively. In scenario II, after locating two large hog units of 1000 sows each, the percent of watershed area with total nitrogen and total phosphorus loading was 5.7% and 2.85%, respectively (Figures 15 and 16). The decrease in nitrogen percentage is mainly due to the reduction in corn crop area after locating hog units since the suitable sites for hog units are in the cropped regions. As phosphorus is lost primarily in sediment, there was a slight increase observed in few fields in the proximity of animal units. In third scenario, manure generated from hog units were uniformly applied to crop fields in addition to fertilizer requirements. Additional nitrogen and phosphorus in manure, from the two hog units, was estimated as 150 and 176 lb/acre, respectively. Total nitrogen and total phosphorus loading under this scenario of excess application of nutrients are shown in Figures 17 and 18. The maximum change of nutrient loading for this management practice, when compared with previous scenarios, was 2.41% and 6.80% for total nitrogen and total phosphorus, respectively. In scenario IV, the total amount of nutrient supplied through manure and commercial fertilizer was restricted to nutrient requirement of crops. The amount of commercial fertilizer applied was estimated to meet any nutrient deficits from manure. The results from this scenario indicate a decrease in high nutrient loading values and an increase in the area under low nutrient loading. Watershed area with total nitrogen loading greater than 5.2 lb/acre decreased from 8.1% under the third scenario to 3.1%. Similarly, the watershed area with total phosphorus loading greater than 3.0
lb/acre decreased from 8.6% to 1.5%, indicating the impacts of manure utilization from feedlot operations (Figures 19 and 20).

The main objective of the example application was to demonstrate the utility of integrated system to examine management practices and to ascertain whether nonpoint source pollution levels changes as a consequence of alternative management practices in watershed with feedlots. The utility of the system is not only limited to these scenario, indeed other watershed management scenarios can also be evaluated using the integrated modeling framework. The ease of interactively specifying the location of point sources in a watershed, data extraction, and evaluation of alternative management practices are major advantages of the system developed in this study.

CONCLUSION

Hydrologic and water quality model can be utilized as planning tools for determining management practices that minimizes nutrient loading from an agricultural activity. However, in simulating the effect of management practices in large watersheds, selection of model is mostly restricted to the availability of data and the ease of preparing data inputs. Recently, it has been recognized that GIS can play an important role in generating, handling, organizing, and displaying model parameter for very large areas. The GIS can, very efficiently, be used to prepare spatial data such as slope, soil type, land use and soil properties on regional or local scales. It enables user
to selectively manage data pertinent to the situation and to cost-effectively analyze management alternatives for resource allocation and decision making.

In this paper, an integrated AGNPS-ARC/INFO modeling system with a graphical user interface was developed to: interactively design watershed level management plans that to include animal feedlots; run the AGNPS model; and display and analyze model results. In addition to its decision making capabilities, the modeling system makes parameter determination fast and efficient, by extracting required information from basic data layers in the GIS. All the data extraction, manipulation, simulation and interpretation can be interactively performed within the ARC/INFO in an user-friendly manner. The modeling system allows determination of other landscape reconfiguration options and impacts of agricultural management practices on surface water quality. Furthermore, it complements the system components described earlier for livestock site planning and groundwater quality impact assessment.

REFERENCES


Table 1. A summary of input parameters for AGNPS model (Version 4.0.3).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Watershed name</td>
<td>-</td>
</tr>
<tr>
<td>Description</td>
<td>Watershed description</td>
</tr>
<tr>
<td>Base cell area</td>
<td>Same base cell area for all the cell in watershed</td>
</tr>
<tr>
<td>Number of base cells</td>
<td>Total number of cells in watershed</td>
</tr>
<tr>
<td>Hydrology calculation</td>
<td>Method of peak flow calculation</td>
</tr>
<tr>
<td></td>
<td>0 = TR55, 1 = CREAMS</td>
</tr>
<tr>
<td>Geomorphic indicator</td>
<td>0 = Non-geomorphic</td>
</tr>
<tr>
<td></td>
<td>1 = Use geomorphic</td>
</tr>
<tr>
<td>k-coefficient</td>
<td>Indicator for which way to calculate the peak of the hydrograph</td>
</tr>
<tr>
<td></td>
<td>0 = calculate using prepeak fraction</td>
</tr>
<tr>
<td></td>
<td>1 = calculate using the K-coefficient</td>
</tr>
<tr>
<td>k coefficient value or</td>
<td>if k coefficient = 1 this is the k coefficient value</td>
</tr>
<tr>
<td>prepeak %</td>
<td>if k coefficient = 0 this is the prepeak %</td>
</tr>
<tr>
<td>Storm type</td>
<td>SCS storm type (1, 2, 3, I, Ia, II, III)</td>
</tr>
<tr>
<td>Storm energy intensity</td>
<td>Energy intensity value for the storm</td>
</tr>
<tr>
<td>Storm duration</td>
<td>Duration of storm rainfall (hours)</td>
</tr>
<tr>
<td>Storm rainfall</td>
<td>Amount of rainfall during storm (inches)</td>
</tr>
<tr>
<td>Rainfall nitrogen</td>
<td>Nitrogen concentration in rainfall (PPM)</td>
</tr>
<tr>
<td>Cell number</td>
<td>Cell index of individual cell after rasterizing watershed</td>
</tr>
<tr>
<td>Cell division</td>
<td>Cell index, if a base cell is further divided into sub cells.</td>
</tr>
<tr>
<td>Receiving cell number</td>
<td>Cell base number of the cell receiving outflow from current cell</td>
</tr>
<tr>
<td>Receiving cell division</td>
<td>Receiving Cell index, if a base cell is further divided</td>
</tr>
<tr>
<td>Flow direction</td>
<td>Direction of flow from current cell to receiving cell</td>
</tr>
<tr>
<td></td>
<td>0 = sink hole cell</td>
</tr>
<tr>
<td></td>
<td>1 = north direction</td>
</tr>
<tr>
<td></td>
<td>2 = northeast direction</td>
</tr>
<tr>
<td></td>
<td>3 = east direction</td>
</tr>
<tr>
<td></td>
<td>4 = southeast</td>
</tr>
<tr>
<td></td>
<td>5 = south direction</td>
</tr>
<tr>
<td></td>
<td>6 = southwest direction</td>
</tr>
<tr>
<td></td>
<td>7 = west direction</td>
</tr>
<tr>
<td></td>
<td>8 = northwest direction</td>
</tr>
<tr>
<td>Curve number</td>
<td>SCS curve number for the current cell</td>
</tr>
<tr>
<td>Average land slope</td>
<td>Average land slope of the land falling in the cell</td>
</tr>
<tr>
<td>Slope shape code</td>
<td>Land slope shape code</td>
</tr>
<tr>
<td></td>
<td>1 = uniform, 2 = convex slope, 3 = concave slope</td>
</tr>
<tr>
<td>Slope length</td>
<td>Overland slope length (feet)</td>
</tr>
<tr>
<td>Overland Manning</td>
<td>Manning's roughness coefficient</td>
</tr>
<tr>
<td>Soil erodibility factor</td>
<td>K factor used in USLE equation</td>
</tr>
<tr>
<td>Cropping factor</td>
<td>C factor used in USLE equation</td>
</tr>
<tr>
<td>Practice factor</td>
<td>P factor used in USLE equation</td>
</tr>
<tr>
<td>Surface condition constant</td>
<td>To make adjustments for overland flow velocity.</td>
</tr>
<tr>
<td>COD factor</td>
<td>COD concentration in runoff, based on the land use in the cell</td>
</tr>
</tbody>
</table>
Table 1 (continued).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil type</td>
<td>Major soil texture classification for the cell</td>
</tr>
<tr>
<td></td>
<td>0 = water</td>
</tr>
<tr>
<td></td>
<td>1 = sand</td>
</tr>
<tr>
<td></td>
<td>2 = silt</td>
</tr>
<tr>
<td></td>
<td>3 = clay</td>
</tr>
<tr>
<td></td>
<td>4 = peat</td>
</tr>
<tr>
<td>Fertilizer level</td>
<td>Level of fertilizer applied</td>
</tr>
<tr>
<td></td>
<td>0 = no application</td>
</tr>
<tr>
<td></td>
<td>1 = low</td>
</tr>
<tr>
<td></td>
<td>2 = average</td>
</tr>
<tr>
<td></td>
<td>3 = high</td>
</tr>
<tr>
<td></td>
<td>4 = user supplied amounts</td>
</tr>
<tr>
<td>Pesticide type</td>
<td>Type of pesticide applied</td>
</tr>
<tr>
<td></td>
<td>0 = none</td>
</tr>
<tr>
<td></td>
<td>1 = herbicide</td>
</tr>
<tr>
<td></td>
<td>2 = insecticide</td>
</tr>
<tr>
<td></td>
<td>3 = fungicide</td>
</tr>
<tr>
<td></td>
<td>4 = nematicide</td>
</tr>
<tr>
<td></td>
<td>5 = plant growth regulator</td>
</tr>
<tr>
<td></td>
<td>6 = desiccant or defoliant</td>
</tr>
<tr>
<td>Number of point sources</td>
<td>Total number of point sources, both feedlots and nonfeedlots</td>
</tr>
<tr>
<td>Additional erosion indicator</td>
<td>A value estimating the amounts of erosion (in tons) originating from a gully or other sources occurring within the cell</td>
</tr>
<tr>
<td>Number of impoundment</td>
<td>-</td>
</tr>
<tr>
<td>Type of channel</td>
<td>Channel indicator</td>
</tr>
<tr>
<td></td>
<td>0 = water cell</td>
</tr>
<tr>
<td></td>
<td>1 = no definitive channel</td>
</tr>
<tr>
<td></td>
<td>2 = drainage ditch</td>
</tr>
<tr>
<td></td>
<td>3 = road ditch</td>
</tr>
<tr>
<td></td>
<td>4 = grass waterways</td>
</tr>
<tr>
<td></td>
<td>5 = ephemeral stream</td>
</tr>
<tr>
<td></td>
<td>6 = intermittent stream</td>
</tr>
<tr>
<td></td>
<td>7 = perennial stream</td>
</tr>
<tr>
<td></td>
<td>8 = other type of channel</td>
</tr>
</tbody>
</table>
Table 2. Lake Icaria landuse attribute table.

<table>
<thead>
<tr>
<th>Land Use Type</th>
<th>Manning Coefficient</th>
<th>Cropping Factor</th>
<th>Practice Factor</th>
<th>Fertilization Availability Factor (%)*</th>
<th>Surface Condition</th>
<th>Chemical Oxygen Demand (COD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn</td>
<td>0.08</td>
<td>0.26</td>
<td>1</td>
<td>67</td>
<td>0.05</td>
<td>170</td>
</tr>
<tr>
<td>Soybeans</td>
<td>0.08</td>
<td>0.31</td>
<td>1</td>
<td>0</td>
<td>0.29</td>
<td>117</td>
</tr>
<tr>
<td>Hay</td>
<td>0.13</td>
<td>0.26</td>
<td>1</td>
<td>50</td>
<td>0.29</td>
<td>80</td>
</tr>
<tr>
<td>Pasture</td>
<td>0.25</td>
<td>0.01</td>
<td>1</td>
<td>85</td>
<td>0.29</td>
<td>20</td>
</tr>
<tr>
<td>Woodland</td>
<td>0.15</td>
<td>0.04</td>
<td>1</td>
<td>0</td>
<td>0.15</td>
<td>60</td>
</tr>
<tr>
<td>Hay</td>
<td>0.35</td>
<td>0.01</td>
<td>1</td>
<td>0</td>
<td>0.00</td>
<td>65</td>
</tr>
<tr>
<td>Fallow</td>
<td>0.25</td>
<td>0.45</td>
<td>1</td>
<td>0</td>
<td>0.22</td>
<td>60</td>
</tr>
<tr>
<td>Water/Pond</td>
<td>0.99</td>
<td>0.00</td>
<td>0</td>
<td>0</td>
<td>0.00</td>
<td></td>
</tr>
</tbody>
</table>

* based on soil incorporation using chisel plow.

Table 3. Nitrogen, phosphorus, and COD ratio for different animal type.

<table>
<thead>
<tr>
<th>Animal Type</th>
<th>Design Weight (lbs)</th>
<th>Nitrogen Ratio</th>
<th>Phosphorus Ratio</th>
<th>COD Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slaughter steer</td>
<td>1000</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Young beef</td>
<td>500</td>
<td>0.60</td>
<td>0.51</td>
<td>0.50</td>
</tr>
<tr>
<td>Dairy cow</td>
<td>1400</td>
<td>1.68</td>
<td>0.92</td>
<td>1.96</td>
</tr>
<tr>
<td>Young dairy stock</td>
<td>500</td>
<td>0.46</td>
<td>0.33</td>
<td>0.70</td>
</tr>
<tr>
<td>Swine</td>
<td>200</td>
<td>0.26</td>
<td>0.27</td>
<td>0.17</td>
</tr>
<tr>
<td>Feeder pig</td>
<td>50</td>
<td>0.07</td>
<td>0.07</td>
<td>0.04</td>
</tr>
<tr>
<td>Sheep</td>
<td>100</td>
<td>0.13</td>
<td>0.06</td>
<td>0.18</td>
</tr>
<tr>
<td>Turkey</td>
<td>10</td>
<td>0.02</td>
<td>0.03</td>
<td>0.02</td>
</tr>
<tr>
<td>Chicken</td>
<td>4</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Duck</td>
<td>4</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Horse</td>
<td>1000</td>
<td>0.81</td>
<td>0.42</td>
<td>0.42</td>
</tr>
</tbody>
</table>
Figure 1. Complete architecture of integrating GIS with water quality models.
Figure 2. Primary interaction screen for data input option.
Figure 3. Threaded menus for user input on different model parameters.
Figure 4. A menu for user input of watershed parameters.
Figure 5. A menu for user input of cell parameters.
Figure 6. A menu for user input of soil parameters.
Figure 7. A menu for user input of channel parameters.
Figure 8a. A menu for user input of feedlot parameters.
Figure 8b. Interactive selection of feedlot to include in AGNPS model simulation.
Figure 9a. A menu for user input of feclot subarea information.
Figure 9b. Additional data input of user selected feedlot.
Figure 10. Specification of model results to be displayed.
Figure 11. Spatial distribution of land use in Lake Icaria watershed
Figure 12. Location of previously selected large hog feedlot unit of 1000 sows.
Figure 13. Spatial distribution of total nitrogen loading for scenario I.
Figure 14. Spatial distribution of total phosphorus loading for scenario I.
Figure 15. Spatial distribution of total nitrogen loading for scenario II.
Figure 16. Spatial distribution of total phosphorus loading for scenario II.
Figure 17. Spatial distribution of total nitrogen loading for scenario III.
Figure 18. Spatial distribution of total phosphorus loading for scenario III.
Figure 19. Spatial distribution of total nitrogen loading for scenario IV.
Figure 20. Spatial distribution of total phosphorus loading for scenario IV.
OVERALL CONCLUSION

The overall study, by combining four papers, resulted in an interactive modeling framework for planning crop and livestock production with procedures for evaluating environmental impacts of alternative management practices. Integrated (GIS modeling techniques/groundwater quality model/surface water quality model) system, which is regarded as spatial decision support system, will help planners and policy makers in evaluating environmental consequences of expanding livestock enterprise and integrating crop-livestock productions systems on watershed scale. Following are the key procedures of this system in designing an environmentally sound integration of crop and livestock production.

1. Delineation of optimal land areas for locating a number of livestock production strategies.

2. Delineation of subareas of a watershed that are environmentally suitable for land utilization of animal manure from an integrated crop-livestock production systems.

3. Assessment of nitrate leaching potential of alternative nutrient management scenarios integrating crop and livestock production systems.

4. Evaluation of effectiveness of animal manure and fertilizer management practices in reducing potential nutrient loading to surface water.
All the four procedures are performed sequentially for a complete environmental impact analysis. However, this is not a limitation of the system, procedures can be initiated in any order, if necessary data layers already exist.

All the components of the system were threaded together using one front end graphical interface. This not only hides complexities of: multi-criteria analysis techniques in locating optimal crop and livestock production sites; and modeling nutrient transport to surface and subsurface water on a watershed scale but also provides user ease of managing input/output parameters.

Although system was primarily developed to run on DEC workstation running on ULTRIX operating system but can be adopted to any other operating system after few minor changes. Major limitation of the systems are in terms of the levels of the spatial information stored in the database.

**Future Research Direction**

Most immediate need of future research in continuation of this study is to simulate air quality as effected by the livestock production units. Odor nuisances originating particularly from the area of concentrated livestock production are becoming serious concern of the society. In a sample study, not included in this dissertation, contours of odor concentration originating from a livestock point pollution source were generated by simulating Gaussian Plume Model in GRID environment of ARC/INFO
GIS. A similar procedure need to be added in this system for odor dispersion modeling to determine setback distances for residential areas.

Extending current knowledge-base of the system to include more types of soils and other land attribute data will be another area of future research to extend the utility of the system beyond the case study site. Further, this system will be more comprehensive if procedures are included to evaluate the potential economic and social impacts of integrating livestock production with cropping systems. The modified system with an economic analysis component will enable resource managers and planners in developing alternative cropping and animal production system that are not only environmentally sound but economically profitable too. The economic analysis will address technology type, scale, and location that are consistent with a given objective function as well as a set of environmental quality constraints. The social analysis component of the system will assess impacts of alternative livestock expansion strategy on rural communities and evaluate other behavioral aspects related to adoption of new farming systems. The key determinants of technology adoption will be risk and efforts required by the new system relative to the existing technology.
ACKNOWLEDGMENTS

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APPENDIX I

COPY OF PAPER II (PUBLICATION)
SPATIAL DECISION SUPPORT SYSTEM FOR PLANNING SUSTAINABLE LIVESTOCK PRODUCTION

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ABSTRACT. Recent shifts toward intensive and large confined livestock production units to enhance economic growth coupled with increased concerns for air, soil, and water quality have necessitated the development of computer-based management decision support systems for selecting environmentally sound production sites and for planning sustainable production systems. An integral part of a sustainable livestock production system is the selection of appropriate land areas that meet several environmental, socio-economic, and aesthetic constraints. Traditionally, regulatory and zoning criteria, in conjunction with manual review and overlay of land cover, soils, and topographic maps, have been used to select sites for livestock production. This approach can be both time-consuming and expensive, and the land areas delineated by this method have been shown to be problematic from the odor nuisance and water pollution standpoint. A more rational approach that narrows down large areas under consideration to a finite set of optimal sites that satisfy the environmental protection goals is needed. This paper describes the development and application of an interactive spatial decision support system to delineate optimal land areas for locating a number of livestock production strategies. The spatial decision support system is based on the ARC/INFO geographic information system and incorporates the effects of land use, soil type, topography, proximity to roads and surface water bodies, and other aesthetic and political considerations, as well as multicriteria analysis techniques. The design and implementation of the system as well as an example application involving several alternative livestock production strategies are presented.

INTRODUCTION

In the United States, livestock production represents a major economic force for many rural communities. It is the basic industry for a number of states, providing jobs and generating cash.
revenue. In Iowa, for example, the livestock industry is a major source of jobs for both rural and urban populations. It is estimated that approximately 166,000 jobs in Iowa, which represents about 12% of the 1989 workforce, are directly or indirectly linked to the livestock production industry (Iowa Business Council, 1990). In 1992, revenue from livestock activities accounted for about 55% of Iowa's cash receipt from all farming activities (Figure 1) (Iowa Farm Bureau Federation, 1994). In addition, for many rural communities, livestock production represents an important value-added industry by taking new materials such as forage and grains and transforming them into other products.

Although economically viable, the livestock industry is currently facing a number of challenging environmental problems and highly complex social issues, many of which are related to its size and geographically concentrated nature. From an agricultural perspective, the role of livestock waste in the nitrate contamination of groundwater, the nitrogen and phosphorus eutrophication of surface water, and the fate of heavy metals and pathogens in livestock wastes applied to soils are the central environmental issues. Other related social and public health issues, including odor nuisances, disposal or composting of dead animals, food safety, and animal health and welfare, also confront the livestock industry. Furthermore, the polluting effect of ammonia volatilization from livestock production systems and the contributions of nitrogen oxide and methane to global warming and of sulphur dioxide to acid rain are now receiving increased attention.

Increased emphasis on environmental quality has also placed new demands on livestock producers to ensure that their production practices are in harmony with the natural environment. Citizens are urging their local and state governments to pass land-use ordinances that control the location of new livestock facilities and to increase the level of regulations. Furthermore, as nonfarm people move into rural areas, the potential for lawsuits concerning the effects of livestock production has increased. For example, in 1990 an Iowa District Court in Boone County issued an injunction against Iowa State University's state-of-the-art Swine Research Facility because of odor complaints. Also in 1990, the Iowa Court of Appeals heard a case in which a sweet corn producer alleged that a hog producer spilled a substantial amount of livestock waste on the road near his farm, rendering over 30 acres of sweet corn unmarketable (Hamilton, 1992). Similar cases against livestock producers and related to odor and environmental degradation from livestock production have been documented in other regions of the United States. The cases exemplify some of the legal issues and environmental quality problems associated with livestock production.

Since the farm crisis, farmers have attempted to identify opportunities for expanding their economic outlook, thereby increasing individual farm profitability. In Iowa for example, a task force composed of agricultural and business leaders has suggested that expansion of the state's livestock production industry offers some potential for taking advantage of the natural and human resources, adding value to the farm commodities that are produced so well. They also argue that expansion and intensification of livestock production are needed to maintain and enhance economic development goals. However, expansion of livestock production requires exploitation of land resources and could lead to potentially deleterious effects on environmental quality. Through proper planning and siting of the livestock production units, most of the associated environmental problems can be minimized. One approach to minimizing potential environmental impact of livestock production and odor complaints from rural residents is to provide a buffer between them. Spatial decision support systems, developed on the basis of geographic information systems (GIS), play a major role.

Recently, the development and application of GIS for efficient handling, manipulation, and analysis of spatial information have substantially improved the identification of land areas suitable for siting and developing livestock production enterprises. The integration of Boolean and logical analysis, fuzzy knowledge, and multicriteria evaluation techniques with GIS provides
FIGURE 1. Revenue and Cash Receipts Generated from Iowa Agriculture.
the decision-maker with an advanced tool to assess the various alternatives on the basis of conflicting criteria and multiple objectives. In traditional site-selection procedures, identification of potentially suitable land areas, because of restrictions on time and capital resources, was based solely on regulatory limits, municipal bylaws, and manual overlay of topographic, soil, and land-use maps. By using GIS, associated time and capital expense can be drastically reduced, and economic development and environmental protection goals can be incorporated into the site-selection process.

In the study reported here, an ARC/INFO GIS-based spatial decision support system was developed to facilitate delineation of land areas that are suitable for the location of various livestock production strategies. This study is part of a comprehensive project that attempts to evaluate the environmental, social, and economic impacts of livestock production expansion in Iowa. This paper is intended to demonstrate the use of GIS in identifying optimal land areas for livestock production, taking into account several environmental, aesthetic, and economic constraints. An example application of the spatial decision support system to the Lake Icaria watershed in southern Iowa is presented.

Southern Iowa was chosen for the study because its landscape is representative of the western Corn Belt and Great Plains — the so-called middle border. Also, this region is agriculturally dependent, and livestock production, grain, and livestock processing industries are frequently identified as potential expansion targets. Concomitantly, southern Iowa has become increasingly dependent upon surface water for recreation and drinking. Hence, the expansion of value-added livestock production, with its large by-products and waste stream, in conjunction with the region's growing rural population, have placed economic development and environmental quality on a collision course.

The rest of this paper is structured in several sections as follows. First, an overview of the GIS and spatial decision support system is presented. Then, some of the multicriteria site-selection techniques and the hierarchical optimization/spatial weighting technique used in the livestock production and site-selection spatial decision support system are briefly discussed. The spatial decision support system is described primarily from the user's point of view. Finally, the remaining part of the paper, except for the summary and conclusions, is devoted to describing an example application of the spatial decision support system for livestock production planning.

**METHODOLOGY**

**An Overview of GIS**

The GIS technology has come a long way in the past decade and continues to evolve. New application areas have been found, including agriculture, forestry, hydrology, resource management, and coastal resource management; new products have appeared in the marketplace; dramatic improvements continue in the capability of hardware and software operating platforms; and large volumes of data sets have become available. In fact, since its initial development in the early 1960s, the GIS technology has grown rapidly to become a valuable tool in the analysis and management of spatial ecological problems. Defined by Burrough (1986, p. 6) as "a powerful set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world," the GIS technology supports a wide range of spatial analysis that includes processes to create new classes of spatial objects, analyze the locations and attributes of objects, and perform spatial modeling using multiple classes of objects and the relationship between them.

A GIS also includes primitive operations for (a) calculating the centroid of polygons; (b) performing geometric operations on lines, points, and polygons; (c) building buffers around spatial objects; and (d) determining the shortest path through a spatial network. The functionality of
leading GIS products and software as well as the potential application areas continue to grow, with no obvious end in sight. Thus, the GIS technology has been widely adopted in local, state, and federal resource planning agencies as well as in the utilities and transportation industry.

In resource management and planning, several advantages of a GIS have been identified (Tim & Jolly, 1994). It provides resource planners and decision-makers with a set of tools to analyze spatial data effectively, and when combined with other information (e.g., economic, demographic) and with computer-based systems (e.g., spatial and process modeling, expert systems), can provide a flexible management decision support system. Typical examples of recent GIS applications in natural resource management and site planning include characterization and prioritization of hazardous waste sites (Soby, Connolly, & Folsom, 1992); selection of optimal sites for land application of sewage sludge (Younos & Metz, 1988); modeling changes in water quality from land use activities (Jao & Walsh, 1992; Johnston, 1989); delineation of critical areas of nonpoint pollution and planning of pollution control strategies (Tim & Jolly, 1994; Tim, Mostaghimi, & Shanholtz, 1992); and delineation of wetland protection zones (Zimmont, 1993). In these applications, GIS not only provide the ability to integrate and examine disparate spatial data but allow large-scale ecological models to be constructed and tested. As the diversity of users and uses of GIS increase, more and more application areas of GIS are likely to emerge.

Spatial Decision Support System

In recent years, the livestock production industry in the United States has undergone considerable changes. The number of animals in a given production unit has increased enormously, while the production system has become more concentrated, with a general trend toward larger units. With these changes, the following environmental quality issues emerge: (a) Given a finite land base (e.g., a watershed constrained by landscape characteristics, including soils, land use and land cover, and topography), what type and size of livestock production facilities (or units) can be located to maintain the complementary relationship between crop and livestock production? (b) Where should these facilities be located within the landscape to minimize environmental problems, including odor and water pollution? Answers to these questions require the use of spatial decision support systems that (a) provide geoprocessing capability for evaluating a large number of alternative and competing land areas to obtain an optimal site; (b) facilitate the introduction of multiple criteria into the site-selection process; (c) enable the decision-maker to change the relative importance of a criterion to reflect the different objectives and opinions of the "players" involved in the site-selection process; and (d) present, in an interactive mode, the results of the analyses in a variety of media that help the decision-maker understand them.

Depending on the application area, the definition of a spatial decision support system can take many forms. In the simplest and most general form, a spatial decision support system is defined as a computer-based system that integrates spatial database management, spatial (or process) modeling, and map display capabilities to help decision-makers analyze semi- or ill-structured problems (Armstrong et al., 1991; Densham, 1991). The system helps decision-makers generate solutions that are optimal with respect to a set of criteria and analyze trade-offs between those criteria. Its primary functions are to (a) provide the mechanisms for interactive input and manipulation of large volumes of spatial data; (b) allow representation of the complex spatial relationships and structures that are common in spatial data, including analytical techniques that are unique to both spatial analysis and modeling; (c) provide output in a variety of spatial forms; and (d) facilitate decision-making and improve the effectiveness of the decision made (Turban, 1988).

Spatial decision support systems are explicitly designed to provide the user with an interactive decision-making environment that enables geographic data analysis and spatial modeling.
to be performed in an efficient and flexible manner. Generally, these systems have evolved in parallel with management decision support systems developed for the business community. Here, the management decision support systems are used for such activities as strategic planning, scheduling of business operations, and investment appraisals. Spatial decision support systems extend these capabilities to provide a rational and objective approach to spatial decision analysis and enable the decision-maker to assess the implications of the trade-offs between alternatives. In livestock production, which is the central theme of this paper, a spatial decision support system assists the decision-maker in planning sustainable (economically profitable, environmentally sound, socially acceptable) production systems.

A number of prototype spatial decision support systems have been developed for site planning and to facilitate analysis of ill-structured (environmental) problems. Openshaw, Carver, and Fernie (1989) described a spatial decision support system, developed with ARC/INFO GIS, to delineate feasible sites for the disposal of radioactive waste. Carver (1991) incorporated multi-criteria evaluation techniques with GIS to obtain a spatial decision support system that identifies suitable sites for the disposal of radioactive waste. Diamond and Wright (1989) described the development of a spatial decision support system that enables planners to address the multiobjective nature of a site-screening process. In their study, a rule-based "expert" system and a multiobjective integer programming model were linked to the GRASS GIS (USACERL, 1988) to obtain an interactive spatial decision support system for environmental planning and management. Tomlin and Johnston (1988) described ORPHEUS, a prototype spatial decision support system for environmental planning and land-use allocation. In the following section, details of the livestock production site-selection spatial decision support system are presented.

Overview of Site Selection Techniques

The techniques for evaluating alternative choices in land suitability assessment are many and varied. Generally, they range from manual review of land-use/land-cover records in conjunction with municipal bylaws to the map overlay technique pioneered by McHarg (1969) and to more complex multi-criteria optimization techniques described in Cochrane and Zeleny (1973). The multi-criteria optimization techniques include such methods as ideal point analysis, concordance-discordance analysis (otherwise known as the conjunctive-disjunctive constraint procedure), and hierarchical optimization (Jankowski & Richard, 1994). These techniques have been described in detail in McCrimmon (1977) and Wright, ReVelle, and Cohon (1983); therefore, an exhaustive treatment is unnecessary in this paper.

Briefly, however, the ideal point analysis technique is based on the deviation of a set of ideal solutions (or feasible regions) from a set of efficient solutions that are weighted according to specified criteria governing the site-selection process. Since the ideal solution rarely exists, this technique involves the use of a best compromise solution that minimizes the distance from the "theoretical" ideal solution. Carver (1991) expressed this minimum distance, $d_{\text{min}}$, as follows:

$$d_{\text{min}} = \sum_j (1-e_{ij}) w_j$$

(1)

where $w_j$ is the $j$th criterion weight, and $e_{ij}$ is the standardized score defined by:

$$e_{ij} = \frac{\max S_{ij} - S_{ij}}{\max S_{ij} - \min S_{ij}}$$

(2)

where $S_{ij}$ is the raw score of alternative $i$ according to criterion $j$ derived from an evaluation matrix $S$, and $\max S_{ij}$ and $\min S_{ij}$ are, respectively, the maximum and minimum values.
of the raw score. To evaluate the attractiveness of an alternative \( i \), the decision-maker weights the distances from the ideal solution with respect to individual criterion considered in the analysis.

The concordance-discordance analysis technique is based on pair-wise comparison of alternative choices (a real choice and a hypothetical alternative choice) in which the feasible region is characterized by increasing high dominance indices (Voogd, 1983). For an alternative to dominate, its cumulative score for all the attributes must be at least as good as or better than that of another alternative. By using a predefined minimum concordance index (characterized by the AND logical operation) and a maximum discordance index (characterized by the OR logical operation), a dominance matrix can be generated that shows the outranking relationship of an alternative \( a \). The concordance index of an alternative \( a \) with respect to competing alternative \( a' \) can be represented (Carver, 1991) as follows:

\[
C_{a|a'} = \frac{\sum_{j \in a} w_j}{\sum_{j} w_j}
\]  

where \( \sum_{j \in a} w_j \) is the sum of weights of the criterion for which \( a \geq a' \), and \( \sum_{j} w_j \) is the sum of weights for all criteria \( a \geq a' \). The discordance index of alternative \( a \) with respect to \( a' \) is the ratio of maximum difference between weighted scores when \( a < a' \) and maximum difference between weighted scores for the criterion yielding the maximum difference between the weighted scores when \( a < a' \) for all alternatives. In this technique, a score of 1 is accumulated each time an alternative solution set outranks the other. By direct summation of the dominance score, the index of preferability of an alternative solution can be determined and the site ranked accordingly.

The hierarchical optimization technique attempts to rank all criteria according to their respective priorities. Subsequent optimization of the process is carried out in a stepwise manner such that higher-order ranking criteria are maximized before low ranking criteria. The resulting evaluation matrix can be truncated according to the goals of the decision-maker. In this technique, the decision-maker assigns preferences to the high-level objectives and then assesses the instrumentality of each criteria in attaining those objectives. In so doing, direct assessment of the high-level objectives results in inferences being drawn about intercriteria weightings.

The multicriteria site-analysis techniques briefly described above are by no means exhaustive. Other approaches based on fuzzy knowledge and neural networks have been proposed (Hall & Wang, 1992). Diamond and Wright (1989) used a rule-based expert system with GIS to develop a spatial information system for land-use planning. Wang (1994) used artificial neural networks and GIS to develop a land suitability assessment tool for agricultural production planning.

**Overview of Our Model**

The livestock production planning and site-selection spatial decision support system described in this paper combines the hierarchical optimization technique and spatial weighting scheme, spatial databases, and ARC/INFO GIS (ESRI, 1992) to facilitate evaluation of trade-offs between livestock production expansion (and economic development) and environmental quality. The spatial weighting scheme adopted in this study has the following characteristics: (a) a set of available alternatives with specified criteria and criteria ratings; (b) a process for comparing criteria by obtaining numerical scaling of criteria ratings (intracriteria preferences) and numerical weights across criteria (intercriteria preferences); (c) a well-specified objective function for aggregating the preferences into a single number for each criterion; and (d) a rule for choosing the alternative (or ranking of alternatives) on the basis of the highest cumulative
weight. Using this scheme, the desirability or suitability of a given land area \( a \) (represented in ARC/INFO as a grid cell) is expressed as follows:

\[
S_{Aj} = \sum_{i=1}^{N} f_i w_j
\]

where \( S_{Aj} \) is the cumulative suitability score of the land area \( a \) for a given criterion \( j \); \( f_i \) is the rating (or numeric score) of a criterion and represents a unique spatial attribute (e.g., slope, aspect, proximity to blueline stream); \( w_j \) is the corresponding weight of the criterion; and \( N \) is the total number of discrete land areas (grid cells) in, for example, a watershed. The rating \( f_i \) (range from 0 to 10) of a particular criterion reflects its relative importance, while the weight, \( w_j \) (range from 0 to 100), allows the decision-maker to specify the importance of a particular criterion relative to other criteria.

In evaluating the suitability of a land area \( a \), the spatial modeling capabilities of the ARC-GRID module of ARC/INFO were used. Figure 2 illustrates the criteria and criteria ratings.

FIGURE 2. Procedure Flowchart for Delineating Suitable Sites for Sustainable Livestock Production.
Table 1 summarizes the steps involved in the analysis. The first step in obtaining a composite suitability map of a potential land area involved the generation of map coverages, the assignment of criteria ratings (f_i) to individual criteria through the remap table, and the assembly of criteria and weight grids. Once these grid coverages have been assembled, a composite cumulative suitability grid can be created by using the spatial modeling tools in ARCGRID. Thus, the composite suitability grid was calculated by using:

\[
\text{Suitability Grid} = \sum \text{Criteria i grid} \times \text{Criteria i weight}
\]

in which Criteria 1 can represent aspect, slope, permeability, road proximity, or land-use class. Numeric scores that correspond to suitability classes are assigned to each grid. The values in the suitability_grid, which can exceed 100, are then rescaled to a value ranging from 0 to 100, with 100 representing very high suitability. In ARCGRID, rescaling of the composite suitability_grid was performed by using the expression:

\[
\text{Scaled Suitability Grid} = \frac{\text{Suitability Grid} \times 100}{\text{Max. value of Suitability Grid}}
\]
The suitable land areas in the scaled suitability grid can be identified either on the basis of their relative or absolute suitability. In the relative suitability classification, the land grid cells in the scaled suitability grid were categorized as not suitable, marginally suitable, moderately suitable, and highly suitable, depending on their respective cumulative scores. In the absolute suitability assessment, only one suitabili classification can be obtained and no intracriteria preferences were considered (e.g., if a slope range of 0–2% is preferred, a score of 10 is assigned and other slope ranges are scored zero).

**System Implementation**

*The GIS*

Two GIS software programs — ARC/INFO developed by the Environmental Systems Research Institute in Redlands, California, and ERDAS developed by Earth Resources Data Analysis Systems, Inc. of Atlanta, Georgia — were used extensively in the development of the spatial decision support system for livestock production planning and site selection. The ARC/INFO software, primarily the ARCGRID module, was used in the manipulation, analysis, and modeling of spatial and nonspatial data. ERDAS was used primarily in the classification and processing of land use and land cover data. Morehouse (1992) and Maguire (1992) present comprehensive overviews and profiles of ARC/INFO and ERDAS GIS software, respectively.

Summarily, the ARC/INFO software uses a hybrid vector data model to manage both locational and thematic data. Locational data are represented in ARC using a topological data model, while thematic data in INFO are represented by a relational data model. The data model consists of a georelational model that combines a specialized geographic view of the data with a conventional relational database model structure. Within ARC, a set of unique spatial operators facilitate data analysis. These operators include coverage operators for point, line, and polygon overlays; spatial interpolation using conventional techniques and geostatistics; map projection and coordinate transformation; and Boolean operations and logical combinations of attribute data (Morehouse, 1992).

The ERDAS software is an image processing and geographic data analysis program that supports some basic GIS functions such as data capture, data manipulation and analysis, and data display (Maguire, 1992). The software program is based on the raster data structure that tessellates geographic space into regular square cells or pixels. Generally, ERDAS is organized into several modules that support basic functions such as input/output processing, multivariate image processing and analysis, raster-based modeling (using GISMO), 2.5D and 3D topographic modeling, and other specialized modules for software development and analysis of attribute databases (Maguire, 1992). The ERDAS-ARC/INFO Live Link also provides users with advanced raster-vector data integration and conversion.

*The User Interface*

The livestock production planning and site-selection spatial decision support system is designed to run on a DEC workstation in the UNIX operating environment. The main component of the system design is the user-friendly graphical interface, which allows the user to control most of the system by direct interaction using a mouse. The graphical user interface (GUI) allows the user immediate access to, and direct manipulation of, all relevant elements of the spatial decision support system. Figure 3 shows the main interaction screen of the system. The screen follows the standard established for modern GUIs.

In operating the system, the user inputs the various GRID coverages for all the criteria involved in the analysis (e.g., aspect, land slope, soil drainage class, hydrography, etc.). Then, the user assigns the corresponding weights. Upon specification of the criteria and weight grid coverages, the user may opt to edit the remap table or view the input grids (Figure 3). These options are provided as icons on the right side of the screen. Clicking on the “Process Selection” icon
initiates spatial modeling using ARC/INFO GRID. At this point, the system opens ARCGRID and performs the modeling using the hierarchical optimization/spatial weighting procedures described earlier. The user can display the results showing suitable land areas in ARCPLOT and ARCVIEW. Hardcopy of the selected sites can also be obtained from a sequence of ARC macro languages developed to facilitate spatial modeling. In general, the spatial decision support system provides immediate response to changes in the criteria; whenever criteria are directly changed, the graphical screen display is updated to reflect the new ranking of suitable sites.

EXAMPLE APPLICATION

Description of Study Area

The spatial decision support system described in this paper was applied to the Lake Icaria watershed to delineate suitable land areas for implementing a number of livestock production
strategies. The 7,075-ha (17,280-acre) Lake Icaria watershed is located in Adams County about 8 km (5 miles) from Corning, Iowa, and approximately 112 km (70 miles) southwest of Des Moines. Drainage from the watershed empties into Lake Icaria, which is the major source of rural drinking water for the region. Lake Icaria has a surface area of about 280 ha (700 acres) and is part of the 760-ha (1,900-acre) Lake Icaria Recreational Area, which provides facilities for boating, fishing, swimming, camping, and other recreational activities. Lake Icaria also provides water for domestic and industrial use within Corning and surrounding towns. A creamery, the second largest in Iowa, is located at Corning and produces about 4 million kg of butter annually. Much of the water for food processing at this industry is obtained from Lake Icaria.

Soils in the Lake Icaria watershed are prairie-derived and include the Macksburg-Winterset (nearly level to gently sloping), Sharpsburg-Adair (nearly level to moderately steep), and Shelby-Sharpsburg (moderately sloping to steep) soil associations. Agricultural land use and land cover in the Lake Icaria watershed consist primarily of row crops integrated with livestock (hog, beef cattle, poultry, sheep) production enterprises (Figure 4). Cropped areas compose approximately 49% of the watershed, while 4.6% of the watershed area is identified as idle land. Pasture covers 22.4% of the watershed area, while 11.6% of the watershed is placed under the cropland reserve program. The remaining 12.5% of the Lake Icaria watershed consists of water bodies, farmsteads, roads, and parkland.

Raising livestock, primarily hogs and cow-calf herds, is an important enterprise for farmers in the watershed. A recent field survey identified 580 cattle and several medium-scale hog-confinement operations in the watershed. The cattle herds are divided between 14 pasture operations distributed throughout the watershed. The hog-confinement operations are located adjacent to parkland on the north side of the watershed. In general, the livestock operations in the Lake Icaria watershed show significant overgrazing with about 50 ha (125 acres) of pasture land showing severe soil-erosion problems. A recent preliminary soil-erosion study of the watershed also indicates that about 2,600 ha (6,500 acres) of cropland have soil-erosion rates that exceed established tolerable limits. Almost all of the soil eroding from the watershed ends up as siltation within the lake, causing an annual loss in storage capacity of 17,500 m³.

Livestock Expansion Strategies

Table 2 summarizes the various livestock expansion strategies for the Lake Icaria watershed example application of the spatial decision support system. These expansion strategies were designed with the objective of demonstrating the applicability and utility of the site-selection spatial decision support system and were chosen to represent the production strategies currently being promoted in southern Iowa. Associated with each production strategy are landscape characteristics (e.g., contiguous land area requirement), production size, nature and amount of manure (liquid or solid) generated, and acceptable manure-management practices.

Results of Example Application

The spatial decision support system described in this paper was used to delineate suitable land areas in the Lake Icaria watershed for the siting of several livestock production strategies listed in Table 2. This paper presents only the delineated land areas that are suitable for large- and small-scale livestock production strategies. Figures 5 and 6 show the optimal land areas, aggregated on a land tract level, for siting the indicated livestock production strategies, given the various social (e.g., aspect, distance to roads), economic (e.g., profitability of the strategy represented by size of production), and environmental (proximity to surface water, soil permeability, slope) constraints. Figures 7 and 8 show the corresponding suitable land areas for the location of small-scale livestock production units. In general, for the 7075-ha Lake Icaria
FIGURE 4. Spatial Distribution of Land Use in the Lake Icaria Watershed.
TABLE 2. Livestock Production Expansion Strategies

<table>
<thead>
<tr>
<th>Production strategy</th>
<th>Small</th>
<th>Medium</th>
<th>Large</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hog (Confinement)</td>
<td>100 sows</td>
<td>250 sows</td>
<td>1,000 sows</td>
</tr>
<tr>
<td>0.8 ha&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.2 ha</td>
<td>4 ha</td>
<td></td>
</tr>
<tr>
<td>2,080,236 litres&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5,319,818 litres</td>
<td>21,279,270 litres</td>
<td></td>
</tr>
<tr>
<td>Hog (Deep-bedded)</td>
<td>100 sows</td>
<td>250 sows</td>
<td>500 sows</td>
</tr>
<tr>
<td>1 ha</td>
<td>1.2 ha</td>
<td>2 ha</td>
<td></td>
</tr>
<tr>
<td>612.9 tonnes&lt;sup&gt;c&lt;/sup&gt;</td>
<td>2,030.3 tonnes</td>
<td>4,631.3 tonnes</td>
<td></td>
</tr>
<tr>
<td>Hog (Pasture)</td>
<td>50 sows</td>
<td>100 sows</td>
<td>250 sows</td>
</tr>
<tr>
<td>0.8 ha</td>
<td>1.2 ha</td>
<td>1.6 ha</td>
<td></td>
</tr>
<tr>
<td>3.6 ha of pasture</td>
<td>7.1 ha of pasture</td>
<td>19 ha of pasture</td>
<td></td>
</tr>
<tr>
<td>193.2 tonnes</td>
<td>387.4 tonnes</td>
<td>967.1 tonnes</td>
<td></td>
</tr>
<tr>
<td>Beef (Rotational grazing)</td>
<td>40 cows</td>
<td>100 cows</td>
<td>250 cows</td>
</tr>
<tr>
<td>0.8 ha</td>
<td>1.2 ha</td>
<td>1.6 ha</td>
<td></td>
</tr>
<tr>
<td>25.9 ha of pasture</td>
<td>64.8 ha of pasture</td>
<td>161.9 ha of pasture</td>
<td></td>
</tr>
<tr>
<td>54.4 tonnes</td>
<td>136.1 tonnes</td>
<td>340.2 tonnes</td>
<td></td>
</tr>
<tr>
<td>Beef (Conventional grazing)</td>
<td>40 cows</td>
<td>100 cows</td>
<td>250 cows</td>
</tr>
<tr>
<td>0.8 ha</td>
<td>1.2 ha</td>
<td>1.6 ha</td>
<td></td>
</tr>
<tr>
<td>40.5 ha of pasture</td>
<td>101.2 ha of pasture</td>
<td>253 ha of pasture</td>
<td></td>
</tr>
<tr>
<td>54.4 tonnes</td>
<td>136.1 tonnes</td>
<td>340.2 tonnes</td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup>Minimum contiguous area required for facility.
<sup>b</sup>Manure (waste) generated by production strategy.
<sup>c</sup>Metric tonnes (1 metric tonne = 1.094 tons).

watershed, about 10, 57, 14, and 22 ha of land area were suitable for siting large-scale deep-bedded hog, large-scale hog-confinement, large-scale hog pasture, and large-scale beef-grazing systems, respectively. For the small-scale livestock production strategies (Table 2), about 125, 116, 183, and 208 ha of the watershed land areas were found to be suitable. These differences in the suitable land areas for large- and small-scale production systems reflect contiguous land area requirement as well as the nature of each production system. The location of existing livestock production units in the Lake Icaria watershed matched closely with the sites selected by the spatial decision support system developed in this study. This agreement provides some level of confidence with the capability and applicability of the spatial decision support system for site-selection and planning livestock production systems.

SUMMARY AND CONCLUSIONS

To address the environmental pollution problems associated with livestock production, local, state, and federal governments have passed a number of enabling and far-reaching regulations. Also, lawsuits seeking to reduce odors and other nuisances are emerging, with the majority in the swine/hog production sector. The general public is becoming more conscious of the impact that livestock production can have on the quality of air, soil, and water. Consequently, there is tremendous pressure on livestock producers to ensure that all forms of pollution resulting from their production practices are controlled. However, the potentially adverse environmental impacts of livestock production can only be minimized if resource managers, farm planners, and decision-makers are equipped with decision support systems for adequate planning of the sustainable production systems. An integral part of sustainable livestock production planning is the delineation of optimal production sites.
The selection of suitable sites for locating any facility is a complex process. The decision-maker must be able to manipulate large amounts of geographic data and address multiple planning objectives in an efficient and systematic manner. Traditional site-selection techniques have proved inefficient because of the large amounts of data required and the multicriteria nature of the process. Therefore, the use of spatial decision support systems for livestock production planning and site selection is a cost-effective alternative that allows incorporation of numerous variables as well as efficient handling of large amounts of data. These computer-based
systems facilitate delineation of alternative siting strategies that are consistent with specified planning objectives.

This paper described a spatial decision support system for planning livestock production, specifically for delineating suitable land areas for locating the facility. The spatial decision support system, which uses hierarchical optimization, spatial weighting techniques, and ARC/INFO GIS, can improve decision-making when several criteria are involved and a large number of
alternative sites are to be evaluated. When applied to the Lake Icaria watershed, the spatial decision support system shows great promise as an efficient and cost-effective tool for addressing some of the environmental problems associated with livestock production. Compared to traditional site-selection techniques, the spatial decision support system enables disproportionate allocation of weights, which gives the decision-maker added flexibility to assess the relative importance of a criterion. It also provides an interactive framework and user-friendly spatial modeling environment that the planner or decision-maker can use to incorporate physical,
FIGURE 8. Suitable Land Areas (Aggregated at the Tract Level) for Siting Small-Scale: (a) Conventional Beef-Grazing, and (b) Hog Deep-Bedded Systems. Location: Lake Icaria Watershed, Adams County, IA.

Although the spatial decision support system described in this paper is an advancement in decision analysis for planning sustainable livestock production systems, the system clearly needs continued refinement. First, application of the spatial decision support system to more complex decision-making is required to further verify its feasibility and capability. Second,
integration of other multicriteria decision-making techniques into the existing system is needed to increase the applicability of the system and extend the usefulness of GIS for spatial decision-making. Finally, incorporation of "expert" systems and process models into the existing system would extend its usefulness.

Acknowledgement: The support of the Leopold Center for Sustainable Agriculture, Iowa State University is gratefully appreciated.

REFERENCES


APPENDIX II

LISTING OF SITE SELECTION SYSTEM PROGRAM
Command name: ss_start_siteselection
Language: ami

Purpose: start site selection menu front end

Arguments:
Variable name, I/O, Type, Definition

History:
Author/Site, Date, Event

Dharmesh Jain, Aug 20, 93
Dharmesh Jain, Sep 12, 93, modified
Dharmesh Jain Nov 5, 93, modified

Notes:

&* &s
V &.debug .FALSE.
&*
& confirm running in grid
&*
&if [show program] ne GRID &then &do
& &type Site selection program must be run from within grid.
& &type Please enter grid and restart the site selection system.
& &return
&end
&fullscreen &popup
&*
& set error level and response
&*
 &severity &error &routine cleanup
&if % .debug% &then &type Entering ss_create_outputs
&*
& setup aml and menu paths
&*
 &sv .OLDAMLPATH [show &amlpath]
 &sv .OLDMENOPATH [show &menupath]
 &menupath /home/dharmesh/sitesel/atool/menu
 &amlpath [show &amlpath] /home/dharmesh/sitesel/atool/aml
 &amlpath [show &amlpath] /home/dharmesh/sitesel/atool/aml
 &* &remove all .SS_* variables
 &*
 &delvar .SS_*
&*
& start main menu now
&*
 &pop title2.txt
 &kill.aml
 &menu ss_main.menu &stripe 'A Spatial Decision Support System'
 &return
 &routine cleanup
Type error encountered in ss_load_settings. Cleaning up and exiting.
run ss_cleanup_menu
stop
/* Spatial Information Support Systems Lab
   Agricultural and Biosystems Engineering Department
   Iowa State University AMES IA
   */
/* Command name: ss_main
   Language: aml
   */
/* Purpose: main program for site selection analysis system
   */
/* Arguments:
   Variable name, I/O, Type, Definition
   */
/* def_name, I, str, input def file name including path
   */
/* History:
   Author/Site, Date, Event
   dharmesh jain, 11.2.93
   dharmesh jain, 11.7.94
   dharmesh jain, 12.5.94 Now will load knowledge-base in LISP.
   Notes: def file contains input grids, remap tables, and weight values
   plus other misc information.
   */
/* read in def file name
   */
&args def_name
&if [null %def_name%] &then &do
  &type USAGE: ss_main <def file name including path>
  &return
&end
&if [exists %def_name% -file] &then &do
  &type %def_name% does not exist. Exiting program.
  &return
&end
/* set error level and response
   */
&severity &error &routine cleanup
/* set debug status
   */
&sv .debug .FALSE.
/* confirm GRID is running
   */
&if [show program] ne GRID &then &do
  &type Please run ss_main of the Generic Site Selection System in GRID
  &return
&end
/* set aml paths
   */
&sv .SS_OLDAMLPATH2 [show &amlpath]
&amlpath [show &amlpath] /home/dharmesh/sitesel/atooll/aml
/* process user input parameters 
*/ 
&run ss_proc_def_file %def_name%
&if %SS_ERROR% &then &do
 &type Error occurred in input definition file. Please correct and &type run again.
 &return
 &end

/* check user input parameters for correctness 
*/
&run ss_check_inputs
&if %SS_ERROR% &then &do
 &type Error occurred in input definition file. Please correct and &type run again.
 &return
 &end

/* create remap grids 
*/
&run ss_remap_ingrids

/* create elimination grids 
*/
&run ss_create_elim

/* create weight grid 
*/
&run ss_create_weight_grid

/* calculate statistics 
*/
&run ss_calc_stats

/* create outputs 
*/
&run ss_create_outputs

/* if %debug% &then &do 
*/
/* display resulting selection grid 
*/
&popup %SS_STATNAME%
quit
&mess &pop

&if [query 'Do you want to create graphic file for PS output'] &then &do
ap
mape ss sitegrid
&sv grafile sites
&sv animal_type = [response 'Enter the title, Technology type']
pagesize 8.5 11
 box 0 0 8.5 11
 mapunits meters
 maplimits 0.5 0.5 8 9
 mappos cen cen
 startmap &grafile%
textset font
textsymbol 16
 linecolor 1
 move 4 10
textsize .4 .4
text 'LAKE ICARIA: ADAMS COUNTY' cc
textsize .3 .3
 move 4 9.6
text 'Suitable Sites for Livestock Production' cc
move 4 9.2
/*text 'Technology:' cc
text %animal_type% cc
/*move 4.5 1
/*textsize .2 .2
/*text 'Tech: Deep Bed - M; 3 acres; 0% cutoff; non absolute remapping' cc

/* gridpaint s3_sitegrid # linear # gray
shadeset coloxnames
gridnodatasybol 26
gridshades s3_sitegrid value sitegrid.rem
lineset plotter.lin
linesymbol 6
/* arcs /home/dharmesh/icaria/boundary
polygons shades /home/dharmesh/icaria/waterbodies 77
linesymbol 4
arcs /home/dharmesh/icaria/tracts
linesymbol 4
arcs /home/dharmesh/icaria/boundary

textsfont
textsfont 12
linesymbol 5
/* &sv scale [show mapscale]
/* scalebar 3.5 1 3
lineset plotter.lin
linesymbol 4
map end
&do &until %donee%
&sv done = [query 'OK']
&end
makrgraph %grafile% # 2
quit
&end
&do &until %donee%
&if [query 'Evaluate NL Potential for Individual Sites'] &then &do
/* quit
  &r aetry.am1
  quit
  &r tab.am1
  &pop lisp.txt
/* &sys cc conv.c
&sys a.out
/* &pop nl.txt
&sys echo '(load "test.lsp")' | lisp
&sys char.out
/* 27thaug &end
/* addition on 19th aug
&r nl.am1
&r shadnl.am1
/*dropitem /home/dharmesh/icaria/soil.pat /home/dharmesh/icaria/soil.pat nlf
/*dropitem /home/dharmesh/icaria/soil.pat /home/dharmesh/icaria/soil.pat test8#
/*dropitem /home/dharmesh/icaria/soil.pat /home/dharmesh/icaria/soil.pat
&r drop.am1
  kill test8
&end
&else &if [query 'Evaluate NL Potential for Whole Watershed'] &then &do
/* quit
  &r sewsh.am1
  quit
  &r tab.am1
  &pop lisp.txt
/* &sys cc conv.c
&sys washed.out
/* &pop nl.txt
&sys echo '(load "test.lsp")' | lisp
&sys char.out
/* 27thaug &end
/* addition on 19th aug
&r nl.am1
&r shadnl.am1
/*dropitem /home/dharmesh/icaria/soil.pat /home/dharmesh/icaria/soil.pat nlf
/*dropitem /home/dharmesh/icaria/soil.pat /home/dharmesh/icaria/soil.pat test8#
/*dropitem /home/dharmesh/icaria/soil.pat /home/dharmesh/icaria/soil.pat
& r drop.aml
kill test8
&end

="/m ess &on
/* &end
&else &type Nitrate Leaching Potential Evaluation is not opted
&sv donee = [query 'Hope you are done with assessment of Nitrogen leaching potential']
&end
grid
/*
/* cleanup
/*
&run ss_cleanup no
&return; &return

/*
/* error cleanup routine
/*
&routine cleanup
&type An Error has occurred in the main site selection program.
&type Error cleanup in progress. Please contact the GIS facility for help.
&run ss_cleanup yes
&return; &return
set error level and response
severity error routine cleanup
if %.debug% then type Entering ss_create_outputs
/* create settings file */
if [exists %.SS_SETTINGS% -file] then
sv junk [delete %.SS_SETTINGS% -file]
sv fileunit [open %.SS_SETTINGS% status -write]
if %status% ne 0 then do
  sv fileunit [open %.SS_SETTINGS% status -write]
  !type Unable to open file %.SS_SETTINGS% due to error %status%
  run ss_cleanup_menu
  stop
end
/* write information out now */
do x = list .SS_CELLSIZE .SS_WINDOWGRID .SS_CUTOFF .SS_MINAREA .SS_OUTNAME .SS_WEIGHTNAME .SS_STATNAME
sv status [write %fileunit% [value %x%]]
if %status% ne 0 then do
  !type error writing to %.SS_SETTINGS% file
  run ss_cleanup_menu
  stop
end
end
do x = 1 to 10
sv status [write %fileunit% [value .SS_USE%\x%]]
if %status% ne 0 then do
  !type error writing to %.SS_SETTINGS% file
  run ss_cleanup_menu
  stop
end
sv status [write %fileunit% [value .SS_GRID%\x%]]
if %status% ne 0 then do
  !type error writing to %.SS_SETTINGS% file
  run ss_cleanup_menu
  stop
end
&type error writing to %.SS_SETTINGS% file
&run ss_cleanup_menu
&stop
&end
&sv status [write %fileunit% [value .SS_REMAP\%x%]]
&if %status% ne 0 &then &do
    &type error writing to %.SS_SETTINGS% file
    &run ss_cleanup_menu
    &stop
&end
&sv status [write %fileunit% [value .SS_WEIGHT\%x%]]
&if %status% ne 0 &then &do
    &type error writing to %.SS_SETTINGS% file
    &run ss_cleanup_menu
    &stop
&end
&end

/*
/* close file
/*
&sv status [close %fileunit%]
&return

&routine cleanup
&Type error encountered in ss_save_settings. Cleaning up and exiting.
&run ss_cleanup_menu
&stop
/* Spatial Information Support Systems Lab
/* Agricultural and Biosystems Engineering Department
/* Iowa State University AMES IA
/*
/* Command name: ss_load_settings
/* Language: ami
/*
/* Purpose: load settings for generic site selection main menu
/*
/* Arguments:
/*  Variable name, I/O, Type, Definition
/*
/* History:
/*  Author/Site, Date, Event
/*
/* Dharmesh Jain, 24 April, 1993, initial coding
/* Dharmesh Jain, 26 April, 1993, modified
/* Dharmesh Jain, 28 April, 1993, modified
/*
/* Notes:
/*
/*
/* set error level and response
/* severity &error &routine cleanup
&if %.debug% &then &type Entering ss_create_outputs
/*
/* open settings file for reading
&if ^ [exists %.SS_SETTINGS% -file] &then &do
 &type Error: %.SS_SETTINGS% does not exist.
 &return
 &end
&sv fileunit [open %.SS_SETTINGS% status -read]
&if %status% ne 0 &then &do
 &type Unable to open file %.SS_SETTINGS% due to error %status%.
 &run ss_cleanup_menu
 &stop
 &end
/*
/* read information out now
&do x &list .SS_CELLSIZE .SS_WINDOWGRID .SS_CUTOFF .SS_MINAREA .SS_OUTNAME -
 .SS_WEIGHTNAME .SS_STATNAME
 &sv x% [unquote [read %fileunit% status]]
&if %status% ne 0 &then &do
 &type error reading from %.SS_SETTINGS% file
 &run ss_cleanup_menu
 &stop
 &end
&end
&do x = 1 &to 10
 &sv .SS_USE%x% [unquote [read %fileunit% status]]
&if %status% ne 0 &then &do
 &type error reading from %.SS_SETTINGS% file
 &run ss_cleanup_menu
 &stop
&end
&sv .SS_GRID%x% [unquote [read %fileunit% status]]
 &if %status% ne 0 &then &do
 &type error reading from %SS_SETTINGS% file
 &run ss_cleanup_menu
 &stop
 &end
&sv .SS_REMAP%x% [unquote [read %fileunit% status]]
 &if %status% ne 0 &then &do
 &type error reading from %SS_SETTINGS% file
 &run ss_cleanup_menu
 &stop
 &end
&sv .SS_HEIGHT%x% [unquote [read %fileunit% status]]
 &if %status% ne 0 &then &do
 &type error reading from %SS_SETTINGS% file
 &run ss_cleanup_menu
 &stop
 &end

/*
/*/ close file
/*
&sv status [close %fileunit%]
&return

&routine cleanup
&type error encountered in ss_load_settings. Cleaning up and exiting.
&run ss_cleanup_menu
&stop
/* Spatial Information Support Systems Lab
 * Agricultural and Biosystems Engineering Department
 * Iowa State University AMES IA
 */

/* Command name: ss_process_selection
 * Language: aml
 */

/* Purpose: process menu selection information
 */

/* Arguments:
 * Variable name, I/O, Type, Definition
 */

/* History:
 * Author/Site, Date, Event
 * --------------------------------------------------------------
 * Dharmesh Jain, July 14, 93, initial coding
 * Dharmesh Jain, July 19, 93
 * Dharmesh Jain, July 13, 93, Definition file is an argument to ss_main.aml
 */

/* Notes: File format follows
 */

/**
 * HEADER: file description line
 * OUTNAME: output site selection grid name
 * WEIGHTNAME: no | output weight grid name
 * STATNAME: no | output statistics file name
 * WINDOWGRID: no | calculations occur where this grid is defined
 * CUTOFF: minimum cutoff level accepted. (0 if want all)
 * MINAREA: minimum area requirements. Same units as grids
 * CELLSIZE: cell size
 * NUMBERGRID: number of input grids/ remap tables which follow
 * GRIDX: grid x's name including path if not the current dir
 * REMAPX: remap table x's name including path if not current
 * WEIGHTX: weight value for grid x.
 */

/* notes: the last three entries are patterns and should be included once
 for each of the input grid/remap/weights that will be used in
 the site selection analysis system.
 */

/*
 * set error level and response
 */

$severity &error &routine cleanup

$id $&debug% $then $type Entering ss_process_selection

/*
 * set error variable default value
 */

$sv error .FALSE.

/*
 * check input parameters for null values
 */

/* start checking general vars */
$do var $&list CELLSIZE CUTOFF MINAREA OUTNAME
$id [null [value .SS $var%]] $then $do
 $type Error in input parameter $var%.
 $sv error .TRUE.
 $return
 $end
$end
$do var $&list WINDOWGRID WEIGHTNAME STATNAME
&if [null [value .SS_%var%]] &then &sv .SS_%var% no
&end
&do x = 1 &to 10
&do var &list GRID REMAP WEIGHT
   &if [value .SS_USE%x%] and [null [value .SS_%var%%x%]] &then &do
      &type Error in input parameter %var%%x%.
      &sv error .TRUE.
      &return
   &end &end
&end

/*
/* create def file
/*
&run ss_create_def

/*
/* start site selection routines now
/*
&run ss_main xxdef
&return

/*
/* error cleanup routine
/*
&routine cleanup
&type An Error has occurred while processing the input file.
&type Error cleanup in progress. Please contact the GIS facility for help.
&run ss_cleanup_menu
&return
/* Spatial Information Support Systems Lab
/* Agricultural and Biosystems Engineering Department
/* Iowa State University AMES IA

Command name: ss_cleanup
Language: ami

Purpose: cleans up after site selection process

Arguments:
Variable name, I/O, Type, Definition

History:
Author/Site, Date, Event

Dharmesh Jain, April 1, 1993, initial coding

Notes:

read in arguments and process them
args error
if [null %error%] or %error% ne no &then &sv error yes
if %.debug% &then &type Entering ss_cleanup
%@mess %pop
if %.debug% &then &if [query 'Delete temp files'] &then &do
%@mess &on
* delete all temporary coverages
if [exists ss_sitegrid -grid] &then kill ss_sitegrid
if [exists ss_weightgrid -grid] &then kill ss_weightgrid
if [exists ss_elimgrid -grid] &then kill ss_elimgrid
if [exists ss_passed -grid] &then kill ss_passed
if [exists ss_region -grid] &then kill ss_region
if [exists ss_area -grid] &then kill ss_area
if [exists ss_sites -grid] &then kill ss_sites
if [null %.SS_NUMBERGRID%] &then &do x = 1 to %.SS_NUMBERGRID%
if [exists ss_grd%x% -grid] &then kill ss_grid%x%
end
%end
%mess &on

/* remove the following global variables
*/ copy some to globals to keep
if %error% eq no &then &do
 &sv .AAREASELECTED %.SS_AREASEL%
 &sv .AREAELIMINATED %.SS_AREAELIM%
 &sv .MAXVALUE %.SS_MAXVAL%
end

/* set ami and menu paths back
*/
&amopath $.SS_OLDAMLPATH2$

/*
* delete global vars now
*/

&delvar $.SS_*

&if %error% eq yes &then &stop
&else &return
/* Spatial Information Support Systems Lab
/* Agricultural and Biosystems Engineering Department
/* Iowa State University AMES IA

/* Command name: ss_create_def
/* Language: ami

/* Purpose: create def file for use in generic site selection amis

/* Arguments:
/* Variable name, I/O, Type, Definition

/* History:
/* Author/Site, Date, Event
/* ---------------------------------------------------------------
/* Dharmesh Jain, April 3, 1993 initial coding
/* Dharmesh Jain, April 4, 1994, New parameters are added

/* Notes: File format follows
/* HEADER: file description line
/* OUTNAME: output site selection grid name
/* WEIGHTNAME: no | output weight grid name
/* STATNAME: no | output statistics file name
/* WINDOWGRID: no | calculations occur where this grid is defined
/* CUTOFF: minimum cutoff level accepted. (0 if want all)
/* MINAREA: minimum area requirements. same units as grids
/* CELLSIZE: cell size
/* NUMBERGRID: number of input grids/remap tables which follow
/* GRIDX: grid x's name including path if not the current dir
/* REMAPX: remap table x's name including path if not current
/* WEIGHTX: weight value for grid x.
/* Notes: the last three entries are patterns and should be included once
/* for each of the input grid/remap/weights that will be used in
/* the site selection analysis system.

/* set error level and response
*/

-severity &error &routine cleanup

@if %.debug% &then &type Entering ss_create_def
*/

/* open xxdef file
*/

@if [exists xxdef -file] &then &sys rm xxdef
&sv fileunit [open xxdef status -write]
@if %status% ne 0 &then &do
&type Unable to open file xxdef due to error %status%.
&sv .SS_ERROR .TRUE.
&return
&end

/* do initial processing necessary to write def file
*/
&sv .SS_HEADER def file from generic site selection menu

/* count number of remap grids
&sv .SS_NUMBERGRID 0
&do x = 1 &to 10
  &if [value .SS_USE%x%] &then &sv .SS_NUMBERGRID [calc %.SS_NUMBERGRID% + 1]
  &end

/* write in lines 1 through 9 here */

&sv var HEADER OUTNAME WEIGHTNAME STATNAME WINDOWGRID CUTOFF MINAREA CELLSIZE NUMBERGRID
&do x = 1 &to 9
  &sv var [extract %x% %vars%]
  &sv status [write %fileunit% [quote %var%: [value .SS_%var%]]]
  &if %status% ne 0 &then &do
    &type Unable to write line %x% of file xxdef due to error %status%.
    &run ss_cleanup_menu
    &stop
  &end
&end

/* write rest of the grid names, remap table names, and weights */

&do x = 1 &to 10
  &if [value .SS_USE%x%] &then &do var &list GRID REMAP WEIGHT
    &sv status [write %fileunit% [quote %var%: [value .SS_%var%]]]
    &if %status% ne 0 &then &do
      &type Error occurred while writing xxdef file.
      &run ss_cleanup_menu
      &stop
    &end
  &end
&end

&sv status [close %fileunit%]
$return

/* error cleanup routine */

&routine cleanup
&type An Error has occurred while processing the input file.
&type Error cleanup in progress. Please contact the GIS facility for help.
&run ss_cleanup_menu
$return
/* Spatial Information Support Systems Lab
/* Agricultural and Biosystems Engineering Department
/* Iowa State University AMES IA

/* Command name: ss_check_inputs
/* Language: ami
/* Purpose: main program for site selection analysis system
/* Arguments:
/* Variable name, I/O, Type, Definition
/* History:
/* Author/Site, Date, Event
/* Notes:
/* set error level and response
/* severity &error &routine cleanup
@if %.debug% &then &type Entering ss_check_inputs
/* set startup values
&sv .SS_ERROR .FALSE.
/* confirm outgrid does not already exist
@if [exists %.SS_OUTNAME% -file] &then &do
&type ERROR: %.SS_OUTNAME% already exists. Please delete and run again.
&sv .SS_ERROR .TRUE.
&end
/* confirm output weight grid does not already exist
@if [exists %.SS_WEIGHTNAME% -file] &then &do
&type ERROR: %.SS_WEIGHTNAME% already exists. Please delete and run again.
&sv .SS_ERROR .TRUE.
&end
/* confirm output statfile does not already exist
@if [exists %.SS_STATNAME% -file] &then &do
&type ERROR: %.SS_STATNAME% already exists. Please delete and run again.
&sv .SS_ERROR .TRUE.
&end
/* confirm windowgrid exists or set it too name of .SS_GRID1
@if ^ [exists %.SS_WINDOWGRID% -file] &then &do
&sv .SS_WINDOWGRID %.SS_GRID1
&end
/* confirm numerical items are numerical
@if [type %.SS_CUTOFF%] ge 0 &then &do
&type ERROR: Cutoff value is not numeric.
&sv .SS_ERROR .TRUE.
&end
@if [type %.SS_MINAREA%] ge 0 &then &do
&type ERROR: Minarea value is not numeric.
&sv .SS_ERROR .TRUE.
&end
&if [type %.SS_CELLSIZE%] ge 0 &then &do
 &type ERROR: Cellsize value is not numeric.
 &sv .SS_ERROR .TRUE.
&end
&if [type %.SS_NDMBERGRID%] ge 0 &then &do
 &type ERROR: Numbergrid value is not numeric.
 &sv .SS_ERROR .TRUE.
&return
&end

/* confirm existence of all input grids and remap tables
/* and that weight values are numeric
&do x = 1 &to %.SS_NDMBERGRID%
 &if ^ [exists [value .SS_GRID%x%] -grid] &then &do
 &type Error: input grid %x% does not exist.
 &sv .SS_ERROR .TRUE.
 &end
 &if ^ [exists [value .SS_REMAP%x%] -file] &then &do
 &type Error: input remap table %x% does not exist.
 &sv .SS_ERROR .TRUE.
 &end
 &if [type [value .SS_WEIGHT%x%]] ge 0 &then &do
 &type ERROR: Weight value for %x% is not numeric.
 &sv .SS_ERROR .TRUE.
&return
&end
&return

/* error cleanup routine
/*
&routine cleanup
&type An Error has occurred while checking the input file data.
&type Error cleanup in progress. Please contact the GIS facility for help.
&run ss_cleanup yes
&return
Spatial Information Support Systems Lab
Agricultural and Biosystems Engineering Department
Iowa State University AMES IA

Command name: ss_proc_def_file
Language: ami

Purpose: process text file which contains info on selection process

Arguments:
Variable name, I/O, Type, Definition

History:
Author/Site, Date, Event

Dharmesh Jain, July 10, 93, initial coding

Notes: File format follows

HEADER: file description line
OUTNAME: output site selection grid name
WEIGHTNAME: no | output weight grid name
STATNAME: no | output statistics file name
WINDOWGRID: no | calculations occur where this grid is defined
CUTOFF: minimum cutoff level accepted. (0 if want all)
MINAREA: minimum area requirements. same units as grids
CELLSIZE: cell size
NUMBERGRID: number of input grids/remap tables which follow
GRIDX: grid x's name including path if not the current dir
REMAPX: remap table x's name including path if not current
WEIGHTX: weight value for grid x.

Notes: the last three entries are patterns and should be included once
for each of the input grid/remap/weights that will be used in
the site selection analysis system.

* read input args
* &args def_name

* set error level and response
* &severity &error &routine cleanup
&if %.debug% &then &type Entering ss_proc_def_file
*
* setup initial variables as needed
*
&sv .SS_ERROR .FALSE.
*
* open input file
*
&sv fileunit [open %def_name% status -read]
&if %status% ne 0 &then &do
  &type Unable to open file %def_name% due to error %status%.
  &sv .SS_ERROR .TRUE.
&return
&end
/* start processing lines now */

/* read in lines 1 through 9 here */

&sv var HEADER OUTNAME WEIGHTNAME STATNAME WINDOWGRID CUTOFF MINAREA CELLSIZE NUMBERGRID
&do x = 1 &to 9
 &sv line [unquote [read %fileunit% status]]
 &if %.debug% &then &do
   &type line %x% is: %line%
   &type extract 1: [extract 1 %line%]
   &type extract 2: [extract 2 %line%]
   &type extract var: [extract %x% %var%]
 &end
 &if %status% ne 0 &then &do
   &type Unable to read line %x% of file %def_name% due to error %status%.
   &sv .SS_ERROR .TRUE.
 &return
 &end
 &if [extract 1 %line%] eq [extract %x% %var%]: and ~
   ^[null [extract 2 %line%]] &then
   &sv .SS [extract %x% %var%] [extract 2 %line%]
 &else &do
   &type format error in line %x%.
   &sv .SS_ERROR .TRUE.
 &return
 &end
 &end

/* delete unneeded variable .SS_HEADER now */
&delvar .SS_HEADER

/* read in the rest of the grid names, remap table names, and weights */
&do x = 1 &to %.SS_NUMBERGRID%
 &sv line [unquote [read %fileunit% %status%]]
 &if %.debug% &then &do
   &type line %x% is: %line%
   &type extract 1: [extract 1 %line%]
   &type extract 2: [extract 2 %line%]
 &end
 &if %status% ne 0 &then &do
   &type Unable to read line [calc 3 * [calc %x% - 1] + 10] of file %def_name% due to error
   or %status%.
   &sv .SS_ERROR .TRUE.
 &return
 &end
 &if [extract 1 %line%] eq GRID%x%: and ^[null [extract 2 %line%]] &then
   &sv .SS_GRID%x% [extract 2 %line%]
 &else &do
   &type format error in line [calc 3 * [calc %x% - 1] + 10].
   &sv .SS_ERROR .TRUE.
 &return
 &end

&sv line [unquote [read %fileunit% %status%]]
&if %status% ne 0 &then &do
&type Unable to read line [calc 3 * [calc %x% - 1] + 11] of file %def_name% due to error
or %status%.
&sv .SS_ERROR .TRUE.
&return
&end
&if [extract 1 %line%] eq REMAP%x%: and ^[null [extract 2 %line%]] &then
&sv .SS_REMAP%x% [extract 2 %line%]
&else &do
&type format error in line [calc 3 * [calc %x% - 1] + 11].
&sv .SS_ERROR .TRUE.
&return
&end

&sv line [unquote [read %fileunit% %status%]]
&if &status% ne 0 &then &do
  &type Unable to read line [calc 3 * [calc %x% - 1] + 12] of file &def_name% due to error or &status%.
  &sv .SS_ERROR .TRUE.
  &return &end
&if [extract 1 %line%] eq WEIGHT%x%: and ^ [null [extract 2 %line%]] &then
  &sv .SS_WEIGHT%x% [extract 2 %line%]
&else &do
  &type format error in line [calc 3 * [calc %x% - 1] + 12].
  &sv .SS_ERROR .TRUE.
  &return &end
&end
&sv status [close %fileunit%]
&return

/ *
/ error cleanup routine
/ *
&routine cleanup
&type An Error has occurred while processing the input file.
&type Error cleanup in progress. Please contact the GIS facility for help.
&run ss_cleanup yes
&return
Command name: ss_remap_ingrid
Language: ami

Purpose: main program for site selection analysis system

Arguments:

Variable name, I/O, Type, Definition

History:

Author/Site, Date, Event

Dharmesh Jain, August 2, 93, initial coding
Dharmesh Jain, August 3, 93, modified

Notes:

set error level and response
severity &error &routine cleanup

if %.debug% &then &type Entering ss_remap_ingrid

start remapping grids now.

do x = 1 &to %.SS_NUMBERGRID%
   &type reclassifying input grid %x%.
   if [exists ss_grid%x% -grid] &then kill ss_grid%x%
      ss_grid%x% = reclass([], Value .SS_REMAP%x%, nodata)
   &end
&return

error cleanup routine

routine cleanup
&type An Error has occurred while remapping the ingrids.
&type Error cleanup in progress. Please contact the GIS facility for help.
&run ss_cleanup yes
&return
/* Command name: as_create_weight_grid
/* Language: aml
/*
/* Purpose: creates weight grid from remapped grids and weight values.
/*
/* Arguments:
/*  Variable name, I/O, Type, Definition
/*
/* History:
/*  Author/Date, Event
/*
/* Dharmesh Jain, April 9, 93, initial coding
/*
/* Notes:
/*
/*
/* set error level and response
/*
severity &error &routine cleanup

&if %.debug% &then &type Entering ss_create_weight_grid
/*
/* create command that combines all grids and weight factors
/*
&sv command ( ss_grid1 * %.SS_WEIGHT1% )
&do x = 2 &to %.SS_NUMBERGRID%
 &sv command %command% + ( ss_grid%x% * [value .SS_WEIGHT%x%] )
&end
&if %.debug% &then &type command =%command%
ss_weightgrid = %command% * ss_elimgrid
/*
/* build statistics info file for ss_weightgrid now
/* and pull out max value
&if %.debug% &then &type building statistics for weight grid now.
builddta ss_weightgrid minmax
&sv .SS_MAXVAL [show select ss_weightgrid.sta info 1 item max]
/*
/* select only areas that meet minimum size criteria
/*
/* first remove areas that d/n meet minimum cutoff
ss_passed = con(ss_weightgrid ge [calc %.SS_CUTOFF% / 100 * %.SS_MAXVAL%], 1)
/* create zonal regions now
ss_region = regiongroup(ss_passed)
/* create area grid now
ss_area = zonalarea(ss_region)
/* select only areas that meet minimum area requirements and reassign weights
ss_sites = con(ss_area ge %.SS_MINARE%, 1) * ss_weightgrid * ss_elimgrid
/*
/* rescale site grid so that max value is 100
/*
 ss_sitegrid = ss_sites * 100 / \%SS_MAXVAL\%
 &return

/* error cleanup routine */
&routine cleanup
&type An Error has occurred while creating the site selection weight grid.
&type Error cleanup in progress. Please contact the GIS facility for help.
&run ss_cleanup yes
&return
/* Spatial Information Support Systems Lab
/* Agricultural and Biosystems Engineering Department
/* -- « • jiMES lA
/*
/* Command name: ss_create_elim
/* Language: aml
/*
/* Purpose: creates elimination grid
/*
/* Arguments:
/* Variable name, I/O, Type, Definition
/*
/* History:
/* Author/Site, Date, Event
/*
/* Dharmesh Jain, April 4, 1993, final coding
/*
/* Notes:
/*
/* set error level and response
/*
&severity &error &routine cleanup
&if %.debug% &then &type Entering ss_create_elim
/*
/* create variable containing command to create elimination grid
/*
&sv command ss_grid
&do x = 2 &to %SS_NUMBERGRID%
&sv command %command% * ss_grid%x%
&end
/*
/* execute command
/* Note that the ss_elimgrid grid is created by multiplying all the remapped
/* grids together and then assigned a value of 1 for all areas that are not
/* eliminated from consideration.
/*
ss_elimgrid = %command% * 0 + 1
&return
/*
/* error cleanup routine
/*
&routine cleanup
&type An Error has occurred while creating the elimination grid.
&type Error cleanup in progress. Please contact the GIS facility for help.
&run ss_cleanup yes
&return
/* Spatial Information Support Systems Lab
/* Agricultural and Biosystems Engineering Department
/* Iowa State University AMES IA
/*
/* Command name: ss_create_outputs
/* Language: ami
/*
/* Purpose: creates output statistics text file and copy output grids to
/* their appropriate locations.
/*
/* Arguments:
/* Variable name, I/O, Type, Definition
/*
/* History:
/* Author/Site, Date, Event
/*
/* Dharmesh Jain, April 5, 93, initial coding
/* Dharmesh Jain, April 7
/* Dharmesh Jain, June 93, changed precision.
/*
/* Notes:
/*
*/
/*
/* set error level and response
*/
$severity $error $routine cleanup

@if %.debug% $then $type Entering ss_create_outputs

/* check to see if user wants a stat file created
/*
@if [translate %.SS_STATNAME%] ne NO $then $do
/* open output text file
/*
$sv fileunit [open %.SS_STATNAME% status -write]
$if %status% ne 0 $then $do
atype Unable to open file %.SS_STATNAME% due to error %status%.
$sv .SS_ERROR .TRUE.
$return
$end

/* write data out
/*
$sv status [write %fileunit% [quote Statistics data for %.SS_OUTNAME%]]
$if %status% ne 0 $then $do
atype error writing to statistics file
$return
$end
$sv status [write %fileunit% [quote Maximum Rating Selected: %.SS_MAXVAL%]]
$if %status% ne 0 $then $do
atype error writing to statistics file
$return
$end
$sv status [write %fileunit% [quote Mean rating of selected sites: %.SS_MEAN%]]
$if %status% ne 0 $then $do
atype error writing to statistics file
$return
$end
&sv status [write %fileunit% [quote Percent area selected as potential sites: %.SS AREAS EL%]]
&if %status% ne 0 &then &do
   &type error writing to statistics file
   &return
&end
&sv status [write %fileunit% [quote Percent area eliminated: %.SS AREAILIM%]]
&if %status% ne 0 &then &do
   &type error writing to statistics file
   &return
&end
&sv status [close %fileunit%]
&end

/*
/* if needed create user copies of output grids
/*

copy ss_sitegrid %.SS_OUTNAME%
&if [translate %.SS WEIGHTNAME%] ne NO &then &do
   copy ss_weightgrid %.SS WEIGHTNAME%
&end
&return

/*
/* error cleanup routine
/*
&routine cleanup
&type An Error has occurred while creating the output statistics file.
&type Error cleanup in progress. Please contact the GIS facility for help.
&run ss_cleanup yes
&return
/* Command name: ss_calc_stats
   Language: ami
*/

Purpose: calculates statistical information on ss_sitegrid

Arguments:
Variable name, I/O, Type, Definition

History:
Author/Site, Date, Event

Notes:

--

set error level and response
&severity &error &routine cleanup
&if %.debug% &then &type Entering ss_calc_stats

/*
calculate number of cells in each grid
/*
wingrid = scalar(0)
selsites = scalar(0)
elim = scalar(0)
do
cell
wingrid = %.SS_WINDOWGRID% * 0 + 1
selsites = ss_sitegrid * 0 + 1
elim = ss_elimgrid * 0 + 1
end
&sizewingrid = [show wingrid]
&sizeselsites = [show selsites]
&sizeelim = [show elim]
&if %.debug% &then &do
&type sizewingrid = %sizewingrid%
&type sizeselsites = %sizeselsites%
&type sizeelim = %sizeelim%
&end
&s = %.SS_AREASEL% = [calc %sizeselsites% / %sizewingrid% * 100]
&s = %.SS_AREALEL% = [calc ( %sizewingrid% - %sizeelim% ) / %sizewingrid% * 100]
/*
build statistics info file for ss_sitegrid now
/* and pull out mean
&if %.debug% &then &type building statistics for site grid now.
bldsta ss_sitegrid all
&s = %.SS_MEAN% [show select ss_sitegrid.sta info 1 item mean]
&return
/*
/* error cleanup routine
 */

&routine cleanup
&type An Error has occurred while calculating statistics.
&type Error cleanup in progress. Please contact the GIS facility for help.
&run ss_cleanup yes
&return; &return
Command name: ss_cleanup_menu
Language: aml

Purpose: cleanup after an aml error

Arguments:
Variable name, I/O, Type, Definition

History:
Author/Site, Date, Event

Dharmesh Jain, April 1, 1993, initial coding
Dharmesh Jain, April 2, 1993, final coding
April 2, 1993: backup so far in /home/agemon/sitesel/

Notes:

set aml and menu paths back
&amipath %.OLDAMLPATH%
&menupath %.OLDMENUPATH%

delete variables and xxdef file
&delvar .SS*
&delvar .OLDAMLPATH .OLDMENUPATH
&sys rm xxdef
&stop
This program converts the arc/info data file into an ID3 query format. Program also prompts for user’s input on chemical, fertilizer, and manure management.

```c
#include <stdio.h>
#include <string.h>
#include <stdlib.h>
#include <stdlib.h>
#define TESTFILE "test8.e00"
#define MAX 80

int main()
{
    long num = 0;
    long cnt = 0;
    long cnt2 = 0;
    long sites;
    long c;
    long cnt4;
    /* int strcmp(char *s1, char *s2);*/
    char astr[200];
    char fert[10], manure[10], mgmt[10], numstr[80];
    /* int fert, manure, mgmt; */
    char a[900];
    FILE *fp;
    FILE *fptr;
    FILE *sfp;
    FILE *dfp;

    fp = fopen("testp", "w");
    fptr = fopen("dest", "w");

    str1 = "\'sl\'";
    str2 = "\'sicl\'";
    str3 = "\'cl\'";
    str4 = "\'loam\'";
    str5 = "\'scl\'";
    str6 = "\'c\'";
    str7 = "\'b\'";
    str8 = "\'d\'";
    str9 = "\'a\'";
    cmp1 = "y";
    cmp2 = "n";

    printf("Enter number of sites to be evaluated for Nitrate leaching potential\n");
    scanf("%d", &sites);

    if ((sfp = fopen("source", "r")) == NULL)
        printf("Can't open source for reading\n");
    else
    {
        if ((dfp = fopen("dest", "w")) == NULL)
            printf("Can't open dest for writing\n");
        else
        {
            while (cnt2 < (21*sites -1))
            {
                for (cnt4 = 0; (c = getc(sfp)) != ','; cnt4++)
                    putc(c, dfp);
```
fprintf(fp, "hydrogp %s", a); 219
fprintf(fp, ")");
printf("**************************************************************************

Answer the following to complete this query on Nitrogen leaching potential for the %d sites you have selected which is under Corn-Soybean rotation.

Select a fertilizer application rate for SITE# %d
XnYES — full fertilizer is applied : NO = no fertilizer is applied : Half = half of crop requirement is applied
If you select ‘y’ or ‘n’ or ‘hf’, you are required to enter your responses in the form of ‘Y’ or ‘N’ or ‘HF’
XnYES = Full fertilizer; NO = no fertilizer; Half = half of crop requirement

Choose among ‘y’ or ‘n’ or ‘hf’

Select a manure application rate for SITE# %d
XnLOW - 50 Ib/ac-N : MEDIUM - 100 Ib/ac-N : HIGH - 150 lb/ac-N
If you select ‘l’ or ‘m’ or ‘h’, you are required to enter your responses in the form of ‘L’ or ‘M’ or ‘H’
XnLOW = Low; MEDIUM = Medium; HIGH = High

Choose among ‘l’ or ‘m’ or ‘h’ or ‘HF’ or ‘f’

Select a management practice for SITE# %d
XnSelect as nt (no-till) or ct (conservation till)

Choose among ‘nt’ or ‘ct’

if ( strcmp(fert, "y") != 0 && strcmp(fert, "n") != 0 && strcmp(fert, "hf") != 0 )
{
printf("**********invalid entry**********\n");  
printf("CHOOSE AGAIN**********\n"); goto err1;
}

if ( strcmp(fert, "n") == 0 && strcmp(manure, "f") != 0 )
{
printf("**********invalid entry**********\n");  
printf("WITH ‘NO’ FERTILIZER, MANURE HAS TO SUPPLY MINIMUM NUTRIENT REQUIREMENT OF CROP\n");
printf("CHOOSE AGAIN**********\n");
goto err2;
}

if ( strcmp(manure, "l") != 0 && strcmp(manure, "m") != 0 && strcmp(manure, "hf") != 0 )
{
printf("**********invalid entry**********\n");  
printf("CHOOSE AGAIN**********\n");
goto err2;
}

if ( strcmp(mgmt, "nt") != 0 && strcmp(mgmt, "ct") )
{
printf("**********invalid entry**********\n");  
printf("CHOOSE AMONG ‘ct’ OR ‘nt’\n");
printf("CHOOSE AGAIN**********\n");
goto err3;
}

/*printf("mgmt entered is %s\n", mgmt); */
fprintf(fp, "(");
fprintf(fp, "fert %s", fert);
fprintf(fp, ")");
fprintf(fp, "(");
fprintf(fp, ")");
fprintf(fp, "(");
fprintf(fp, "manure %s", manure);
fprintf(fp, ")");
fprintf(fp, "(");
fprintf(fp, "mgmt %s", mgmt);
fprintf(fp, ")");
fprintf(fp, "\n");
putc('
', dfp);

cnt2 = cnt2 + 1;
}
fclose(dfp);
}
fclose(sfp);

fprintf(fp, "\n'axter 'a' ");
while (cnt < sites*21)
{
    fscanf(fptr, "s", a);
    cnt++;
    if (cnt == (num + 8))
    {
        /*printf("cnt is %d
", cnt);*/
        fprintf(fp, "(');
        fprintf(fp, "? ");
        fprintf(fp, "(');
        fprintf(fp, "slope %s", a);
        fscanf(fptr, "%s", a);
        fscanf(fptr, "%s", a);
        fscanf(fptr, "%s", a);
        fscanf(fptr, "%s", a);
        cnt = cnt + 5;
        fprintf(fp, ")")
        fprintf(fp, "(');
        str5 = a;
        /*printf("str5 is %s", str5);*/
        *printf("a is %s", a); */
        *printf("str2 is %s", str2); */
        if (strcmp(a, str1) == 0)
        {
            strcpy(&a[0], &a[1]);
            strcpy(&a[2], &a[3]);
        }
        if (strcmp(a, str3) == 0)
        {
            strcpy(&a[0], &a[1]);
            strcpy(&a[2], &a[3]);
        }
        if (strcmp(a, str2) == 0)
        {
            strcpy(&a[0], &a[1]);
            strcpy(&a[2], &a[3]);
        }
        if (strcmp(a, str4) == 0)
        {
            strcpy(&a[0], &a[1]);
            strcpy(&a[2], &a[3]);
        }
        if (strcmp(a, str10) == 0)
        {
            strcpy(&a[0], &a[1]);
            strcpy(&a[5], &a[6]);
        }
        fprintf(fp, "soil %s", a);
        fscanf(fptr, "s", a);
        cnt = cnt + 1;
        fprintf(fp, ");
        fprintf(fp, "(');
        if ( (strcmp(a, str6) == 0) || (strcmp(a, str7) == 0) || (strcmp(a, str8) == 0) || (strcmp(a, str9) == 0) )
        {
            strcpy(&a[0], &a[1]);
            strcpy(&a[1], &a[2]);
        }
num = num + 21;
}

close(fptr);
printf("Total values read are %d\n", cnt);

fprintf(fp, "\n");
close(fp);
return 0;
}
APPENDIX III

LISTING OF AGNPS-ARC/INFO INTERFACE
/*------------------------------------------*/
/* Spatial Information Support Systems Lab*/
/* Agricultural and Biosystems Engineering Department*/
/* Iowa State University AMES IA*/
/*******************************************************************************/
/*
* The AML program is used to convert input and output
* files between AGNPS and ARC/INFO
* Environment : ARC
* Call : agnps1.menu
*/
/*******************************************************************************/
&echo &on

initarc
&thread &create menu1 &menu tagnps1.menu &position &ul &stripe ~
'Interface between AGNPS and ARC/INFO'
&thread &focus &on menu1
&thread &create menu2 &menu tagnps2.menu &position &cc &stripe ~
'CELL INFORMATION'
&thread &focus &off menu2
&thread &create menu3 &menu tagnps3.menu &position &lr &stripe ~
'FEEDLOT DATA INPUT'
&thread &focus &off menu3
&thread &delete &self
&echo &off
&return
/* %icon1 display .dispicon 5 icon
%icon2 display .dispicon 5 icon
/* %icon3 display .dispicon 5 icon
%icon4 display .dispicon 5 icon
%icon5 display .dispicon 5 icon
%icon6 display .dispicon 5 icon
%1 button return 'Execute_AGNPS' &r exeagnps.aml
%2 button return 'Prepare_New_AGNPS_Input' &r tagi.ps.aml
%3 button return 'ABOUT_INTERFACE' &pop interface :xt 25 12 10 10
%5 button return 'Edit_Existing_File' &menu loadf:le.menu
%4 button cancel 'CANCEL' &return
%forminit &sv .dispicon world2.icon
Purpose: This will prompt user to select a file or type in name of file to execute agnps on an existing file.

&mess &pop
&pop typename.txt
&if [query 'Will type in file name'] &then &do
  &sv .datafile = [response 'File Name']
  &sys /home/agemon/agnps/a.out %.datafile% 0
&end
&else &do
  &sv .datafile = [getfile *.dat]
  &sys /home/agemon/agnps/a.out %.datafile% 0
&end
&return
********** AGNPS File Header **********

/* [AGNPS INPUT FILE NAME] %0 */ %1 %2 %3

[GENERAL INFO]
Error log flag %4 Base cell area %10
Source accounting flag %5 Total cell number %11
Hydrology file flag %6 Hydrology indicator %12
Sediment file flag %7 Geomorphic indicator %13
Nutrient file flag %8 Peak indicator, k %14
Pesticide file flag %9 k coeff %15

[STORM INFO]
Storm type %16 Storm intensity %17
Storm duration, hr %18 Storm rainfall, in %19
Rainfall nitrogen, ppm %20

tok %cancel
%0 input .filename 30 character
/*%1 button VERSION &sv .version [response 'Version Identify']
/*%2 button Name &sv .shedname [response 'Watershed Name']
/*%3 button Descript .sheddescript [response 'Description']
%4 choice .errorflag single return '0 1'
%5 choice .sourceflag single return '0 1'
%6 choice .hydroflag single return '0 1'
%7 choice .sedflag single return '0 1'
%8 choice .nutriflag single return '0 1'
%9 choice .pestflag single return '0 1'
%10 input .cellarea 10 # real
%11 input .totalcell 10 # real
%12 choice .hydroindx single return '0 1'
%13 choice .geoindx single return '0 1'
%14 choice .peakindx single return '0 1'
%15 input .kind 10 # real
%16 input .stormtype 10 character
%17 input .storminten 10 # real
%18 input .stormdur 10 # real
%19 input .stormrain 10 # real
%20 input .rainnitro 10 # real
tok button NEXT_CELL_INFO &r thread2.aml
cancel button Cancel 'CANCEL' &return
<table>
<thead>
<tr>
<th><strong>[COVERAGE]</strong></th>
<th><strong>CELL Information</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>AGNPS fishnet coverage %1</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>[NAME OF ITEM]</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Cell number</td>
<td>%2</td>
</tr>
<tr>
<td>Receiving cell number</td>
<td>%4</td>
</tr>
<tr>
<td>Flow direction (Aspect)</td>
<td>%6</td>
</tr>
<tr>
<td>Average land slope</td>
<td>%8</td>
</tr>
<tr>
<td>Slope length, ft</td>
<td>%10</td>
</tr>
<tr>
<td>Soil erodibility, K</td>
<td>%12</td>
</tr>
<tr>
<td>Practice factor, P</td>
<td>%14</td>
</tr>
<tr>
<td>COD factor</td>
<td>%16</td>
</tr>
<tr>
<td>Fertilizer level</td>
<td>%18</td>
</tr>
<tr>
<td>Feedlot/Non_feedlot</td>
<td>%20</td>
</tr>
<tr>
<td>Impoundments source</td>
<td>%22</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>[ADDITIONAL INFO]</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>soil</td>
<td>%soil</td>
</tr>
<tr>
<td>fert</td>
<td>%fert</td>
</tr>
<tr>
<td>pest</td>
<td>%pest</td>
</tr>
<tr>
<td>gully</td>
<td>%gully</td>
</tr>
<tr>
<td>impnd</td>
<td>%impnd</td>
</tr>
<tr>
<td>channel</td>
<td>%channel</td>
</tr>
</tbody>
</table>

`%ok %cancel`

`%1 input .fish 50 typein yes cover * -all 'Select a Coverage'`
`%2 button return 'Select from list' &r xcell.aml position ~ &uc &stripe 'Select Cell item'`
`%3 button return 'Select from list' &r xcelld.aml position ~ &uc &stripe 'Select Cell division'`
`%4 button return 'Select from list' &r xcellr.aml position ~ &uc &stripe 'Select Receiving Cell'`
`%5 button return 'Select from list' &r xcellrd.aml position ~ &uc &stripe 'Select Receiving Cell Division'`
`%6 button return 'Select from list' &r xaspect.aml position ~ &uc &stripe 'Select Aspect'`
`%7 button return 'Select from list' &r xslope.aml position ~ &uc &stripe 'Select Av. Land Slope'`
`%9 button return 'Select from list' &r xslopesth.aml position ~ &uc &stripe 'Select Slope Shape'`
`%10 button return 'Select from list' &r xslopele.aml position ~ &uc &stripe 'Select Slope Length'`
`%11 button return 'Select from list' &r xmanning.aml position ~ &uc &stripe 'Select Manning Coefficient'`
`%12 button return 'Select from list' &r xsoiler.aml position ~ &uc &stripe 'Select Soil Erodibility'`
`%13 button return 'Select from list' &r xcropf.aml position ~ &uc &stripe 'Select Cropping Factor'`
`%14 button return 'Select from list' &r xpractf.aml position ~ &uc &stripe 'Select Practice Factor'`
`%15 button return 'Select from list' &r xsurfce.aml position ~ &uc &stripe 'Select Surface Condition'`
`%16 button return 'Select from list' &r xcodf.aml position ~ &uc &stripe 'Select COD Factor'`
`%17 button return 'Select from list' &r xsoilt.aml position ~ &uc &stripe 'Select Soil Type'`
`%18 button return 'Select from list' &r xfertl.aml position ~ &uc &stripe 'Select Fertilizer type'`
`%19 button return 'Select from list' &r xppest.aml position ~ &uc &stripe 'Select Pesticide Type'`
`%20 button return 'Select from list' &r xfeedl.aml position ~ &uc &stripe 'Select Feedlot/Non_feedlot'`
`%21 button return 'Select from list' &r xerosion.aml position ~ &uc &stripe 'Select Additional erosion source'`
`%22 button return 'Select from list' &r ximpd.aml position ~ &uc &stripe 'Select Impoundments source'`
`%23 button return 'Select from list' &r xchnx.aml position ~ &uc &stripe 'Select Type of Channel'`
@gully button EROSION &menu ag_gully.menu
@impnd button IMPOUNDMENT &menu ag_impnd.menu
@channel button CHANNEL &menu ag_channel.menu
@ok button DONE &r tagmps3.aml
@cancel button cancel 'CANCEL' &return
****Feedlot Input****

[Feedlot]
Feedlot selection will be interactive.
User need to specify the workspace containing feedlots locations.

%0
Select feedlot grid %1
Select feedlot item %2
Select the shade to display feedlot %3
Select fishnet %4
select fishnet-id %5

%OK %CANCEL

%0 input .workspace 30 character

%1 button return 'Select from list' &r feed.a ml &position ~
&uc &stripe 'Feedlot Coverage'
%2 button return 'Select from list' &r feeditem.a ml &position ~
&uc &stripe 'Select feedlot item'
%3 button return 'Select from list' &r symbol.a ml &position ~
&uc &stripe 'Select a shade to display feedlots'
%4 button return 'Select a fishnet coverage' ~
&run fishnet.a ml &position &uc ~
&stripe 'Select a shade symbol'
%5 button return 'Select fishnet-id' &r fishnetid.a ml &position ~
&uc &stripe 'Select fishnet id'
%ok button DONE &r selfeed.a ml
%cancel button cancel 'CANCEL' &r thread2.a ml
The subprogram is used to write a INPDT file for Unix version of AGNPS 4.02a.

Environment: ARC

Call by: ap_soil.menu

Oharmesh Jain

SOIL INFORMATION: 1st line

SOIL INFORMATION: 2nd line

SOIL INFORMATION: END OF INFORMATION
**Feedlot Subarea Information**

**Feedlot no. **%feedlotid**

### [SUBAREA CHARACTERISTICS]

<table>
<thead>
<tr>
<th>Subarea 2-1: Area</th>
<th>1</th>
<th>Curve#</th>
<th>2</th>
<th>Subarea 3-1: Area</th>
<th>3</th>
<th>Curve#</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subarea 2-2: Area</td>
<td>5</td>
<td>Curve#</td>
<td>6</td>
<td>Subarea 3-2: Area</td>
<td>7</td>
<td>Curve#</td>
<td>8</td>
</tr>
<tr>
<td>Subarea 2-3: Area</td>
<td>9</td>
<td>Curve#</td>
<td>10</td>
<td>Subarea 3-3: Area</td>
<td>11</td>
<td>Curve#</td>
<td>12</td>
</tr>
<tr>
<td>Subarea 2-4: Area</td>
<td>13</td>
<td>Curve#</td>
<td>14</td>
<td>Subarea 3-4: Area</td>
<td>15</td>
<td>Curve#</td>
<td>16</td>
</tr>
<tr>
<td>Subarea 2-5: Area</td>
<td>17</td>
<td>Curve#</td>
<td>18</td>
<td>Subarea 3-5: Area</td>
<td>19</td>
<td>Curve#</td>
<td>20</td>
</tr>
<tr>
<td>Subarea 2-6: Area</td>
<td>21</td>
<td>Curve#</td>
<td>22</td>
<td>Subarea 3-6: Area</td>
<td>23</td>
<td>Curve#</td>
<td>24</td>
</tr>
</tbody>
</table>

### [BUFFER AREA CHARACTERISTICS]

| Buffer 1: Slope | 25 | Surface constant | 26 | Flow Length | 27 |
| Buffer 2: Slope | 28 | Surface constant | 29 | Flow Length | 30 |
| Buffer 3: Slope | 31 | Surface constant | 32 | Flow Length | 33 |

### [ANIMAL TYPE]

| Type 1 | Animal# | 34 | COD: | 35 | Phosphorus: | 36 | Nitrogen: | 37 |
| Type 2 | Animal# | 38 | COD: | 39 | Phosphorus: | 40 | Nitrogen: | 41 |
| Type 3 | Animal# | 42 | COD: | 43 | Phosphorus: | 44 | Nitrogen: | 45 |

%DONE

%feedlotid display .count 2 value

%1 input .fs1 5 character
%2 input .fs2 5 character
%3 input .fs3 5 character
%4 input .fs4 5 character
%5 input .fs5 5 character
%6 input .fs6 5 character
%7 input .fs7 5 character
%8 input .fs8 5 character
%9 input .fs9 5 character
%10 input .fs10 5 character
%11 input .fs11 5 character
%12 input .fs12 5 character
%13 input .fs13 5 character
%14 input .fs14 5 character
%15 input .fs15 5 character
%16 input .fs16 5 character
%17 input .fs17 5 character
%18 input .fs18 5 character
%19 input .fs19 5 character
%20 input .fs20 5 character
%21 input .fs21 5 character
%22 input .fs22 5 character
%23 input .fs23 5 character
%24 input .fs24 5 character
%25 input .fs25 5 character
%26 input .fs26 5 character
%27 input .fs27 5 character
%28 input .fs28 5 character
%29 input .fs29 5 character
%30 input .fs30 5 character
%31 input .fs31 5 character
%32 input .fs32 5 character
%33 input .fs33 5 character
%34 input .fs34 5 character
%35 input .fs35 5 character
%36 input .fs36 5 character
%37 input .fs37 5 character
%38 input .fs38 5 character
%39 input .fs39 5 character
%40 input .fs40 5 character
%41 input .fs41 5 character
%42 input .fs42 5 character
%43 input .fs43 5 character
%44 input .fs44 5 character
%45 input .fs45 5 character

%DONE button DONE &return
****Additional data input on feedlots****

Input data for feedlot#: %feedlot
Feedlot area: %1
Feedlot curve number: %2
Feedlot roofed area: %3
Feedlot nitrogen: %4
Feedlot phosphorus: %5
Feedlot potassium: %6
Feedlot COD: %7

AGNPS buffer coeff. Ind. %8

Select next feedlot %ok

%feedlot display .count 2 value
%1 input .farea 10 real
%2 input .fcurve 10 real
%3 input .frarea 10 real
%4 input .fn 10 real
%5 input .fp 10 real
%6 input .fk 10 real
%7 input .food 10 real
%8 choice .coef single return ' 0 1
%ok button done &return
*******SAVE CURRENT VALUES IN AGNPS INPUT FILE*******

Settings file %input57 %button53

%DONE

%input57 INPUT .SS_SETTINGS 12 TYPEIN YES SCROLL NO ~
HELP 'Enter settings file name' ~
CHARACTER

%button53 BUTTON KEEP ~
HELP 'Save settings to a file' ~
'Save settings' &run ss_save_settings

%DONE button DONE &return
********** LOAD AN EXISTING AGNPS INPUT FILE **********

Settings file %input57  %b52

%DONE

%input57 INPUT .SS_SETTINGS 12 TYPEIN YES SCROLL NO -
HELP 'Enter settings file name' -
CHARACTER
%b52 BUTTON KEEP -
HELP 'Load settings from a file' -
'Load settings' &run ss_load_settings

%DONE button DONE  &r tagnps.aml
You have successfully simulated the watershed and have generated one AGNPS dat input file.

"Name of the file generated"  
| _________________________ |  
| input.dat  
Name of output files are:  
| _________________ |  
| input.nps  
| input.gis  
| input.kyd  
| input.kyr  
From here, Interface will return to ARC: prompt.

%2  
%3  
%2 button cancel 'OK' &return  
%3 button OUTPUT &m seloutput.menu
AGNPS Simulation Results

Check the Desired Output

SOIL LOSS OUTPUT
%icon1 Cell Erosion %icon2 Sediment Within Cell
%icon3 Sediment Yield %icon4 Sediment Deposit

NUTRIENT LOSS OUTPUT
%icon5 N-loss (cell) %icon6 N-Loss (outlet)
%icon7 N-loss in water (cell) %icon8 N Loss in water (outlet)
%icon9 P-loss (cell) %icon10 P-Loss (outlet)
%icon11 P-loss in water (cell) %icon12 P-loss in water (outlet)
%icon13 COD at cell outlet

%done

%icon1 checkbox .outvar1
%icon2 checkbox .outvar2
%icon3 checkbox .outvar3
%icon4 checkbox .outvar4
%icon5 checkbox .outvar5
%icon6 checkbox .outvar6
%icon7 checkbox .outvar7
%icon8 checkbox .outvar8
%icon9 checkbox .outvar9
%icon10 checkbox .outvar10
%icon11 checkbox .outvar11
%icon12 checkbox .outvar12
%icon13 checkbox .outvar13
%done button DONE & if.a1
This program will extract the columns of data to be displayed in ARCPLOT.
Choice of data to be displayed will come from the user. There may be more than one
choice. This particular code is for the erosion results.

USAGE: extract12 filename col_no.

AML will pickup the col_no. from user input on labeled buttons

```c
#include <stdio.h>
#include <string.h>
#include <ctype.h>
#include <stddef.h>
#include <stdlib.h>
#define MAX 200

int main(argc, argv)
int argc;
char *argv[];
{
    char line[200];
    int vari[99];
    float varf[99];
    int n, s, t;
/* int var1, var2, var3, var6, var8, var14, var, n; */
/* float var4, var5, var7, var9, var10, var11, var12, var13; */
    FILE *fptr1;
    FILE *fptr2;
    if ((fptr1 = fopen("input.gis", "r")) == NULL)
        printf("Can not open GIS data input file\n");
    else
        printf("Successfully opened GIS input data file\n");
    fptr2 = fopen("record", "w");
    n = atoi(argv[1]);
    s = atoi(argv[2]);
    printf("value of second arg is : %d \n", n);
    printf("valuse of third arg is : %d \n", s);
    fgets(line, MAX, fptr1);
    for(t=0; t < s; t++)
    {
        fscanf(fptr1, "%d %d %d %f %f %d %f %d %f %f %f
%f %f %d", &vari[1],
            &vari[2], &vari[3], &varf[4], &varf[5], &vari[6], &varf[7], &vari[8],
            &varf[9], &varf[10], &varf[11], &varf[12], &varf[13], &vari[14]);
        if (n < 4 || n == 6 || n ==8 || n == 14)
            {fprintf(fptr2, "%d\n", vari[n]);
        } else if (n == 4 || n == 5 || n == 7 || n == 9 || n == 10
            || n == 11 || n == 12 || n == 13)
            {fprintf(fptr2, "%f\n", varf[n]);
        }
    }
    fclose(fptr1);
    fclose(fptr2);
}
/* Spatial Information Support Systems Lab
Agricultural and Biosystems Engineering Department
Iowa State University AMES IA

Dharmesh Jain

This program will extract the columns of data to be displayed in ARCPLOT.
Choice of data to be displayed will come from the user. There may be more than one
choice. This particular code is for the nitrate results.

CALL: Called from if.aml running in arc.
USAGE: extract13 filename col_no.

AML will pickup the col_no. from user input on labeled buttons
*/

#include <stdio.h>
#include <string.h>
#include <ctype.h>
#include <stddef.h>
#include <stdlib.h>
#define MAX 200

int main(argc, argv)
int argc;
char *argv[];
{char line[200];
 int vari[99];
 float varf[99];
 int n, s, t;
/* int var1, var2, var3, var6, var8, var14, var, n; */
/* float var4, var5, var7, var9, var10, var11, var12, var13; */

FILE *fptrl;
FILE *fptr2;

if (( fptrl = fopen("input.gis", "r")) == NULL)
 printf("Can not open GIS data input file\n");
else
 printf("Successfully opened GIS input data file\n");

 n = atoi(argv[1]);
s = atoi(argv[2]);
printf("value of second arg is : %d \n", n);
printf("value of third arg is : %d \n", s);
for(t=0; t < (s+2); t++)
 fgets(line, MAX, fptrl);
for(t=0; t < s; t++)
 fscanf(fptrl, "%d %d %f %f %f %f %d %f %f %f %f
"%d %f %d", &vari[1],
 &vari[2], &varf[3], &varf[4], &varf[5], &varf[6], &vari[7], &varf[8],
 &varf[9], &varf[10], &vari[11], &varf[12], &varf[13], &varf[14], &vari[15]);

if (n < 3 || n == 7 || n == 12 || n == 15)
 { fprintf(fptr2, "%d\n", vari[n]);
 }
else if (n == 3 || n == 4 || n == 5 || n == 6 || n == 8 || n == 9 || n == 10 || n == 11 || n == 13 || n == 14)
 { fprintf(fptr2, "%f\n", varf[n]);
 }

fclose(fptr1);
fclose(fptr2);
/* printf( "i am here\n" ); */
while ( fgets(line, MAXLINE, fp) != NULL)
{
    fprintf(new, "%s", line);
    for(i=0; i<9; i++)
    {
        if (isdigit(*(line+i)))
        {
            sscanf(line, "%d", &a2);
        }
    }
    if (al == a2)
    {
        fgets(line, MAXLINE, fp);  
        fprintf(new, "%s", line);
        fscanf(fp, "%d", &a4);
        fprintf(new, "%16d", a4);
        for (i=0; i<2; i++)
        {
            fscanf(fp, "%d", &a4);
            fprintf(new, "%8d", a4);
        }
        fprintf(new, "%8.2f", varl);  
        fprintf(new, "%8.1f", var2);
        fprintf(new, "%8d", var3);
        fprintf(new, "%8d", var4);
        fprintf(new, "%8d\n", var5);
        fprintf(new, "%16d", var6);
        fprintf(new, "%8.1f", zerol);
        fprintf(new, "\n");
        for (i = 0; i<12; i++)
        {
            fgets(line, MAXLINE, fdata);
            fprintf(new, "%s", line);
        }
        / *
        for (i=0; i<3; i++)
        {
            fgets(line, MAXLINE, fp6);
            fprintf(new, "%s", line);
        }
        */
}
This program will merge arc/info file for feedlot data with arc/info file for basic data, based on the index provided in arc/info file. Insertion of feedlot data in basic data file is primarily based on the record no. in feedlot data.

```c
#include <stdio.h>
#include <string.h>
#include <stddef.h>
#include <stdlib.h>
#include <ctype.h>
#define MAXLINE 200

int main()
{
    float var1, var2, var3, zerol;
    int zero2, rec, i;
    long c1, c2;
    int var4, var5, var6, var7;
    char buffer1[MAXLINE + 1];
    char buffer2[MAXLINE + 1];
    /* char al[20];
    char a2[50];
    */
    int a1, a2, a4, a6;
    char line[MAXLINE];
    char *feedlot;
    FILE *fp;
    FILE *fptr;
    FILE *new;
    FILE *fdata;
    FILE *fp6;
    /* I/O */
    if ( (fp = fopen("basic.dat", "r+")) == NULL)
        printf("Can not open basic data file\n");
    else
        printf("Successfully opened basic data file\n");
    if ( (fptr = fopen("sdata.file", "r")) == NULL)
        printf("Can not open feedlot data file\n");
    else
        printf("Successfully opened feedlot data file\n");
    new = fopen("input.dat", "w");
    if ( (fdata = fopen("sfdata. file", "r")) == NULL)
        printf("Can not open fdata file\n");
    else
        printf("Successfully opened fdata file\n");
    fp6 = fopen("gully", "r");
    feedlot = "feedlot:"
    zerol = 0.00;
    zero2 = 0;
    var7 = 1;
    a6 = 1;
    fscanf(fptr, "%d", &a1);
    fscanf(fptr, "%f", &var1);
    fscanf(fptr, "%f", &var2);
    fscanf(fptr, "%f", &var3);
    fscanf(fptr, "%d", &var4);
    fscanf(fptr, "%d", &var5);
    fscanf(fptr, "%d", &var6);
    /* fscanf(fptr, "%d", &var7); */
    for(i = 0; i<6; i++)
    { 
        fgets(line, MAXLINE, fp);
        fprintf(new, "%s", line);
    }
}
```
while (fgets(line, MAXLINE, fp) != NULL) {
    fprintf(new, "%s", line);
    for (i=0; i<9; i++)
    {
        if (isdigit(*(line+i)))
        {
            sscanf(line, "%d", &a2);
            if (a1 == a2)
            {
                fgets(line, MAXLINE, fp);
                fprintf(new, "%s", line);
                fscanf(fp, "%d", &a4);
                fprintf(new, "%d", a4);
                for (i=0; i<2; i++)
                {
                    fscanf(fp, "%d", &a4);
                    fprintf(new, "%d", a4);
                }
                fscanf(fp, "%d", &a6);
                fprintf(new, "%d", a6);
                for (i=0; i<3; i++)
                {
                    fscanf(fp, "%d", &a4);
                    fprintf(new, "%d", a4);
                }
                fscanf(fp, "\n");
            }
            else
            {
                fgets(line, MAXLINE, fp);
                fprintf(new, "%s", line);
            }
        }
    }
    if (a1 == a2)
    {
        fprintf(new, "%s", feedlot);
        fprintf(new, "%d", var1);
        fprintf(new, "%d", var2);
        fprintf(new, "%d", var3);
        fprintf(new, "%d", var4);
        fprintf(new, "%d", var5);
        fprintf(new, "%d", var6);
        fprintf(new, "%d", var7);
        for (i=0; i<6; i++)
            fprintf(new, "%d", zerol);
        fprintf(new, "\n");
        for (i=0; i<12; i++)
        {
            fgets(line, MAXLINE, fdata);
            fprintf(new, "%s", line);
        }
    }
} /* for (i=0; i<3; i++):
{ fgets(line, MAXLINE, fp6);
 fprintf(new, "%s", line);
 */
APPENDIX IV

A PROGRAM FOR CLASSIFYING NUTRIENT LEACHING BASED ON
INDUCTION DICHOTOMY IMPLEMENTED IN LIST PROCESSING (LISP)
LANGUAGE
This implementation of ID3 produces decision trees discriminating positive and negative instances. Instances are represented by simple nominal features. A keyword rather than a positional representation is used.

(defun id3 (examples list-class possible-attributes splitting-function)
  This function produces a decision tree that classifies the examples provided, using these attributes. The splitting function determines which attribute should be used to split a collection of + and - examples. If all the examples are of the same type, a leaf node is returned.

  The resulting decision tree is a list of the form
  (attribute (valuel subtree1) (value2 subtree2) ... )
  or (decision #of-examples-in-training-set-located-here)
  In the first case, depending on the value of attribute, another decision tree must be traversed to make a decision. In the second case, a decision is recorded, along with the number of examples from the training set that would be placed at this node.

  See RUN-ID3 for a nice user interface to this function.

  It is assumed that every example has a valid value for each attribute.
  The function TEST-EXAMPLES can be used to pre-process examples.

  (cond ((null examples) '("NULL* 0)) ; No more examples, an "undecided" node.
        ((all-uniform examples list-class) (list (all-uniform examples list-class) (length examples)))

        (null possible-attributes) (error "Out of features - inconsistent data.")
        (t (list* (chose-attribute (choose-attribute examples possible-attributes splitting-function))
               (remaining-attributes (remove chosen-attribute possible-attributes)))

        (cons chosen-attribute
               (mapcar #'(lambda (value)
                           (list value
                                 (id3 (collect-examples-with-this-value examples chosen-attribute value)
                                     list-class remaining-attributes splitting-function)))
               (get-attribute-values chosen-attribute)))))))

(defun all-uniform (examples list-class)
  (do ((class1 list-class (rest class1)) (match nil) (result nil) )
       (or (equal match 't) (endp class1) ) (return result)
    (do ((example1 examples (rest example1)) (status nil) (class1 (first class1)) )
        (((or (endp example1) (equal status 'f)) (return status))
         (cond ((equal (first (first example1)) class1) (setq status 't) (setq match 't) (setq result class1) )
               (t (setq status 'f) (setq match 'f) (setq result
(defun choose-attribute (examples attributes splitting-function)
  ;; Choose an attribute to split these examples into sub-groups.
  ;; The method of doing so is specified by the third argument.
  (case splitting-function
    (random (nth (random (length attributes)) attributes)) ; make an arbitrary choice
    (least-values (least-values attributes)) ; choose the attribute with the least possible values
    (most-values (most-values attributes)) ; choose the one with the most
    (max-gain (max-gain examples attributes)) ; use Quinlan's gain measure to choose
    (gain-ratio (gain-ratio examples attributes)) ; use the gain ratio measure to choose
    (otherwise (error "ERROR: unknown splitting function"))
  ))

(defun most-values (attributes)
  (setf new-dom
    (do ((list attributes (rest list)) (new-domain nil))
      ((endp list) (return new-domain))
      (setf new-domain (append (list (assoc (first list) *domains*))
                              new-domain))))

(defun least-values (attributes)
  (setf new-dom
    (do ((list attributes (rest list)) (new-domain nil))
      ((endp list) (return new-domain))
      (setf new-domain (append (list (assoc (first list) *domains*))
                              new-domain))))

(defun cal-neg (examples)
  (do ((sum-neg 0) (list1 examples (rest list1)))
    (endp list1) (return sum-neg)
    (cond ((equal '¬ (first (first list1))) (setq sum-neg (+ sum-neg 1))))
)

(defun cal-pos (examples)
  (do ((sum-pos 0) (list1 examples (rest list1)))
    (endp list1) (return sum-pos)
    (cond
(defun cal-I (examples)
  (setq I (- (+ (* (/ (cal-pos examples) (length examples)) (log (/ (cal-pos examples) (length examples)) 2)) (* (/ (cal-neg examples) (length examples)) (log (/ (cal-neg examples) (length examples)) 2))))))

(defun gain-ratio (examples attributes)
  (do ((remain-domain (list attributes) (new-domain nil))
       (endp list) (return new-domain))
    (setf new-domain (append (list (assoc (first list) *domains*))
                         new-domain))
    (rest remain-domain)
    (do ((list attributes) (rest list))
        ((endp list) (return attri))
      (do (nth 1 (first (first remain-domain)))
          (rest (first remain-domain))
          (assoc attributel (nth 1 (first list-examples)))))
    (setq gr (/ (- (cal-I examples) entropy-atr)• split-funct )))
  (cond ((equal ' + (first (first listl))) (setq sum-pos (+ sum-pos 1))))))

(defun max-gain (examples attributes)
  (do ((remain-domain (list attributes) (new-domain nil))
       (endp list) (return new-domain))
    (setf new-domain (append (list (assoc (first list) *domains*))
                         new-domain)))

(rest remain-domain)  (attri nil) (e 0) (e2 0) (entropy-atr 0)  
(  
  (endp remain-domain)  (return attri)  
)  
(  
  (do  
    ( (listl (rest (first remain-domain)) (rest listl))  
      (attributel (first (first remain-domain))) (k 1) (el 0) (p 0) (npos 0) (nneg 0) (entropy 0)  
    )  
  )  
  (  
    (endp listl)  (return e2)  
  )  
)  
(do  
  ( (list-examples examples (rest list-examples))  
  (n1 0) (pos 0) (neg 0) (entropyl 0) (entropy2 0) (entropy)  
  )  
  (  
    (endp list-examples) (return n1)  
  )  
  (assoc attributel (nth 1 (first list-examples)))  
  (setq n1 (+ n1 1))  
  (cond  
    ((equal '+ (first (first list-examples)))  
    (setq pos (+ pos 1)))  
  )  
)  
(setq nneg neg)  
(setq p nl) (setq npos pos)  
(cond  
  ( (> p 0)  
    (setq el (+ (* (/ p (length examples))) (log (/ p (length examples)) 2)) el)  
  )  
  (cond  
    ( (> npos 0) (setq entropyl (* (/- npos p) (log (/- npos p) 2)))  
  )  
  (cond  
    ( (> nneg 0) (setq entropy2 (* (/- nneg p) (log (/- nneg p) 2)))  
  )  
  (t (setq entropy 0)))  
(setq e2 el)  
(setq entropy-atr entropy)  
(info-gain (cal-I examples) entropy -atr)  
(setq attri (first (first remain-domain))))))))  

(defun collect-examples-with-this-value (examples attribute value)  
  ;; Collect those examples with the given value for the given attribute.  
  (remove-if-not #'(lambda (example)  
    (equal value (second (assoc attribute (second example)))) examples))  
(defun get-attribute-values (attribute)  
  ;; Return the possible values of this attribute.  
  (rest (assoc attribute *domains*))  
(defun make-decision ( *current-tree* instances)  
  (do ( (result nil) (status nil) (list2 instances) (attri (first *current-tree*)  
    (tree *current-tree*)  
    (equal status 't) (return result)  
  )  
  (do ( (k 0) (flag nil) (tree treel)  
    (equal flag 't) (return flag)  
  )  
  (cond  
    ( (equal (nth 1 (assoc attri (nth 1 list2)))  
      (first (nth k (rest tr  

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  (rest (assoc attribute *domains*))  
(defun make-decision ( *current-tree* instances)  
  (do ( (result nil) (status nil) (list2 instances) (attri (first *current-tree*)  
    (tree *current-tree*)  
    (equal status 't) (return result)  
  )  
  (do ( (k 0) (flag nil) (tree treel)  
    (equal flag 't) (return flag)  
  )  
  (cond  
    ( (equal (nth 1 (assoc attri (nth 1 list2)))  
      (first (nth k (rest tr
(setq flag 't)

(cond ((numberp (second (nth 1 (nth k (cdr tree)))))
(setq result (first (nth 1 (nth k (cdr tree)))))
(t (setq treel (first (cdr (nth (+ k 1) tree))))
(setq attri (first treel))
(t (setq k (+ k 1))
(cond ((> k (- (length treel) 1))
(setq status 't)
(setq result 'not classified)))))))))))

(defun PRINT-TO-FILE (EXP FILE)
(with-open-file (STR FILE :DIRECTION :OUTPUT :IF-EXISTS :APPEND
:IF-DOES-NOT-EXIST :CREATE)
(PRINT EXP STR))

;;; TESTRUN FUNCTION
(defun testrun (tree examples)
(do ((inst examples (rest inst)) (classification 0) (total 0)
((endp inst)
(format t "-% *****Percentage of correct classification***** = -A -%" (* 100 (/ classification total))
(format t "-% *****Percentage of incorrect classification***** = -A -%" (* 100 (/ (- total classification) total))))
(format t "-% Site with attributes ~A is estimated for ~A lb/ac of Nitrate Leached." (first inst) (make-decision tree (first inst)))
(format t "-% The most recently learned decision tree."))
(PRINT-TO-FILE (make-decision tree (first inst)) 'nlf)

(t (setq total (+ total 1))))

;;; Global variables used by ID3.
(defvar *domains* nil "Attributes and their range of possible values - set by user")
(defvar *all-attributes* nil "List of attributes - need not be set by user if RUN-ID3 used")
(defvar *current-tree* nil "The most recently learned decision tree.")

;;; Some useful utility functions.
(defun run-id3 (examples optional (splitting-function 'random) (report-tree? t))
;; Check these examples for correctness, build a decision tree, then;
;; draw the tree (if requested) and, finally, report some statistics about it.
(format t "-% Building Decision Tree ...")
(setf class-list '(0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40
41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60
(if (test-examples examples)
    (progn
        (setf *current-tree* (id3 examples class-list *all-attributes* splitting-function))
        (format t " finished.-%")
        (setf *current-class-list* (append class-list '(*null*)))
        (if report-tree? (print-decision-tree))
        (let ((interior-nodes (count-interior-nodes *current-tree*))
              (leaf-nodes (count-leaf-nodes *current-tree*)))
            (format t " Tree size=A interior nodes=A leaf-nodes=A-%"
                    (+ interior-nodes leaf-nodes) interior-nodes leaf-nodes))
    ; (do (( cclass *current-class-list* (rest cclass) ) (re nil))
        ; ( (endp cclass) (return nil))
        ; (format t " class= -A leaves = -A-%"
        ; (first cclass) (count-matching-leaves *current-tree* (first ccla ss)))
  )))

(defun test-examples (examples &aux (no-error? t))
  ;; See if these examples are complete - all attributes specified - and
  ;; consistent - all attribute values valid. (Excess attributes are not detected.
  ;; However excess attributes do not affect the algorithm.)
  ;; Report any errors, returning T if there are none.
  (set-all-attributes)
  (dolist (example examples)
    (dolist (attribute *all-attributes*)
      (let ((value (second (assoc attribute (second example))))
            (cond ((null value)
                       (aetf no-error? nil)
                       (format t "Attribute ~A not present in example ~A-%" attribute example)
            ((member value (get-attribute-values attribute)) nil)
            (t (setf no-error? nil)
                (format t " ~A in example ~A-% is not in the domain of ~A-%" value example attribute)))))))

(defun set-all-attributes ()
  ;; Determine the collection of attributes being used.
  (setf *all-attributes* (mapcar #'first *domains*)))

(defun print-decision-tree (optional (tree *current-tree*) (indent 0))
  ;; Draw this decision tree, using indentation to indicate levels.
  (cond ((leaf-node? tree) (format t "-A " (first tree) (second tree)))
        (t (mapc #'(lambda (sub-tree)
                       (format t "-%")
                       (dotimes (i (floor (/ indent 3))) (format t "1 "))
                       (format t "-A-%" (first tree) (first sub-tree))
                       (print-decision-tree (second sub-tree) (+ indent 3))))
        (rest tree)))))

(defun count-interior-nodes (tree)
  ;; Count the interior (non-leaf) nodes in this tree.
  (cond ((leaf-node? tree) 0)
        (t (1+ (reduce #'+ (mapcar #'(lambda (arc) (count-interior-nodes (second arc)))
                                             (rest tree)))))))

(defun count-leaf-nodes (tree)
  ;; Count the leaf nodes in this tree.
  (cond ((leaf-node? tree) 1)
        (t (reduce #'+ (mapcar #'(lambda (arc) (count-leaf-nodes (second arc)))
                                 (rest tree))))))

(defun count-matching-leaves (tree match)
;;;; Count the number of leaf nodes in this tree that match the second argument.
(cond ((leaf-node? tree) (if (eq (first tree) match) 1 0))
  ((atom tree) 0)
  (t (+ (count-matching-leaves (first tree) match)
       (count-matching-leaves (rest tree) match)))))

(defun leaf-node? (x)
;;;; Determine if this is a leaf node. (Leaf nodes should be implemented as DEFSTRUCTs.)
  (and (consp x) (member (first x) *current-class-list*)))