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Final Report for 1986-87

to

National Aeronautics and Space Administration
Office of Experimental Test and Evaluation

RESEARCH ON ENHANCING THE UTILIZATION OF DIGITAL MULTISPECTRAL DATA AND GEOGRAPHIC INFORMATION SYSTEMS IN GLOBAL HABITABILITY STUDIES

for

NASA Grant NGL 17-004-024

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Edward A. Martinko, Ph.D.
Principal Investigator
Assistant Scientist, Space Technology Center

James W. Merchant, Ph.D.
Co-Investigator
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RESEARCH ON ENHANCING THE UTILIZATION OF DIGITAL MULTISPECTRAL DATA AND GEOGRAPHIC INFORMATION SYSTEMS IN GLOBAL HABITABILITY STUDIES

INTRODUCTION

The University of Kansas Applied Remote Sensing (KARS) Program has been engaged in a long-term research and development effort designed to reveal and facilitate new applications of remote sensing technology for decision-makers in governmental agencies and private firms. This program has developed the concepts and procedures for utilization of products prepared from the data gathered by various remote sensors (e.g., multispectral scanners, cameras) mounted in low and high altitude aircraft and spacecraft. Increasingly, KARS staff are developing mechanisms for integrating remotely sensed data with other data in automated geographic information systems (GIS). KARS staff conduct both basic research and applied research projects. Applied research projects are designed to address specific problems faced by officials in governmental agencies (municipal, county, multi-county, state and federal) and in business and industry. The interaction between the KARS Program and agency and industry personnel as they jointly work on cooperative projects insures the continued relevance of the program and maximizes the extent to which remote sensing/GIS technologies address actual issues, problems and needs.

The key objectives of the KARS Program may be summarized as follows:

- Research and develop new modes of analyzing Multispectral Scanner, Aerial Camera, Thermal Scanner, and Radar data, singly or in concert, in order that more effective use can be made of such systems.

- Merge data derived from remote sensing with data derived from conventional sources in geographic information systems to facilitate better environmental planning and resources management.
- Stimulate the application of the products of remote sensing systems to significant problems of resource management and environmental quality addressed in NASA's Global Habitability directive.
- Apply remote sensing techniques and analysis and geographic information systems technology to the solution of significant concerns of state and local officials and private industry.
- Participate cooperatively on remote sensing projects with public agencies and private firms.
- Effect the transfer of applicable remote sensing technology to governmental agencies and private firms at all levels as a by-product of projects conducted in the KARS Program.
- Assist personnel within public agencies and industry in the evaluation of the capabilities of the rapidly changing remote sensing systems and the benefits which might be achieved through their utilization.
- Guide, assist and stimulate faculty, staff and students in the utilization of information from the Earth Resources Satellite (Landsat) and Aircraft Programs of NASA in research, education and public service activities carried out at the University of Kansas.

1986-87 Project Year

During 1986-87, the KARS Program continued to build upon long-term research efforts oriented towards enhancement and development of new technologies for using remote sensing in the inventory and evaluation of land use and renewable resources (both natural and agricultural). These research efforts directly addressed needs and objectives of NASA's Land-Related Global Habitability Program as well as the needs of and interests of public agencies and private firms. The KARS Program placed particular emphasis on two major areas:

1. Development of intelligent algorithms to improve automated classification of digital multispectral data; and
2. Integrating and merging digital multispectral data with ancillary data in spatial models.

Our 1986-87 research built upon ongoing work of the KARS Program through the following projects:

- **A Paradigm of an Expert System Prototype for Semantic and Syntactic Land Use/Land Cover Classification**

The study of global habitability will require the preparation of a myriad of small scale (i.e., 1:250,000 - 1:5,000,000) thematic maps. Initial assessment of science issues which need to be addressed in the study of global habitability indicated that among others, maps depicting land use, biotic communities and ecological regions will be required. Such maps will need to be prepared for large areas (perhaps the entire Earth), and will need to be periodically updated in order to monitor and evaluate change in the environment, its causes and effects.

Landsat provides both the spatial and multi-temporal coverage required for such mapping. Most remote sensing specialists would agree that computer-based techniques have been rather successfully employed to classify and map land cover from Landsat Multispectral Scanner (MSS) and, more recently, Thematic Mapper (TM) digital data. In a rather typical outcome of computer classification, on a pixel by pixel basis, land cover can be identified quite accurately where such distinctions can be made based upon spectral characteristics of the cover.

Production of the types of thematic maps cited above, however, will require the development of new techniques of data analysis, ones that employ, not only spectral characteristics of the data, but also spatial, structural and contextual attributes. The importance of this task has been recognized in NASA's review of research needs related to the study of land-related global habitability[1].

Spatial/contextual algorithms are required for several reasons:

(1) to help distinguish between land cover types which have similar spectral characteristics, but which may, in fact, be quite different. Such cover types (e.g., irrigated alfalfa and watered urban lawns) would be indistinguishable using conventional spectrally-based algorithms;

(2) to aid in the generalization of classifications in order that small-scale maps can accurately represent the full resolution (i.e., each pixel visible) products from which they were derived; and

(3) to aid in the preparation of maps which portray integrated or synthetic regions (e.g., regions of land use or ecoregions which are comprised of complexes of land cover).

"A Paradigm of an Expert System Prototype for Semantic and Syntactic Land Use/Land Cover Classification" is a KARS project designed to demonstrate a sophisticated classification scheme through the development of a prototype expert system for general-purpose land use/land cover image classification of Landsat Thematic Mapper imagery. These techniques can be important for the production of maps depicting land use, biotic communities and ecological regions required for the study of global habitability.

- **Development of Models for Assessing Biological Productivity of the Land: The Use of Digital Multispectral Data and Spatial Modeling Techniques**

This research was carried out under three separate projects (the third project was funded 75% by the Kansas Fish and Game Commission and 25 % by NASA):

(1) Using Landsat TM Imagery and Spatial Modeling in Automatic Habitat Evaluation and Release Site Selection for the Ruffed Grouse (Galliformes: Tetraonidae)

(2) Automatic Mapping of Avian Species Habitat Using Landsat TM Imagery and Ground Sampling Points

(3) The Interspersion and Juxtaposition of Pronghorn Antelope Habitat

Fundamental to the study of global habitability is an understanding of biological productivity and its relationships to global energy balance and to biogeochemical and hydrological cycles. Biological productivity, however, not only requires the study of the primary productivity of plant communities but also the secondary productivity provided by animal communities. Knowledge of the composition, and the spatial and temporal distribution of plant and animal communities associated with land surface cover changes is therefore of central importance for developing models of biological productivity.

Landsat Multispectral Scanner (MSS) and Thematic Mapper (TM) digital data in conjunction with computer-based techniques have been utilized successfully in the classification and mapping of changes in land use and land cover. The ability to employ digital multispectral data to portray the spatial and temporal distribution of land surface features is essential for establishing a basis for modeling and assessing biological productivity on a regional or ecosystem basis.

NASA's Global Habitability Program reviews the importance of these and other related research needs as a basis for an understanding of the complex processes that offer habitability. Specifically, studies of the biological productivity of land require:

(1) investigation of integrated ecosystems in order to understand the interactions of land surface cover with life support processes;

(2) the assessment of the extent and spatial distributions of biomass and productivity associated with land surface features;

(3) the collection and analysis of remote sensing and ground data to determine normal variations within and among years;

(4) the development of models which characterize natural vs. man-induced surface cover variation to predict spatial and temporal changes in productivities.

"Development of Models for Assessing the Biological Productivity of the Land" is a KARS project designed to utilize digital multispectral data to classify land surface cover as a basis for developing models of biological productivity. Ground data on plant and animal community composition and distribution will be utilized in the biological productivity models for assessment of spatial and temporal productivity changes.

- **Merging Remotely Sensed Data with Ancillary Data: A Geographic Information Systems Approach to Resources Management**

Environmental management and policy decisions must, almost always, be based upon examination and analysis of the interplay of many different factors which may bear upon a particular issue. Decisions concerning conservation of high quality groundwater, for example, must be based upon evaluation of a spectrum of institutional, political, economic and environmental data. These data are usually geographically-referenced (i.e., data tied to specific locations on the Earth's surface). Geographically-referenced data may be considered data that can be mapped. Automated geographic information systems (GIS) enable one to rapidly store, manipulate, compare and display geographically-referenced data. Once stored, such data can be automatically extracted, reconfigured, updated, analyzed, mapped in a format and at a scale designed to meet a specific need, and used for many types of decision-making with a capability to analyze complex spatial interrelationships between variables.

Approximately two-thirds of Kansas water supplies are derived from groundwater sources. The aquifers containing these waters vary appreciably in lateral extent, saturated thickness, specific yield, depth to water and geological composition. The present quality of the groundwater also varies markedly. About 8 percent of public water supplies derived from groundwater contain concentrations of hazardous substances that exceed State primary drinking water standards. The Kansas Department of Health and Environment (KDHE) believes that most of these excesses are due to natural causes, but that some could possibly have been caused by man. The potential exists for additional contamination of groundwater supplies as municipal, industrial, and agricultural activities become more intense and cover a greater portion of the area overlying aquifers.

The purpose of this project was to develop techniques for using remote sensing and GIS technology to assess, monitor, manage, regulate and forecast groundwater conditions. The project was funded 75% by the Kansas Department of Health and Environment and 25% by NASA. It is expected that system use will generate suggestions for refinement and augmentation, unforeseen applications, administrative support for the technology and demand for additional capabilities related to other areas of global habitability.

A PARADIGM OF AN EXPERT SYSTEM PROTOTYPE FOR SEMANTIC & SYNTACTIC LAND-USE/COVER CLASSIFICATION

Tshow Chu

INTRODUCTION

The per-pixel based spectral (gray tone) approach has been the primary methodology employed for thematic mapping/classification research. The results of this method tend to be "noisy" in appearance and possess fairly low classification accuracies for most high level land use categories (e.g., Levels III and IV). Possible reasons for the noisy appearance and low accuracies are suggested by comparison with human interpretation, which generates relatively good classification results.

First, spatial and contextual information that can be visually extracted from the imagery is not fully utilized in a per-pixel based spectral classification. Human interpreters generally use more spatial information than spectral information. They apply some measure of texture, size, shape, pattern, and association of the individual objects in the image, in addition to spectral data (Lillesand, et al., 1979). Second, the traditional per-pixel computer classification process uses a single-stage classification scheme which treats all data equally and in one step. Human interpreters, however, employ a multi-stage classification scheme which involves multi-stage band selection for object identification. For different objects, the interpreter selects appropriate bands in a hierarchical fashion in order to decrease processing time and to eliminate noise from unnecessary bands.

Additionally, human interpreters use a multi-iteration classification process to accumulate information and incrementally increase the certainty/confidence level of classification (Merchant, 1984). Third, ancillary reference information and prior knowledge (experience) are used by human interpreters, yet these are not used in traditional computer-aided interpretation (Miller and Shasby, 1982). Reference information (e.g., a road map) and prior knowledge about the landscape of an area can provide additional information to help an interpreter identify more land use classes via inference.

In order to correct those drawbacks generated by traditional per-pixel spectral classification, a more sophisticated classification process needs to be designed to handle both more complicated data and the knowledge for using those data. Since human interpreters (i.e., experts in classifying land use from images) do achieve a good performance in extracting information to properly identify land use, an appropriate way to classify digital images is to more closely simulate the human (visual) interpretation process and incorporate the knowledge of the experts. What needs to be examined more closely and systematically is the knowledge that experts bring to bear during image classification and selecting an appropriate tool for using this knowledge. An expert system is one such tool.

Expert systems are computer programs that can achieve expert-level performance (Tinney et al., 1983). These systems usually contain knowledge derived from human experts working in the problem domain which the expert systems are designed to resolve. Expert systems are composed of two major parts: a knowledge base and a control strategy. The knowledge base will store the domain-related expertise used in solving problems, whereas the control strategy applies the knowledge in a logical, structured manner to solve the problems.

The primary objective of this research is to demonstrate a sophisticated classification scheme through the development of a prototype expert system for general-purpose land use/cover image classification of Landsat Thematic Mapper imagery. This classification scheme will include several unique features (according to the expert knowledge of the image feature being extracted) such as:

1) region-based primitives (i.e., use homogeneous regions as primitives);
2) multi-level primitives/multi-focus primitives (i.e., different levels of primitives generated according to different segmentation criteria);
3) knowledge-driven pattern matching (i.e., using separate knowledge bases for pattern matching); and
4) the use of ancillary information.

A general purpose land use map at a scale 1:100,000 will serve as the classification product and will be tested to assess the effectiveness of this new approach. The emphasis of this research is on development of interpretation knowledge and a control strategy, not digital extraction of raw information from the imagery.

DATA DESCRIPTION

The imagery used in this study is Thematic Mapper data of the City of Topeka and surrounding area in Northeast Kansas, acquired on September 3, 1982. The major ancillary data include a high altitude aerial photograph and 7.5 minute USGS topographic maps, which can provide information such as road structure, township boundaries, city limits, and other ground truth.

METHODOLOGY

The classification procedure in this study will consist of five basic stages: identification, conceptualization, formalization, implementation, and testing (Waterman, 1986).

1) **Identification.** The identification stage includes selecting the study area and defining the category scheme (problem domain).
2) **Conceptualization.** This stage includes knowledge acquisition, formation of the conceptual representation of the data and design of the control scheme. Expert knowledge is acquired through one of several techniques such as on-site observation of the domain expert and through personal interviews. Selecting a good representation (or data structure) of the acquired knowledge can make problem solving much easier, and selecting a good control strategy can make it more efficient (Winston, 1984).
3) **Formalization.** The third stage includes building the formal data representation and the control scheme. The most popular knowledge representations today are production rules, frames, semantic networks and procedures. According to the nature of the problem, one can select which of these representations to use given the nature of the interpretation knowledge. The best representation may be one pure form or a combination of two or more forms. Three basic control schemes used frequently are: data-driven reasoning (forward infer-

ence), goal-driven reasoning (backward inference), and a combination of these two.

4) **Implementation.** This stage entails selection of the tools to build the knowledge base and construct the control scheme for a working system. There are two different types of tools available. One tool is an Artificial Intelligence (AI) programming language, such as LISP or PROLOG. The other type of tool is an expert system building language, or expert system shell, such as KNOWLEDGE ENGINEER SYSTEM (KES), RULEMASTER and EMYCIN.

5) **Testing.** The last stage focuses on detecting errors in the knowledge base and the control scheme. This stage also provides for their correction via feedback loops. Detected errors are analyzed and used to correct the knowledge or control scheme. The expert system will also be used to classify images at this stage. A correctness and suitability report will be given at the end of the testing stage.

The process does not proceed along a one-way path, but is an iterative process allowing refinement of the system incrementally (see Figure 1).

CURRENT STATUS

The identification and conceptualization stages are complete. The study area and land use/cover category scheme have been selected (see Figure 2 and Table 1). Preliminary basic land cover classes and properties used to describe land use categories have also been compiled from general expert knowledge (Table 2). Construction of this table was accomplished by interviewing several experts in the field of image interpretation. Knowledge was

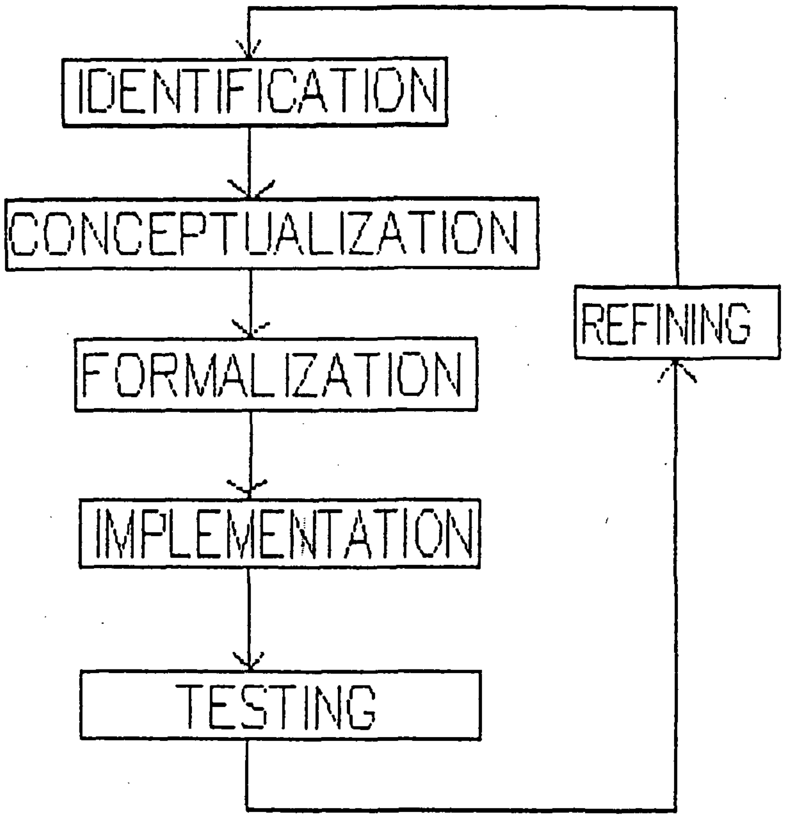

Figure 1. Five stages in the development of an expert system.

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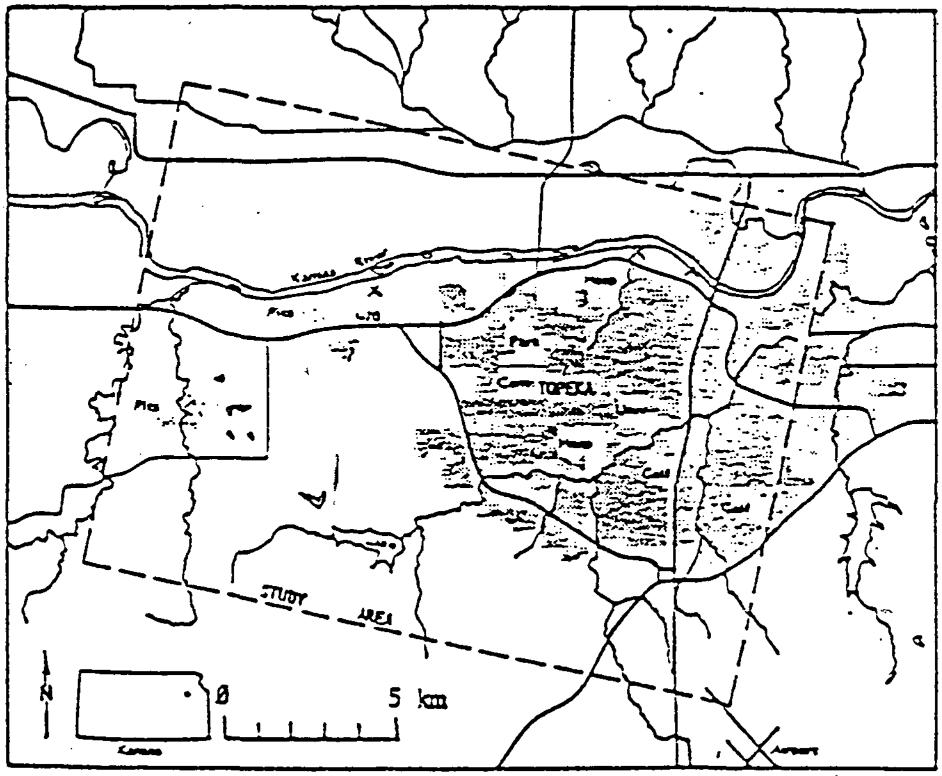

Figure 2. The study area: Topeka, Kansas.

Table 1.

The category scheme of land use/land cover.

LEVEL I	LEVEL II	LEVEL III
BUILD-UP & URBAN	COMMERCIAL& INDUSTRIAL	CBD OTHERS
	RESIDENTIAL	HIGH DENS MEDIUM DENS LOW DENS
	TRANSPORTATION	
	OPEN	GOLF PARK & OTHERS
AGRICUL-TURE LAND	CROP PASTURE	
RANGELAND		
FOREST		
WATER	RIVER POND RESERVOIR	
BARREN	SAND BAR & BEACH	

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Table 2.

All possible and necessary values describing each attribute for a land use category are listed. The expert can fill in the values and their certainty for this category, and check if there is any thing missing. (A1-A7: attributes; V1-V7: values)

LEVEL IIICATEGORY:h-d resid

		V1	V2	V3	V4	V5	V6
A1	categoy ii	residen	open				
A2	color major	dark re	red	green	light b	white	
A3	color minor	white					
A4	size	< 100	>= 100				
A5	texture coarsene	smooth	fine	med-fine	medium	med-coar	coarse
A6	texture conrast	low	medium	high			
A7	assoc distance	close cb	close ed cbd				

LEVEL IIICATEGORY:m-d resid

		V1	V2	V3	V4	V5	V6
A1	categoy ii	residen	open				
A2	color major	dark re	red	green	light b	white	
A3	color minor	white					
A4	size	< 100	>= 100				
A5	texture coarsene	smooth	fine	med-fine	medium	med-coar	coarse
A6	texture conrast	low	medium	high			
A7	assoc distance	close cb	close ed cbd				

acquired from experts using the problem-analysis technique, presenting the interpretation expert with a realistic problem to be solved aloud. The interview method used was the "depth-first probe technique" (Waterman, 1986), which enables acquisition of no more knowledge from the domain expert than is needed for classifying the specified land use categories.

The knowledge is currently being formalized. The expert system tool being used in the investigation is the KNOWLEDGE ENGINEER SYSTEM (KES). Formalization of the knowledge is proceeding using the frame representation method. A "frame" refers to a special way of representing common concepts and situations. A frame contains many slots for different attributes, and there are procedures triggered by the value changes of each attribute. The frames can be linked up by arcs to form a hierarchical relation and to represent the situation from general to specific (Figure 3). Frames are useful for problem domains in which expectations about the form and content of the data play an important role in problem solving, such as interpreting visual scenes or understanding speech. In this research, a frame-like representation is used to implement the knowledge base (most other image classification expert systems use production rule representation), and the procedural-like representation is used to implement the classification strategy.

The classification results produced by the knowledge based interpretation expert system are expected to be much better than the traditional classifications. The expert system approach not only provides a powerful interpretation tool, but also helps to inspect and understand the knowledge and procedures human interpreters use. Therefore, the interpretation

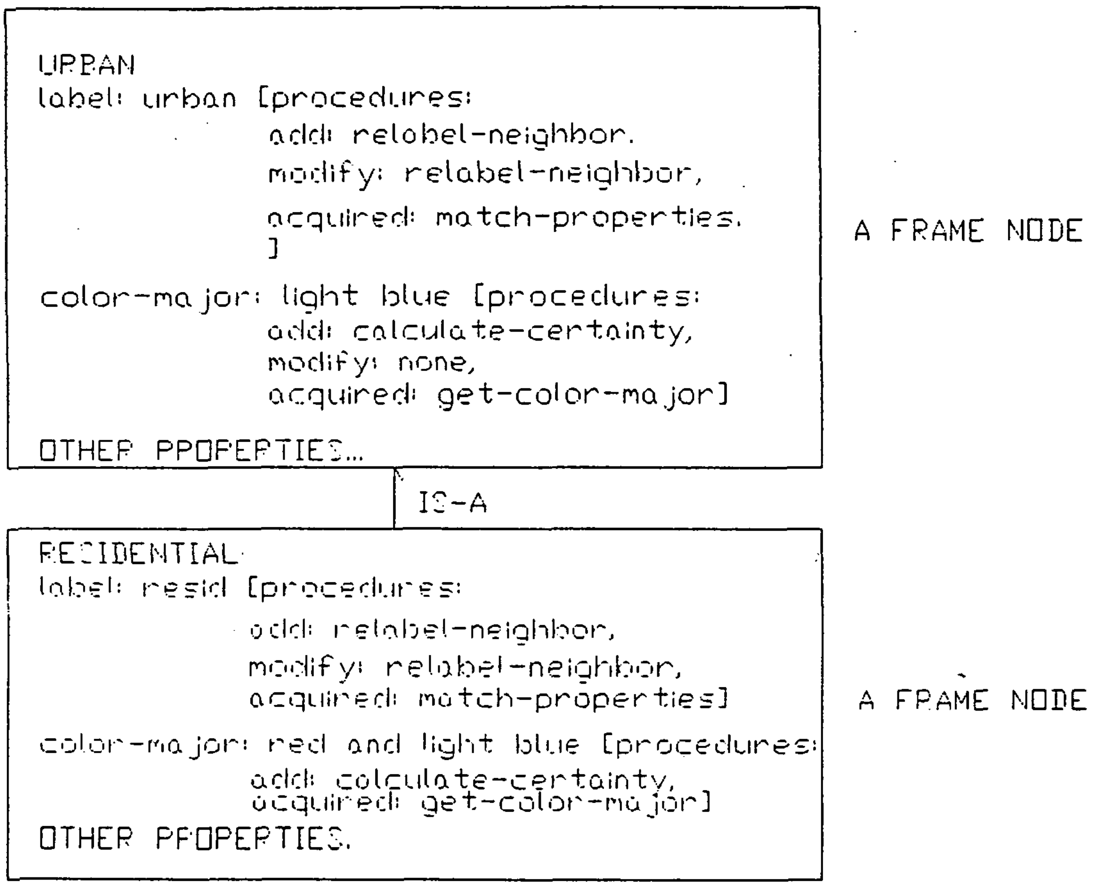

Figure 3. Frame representation. A frame node is a data structure for storing information of an object. In a frame node, there are many "slots" for the properties of the object. Each slot is composed of the value and the procedures triggered by changes on the status of the value.

expert system can be used as a learning tool for training human interpreters.

In this study, only a few simple spatial measurements are used to simulate a human's visual detection functions. Therefore, more sophisticated spatial measurements may be designed and added later in this classification framework for improved results. Moreover, because the knowledge base is separate from the main control program, we can easily add in more land use/cover categories or modify the knowledge base in order to make it suited for interpretation of other areas.

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DEVELOPMENT OF MODELS FOR ASSESSING BIOLOGICAL PRODUCTIVITY OF THE LAND

USING LANDSAT TM IMAGERY AND SPATIAL MODELING IN AUTOMATIC HABITAT EVALUATION AND RELEASE SITE SELECTION FOR THE RUFFED GROUSE (GALLIFORMES: TETRAONIDAE)

Jorge M. Palmeirim

INTRODUCTION

The low ground resolution of the Multispectral Scanner (MSS) (79x79m) has been a major factor limiting the use of its imagery in habitat studies. Nevertheless many papers have been published on the subject in the last few years showing a wide range of applications when a high ground resolution is not critical. In particular the usefulness of MSS Landsat imagery in the selection of sites for reintroduction of locally extinct species has been demonstrated by various projects. Wild turkeys (*Meleagris gallopavo*) were released at sites selected using an MSS-based land cover classification (Katibah and Graves, 1978); monitoring the rates of conversion of rangeland to agricultural land using MSS imagery assisted in the choice of release sites of pronghorn antelope (*Antilocaprá americana*) in Kansas (Martinko, 1978). The higher resolution of the Thematic Mapper (TM) (30x30m) considerably increased the potential to use satellite-borne sensors in wildlife studies.

Most of the previous work focused upon simple identification of habitat elements, such as vegetation. In spite of the usefulness of that work, it is unfortunate that so little effort has been expended in relating these elements to the actual needs or preferences of the individual animal species (but see Thompson, et al., 1980; Lyon, 1983). This project attempted to do this using TM imagery to generate a vegetation map, and GIS models based on the biology of the ruffed grouse (Bonasa umbellus) were used to manipulate the vegetation map. An automated model was developed to evaluate the quality of the identified vegetation types as habitat for the ruffed grouse. This model generated a habitat suitability map which was then used in another model that selected potential sites for reintroduction of the grouse.

The ruffed grouse is a forest species with a wide range in North America. Due to its importance as a game bird various agencies have been reestablishing the grouse in areas where it became extinct in historical times, or even introducing it outside its historic range (Gullion, 1984). The Kansas Department of Wildlife and Parks (formerly the Kansas Fish and Game Commission) is currently attempting to restore this species in wooded areas in northeastern Kansas. Throughout most of its range the grouse depends heavily on aspen (Populus tremuloides, P. grandidentata) for food and cover (Gullion and Svoboda, 1972). However, in the southern part of its range, in the absence of aspen, the grouse seems to be mostly dependent on understory growth of shrubs, vines, and herbs for those requirements (Hale et al., 1982). Not surprisingly it is believed that in these regions it was, prior to settlement by Europeans and widespread extinctions, limited to ecotones and early successional areas (Hunyadi, 1984). Since Kansas is on the southern edge of the historical range of ruffed grouse these are the habitats where it is most likely to thrive in the state.

The study area is located around the intersection of Douglas, Leavenworth and Jefferson counties, just north of Lawrence, Kansas. It includes 52 km

(240x240 TM pixels) of intermixed rangeland, cropland, deciduous forest and old fields.

MATERIALS AND METHODS

All the image processing in this project was done on a Honeywell 66 DPS-3E computer. The figures were generated using a Earth Resources Data Analysis System (ERDAS), installed on a Digital Equipment Corporation PDP-11/23, and an Anadex Silent/Scribe printer.

Spectral Land Cover Classification

An automatic supervised spectral classification was first performed. The image was subdivided into various cover types, according to their spectral characteristics. A series of training areas of known cover was selected to characterize each cover type, and a set of training statistics was developed. These training areas were identified based both on the analysis of high altitude color infrared photographs (National High Altitude Photography Program), and on field checks. A total of 59 training areas were used to characterize seven information classes. After experimenting with various combinations, TM bands 2, 3, 4, 5, and 7 were chosen. The TM image used was obtained by Landsat 4 on September 3, 1982. The spectral image classification was done using a modified version of Kansas University Teaching Image Processing System (KUTIPS) program package (Williams et al., 1983).

Two separate land cover maps were generated using the same training statistics but different classification algorithms. The Maximum Likelihood Classifier produced the map with the highest overall accuracy, but the

Minimum Distance Classifier was more successful in mapping wooded areas. To take advantage of this situation the two forest classes of the Minimum Distance map were digitally overlayed onto the Maximum Likelihood image. The Map Analysis Package (MAP) (Tomlin, 1980) was used to merge the two classified images. The final land cover map used was therefore a combination of the results of both classifications.

Contextual Land Cover Classification

The contextual information in an image can be used to improve the accuracy of pixel identification (e.g., Gurney and Townshend, 1983). Contextual information was incorporated in the land cover classification following a simple and computationally inexpensive approach. Pixels that could not be assigned with acceptable certainty to any of the cover classes based on their spectral characteristics alone were submitted to the spatial classifier; each of these pixels was assigned to the majority cover in its immediate neighborhood.

Two approaches were used to spatially classify pixels, depending on the homogeneity of its neighborhood: (1) if at least five of the eight neighbors in a 3x3 pixel neighborhood of a particular pixel belonged to a single cover class the pixel was assigned to that class; (2) the identity of the remaining unclassified pixels was determined by a larger (5x5 pixel) neighborhood. However, since a pixel adjacent to an unclassified pixel provides a better clue to its identity than a pixel located further away, the individual contributions were proportional to the distance from the pixel being classified. This contextual classification was performed using a modified version of neighborhood functions available in the MAP package.

Habitat and Release Site Evaluation

Extensive processing of the land cover map was needed to generate the habitat and release site maps. All the operations were performed using unmodified functions available in the MAP software. Although MAP is an interactive package, the large number of operations needed for each model made it advantageous to lay out sequences of commands in files; the commands were then executed automatically in the set sequence. This approach resulted in considerable time savings due to the need to make modifications in the models during their development. Implementing the same model in other areas and/or including minor modifications also becomes simpler and more accurate.

RESULTS AND DISCUSSION

Land Cover Classification

The seven class land cover map generated included rangeland, old fields, standing crop, bare soil, water, and two types of deciduous forest. Since the ruffed grouse is a forest species a particular effort was made to optimize the mapping of these latter cover types. A comparison of the results obtained with aerial photography and field checks showed that the generated map (Figure 1) accurately represents the distribution of forest in the study area. Small clumps of trees, the wider tree rows, and the intricate contours of the irregular woodlots characteristic of this area were evident. The gray area on the classified image (Figure 1) indicates forest appearing younger, mostly on south-facing slopes, and black represents the remaining forest. The composition and structure of the forest on the south-

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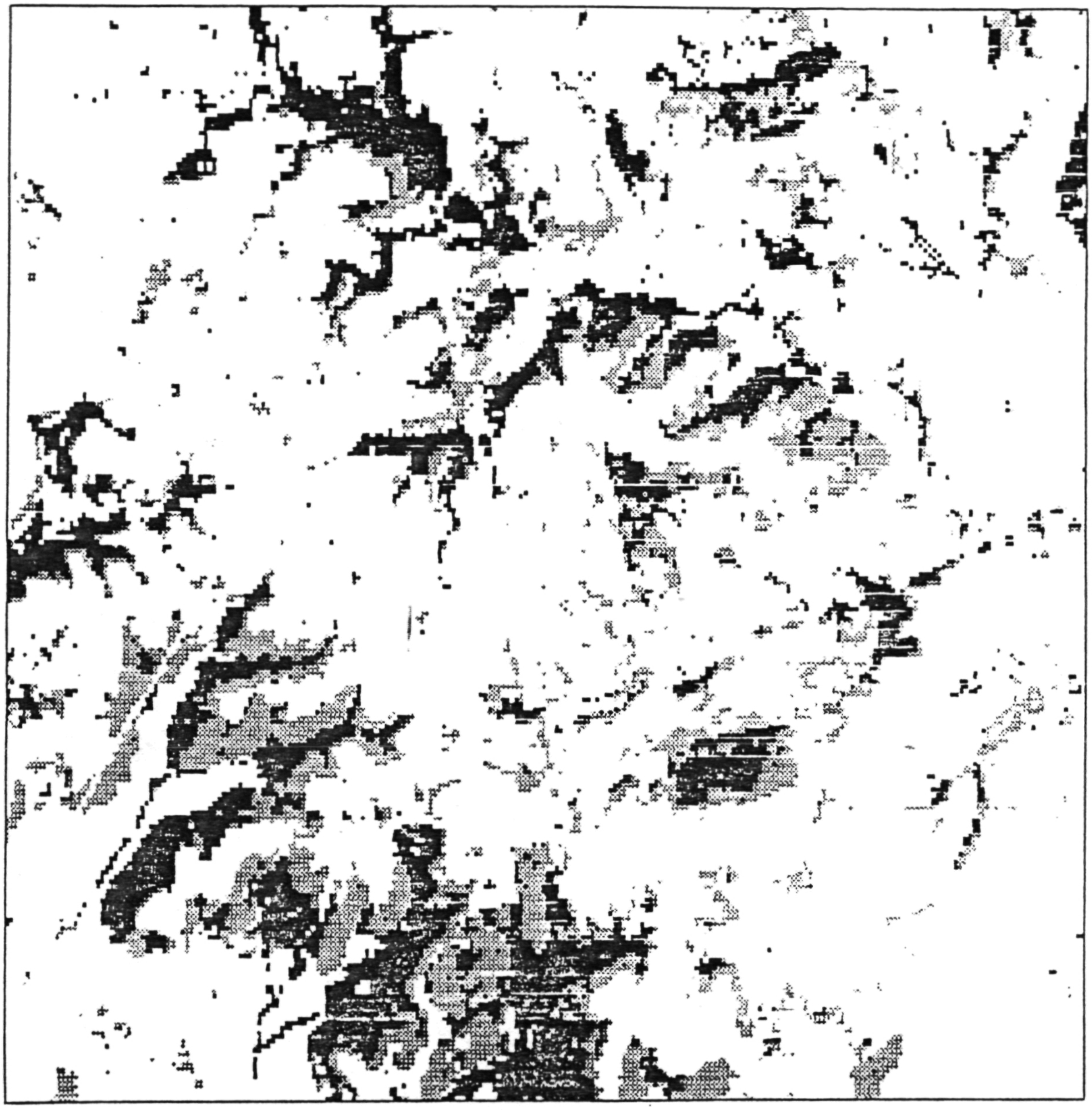

Figure 1. Classified forest cover of the study area. Gray is xeric forest, mostly on south facing slopes; mesic forest is in black.

facing slopes differs considerably from that of other exposures. This seems to be at least partially related to their age (Fitch and McGregor, 1956, include a description and history of some of the forest lots in the study area). The degree of confusion between the two types of forest on the classified map is hard to estimate, because no absolute criteria were established to separate them on the ground.

Habitat Evaluation

When visually classifying ruffed grouse habitat suitability using aerial photographs, the experienced wildlife biologist would make a series of more or less subjective decisions. The models used attempt to process the imagery making similar judgments. This is a particularly hard task because it is often not possible to state absolute rules for those judgments. In the following pages the various "decision steps" made will be illustrated, and explain their biological significance in the context of ruffed grouse habitat will be explained.

Woodlot size and interconnection. The wooded areas were first isolated from the land cover map; other habitats were considered as not fulfilling the minimal ruffed grouse habitat requirements. The analysis will not be seriously affected if grouse use these habitats since this will only happen along forest edges. Although all forested areas can potentially be grouse habitat the high resolution of the TM imagery (30x30m) allows the mapping of very small clumps of trees, many of which are too small to be used by the grouse. Isolated forest pixels were therefore eliminated. Of the remaining woodlots some are still too small, unless they are located close to other woodlots. Forest patches separated from other forest patches by more than

300 meters were eliminated unless they had an area of 4 ha or more (Figure 2). This area was chosen because one pair of grouse per 4 ha is about the highest possible density under most conditions (Gullion and Svoboda, 1972). Figure 2 still includes some woodlots smaller than 4 ha; this is because they are close enough to other forest patches to be considered connected to them. This figure also shows that there is a high level of interconnection among the woodlots and that small patches of forest are important in the interconnection of the larger woodlots.

Edge effects. The most important limitation of a habitat evaluation model based on Landsat imagery is that it can only include variables that can be directly detected and measured on the imagery or easily included as digital ancillary data. In the case of ruffed grouse habitat in Kansas, the inability of Landsat images to detect the structure of the forest understory is a serious limitation because in the southern part of its range the grouse seems to be mostly dependent on the understory (Hale et al., 1982). The imagery is, however, particularly suited for modeling using spatial components of the habitat and closely correlated variables. Forest edges are a good example - they can be accurately mapped and are closely associated with a denser understory. Overgrazing has destroyed much of the forest undergrowth in northeastern Kansas. This factor is likely to have been a major cause for the disappearance of the ruffed grouse in the state (Goss, 1891). Presently, dense undergrowth occurs mostly along edges, where growing conditions are more favorable and regeneration faster. Forest edges are therefore the most important single element in this habitat evaluation. TM imagery is well suited for this project because it allows an accurate

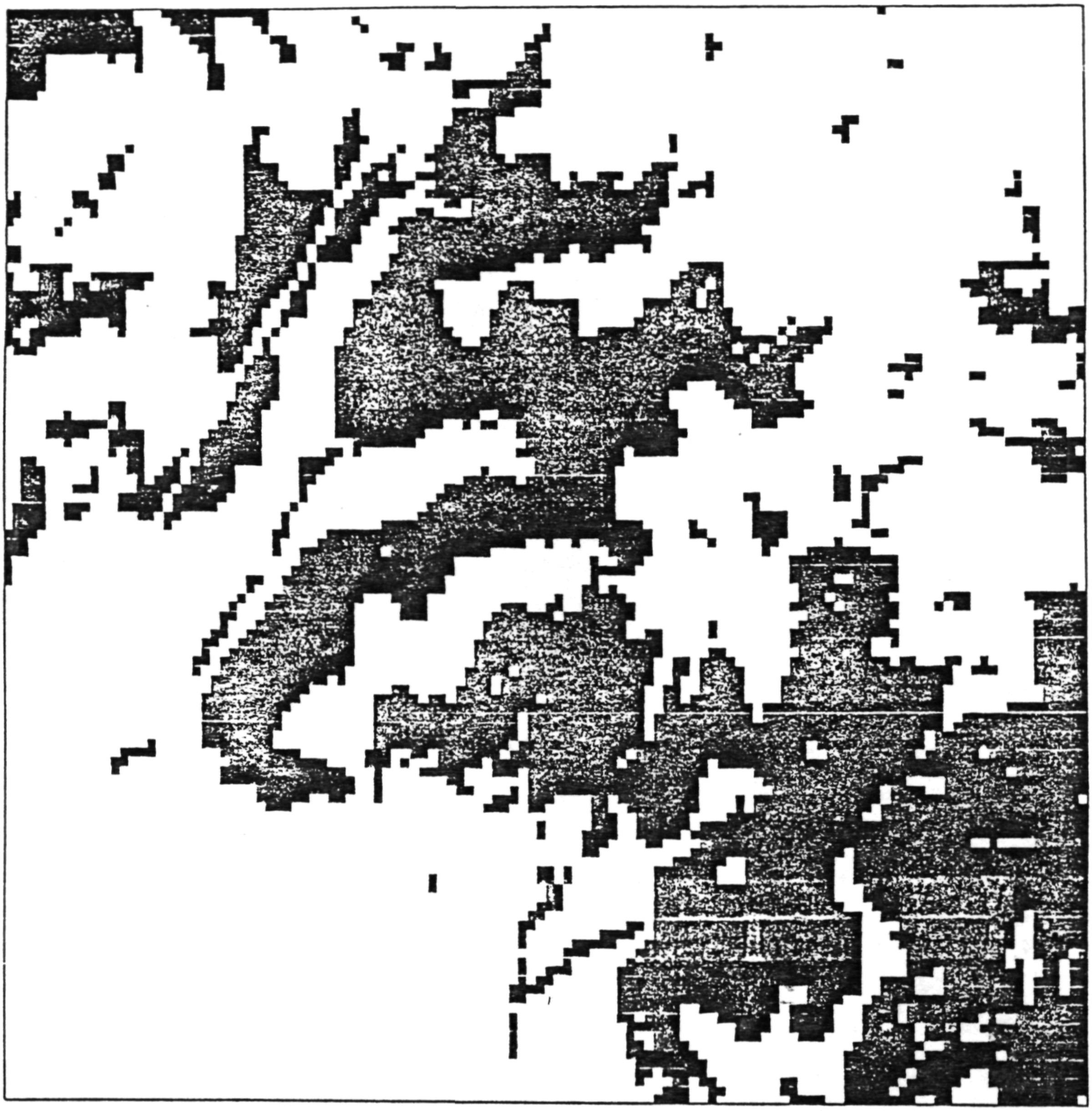

Figure 2. Usable woodlots (SW corner of the study area). Single forest cells and small isolated woodlots were eliminated.

mapping of the forested areas, and its comparatively high resolution portrays the detail of the woodlot edges. Using imagery with a poorer resolution, such as MSS, would result in a considerable loss of detail in these edges, which are so critical for the grouse. Forest clearings are often good habitat for the ruffed grouse in this area since they usually create an edge effect that generates a denser understory in the forest in their vicinity. However, very small clearings are probably not important habitat, and the likelihood that they are the result of a misclassification of the Landsat data is comparatively high. To avoid a major influence on the final habitat evaluation the smallest clearings were eliminated. Figure 3 shows the results of this operation. The appropriateness of this step is however quite debatable because, while it eliminates undesirable image noise, it also causes the loss of some habitat information. Since the final result of the model was acceptable, this step was retained in the analysis.

Since forest edges are most likely the best habitat for the grouse in this area, the edge pixels were given the highest ratings on a scale of 0 (no habitat, lightest on Figure 4) through 5 ("best" habitat, darkest on Figure 4). In the map on Figure 4 the relative quality of each pixel is proportional to its location in relation to the forest edge. Rating 5 was given to the actual edge pixels, 3 to pixels between 30 and 90 meters away from the edge, 2 to the pixels between 90 and 180 meters, and 1 to the innermost forest. Non-forest pixels were assigned a rating of 0. The scale is arbitrary and is designed to reflect relative probability of habitat quality: the probability of a pixel being suitable as habitat for the grouse is higher when located near an edge than in the innermost part of a woodlot.

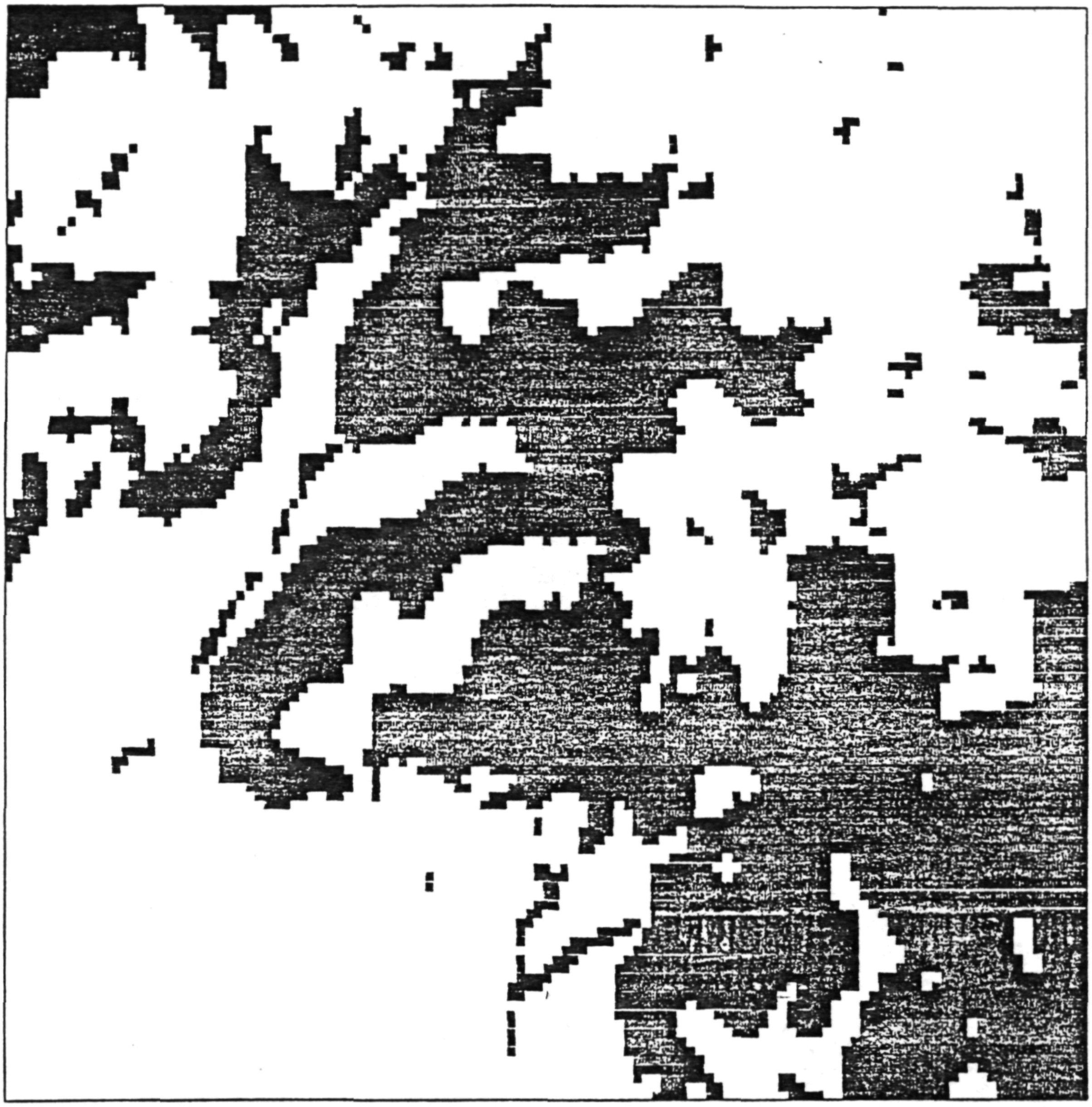

Figure 3. Forest minus small clearings (SW corner of study area).

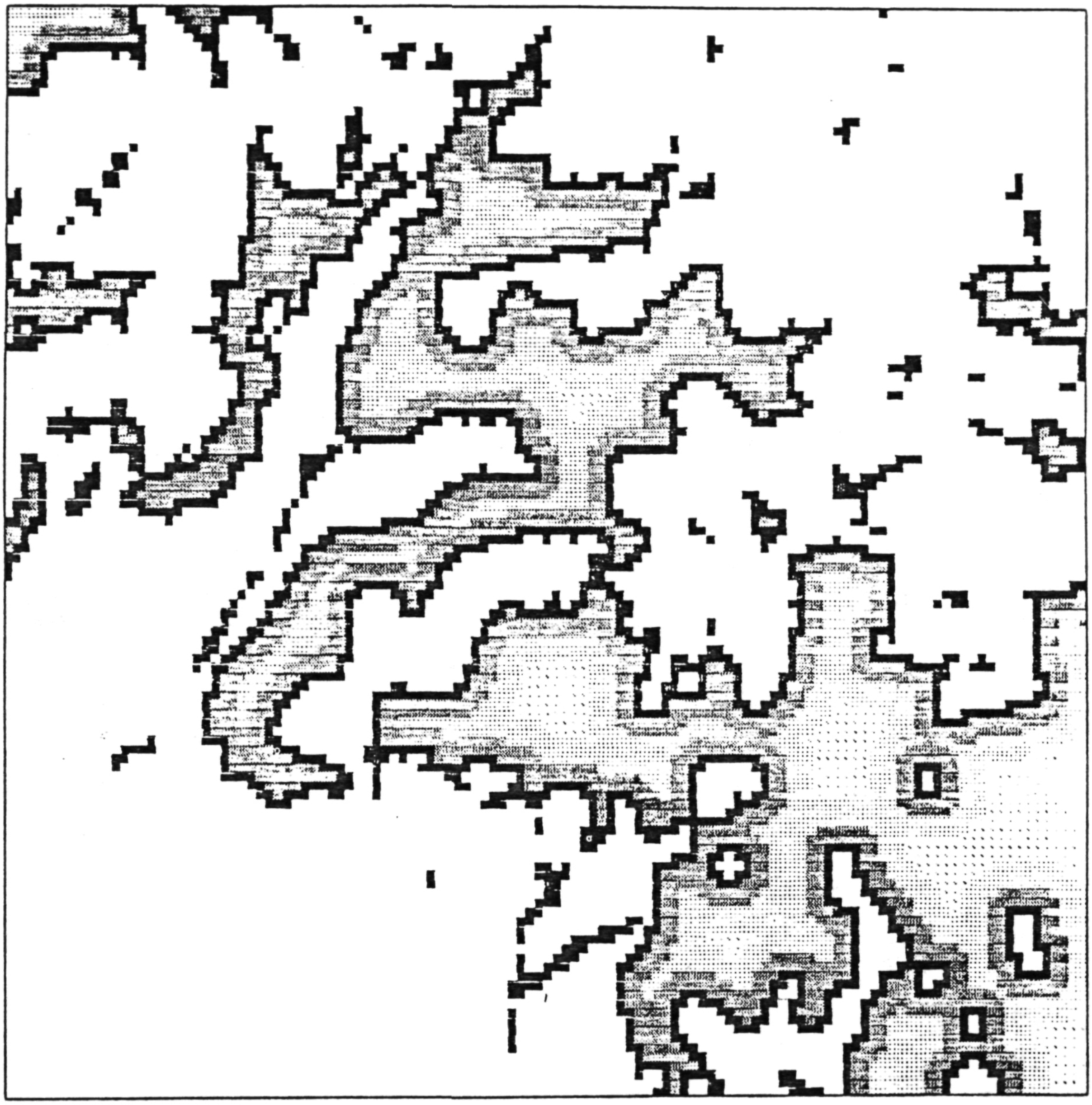

Figure 4. Distance from edge (SW corner of the study area). Darker areas have a higher probability of being good habitat.

Further studies are needed to select an optimal rating scale.

Forest type. The preferred types of forest for the ruffed grouse seem to vary seasonally, even though grouse seem to use all types of hardwood forest (Bump, et al., 1947; Gudlin and Dimmick, 1984). Overall, the grouse seems to prefer second growth hardwood forest over climax forest, particularly for brood cover (Bump et al., 1947). Although preferences shown in other areas may not hold in the study area, the ratings of the areas of younger forest (Figure 1) were increased slightly, by adding one unit to the previously assigned ratings (Figure 5). The suitability scale now varied between 0 and 6, the highest value corresponding to second growth forest edge pixels.

Final habitat suitability map. Habitat suitability is better measured by an average of quality over an area than by the ratings assigned to individual pixels as in Figure 5. The quality of each pixel as potential habitat for the grouse is not only a function of its characteristics but also of the forest pixels in its neighborhood. The rating of each pixel was, consequently, substituted by the average rating of the forest located within a circle of about 30 ha centered on the pixel (Figure 6). Although the size of the scanning area is not critical, (because the technique is deriving a relative not absolute quality rating), the choice of 30 ha as the scanning area is based on the fact that this is a reasonable size for the home range of a male grouse (Gudlin and Dimmick, 1984; Woolf, et al., 1984). The cell ratings on this image can, thus, be considered a measure of the relative quality of home range of a bird that used the area within a circle of 30 ha centered on each cell. However, since nonforested pixels were

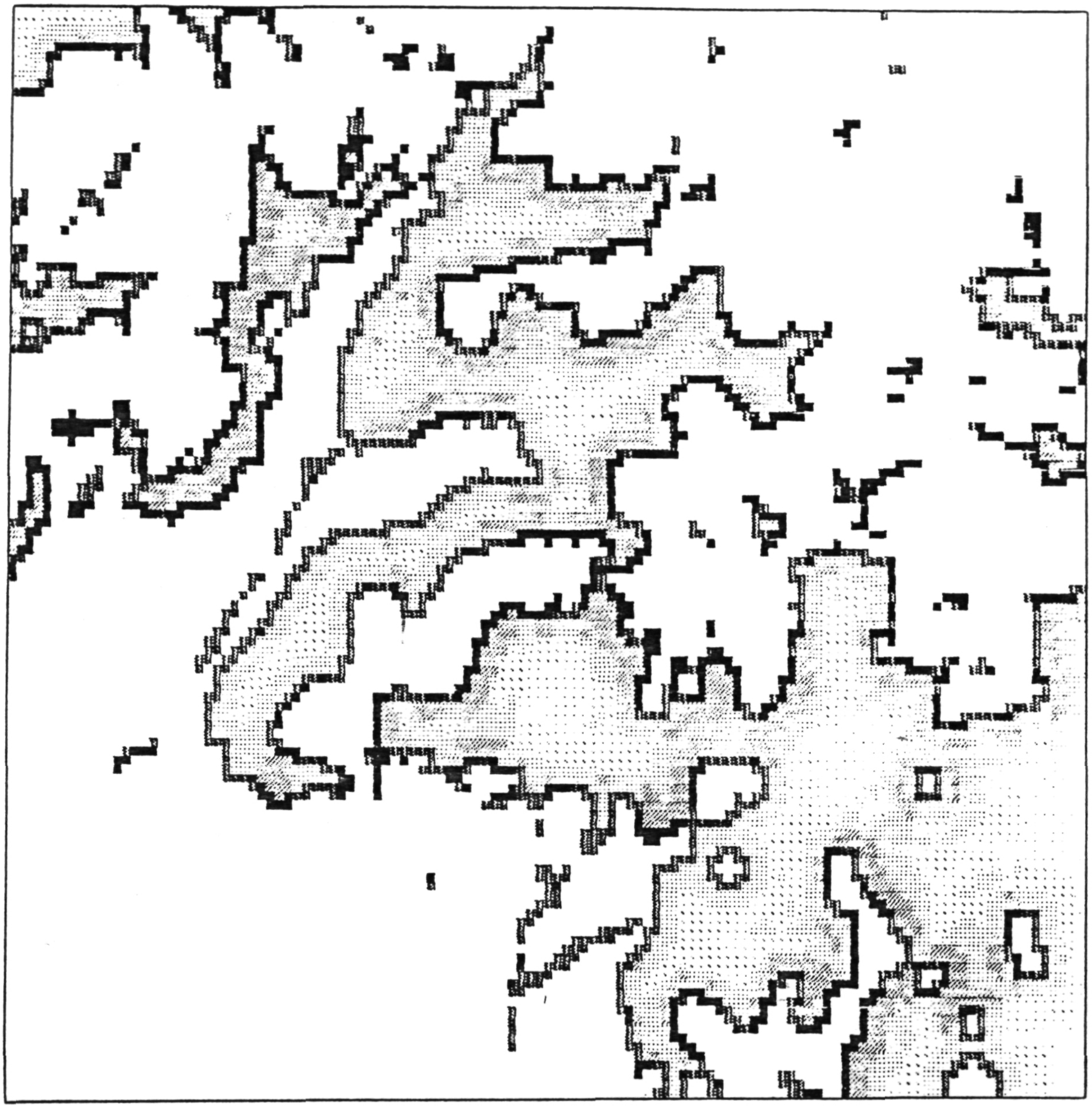

Figure 5. Distance from edge and forest type (SW corner of the study area). Darker areas have a higher probability of being good habitat.

Figure 6. Habitat suitability map (SW corner of the study area). Darker areas have a higher probability of being good habitat.

excluded from these calculations, the actual averaged area may be much less than the 30 ha scanning circle. Notice on this figure that the highest ratings have been assigned to small and/or irregularly shaped woodlots due to the greater importance of edges in those lots. The lowest probability habitat suitability ratings were assigned to the innermost areas of the larger lots.

The road network was digitized and superimposed on the habitat suitability and following maps (Figures 6, 7, 8, and 9) to make them easier to use. The signal of the roads on the original imagery was deleted to avoid confusion with the road overlay.

The suitability map on Figure 6 is needed for the process of selection of release sites, but it can also have other applications in a grouse management project. For example, it can be used to help in the choice of sites to place man made drumming logs, since the areas with darker tones are more likely to become grouse territories.

Release Site Selection

Despite its usefulness the habitat suitability map generated (Figure 6) still leaves open the question of where the release points should be located. One could select these points using the habitat suitability map by visually choosing areas including large amounts of good habitat. To locate the best candidate sites automatically the rating of each forest cell was made proportional to the amount and quality of the forest habitat within a circle having a diameter of 1800 meters centered on the pixel (Figure 7). The choice of diameter is a compromise between the need to sample a considerable amount of habitat and the advantages of keeping a small scanning

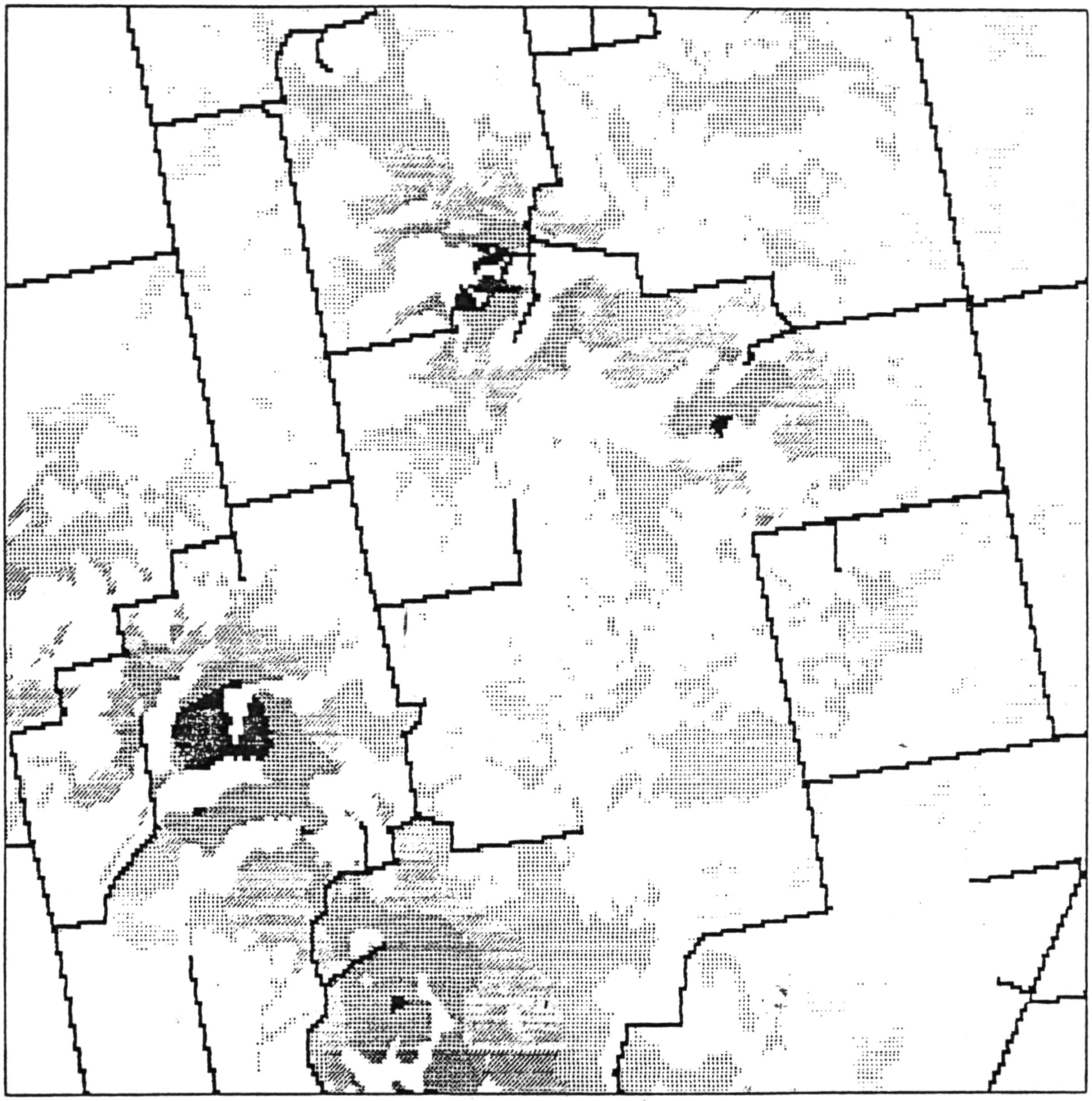

Figure 7. Suggested release sites. Darker areas are more likely to be good release sites. Black lines are roads.

radius. The use of a larger radius could result in suggested release sites located far from patches of good habitat; the spatial correlation between the generated "release sites" map and the "habitat suitability" map is inversely proportional to the length of the radius used. The 1800 meter diameter was chosen to reflect known dispersion patterns of grouse away from release sites (Gudlin and Dimmick, 1984).

Before performing the scanning operation the values on the scanned map (Figure 6) were squared. The squaring operation was designed to increase the relative contribution of the best habitat types in generating the "release sites" map (Figure 7). The rating scale ranged then from 0 (lowest, no habitat) to 36 (highest, best habitat). The values of all the pixels within the scanned area were then averaged; the value obtained was assigned to the center pixel.

The "release sites" map is intended to be an aid in the location of sites to release grouse. The suitability of the areas having the highest ranks should be field checked first. Grouse can then be released either on these high ranking areas or in neighboring areas of good habitat (as suggested by the "habitat suitability" map and field checks).

In the choice of release sites there are usually two main considerations: (1) site quality, which was discussed above and is dependent on the habitat suitability around the potential site (Figure 7), and (2) convenience, a component most often dependent on the accessibility of the site. A very good site may not be used because it is too costly to reach. In this study area the dense road network and the absence of common obstacles such as large water bodies and rough terrain, make the access to all areas fairly easy. However included here, as an example, is a simple extension of the release site selection model that takes in consideration convenience.

The convenience of a release site decreases with the distance from a road. Since it is much easier to move in some land cover types than in others, it would not be appropriate to evaluate convenience with a simple distance measure; the difficulty of moving in the various cover types should also be included. It was estimated to be about three times harder to walk through the forest than through the other major cover types. Figure 8 shows four levels of relative difficulty in reaching the various parts of the study area, taking into consideration the differences in mobility. Figure 9 is a combination of Figure 8 with the release sites map (Figure 7); it combines the quality of release sites with their convenience. For sake of clarity only the higher ranking areas are shown in Figure 7. The darkest tones represent very good quality and very good convenience (accessibility) ratings; the lighter tone also represents very good quality but lower convenience rating.

Validity of the Models

A serious problem with the models presented here is the difficulty in testing their validity. Even if grouse are released and the species becomes established in the study area, it will take several years before its distribution and density will become a useful indication of habitat suitability. However, the experimental results obtained were evaluated by wildlife management professionals familiar with both the grouse and the local habitat conditions. It was concluded that the techniques employed have substantial potential as tools in grouse management. Field checks also support the

Figure 8. Difficulty of access. Darker areas are harder to reach from roads. Black lines are roads.

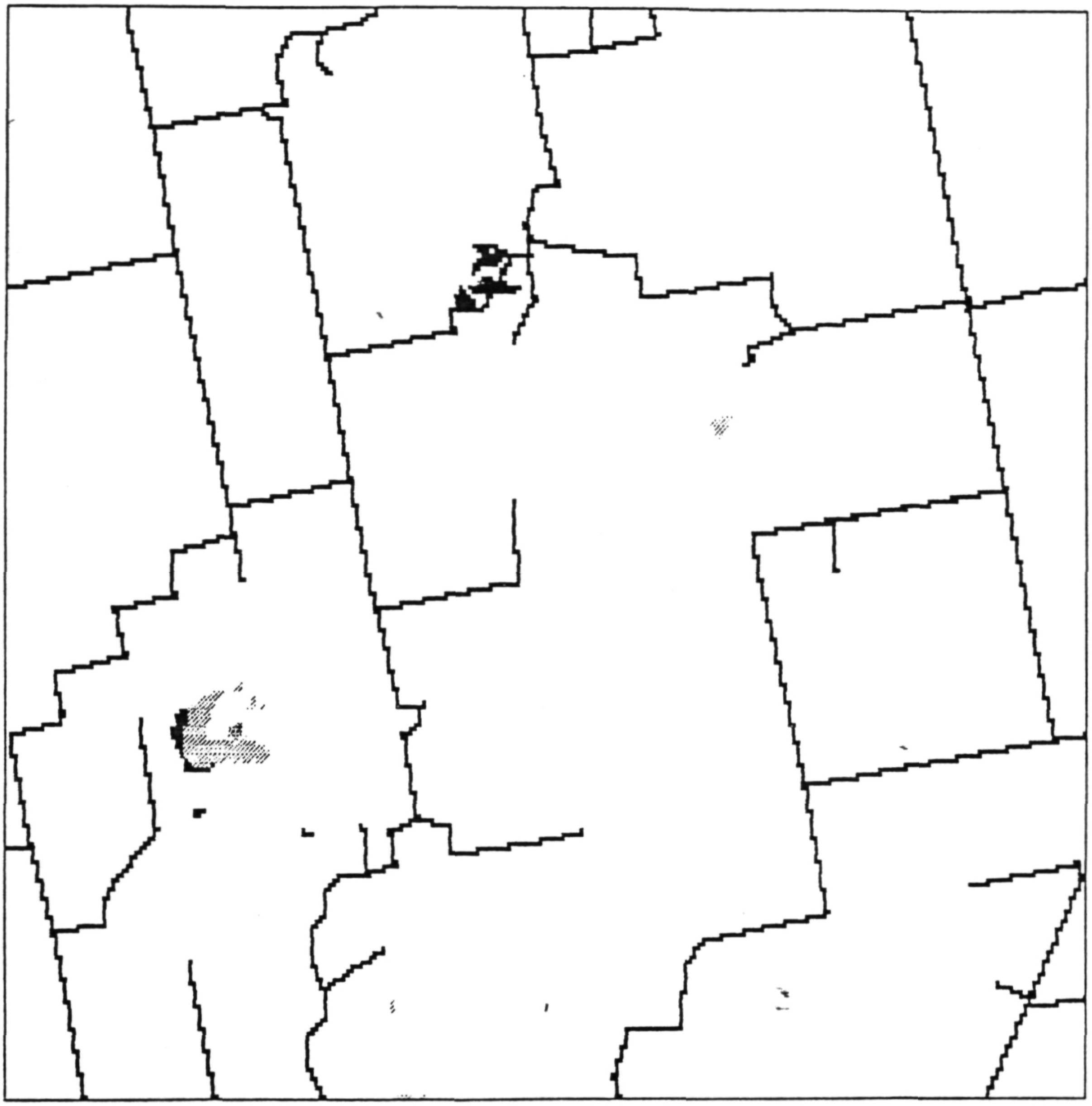

Figure 9. Good and accessible potential release sites.

utility of these TM imagery based models and they will soon be implemented operationally in a much larger area, which will help in their evaluation.

CONCLUSIONS

TM imagery proved to be appropriate for this project, in which accurate forest classification and detailed woodlot edge mapping were needed. The MAP package was an invaluable GIS tool. The many available general use commands when combined allow the implementation of complex image operations. MAP was used in this project not only to implement the models, but also to improve the spectral land cover classification, introducing contextual information in the final land cover map. The package also allowed the inclusion of roads as a reference system on the final maps generated. Various versions of the MAP package are now available, including one for microcomputers (pMAP, Spatial Information Systems) making this technology quite accessible.

The models implemented in this paper were designed to be used in northeastern Kansas. It was assumed that most good ruffed grouse habitat lies along the forest edges. The models are, therefore, applicable only where this assumption is met, as in the many areas lacking aspen along much of the southern range of the species. Model adjustments can be made to adapt the model to different areas. For example, the suitability rating of the non-edge forest, very low in this study area, can be increased if the model is applied to areas where the forest has a more dense understory.

This is one of the first attempts to combine Landsat imagery and spatial modeling in wildlife biology. However, the need for habitat models is great and many models based on habitat variables obtained in the field are now available (for the ruffed grouse see Cade and Sousa, 1985). These models have the advantage of basing their predictions on variables that describe habitat with more detail than TM imagery. The limited capability of satellite-borne sensors to provide information on certain important habitat components restricts the range of situations were the approach described in this paper can be successfully implemented. However, when applicable, models based on digital satellite imagery can be implemented quickly and inexpensively over large geographical areas. Because some of the variables employed (e.g., density of understory) are not directly detectable but are inferred from other variables (e.g., distance to edge), the various suitability maps generated in this project cannot be called absolute maps. The rating assigned to a pixel on these maps is intended to be correlated with the probability of that pixel being good habitat. The maps produced might therefore be better described as "probability" maps than "suitability" maps, as they are referred to for convenience in this paper. The results obtained support the belief that, when their limitations are not underestimated, these and similar models can be very useful tools in decision making for wildlife management.

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AUTOMATIC MAPPING OF AVIAN SPECIES HABITAT USING LANDSAT TM IMAGERY AND GROUND SAMPLING POINTS

Jorge M. Palmeirim

INTRODUCTION

Species distribution maps and habitat suitability maps are included in a great number of biological studies, and are used for a variety of descriptive, analytical, and management projects. These maps are usually based on field collections or observations at a limited number of sites, the results then being generalized to continuous maps using more or less subjective methods. Two recently developed tools, digital satellite imagery and geographic information systems (GIS), have the potential to make this generalization process more objective, detailed, and easier, thus producing more accurate map products. The main objective of this study is to use these tools to develop and test automated methods to produce maps of potential distribution and habitat suitability.

The era of remote sensing from space started in 1972 with the launch of the first satellite in the Landsat series, which carried a Multispectral Scanner (MSS), an instrument designed to transmit images of the earth. Ten years later Landsat 4 was put in orbit with a MSS and a new experimental remote sensing instrument, the Thematic Mapper (TM). The performance of the TM was very good and in 1984 it was launched again, aboard Landsat 5. The view angle of the TM is 15.4, which from an orbit at an altitude of 705 km corresponds to an earth swath width of 185 km. The orbit characteristics of Landsats 4 and 5 allows the TM to cover a particular target once every 16 days, but since adjacent swaths overlap some areas can be covered twice in that period, on successive days. The instrument transmits separate digital images in seven non-overlapping bands of the electromagnetic spectrum, including the blue, green, red, reflected infrared, and thermal infrared spectral regions. These images are composed of many discrete units called pixels, each corresponding to an area of 30x30 m on the ground (120x120 m in the thermal infrared band). The seven images are obtained simultaneously, and therefore each pixel is characterized by seven digital values, a numeric translation of the pixel's spectral properties in each of the bands.

The development of digital satellite images and the capability to generate digital cartographic data created the need for programs to automatically manipulate those images. The greatest advantage of digital cartographic data is that they can be easily processed in a fraction of the time needed to process a similar map manually. Digital processing of a map may, for example, include changes in projection and scale, integration with other maps, editing, and a large array of spatial operations. Very important too is the ease with which accurate map statistics may be produced. Many of the programs created to manipulate digital maps have been integrated to form geographic information systems. Using these program assemblies it is now possible to perform cartographic operations considered to cumbersome to be executed manually.

The usefulness of MSS imagery to map habitat elements, especially broad vegetation classes, has been demonstrated by many works, in spite of its comparatively low ground resolution (80x80 m). The newer TM imagery has not been so widely used, but its potential for habitat mapping is even higher than that of the MSS, mainly because of the finer spatial resolution and larger number of spectral bands (see Palmeirim, in preparation) for an overview of MSS and TM application in wildlife studies). Almost all MSS and TM based habitat studies to date have been basically manual or automatic construction of maps portraying habitat elements such as vegetation, which are then interpreted visually. However, a few studies have included a quantitative evaluation of the suitability of the different types of habitat for particular species. Thompson et al. (1980) mapped broad vegetation types using MSS imagery, and then evaluated each of them as seasonal caribou habitat from winter and summer pellet counts.

For this project, a land cover classification was generated from TM imagery and the resulting habitat map was input to a geographic information system. Results of bird surveys were also included in the GIS in a cartographic format. Landsat TM imagery was used as the only source of information on the available habitat. This information was processed with the GIS to obtain habitat suitability estimates and generate cartographic products that reflect the habitat needs of each species. This processing takes into consideration not only the types of habitat present (e.g. forest, rangeland) but also spatial characteristics of the habitat of a species (e.g. minimal habitat patch size, distance to edge).

The avifauna was used in this study because of the large number of species present in the study area, the broad range of habitat preferences they exhibited, and the relative ease with which field surveys could be carried out. The habitats of some of the studied species can be defined in comparatively broad terms such as "forest" or "rangeland". Others are more specialized and are present mostly in specific types of habitat such as mesic forest. Since the factors that limit the distribution of these later species are more subtle, they are less likely to be detectable on the Landsat imagery. Therefore, while collecting data on a diversity of habitats, particular attention was paid to the detection of distributional and suitability patterns within the forested areas, a challenge to the capabilities of the approach under study.

MATERIALS AND METHODS

Study Area

An area of 13 square km located just north of Lawrence, Kansas (39 3'N - 95 12'W) was selected, mainly because it encompassed fairly large wooded areas, including some mature woods. Rangeland and old fields cover most of the remaining area, but some cropland was also present. Slope exposure influences strongly the type of forest present, and two broad forest classes can be distinguished: (1) on hilltops and south-facing slopes the forest has a relatively xeric character, low canopy, and a high tree density; (2) on bottomlands and north facing slopes the forest is considerably more mesic, and is composed of taller trees with higher canopies, but has a lower tree density. Fitch and McGregor (1956) and Birdsell and Hamrick (1978) described the various forest types present in much of the study area. The vegetation of the University of Kansas Natural History Reservation, included in this study area, was described by Fitch (1958).

Imagery Used

The habitat characterization was based on a TM scene obtained by Landsat 4 on 3 September 1982. High altitude color infrared photography (National

High Altitude Photography Program) was used to check the results of the TM based habitat classification, and to locate bird survey points.

Image classification. Different types of land cover are usually separable on one or more individual TM bands. However, optimal separation is most often achieved using simultaneously two or more bands, and therefore multivariate statistical algorithms to perform image classification were developed. In this project seven land cover types were separated: bare ground, cropland, water, rangeland, old field, xeric forest, and mesic forest. The location of each of these classes in the multivariate space defined by the five bands used (2,3,4,5, and 7) was found from the statistical parameters of sample areas of known cover type. Two different classification algorithms were then used to assign each image pixel to one of the cover classes. In the simpler algorithm, known as the Minimum Distance, each pixel was assigned to the class of the closest centroid. The Gaussian Maximum Likelihood algorithm computes the probability of a pixel belonging to each class, using not only the distance to the centroid but also their relative dispersions, and then assigns the pixel to the class associated with the higher probability value. Each of the two algorithms used produced a separate land cover classification, which was then compared to aerial photography and field notes. These comparisons showed that the maximum likelihood generated the best overall classification, but the minimum distance was more successful in mapping forest. The forest map produced by this later algorithm was therefore digitally merged with the maximum likelihood map. A more complete explanation of the spectral classification process can be obtained in Swain (1978) and Schowengerdt (1983). A modified version of the Kansas University Teaching Image Processing System (KUTIPS) program package (Williams et al., 1983) was used to perform the spectral image classification.

A spectrally classified image can be reclassified using spatial algorithms to improve the quality of the final map products (Gurney and Townshend, 1983). In this project pixels that could not spectrally be assigned to a cover class with a defined level of certainty were reclassified by a neighborhood function; each was assigned to the class having a majority of pixels in its nearest neighborhood. Similar techniques were also used to eliminate small bare ground spots, and enhance old field areas. This spatial processing was performed using the Map Analysis Package (MAP) (Tomlin, 1980).

The accuracy of the land cover map was estimated as the percentage of training pixels correctly classified. The true identity of the pixels used in the accuracy check was obtained from high altitude infrared color aerial photographs (NHAP) and field checks. The mapping accuracy estimated in this manner often exaggerates the accuracy values, which should therefore be used with care, but has the advantage of saving field and processing time. The drawbacks of this technique are, however, less acute when the sample sizes used are large and a large number of training areas is used, which is the case in this project.

<u>Principal component analysis</u>. After image classification was completed, a principal component analysis of the five TM bands was performed, and the two first components were used in various plots necessary for the analysis.

A program available in the package Earth Resources Data Analysis System (ERDAS) was used for this analysis.

Cartographic Processing

Spatial models were designed to generate distribution, suitability, and density maps from the land cover map. These models are composed of image processing operations available in MAP. Flowcharts and listings of the models are on appendix II. A detailed description of the individual operations used is available in the MAP manual (Tomlin, 1980).

Bird Surveys

Bird surveys were done to obtain the composition and abundance of the bird fauna in a number of points representative of all the major habitats present in the study area. A circular point count, similar to the one used by Bond (1957) and Edwards et al. (1981) was used. All the birds detected within 80 meters from the observer during a period of 10 minutes were identified. Singing males were recorded separately from other birds. The distance between the observer and the birds was measured with a range finder or, most often, estimated visually. The approximate location of each bird relative to the observer was recorded to avoid counting the same individuals more than once. A point count technique (as opposed to transects) was selected because of the need for accurate placement on the imagery of all observations. Birds detected more than 80 meters from the observer were not included because of the increasing possibility that they were not on the same habitat type as the observer. In order to determine the duration of the counting period at each location, cumulative species counts lasting 30 minutes were performed in 6 sites, in an area of bottomland forest. Despite the high bird diversity in this habitat an average of 70% of the total number of species found in 30 minutes were detected in the first 10 minutes. This period was therefore chosen. Longer counting periods would have not only reduced the number of stations that could be sampled in one morning, but also would have increased the possibility of counting the same individual more than once in the same period (Scott and Ramsey, 1981). Only the most common and conspicuous species were included because surveys of rare or inconspicuous species require intensive sampling. The survey stations were sampled once during the 1984 breeding season (from 8 June to 25 June) and again in 1985 (from 10 June to 27 June). This double sampling procedure should reduce the bias induced by year to year variation in local species distribution. No surveys were done on rainy or windy days to avoid differences in detectability related to weather (Robbins, 1981). Counts were started soon after sunrise and ended when a decrease in bird activity was obvious, usually between 9:00 a.m. and 11:00 a.m. With a few exceptions the centers of two spatially consecutive stations were at least 200 meters apart to maintain sampling independence.

Processing Hardware

Image classification and spatial processing were done using a Honeywell 66 DPS-3E computer. The principal component analysis was performed by a Digital PDP-11/23 plus. The images shown in this paper were generated with the program package ERDAS installed on this latter computer, and an Anadex Silent/Scribe printer.

RESULTS AND DISCUSSION

Land Cover Classification

The first step in producing a land cover classification, manually or automatically, is the definition of the desired cover classes. The seven classes used in this project were selected to achieve the objective of mapping the habitats of a variety of bird species. Theoretically an optimal class selection is one in which classes are perceived by the species in consideration as distinct from each other but internally homogeneous. This is a difficult objective and various problems were encountered in the selection of classes: (1) the same cover map was to be used with a variety of species; (2) the factors controlling the distribution of the species were not always known; (3) class separability is limited by the information content of the imagery used. Another difficulty was the separation of classes that are actually part of a gradient. There are, for example, in the study area, many stages of succession from old field to forest that had to be separated along a subjective line. The class "old field" therefore ranges from areas with scattered shrubs to thickets of young trees. In some instances it would be possible to separate intermediate stages of these gradients using the TM imagery. However, increasing the number of classes would create a sampling problem; the bird fauna of each class had to be surveyed and, since the total number of stations to be sampled was limited by the time available, increasing the number of classes would decrease the number of stations per class.

The accuracy of the classified map generated is high: water, 96%; bare ground, 98%; cropland, 97%; old field, 75%; xeric forest, 98%; mesic forest, 96%; and rangeland, 93%. In spite of this accuracy level the classified map was further processed to make it more suitable for the particular application described in this paper. Numerous small areas classified as bare ground were scattered through rangeland. They were actually areas of rangeland where the ground was not bare, but the plant density was lower than in most of the rangeland. The image was therefore "filtered" using a 3x3 pixel cell window that reclassified as rangeland all the "bare ground" patches that were less than 10 pixels in size and surrounded by rangeland. This operation eliminated a considerable amount of image "noise". The classified image was also processed spatially to enhance the class "old field". Old fields are often patchy areas with spots in which succession is less advanced. In recently abandoned fields those spots are often classified as rangeland. Therefore these fields usually appear on the classification as a mosaic of the two classes ("rangeland" and "old field"). A spatial filter was used to reclassify as old field the "rangeland" pixels adjacent to three or more old field pixels.

Generating Potential Distribution Maps

The habitat (or land cover) map obtained (Figure 1) is an intermediate step between the raw image and the potential distribution maps that may now be generated. It contains all the information on the habitats present in the study area that will be used in this paper. The objective is to generate maps that portray not just the type of habitat present in each point of the study area, but how suitable each point is for particular bird species. It is difficult to portray directly habitat suitability, but it is possible to do so through variables that are usually correlated with suitaINSERT

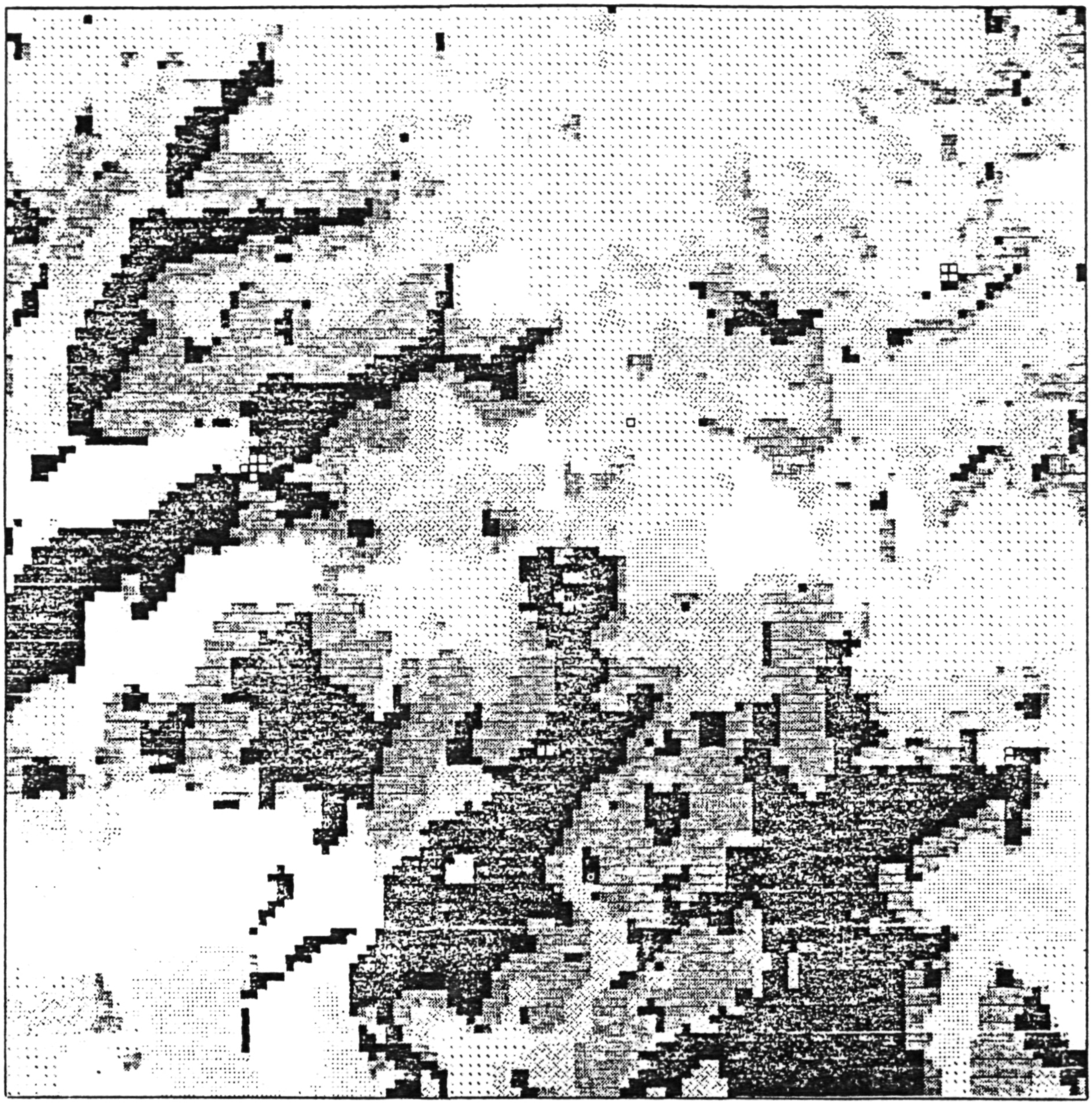

Figure 1. Land cover classification of the study area.

Mesic forest

Xeric forest

Old field

Rangeland

Cropland

Water

Bare ground

bility. In this section, the probability of encountering a species in an area will be used, a variable most often directly proportional to density and therefore suitability. One should, however, be cautious when inferring suitability from density. The process of construction of these maps involves two successive phases that will be dealt with separately. In the first phase each type of habitat mapped will be rated according to the probability of encountering a species on it. In the second the maps generated in the first phase will be reprocessed to incorporate spatial factors that may also be important in the habitat of individual species.

Evaluating Each Cover Type

Knowing the habitat requirements of particular species, it should be possible to make predictions about the distribution of those species in the study area using the generated land cover map (Figure 1). This assumes that the map is accurate and that the land cover classes portrayed are determinant in their distribution. For example, based on the known biology of the white-breasted nuthatch (*Sitta carolinensis*) and the red-eyed vireo (*Vireo olivaceous*) one can predict that these species will be present almost exclusively in the areas shown as forest; the indigo bunting (*Passerina cyana*), however, is likely to be present not only in the forest but also in old fields. The results of the bird counts performed in the study area support the idea that such maps can be used to make meaningful distribution predictions. Almost all the locations where the white-breasted nuthatch and the red-eyed vireo were found are classified as forest on the land cover map (Figures 2 and 3).

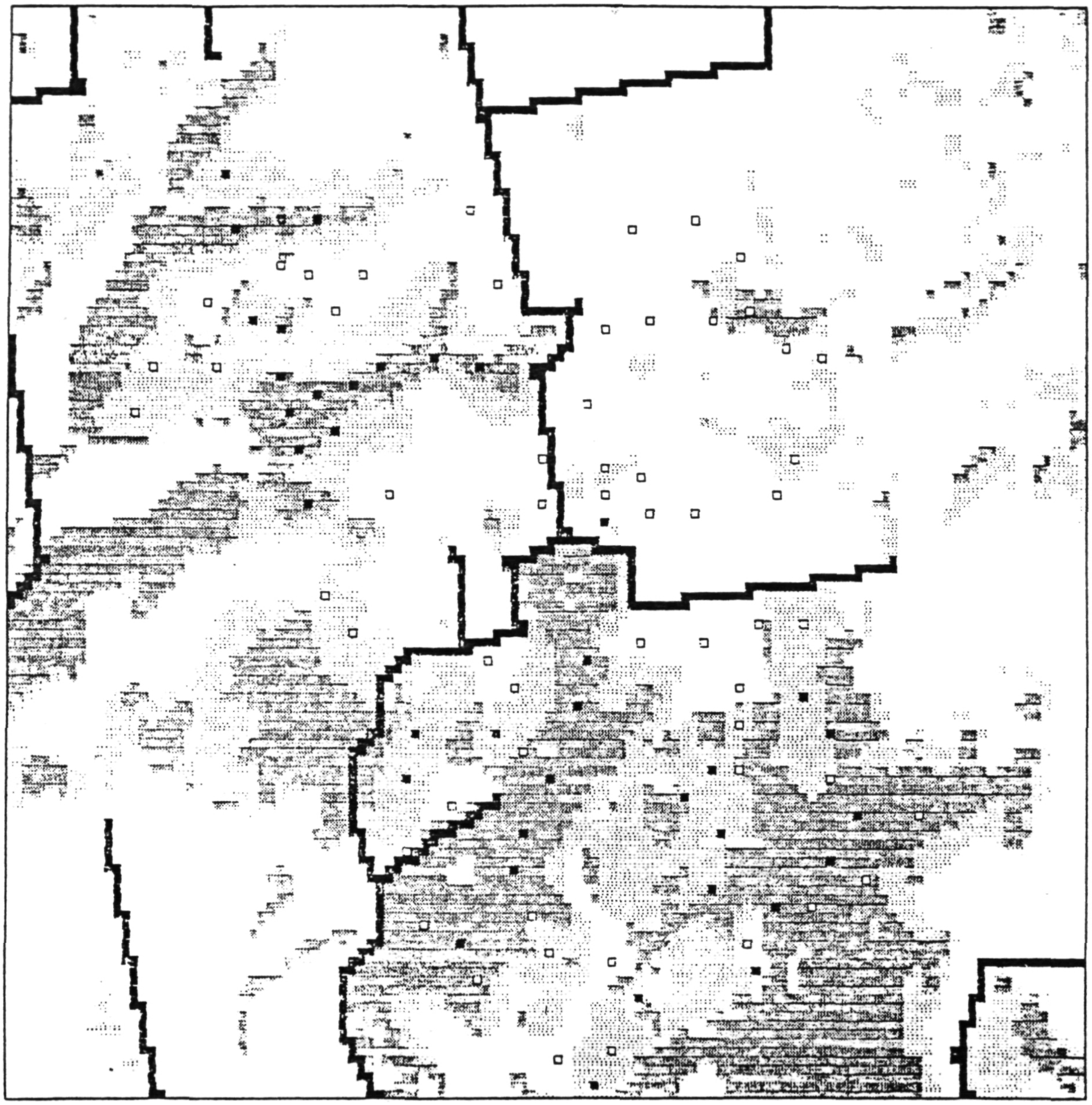

Figure 2. Map of the potential distribution of the white-breasted nuthatch, before spatial processing. Darker tone represents higher probability of finding the species. Squares represent surveyed sites; the white-breasted nuthatch was recorded on the sites with solid squares. Black lines are roads.

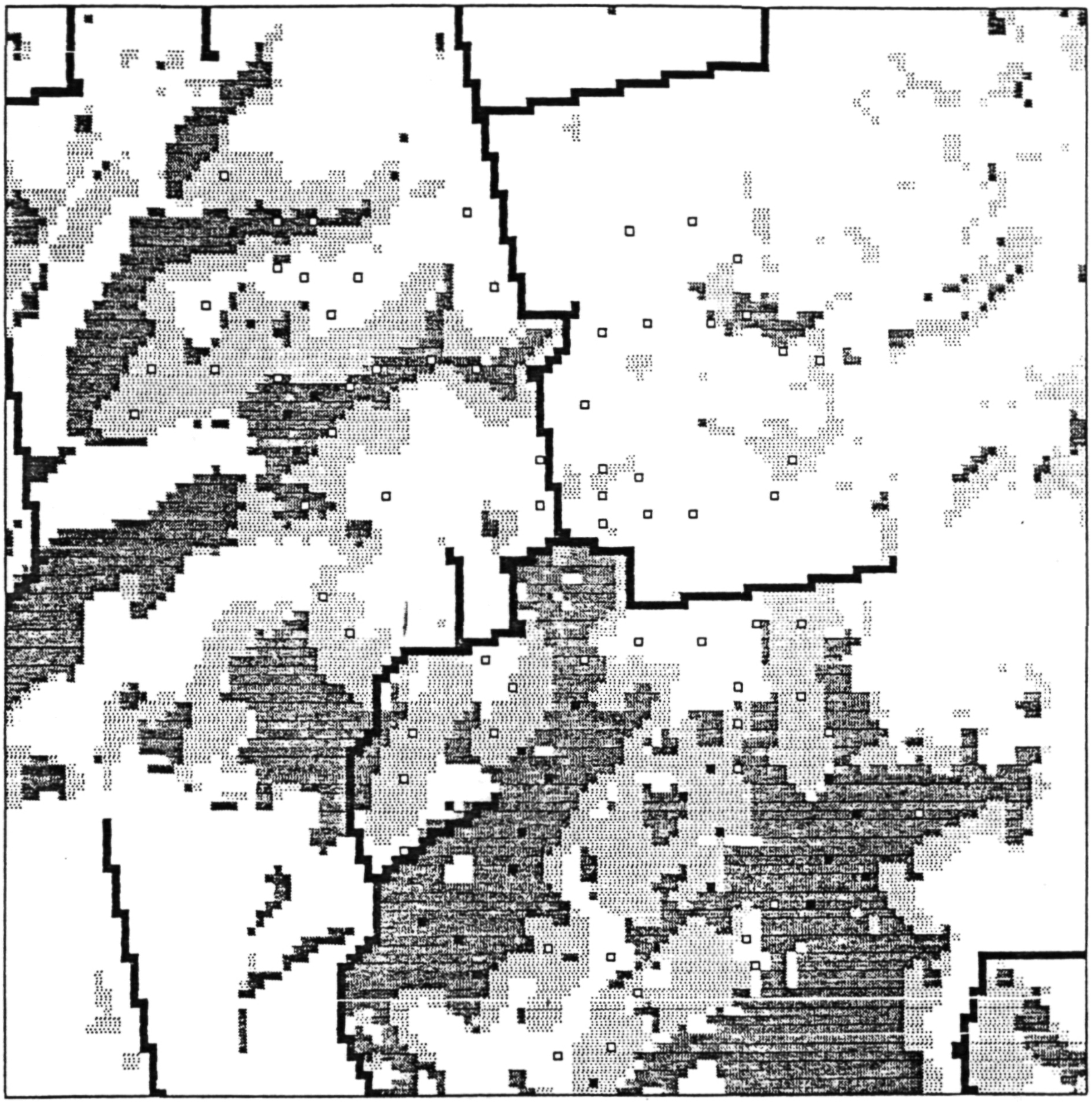

Figure 3. Map of the potential distribution of the red-eyed vireo, before spatial processing. Darker tone represents higher probability of finding the species. Squares represent the surveyed sites; the red-eyed vireo was recorded on the sites with solid squares. Black lines are roads.

Assuming that the faunal sampling was adequate it can now be stated that the two species are present in the area classified as forest and not on the other cover classes. One can, however, question whether they are present throughout the forest class or limited to areas of forest with specific characteristics. A discontinuous distribution within the forest is particularly likely to occur if this class is not homogeneous. When a distribution is indeed not continuous it becomes necessary to determine whether it is possible to detect, using the TM imagery, habitat differences that explain the within-forest distribution patterns.

The closed line on Figure 4 encloses the region of concentration of pixels classified as forest in the space defined by the two first principal components of the TM image used. The numbers represent the location on the same space of the sampled sites where the red-eyed vireo was observed. The dots represent the sampled sites where this species was not found. It is clear that the red-eyed vireo was more frequently found in the sampled locations that are distributed to the left of the straight line. This species was found on 61% of the sites to the left of the line, but only on 22% of the remaining sites. This plot therefore suggests that the within forest distribution of the red-eyed vireo is not homogeneous and that it is possible to map the discontinuities with the spectral information content of the TM imagery. Dividing the forest space along the straight line on Figure 4 separates two types of forest, mapped on Figures 2 and 3. A field verification of these maps shows that the areas portrayed in darker and lighter tones correspond respectively to the mesic and xeric forest types described above. The map on Figure 3 also shows the location of sites sampled in

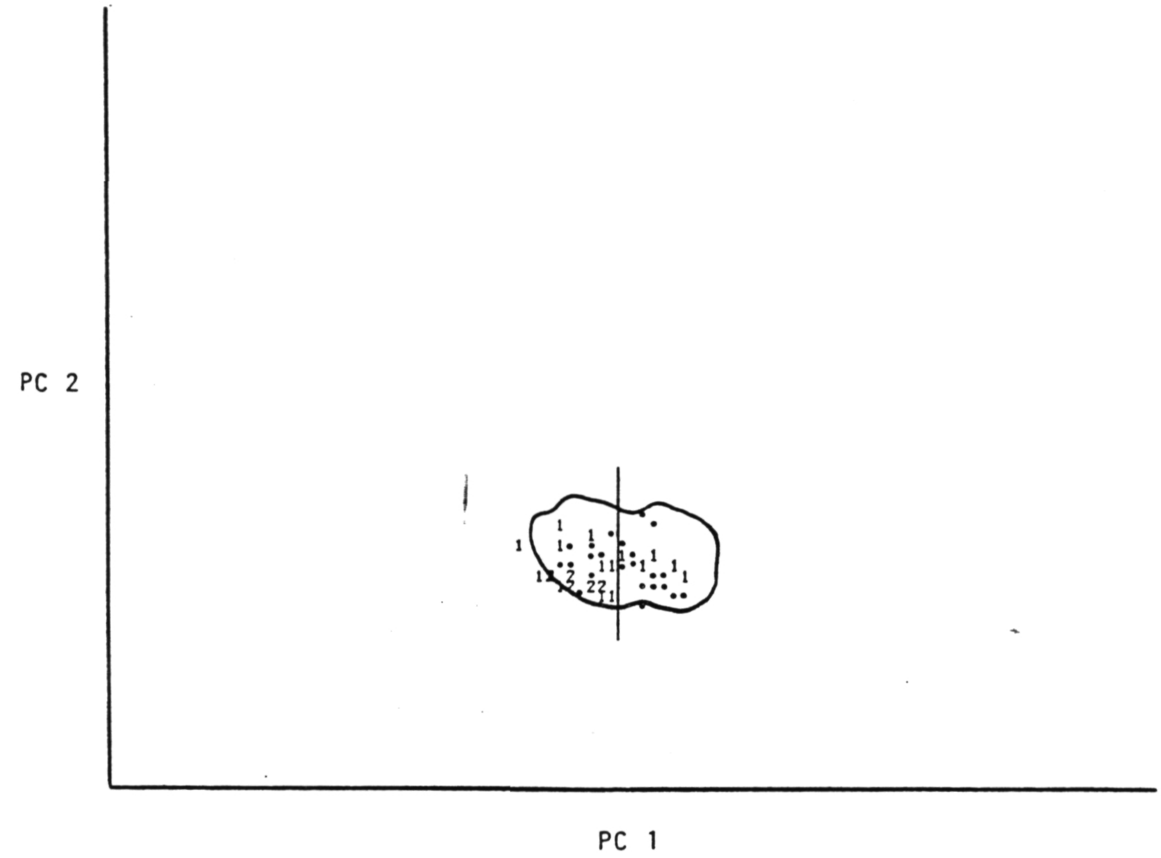

Figure 4. Plot of PC1 and PC2 of the Thematic Mapper image. The curved line encloses the region of concentration of forest pixels. The straight line separates xeric and mesic forest. Numbers represent sites where the red-eyed vireo was recorded and dots the sites where the species was not found.

forest, with those where the red-eyed vireo was found marked with a solid square. Not surprisingly, this species was found almost exclusively on the area classified as mesic forest; the red-eyed vireo is known to avoid xeric forest (Fitch, 1958). A similar analysis may now be performed for the white-breasted nuthatch, also a forest species. The plot on Figure 5 is similar to that on Figure 4, but here the numbers represent sites where the nuthatch was observed. No pattern similar to the one noted on the plot for the red-eyed vireo is seen; the white-breasted nuthatch is found with similar frequency in sites that plot on both sides of the line. This is what would be expected since this species lives in both xeric and mesic forest areas (Figure 2). The absence of a clear pattern on the plot suggests that there are no within-forest discontinuities in the distribution of the white-breasted nuthatch; if discontinuities are in fact present then they are most likely not possible to map using only the spectral data in the TM image.

Table 1 summarizes the results of the bird surveys, showing the frequency with which each of the bird species was found in the surveyed habitats. The numbers tabulated are the proportion of points surveyed in a particular habitat in which each species was found. These values are therefore a measure of the probability of encountering each species in the various habitats. Although no confidence limits are shown on the table, when making generalizations one should take into consideration the sample sizes used to calculate the proportion values. The most reliable values are those of the commoner species in the better surveyed habitats, especially xeric and mesic forest, which are shown as two distinct habitats on this table. Based on what is known about the biology of the bird species included one

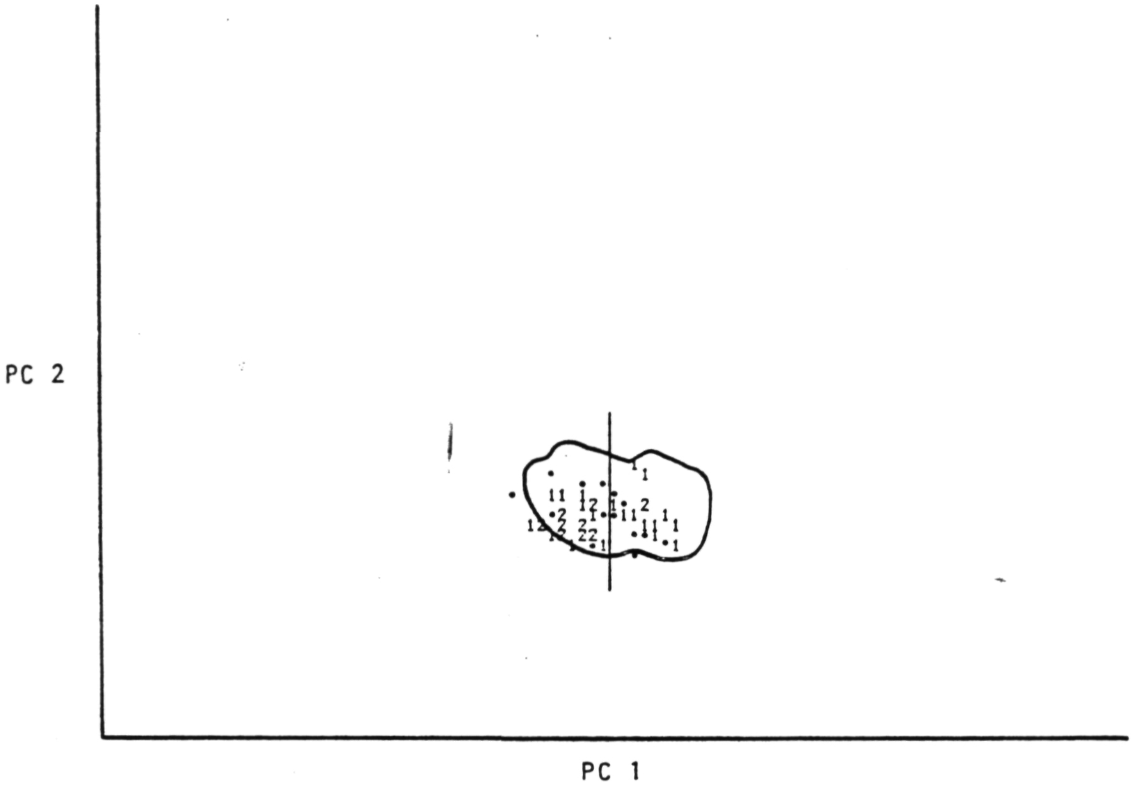

Figure 5. Plot of PC1 and PC2 of the Thematic Mapper image. The curved line encloses the region of concentration of forest pixels. The straight line separates xeric and mesic forest. Numbers represent the sites where the white-breasted nuthatch was recorded and dots the sites where the species was not found.

Table 1.

Results of the bird surveys done. The values in the table are the percentage of surveyed sites in each habitat type where a species was observed. The total columns indicate the number of sites surveyed in each habitat type (horizontal), and the total number of sites where each species was recorded (vertical).

		Old field	Xeric forest	Mesic forest	Range	Forest edge
	Total	16	23	33	10	9
Bobwhite (Colinus virginianus)	28	44	22	3	80	67
Yellow-billed cuckoo (Coccyzus americanus)	67	56	87	94		78
Read-headed woodpecker (Melanerpes erythrocephalus)	16	13	17	24		11
Red-bellied woodpecker (Centurus carolinus)	41	13	43	82		22
Downy woodpecker (Dendrocopos pubescens)	39	13	61	70		
Hairy woodpecker (Dendrocopos villosus)	14		17	30		
Eastern wood pewee (Contopus virens)	28		13	70		22
Great crested flycatcher (Myiarchus crinitus)	24	13	35	42		
Blue jay (Cyanocitta cristata)	55	50	57	79	20	67
Black-capped chickadee (Parus atricapillus)	48	50	74	58	10	33
Tufted titmouse (Parus bicolor)	58	31	74	94		56
White-breasted nuthatch (Sitta carolinensis)	38	13	52	73		
Wood thrush (Hylocichla mustelina)	24		13	64		
Brown thrasher (Toxostoma rufum)	21	38	13	18	20	44
Red-eyed vireo (Vireo olivaceus)	26		22	61		11
Kentucky warbler (Oporornis formosus)	43		61	79		33
Scarlet tanager (Piranga olivacea)	15		17	33		
Northern cardinal (Richmondena cardinalis)	68	75	83	88	20	67
Rose-breasted grosbeak (Pheucticus ludovicianus)	20		22	45		
Indigo bunting (Passerina cyanea)	41	69	52	33	10	67
Dickcissel (Spiza americana)	17	6	4		80	44
Rufous-sided towee (Pipilo erythrophthalmus)	44	56	43	48	20	78
Field sparrow (Spizella pusilla)	38	88	26	3	60	89
Red-winged blackbird (Agelaius phoeniceus)	21	38		3	80	44
Eastern meadowlark (Sturnella magna)	18	25			80	44
Common grackle (Quiscalus quiscula)	33	31	52	33	30	22
Brown-headed cowbird (Molothrus ater)	49	69	43	61	30	56
Northern oriole (Icterus galbula)	20	19	4	42		11

could predict rough values for their relative abundance in the various habitats used. This table illustrates the usefulness of the TM based habitat map because the species' relative abundance among habitats agrees with what would be expected. A similar habitat/bird community association pattern was found in a study using habitat variables measured on the ground in the same area (Johnston, 1977). Of particular interest in Table 1 is the clear separation between the xeric forest and mesic forest bird communities, because it supports the assertion that this technology can be used to discriminate among fairly similar habitats. Notice the consistently larger proportion of positive observations in the forest surveyed points classified as mesic, when compared to the points classified as xeric. This difference is statistically significant and particularly obvious in species known to have a strong preference for mesic forest, such as the red-eyed vireo (Fitch, 1958) or the wood thrush (Hylocichla mustelina) (James et al., 1984). However, in species without such a marked preference for one of the two forest types, the absolute differences between the proportions of positive observations in each of those habitats is too small to show statistical significance with the sample sizes available.

Although the pattern of frequency values in the matrix on Table 1 is overall very good, there are some elements that do not follow what would be expected from the biology of species. Some of these "errors" may be due to unusual behavior of the birds, but there are also some potential sources of error related to the methodology used. Among them are the many problems associated with bird counts, which are discussed in Verner (1985) and in several papers in Ralph and Scott (1981). Using a habitat classification generated from TM imagery instead of ground observations creates two new potential sources of error, which are referred to here as "location errors" and "classification errors". Location errors are due to difficulties in locating with precision a survey point on the imagery used. If one of these points is incorrectly located the survey may be assigned to a different habitat type. "Location errors" are especially important when few ground points of reference are available, such as when surveying inside a woodlot, or when the points of reference used are not visible on the satellite imagery. To minimize this problem one can first locate the survey plots on aerial photographs with a scale large enough to show the ground reference points to be used; the aerial photographs can then be registered to the satellite imagery and the survey points transferred to this base. "Classification errors" occur when a survey plot is assigned to the wrong habitat type in the image classification process. The northern cardinal (Richmondena cardinalis), for example, does not live on rangeland but it appears in the rangeland column of the survey matrix (Table 1); this species lives on old fields and some old field pixels were erroneously classified as rangeland. It is therefore very important to have an accurate habitat map, but it is not usually possible to eliminate all the errors from such maps.

Using the data in Table 1 and the classified habitat map, it is possible to produce potential distribution maps for the species studied. The map on Figure 6 shows the potential distribution of the red-eyed vireo in the study area. The darker tone was assigned to mesic forest, reflecting the higher probability of finding the red-eyed vireo in this habitat than in xeric forest, which is therefore represented in a lighter tone. Although

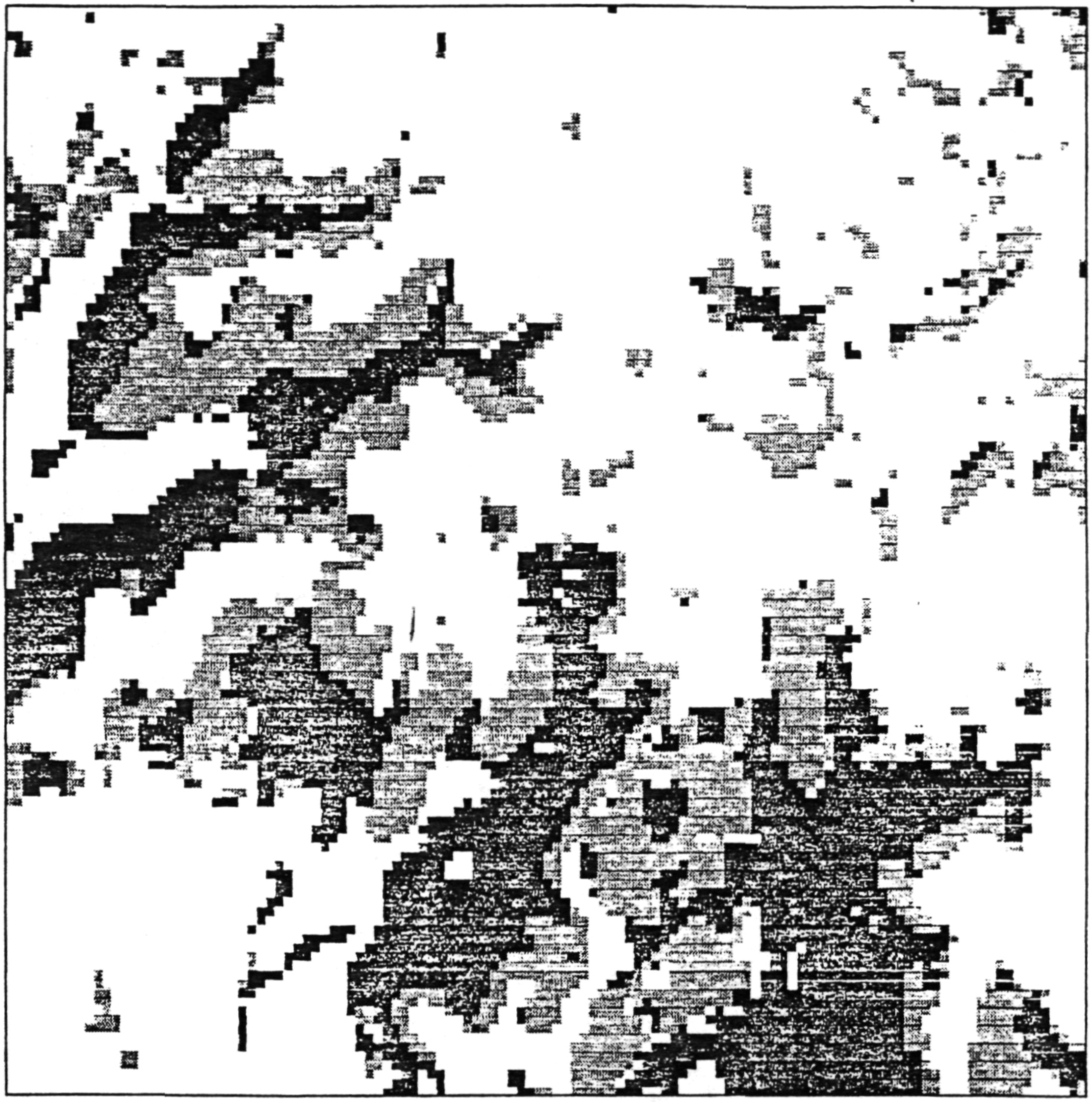

Figure 6. Map of potential distribution of the red-eyed vireo, before spatial processing. Darker tone represents higher probability of finding the species.

the map represents only variations in the probability of encountering the species and not variations in the habitat suitability, there is almost certainly a high positive correlation between these two parameters; the generated map may therefore be a useful substitute for an absolute suitability map.

Including Spatial Factors

Knowing how complex are the factors that determine the suitability of an area for animal species, one may ask if all the shaded area in Figure 6 is actually suitable for the red-eyed vireo, or if there are factors, other than the type of land cover present, that further restrict its distribution. Spatial factors are likely to be quite important, and are suitable for incorporation in digital habitat maps using GIS technology. It is, for example, known that the red-eyed vireo avoids the edges of the forest, although it may be present there (Johnston, 1947). It is then appropriate to reprocess the distribution map on Figure 6 to decrease the probability of finding the species near the edges of the woods (Figure 7). The literature also suggests that the whole territory of a red-eyed vireo must be within a uniform forest area, because of this species' reluctance to fly in open spaces (Sutton, 1949). Woodlots smaller than the size of a territory are therefore not likely to be used. Since the size of the territory of the red-eyed vireo in this region was estimated to be about 1 ha (Fitch, 1958) all the woodlots smaller than this area were eliminated (Figure 7). Figure 7 includes then not only an evaluation of all the cells in the study area based on the land cover present, but also two important spatial factors: minimum forest patch size and proximity to forest edge. However, although

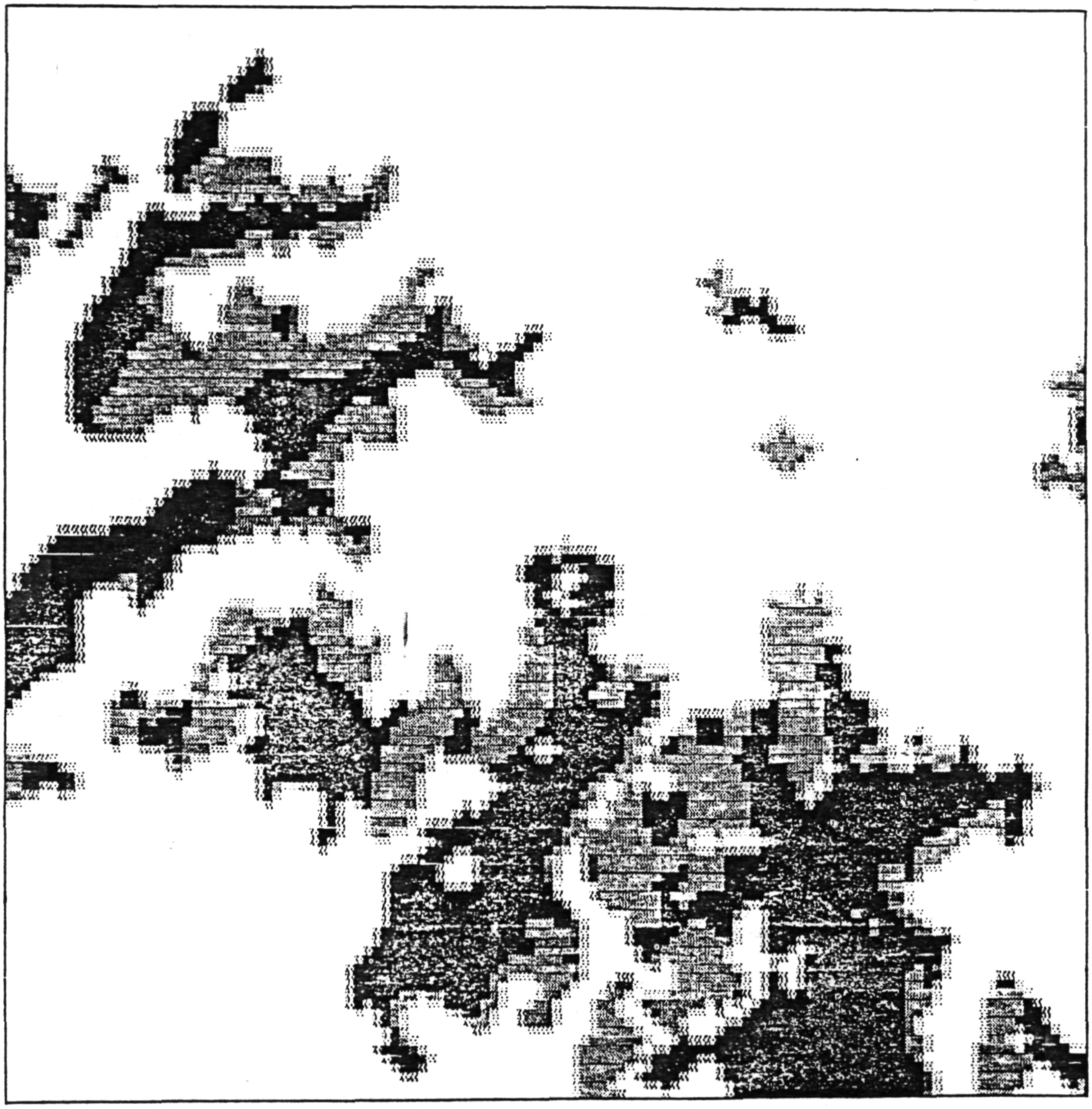

Figure 7. Map of potential distribution of the red-eyed vireo, after spatial processing. Darker tones represent higher probability of finding the species.

this map is an improvement over that of Figure 6 it would be possible to generate a more accurate map if there were quantitative studies of the influence of the included spatial factors on the distribution of the species.

The map on Figure 8 represents the probability of finding the indigo bunting throughout the study area. It was generated in the same manner as the red-eyed vireo map (Figure 7) but reflects the different habitat preferences of this species. The surveys done showed that the indigo bunting is present not only in both xeric and mesic forest, but also in old fields. Moreover, although the difference between the rates of positive observations in xeric and mesic forest is not large enough to show statistical significance, the literature supports the observed trend of a higher abundance in the more xeric habitat (Taber and Johnston, 1968). In contrast to the red-eyed vireo, the indigo bunting does not avoid forest edges, where it is actually particularly abundant (see Table 1, and Johnston, 1947). Its optimal habitat in this region seems to be the zone of contact between forest and old fields. The indigo bunting also differs from the red-eyed vireo in that it can use very small clumps of forest, which were therefore not eliminated from the potential distribution map.

It is possible to calculate confidence limits for the probability values on the distribution maps. Those values are simply the percentage of positive observations in sites surveyed in each habitat; the methods normally used to set confidence limits to percentages can therefore be used (e.g. Fleiss, 1981; Sokal and Rohlf, 1981). For example the 95% confidence limits for the percentage values on the red-eyed vireo distribution maps

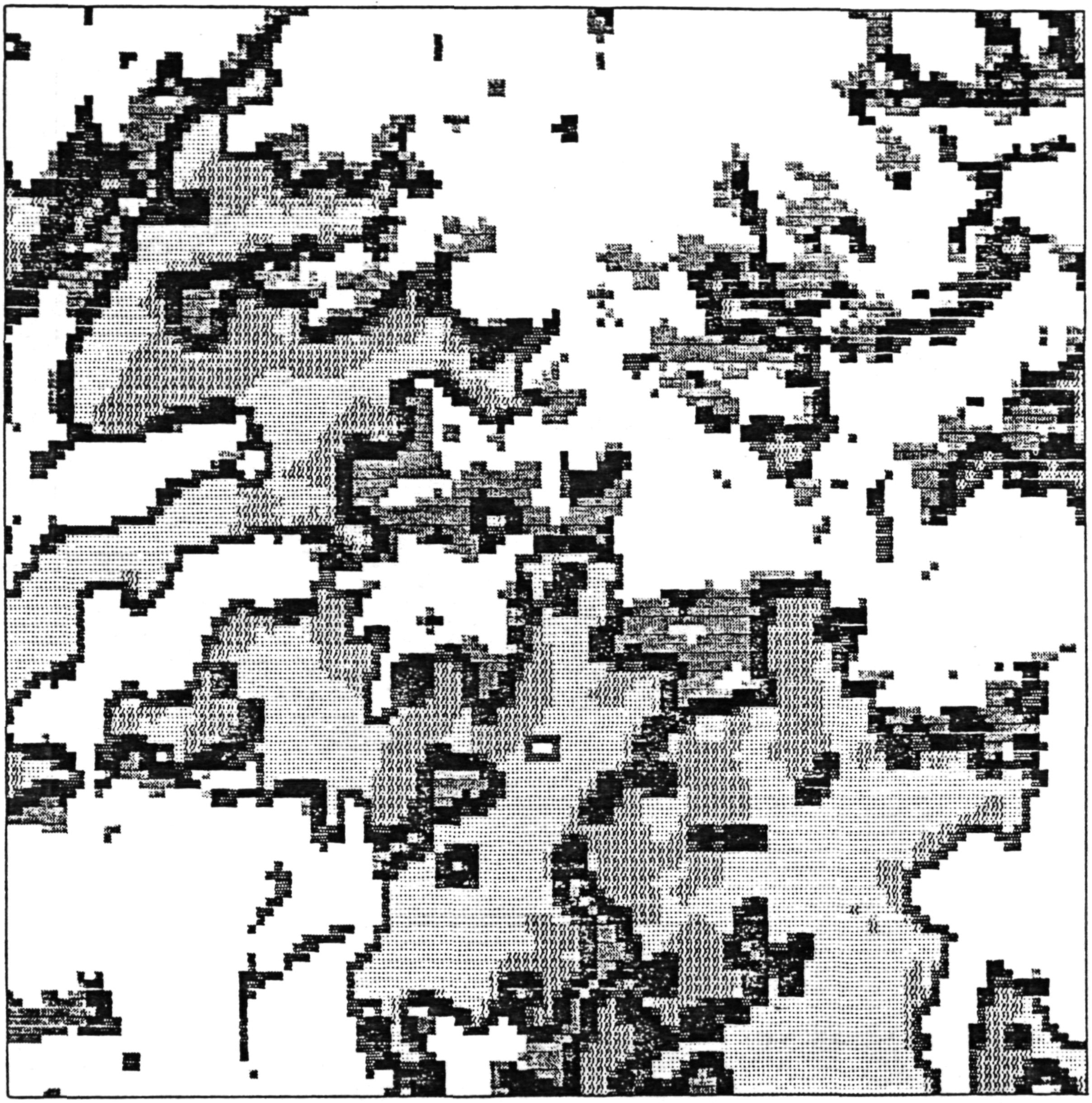

Figure 8. Map of potential distribution of the indigo bunting, after spatial processing. Darker tones represent higher probability of finding the species.

(Figures 6 and 7) are 7.5 to 42.7 in xeric forest, and 43.1 to 76.9 in mesic forest. These values are calculated under the theoretical assumption that the survey points were randomly located within each habitat. In practice it is hard to meet this assumption because it would increase considerably the time spent doing field surveys; it is much easier and faster to locate the survey points along transects, as was done here. However, what is most important is to make the selection of points independent of relevant variations of ecological conditions within each type of habitat, which was attempted. Finally, no confidence limits can be calculated for the areas affected by the spatial analysis because there is actually no measurement of the probability of finding the species in those areas. The different gray tones generated by the spatial analysis are only a representation of the probability relative to that of the other areas where the species is also present. There are, for example, probability values associated with mesic and xeric forest whereas the lighter gray tone of the pixels along the edge of the forest simply means that the probability of finding the species there is lower than in the interior of the woodlots. This inconvenience can be overcome by doing enough surveys in these spatially processed areas to allow making acceptable probability estimates for these areas. This may, however, be a very time-consuming task. To collect such data for the red-eyed vireo it would have been necessary to sample separately xeric forest edge and mesic forest edge. Even a simplified sampling strategy to incorporate the effect of edge on the indigo bunting would include at least mesic forest/old field, mesic forest/"other than old field", xeric forest/old field, and xeric forest/ "other than old field".

Generating Density Maps

The data collected at each survey plot include not only what species were observed there but also the number of singing males heard; using these data it is possible to calculate the density of pairs of each species in the various habitats. Dividing the total number of red-eyed vireo males counted in plots within mesic forest by the sum of the areas of all those plots, the density of this species was calculated to be about 2.8 pairs/10 ha. A similar procedure yielded 0.9 pairs/10 ha for the xeric forest. The map on Figure 9 was generated from the distribution map (Figure 7) but the intensity of the gray tones is here intended to be proportional to the density of the species. The transitions between gray tone levels are also more gradual, which should more closely portray the way bird density changes spatially. To achieve this effect the density assigned to each cell was replaced by a weighted average of the density in a 2 ha neighborhood centered on that cell. The weight of each neighborhood cell used was inversely proportional to its distance from the center cells. This weighted average made the value of each cell mostly dependent of the nearest 1 ha of habitat, which is the estimated size for the home range of the red-eyed vireo in this area (Fitch, 1958).

Assuming that the density values obtained above are reasonably accurate, it is possible to make estimates of the total number of individuals of a particular species in the study area. From the digital density map one learns that there are 217 ha of habitat (mesic forest) with an average density of 2.8 pairs of red-eyed vireo per 10 ha. There are also about 142 ha of less densely occupied habitat (xeric forest) with a density of about

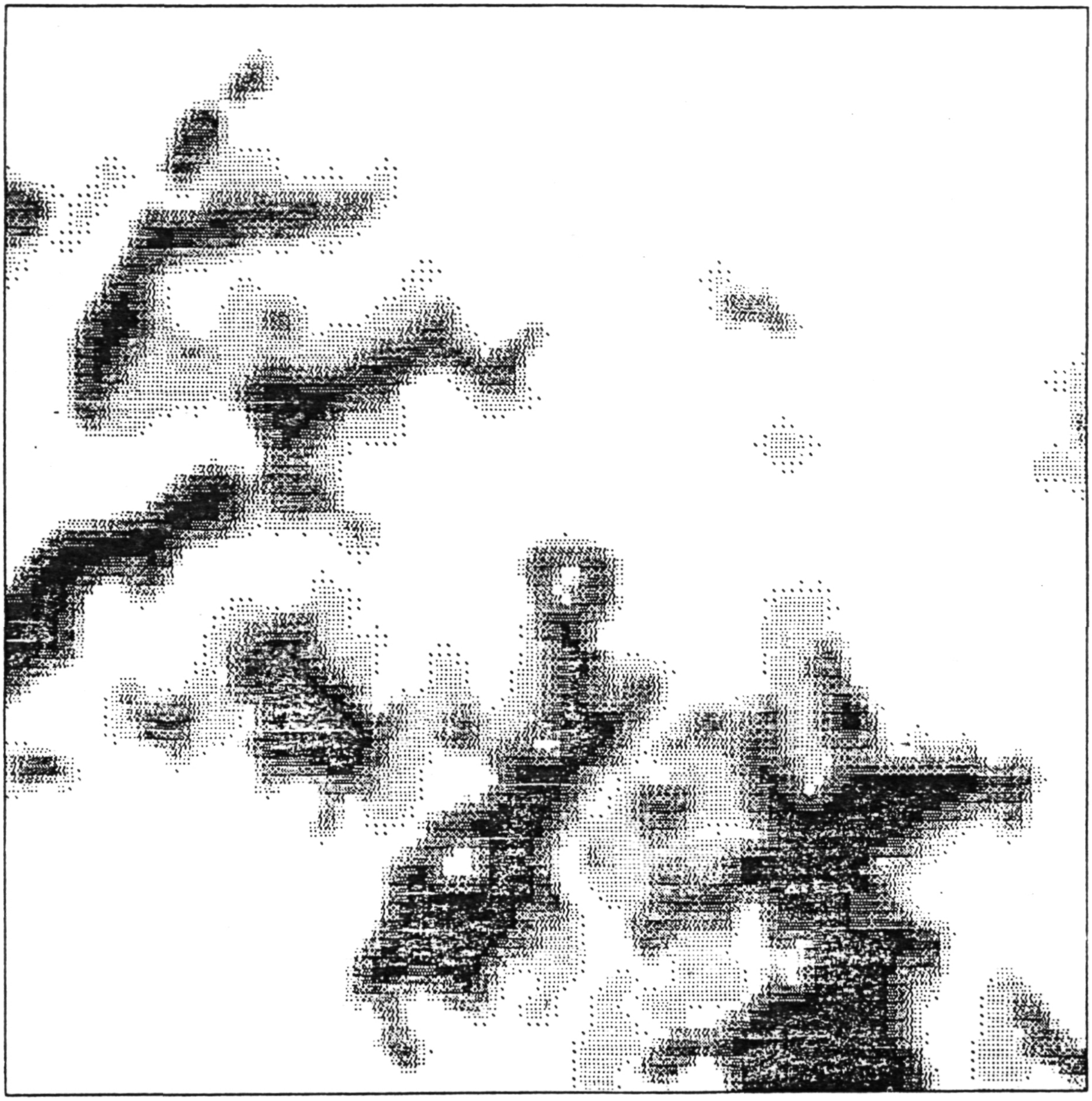

Figure 9. Red-eyed vireo density map. Darker tones represent higher density.

 About 0.9 pairs per ha

 About 2.8 pairs per ha

0.9 pairs per 10 ha. The total number of breeding pairs of red-eyed vireo in the study area is therefore about 73, of which 60 live in mesic forest and 13 in xeric forest.

CONCLUSIONS

The results of this project support the hypothesis that it is possible to produce valid distribution maps using TM imagery. These are actually maps of the habitat where a species potentially lives. Therefore TM imagery can be used only when the habitat characteristics that determine the species distribution are detectable on the imagery. The results of faunal field surveys can be merged with the habitat map, to produce a distribution map that includes a quantitative evaluation of the probability of finding the species in each of the various habitat types where it lives. If data on population density is also collected in those surveys, it is further possible to generate maps that show spatial variation in density, a parameter usually related to habitat suitability. Using these density maps one can also make estimates of population size in the area mapped or in any portion of it.

Spatial habitat factors often influence the distribution of a species, and explain variations in habitat suitability. As shown in the cases of the indigo bunting and red-eyed vireo, it is possible to implement cartographic models mimicking the biology of individual species that incorporate the effect of these spatial factors into digital distribution and suitability maps. The spatial factors used in these models included: distance to forest edge, minimal forest patch size, and co-occurrence of forest and old field. However, other factors can be included for species with different requirements, or areas with different habitat characteristics. Digital maps, like the ones used in this project, make spatial modeling a relatively simple and powerful technique. However, like most modelling in ecology, it faces a major difficulty: the great complexity and variability of ecological phenomena. This technique does, however, have the potential to express cartographically aspects of the biology of a species that would normally only be possible to describe with words. For example, the spatially processed density maps for red-eyed vireo (Figure 9) and indigo bunting (Figure 10) accurately portray the way the density of those species should vary spatially according to what was learned about their biology from the literature and field observations.

This project was performed in a very small area for ease of processing and to allow a detailed comparison between the generated maps and the ground conditions, which could due to its small size be intensively monitored. The models developed in this area could, however, be applied to a much larger area; care is needed in this generalization process because the habitat preferences of species often vary geographically. The cost per unit of area of implementing the methods described in this paper decreases dramatically with an increase in the size of the area under study.

The results of this work suggest that satellite imagery integrated with GIS technology has considerable potential as a tool in ecology. However, much research is still needed to take full advantage of this approach. It is important to gather quantitative data on the way spatial habitat factors influence animal species. Inclusion of ancillary variables, such as alti-

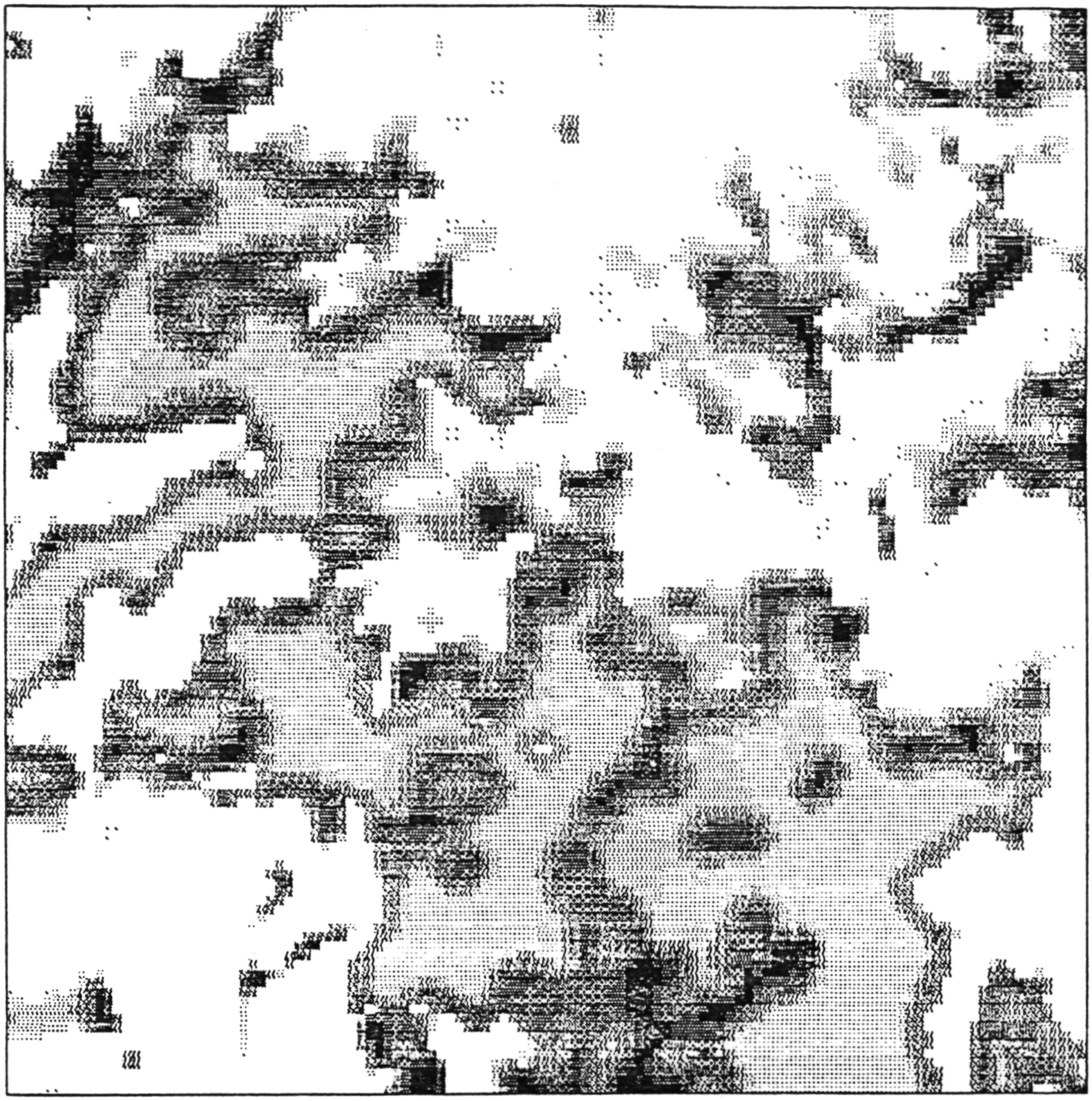

Figure 10. Indigo bunting density map. Darker tones represent higher density.

 About 1.1 pairs per 10 ha

 About 2.5 pairs per 10 ha

tude or latitude, in the models is likely to improve their performance in many situations. Satellite imagery generated by sensors other than the TM may also prove useful in this area. Very little research has been done to develop specific applications for this technology (but see Palmeirim, 1985). Finally, one should always take in consideration the limitations due to the relative coarseness of the available satellite imagery. Moreover the approach here used may not be as successful if applied in another region where important habitat types may not be separable using TM imagery. New sensors now under development are likely to reduce these shortcomings in the future.

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THE INTERSPERSION AND JUXTAPOSITION OF PRONGHORN ANTELOPE (ANTILOCAPRA AMERICANA) IN WESTERN KANSAS

Edward A. Martinko
Lisa M. Thorpe McKinney
L. M. Caron

Pronghorn antelope (Antilocapra americana) were major inhabitants of the Plains as reported by early settlers and explorers (Sexton, 1979). In western Kansas they were commonly found in every county at the time of the first settlers but were nearly extirpated from the state by 1910 (Choate, 1987). Extirpation of the species was apparently the result of hunting rather than agricultural development (Sexton et al., 1981).

Typical pronghorn habitat is characterized as large, wide open terrain areas that range from 25 mi^2 to 100 mi^2 or larger in size (Yoakum, 1980). Their North American habitats are found in areas with 10 to 15 inches of annual precipitation. Snow depth is an important factor since depths in excess of 10-15 inches may increase pronghorn mortality by covering the forage. Adult pronghorns require 1.5 to 1.8 lbs of forage per day, preferable forbs or grasses from a mixture of native community types, and water availability throughout the year (Yoakum, 1980). These habitat and dietary requirements account for the seasonal movement of pronghorn populations over large areas.

In western Kansas forbs account for more than 90 percent of the pronghorn diet during certain months of the year and winter wheat nearly 80 percent in late autumn, winter and early spring (Sexton, 1979). Because of these food habits, the success of pronghorns in western Kansas depends on the availability of open expanses of rangeland interspersed with cropland that is predominantly planted with winter wheat.

In 1964 the Kansas Department of Wildlife and Parks (then the Kansas Forestry, Fish and Game Commission) reestablished pronghorns in Sherman and Wallace Counties with a release of 37 animals (Figure 1). By 1981 this population had increased to 1,100 with current estimates near 2,000. In 1977, a similar release was made in the Gove and Trego County area (Figure 1) in spite of the estimated 37% decline in rangeland over the previous five year period (Martinko, 1982). Current estimates 10 years after reintroduction place the population size in this area at several hundred animals.

Because of the success of the Sherman/Wallace County population in contrast with the small size of the Gove/Trego population after 10 years, we decided to compare these two areas to determine the interspersion and juxtaposition of various cover types in an effort to evaluate the relative availability of typical pronghorn habitat, and further, to determine if habitat availability has changed over time.

MATERIALS AND METHODS

Two study areas encompassing approximately 800 square miles each were selected in two western Kansas counties, Wallace and Gove, known to have populations of pronghorn antelope. Each study area was centered over regions in each county that were representative of the original release sites for Sherman/Wallace counties and Gove/Trego counties.

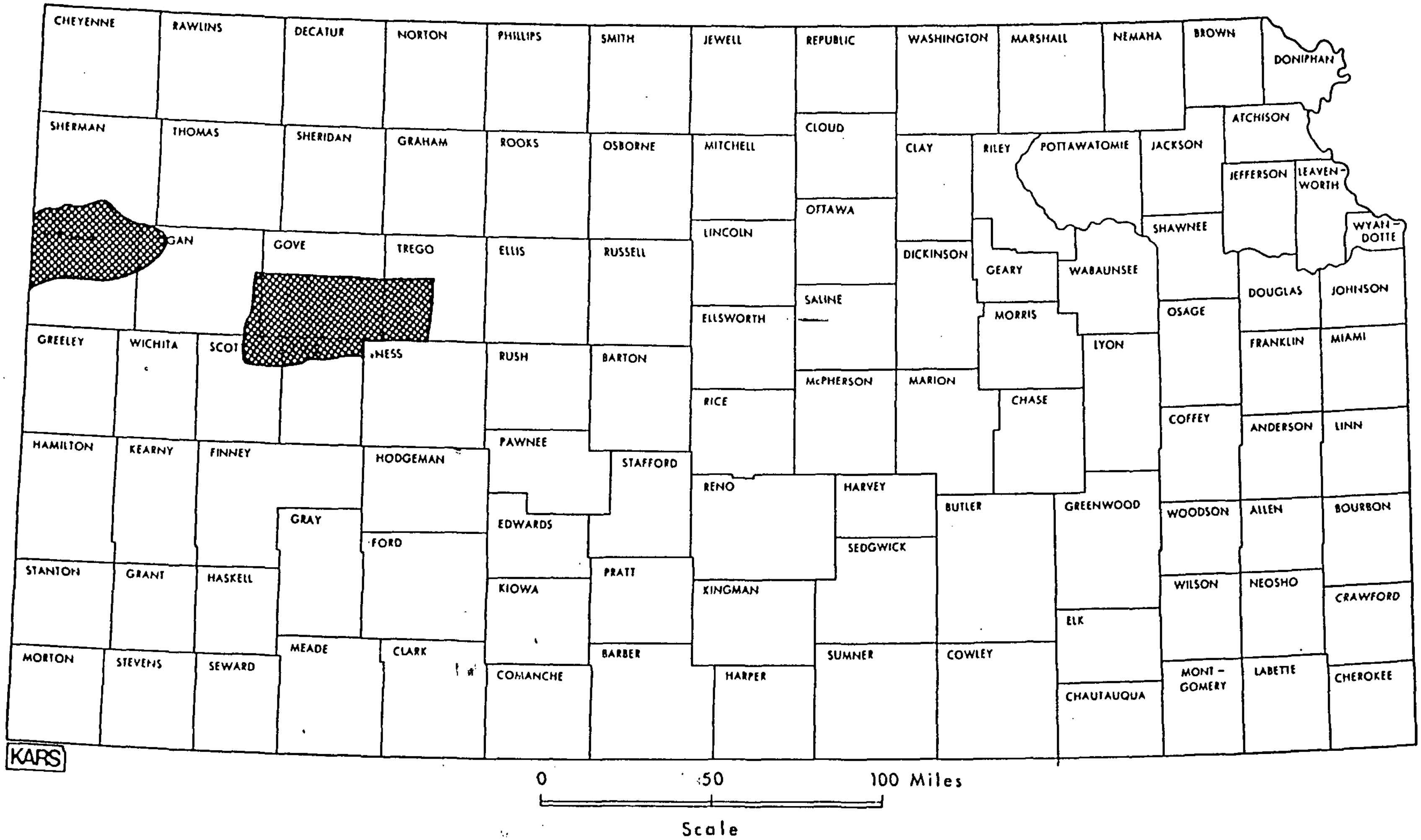

Figure 1. Pronghorns have been reestablished in both the Sherman/Wallace and Gove/Trego county areas.

Landsat tapes for 1978 and 1985 were selected based on crop phenology and availability and were chosen to highlight winter wheat and rangeland. Two seasons, early spring (May) and late summer (August) were selected for each year and study area.

Image Processing Techniques

Registration. Since multitemporal classification was used in this study, it was necessary to geometrically register the images in each study area. The most recent (August 1985) image in each area was registered to a USGS map base by matching the latitude/longitude coordinates of known map ground control points with their corresponding pixel coordinates, then reassigning all the image pixels to their new, registered position using a **cubic convolution** algorithm. Although somewhat slower in processing than a nearest neighbor or bilinear analysis, this algorithm yielded better results (smoother while maintaining data).

Each subsequent image in the study area was registered using the same procedure, substituting known pixel coordinates from the first registered image as the map ground control points. This method provided the best match between dates and use of the finished maps with map-based data.

Classification. Once registered, each image was classified using a supervised spectral classification with nearest neighbor analysis. A supervised/nearest neighbor classification was chosen because of the operator/computer time intensity of the unsupervised clustering and maximum-likelihood methods and because the cover categories necessary for the final output maps were few and broad.

For each image, supervised training site selection resulted in 20-30 training sites representing the range of values in each cover category. The final cover classes obtained were rangeland, cropland, winter wheat, and bare soil. The bare soil category represented chalk outcrops (Gove County only) and some bare soil in agricultural fields (both study areas). There were no water bodies apparent in either study area. Only one city was large enough to be spectrally confused with other categories, and this was eliminated by a road network/city boundary overlay on the final output maps.

Eight classified maps were produced (two for each season, for two years for each study area). Multitemporal classification was achieved by overlaying the August and May classified maps for each year and study area using the MATRIX Function on the Earth Resources Data Analysis System (ERDAS) to form a single classified image. The matrix function creates a classified image by comparing the cover class assignment of a pixel to two different images and assigning that pixel to a new class based on the type of combination found. Most pixels fell easily into one of the final four cover classes. Those that resulted in a "mixed" category were matrixed separately and reassigned to the final image. Using this procedure, four classified images were created: 1978 and 1985 images in each study area.

The final four classified maps were then subjected to post-classification contextual re-assignment of pixels ("smoothing" - 3 x 3 window, majority analysis) to reduce pixel misclassification ("noise"). Because of the east-west orientation of agricultural fields and because of the way the ERDAS smoothing function is carried out, the images were first rotated 90 degrees clockwise. This process maintained field boundaries when the smooth function was run.

Interspersion/Juxtaposition Indices

In this study, indices of interspersion and juxtaposition developed by Mead et al. (1982) were employed. These indices takes into account the degree of interspersion of cover types and relative value of each edge type and the importance of spatial diversity. An index of habitat spatial diversity can be computed for each parcel of land for a specific wildlife species or group of species.

The pixels in the final four images represented an area of 0.8 acres. Each image (rotated 90 degrees) was "averaged" (7 x 7 pixel window, majority analysis) to create maps with a grid cell size of 39.2 acres. A larger grid-cell size was chosen for the indices because it more accurately represented the daily movement potential of pronghorn while still maintaining the spatial detail of the maps, and because wheat fields within 0.5 miles from rangeland received the most use (Cole and Wilkins, 1958). Because both indices use 3 x 3 windows, the area analyzed with the larger grid equals approximately 0.75 square miles.

After averaging, the images were rotated back to their original orientation before generating interspersion and juxtaposition indices. Average interspersion was calculated by passing a 3 x 3 window over the data and counting for each window the number of habitat "edges" (cover classes different from center pixel) within the window. The actual number of changes was summed for all the pixels and divided by the total possible number of changes (8 x the total number of pixels [12543]) to yield an average interspersion index for the images (0-1). In addition, a map of interspersion was created by assigning the pixel interspersion value (for each pixel, the actual number of "edges" divided by 8) to an integer representing an interspersion interval where 1 = low interspersion (0 - 0.33), 2 = medium interspersion (0.34 - 0.67), and 3 = high interspersion (0.68 - 1.00).

The juxtaposition index also used a 3 x 3 window, calculated the number of edges, and then multiplied the edge quantities by an edge quality rating assigned to each particular edge combination. The sum of the quality x quantity values was totaled for all the cells and divided by the total possible edge quality/quantity value (best possible pixel quality/quantity value [0.45] multiplied by the total number of cells) to yield an average image juxtaposition index. A map of juxtaposition was created by assigning each <u>pixel</u> juxtaposition value (sum per pixel of [Edge Quality x Edge Quantity] divided by best possible pixel juxtaposition values = .45) to an integer representing a juxtaposition interval where 1 = low juxtaposition (0 - 0.15), 2 = medium juxtaposition (0.15 - 0.30), or 3 = high juxtaposition (0.30 - 0.45).

To create output interspersion and juxtaposition maps that can be used in conjunction with the original unclassified images, each juxtaposition and interspersion map was rectified back to the original pixel size (using nearest neighbor analysis) and then smoothed using a 7 x 7 window. The interspersion and juxtaposition maps for each area/year were overlayed to produce an output map which ranks the various combinations based on their relative importance of pronghorn.

RESULTS

Acreage measurements for 1978 and 1985 for Wallace and Gove counties from the final classified land cover maps are shown in Table 1. Rangeland and bare soil losses occurred between 1978 and 1985 in both Wallace and Gove counties with corresponding increases registered in the cropland and wheat categories. Interspersion and juxtaposition indices were calculated for 1978 and 1985 for Wallace and Gove counties as shown in Table 2.

Figure 2 illustrates the final "smoothed" classified map cover types patterns for winter wheat, cropland, rangeland and bare soil. These categories were used for the final classified maps for Wallace County, 1978 (Figure 3), Wallace County, 1985 (Figure 4), Gove County, 1978 (Figure 5) and Gove County, 1985 (Figure 6).

Final analysis of these data is underway. This analysis will take into account accuracy assessments of the data for Wallace County 1978, 1985 and Gove County 1978, 1985. Because the interspersion and juxtaposition indices were carried out on "smoothed" data, the accuracy assessment will be conducted for both smoothed and unsmoothed data (i.e., data as originally classified) to determine if accuracy improved with smoothing. Final results will be reported to the Kansas Department of Wildlife and Parks.

Table 1.

LAND COVER CHANGES

Wallace County

COVER	1978 ACRES	1978 % OF TOTAL	1985 ACRES	1985 % OF TOTAL	Change ACRES	Change % OF TOTAL	+/-
Range	321,966	(62.66)	273,766	(53.28)	48,200	(9.38)	loss
Wheat	78,007	(15.18)	117,453	(22.86)	39,446	(7.68)	gain
Crop	113,860	(22.16)	122,615	(23.86)	8,775	(1.70)	gain
Bare	5	(0.0)	3	(0.0)	2	(0.0)	loss

TOTAL ACRES: 513,837.812

Gove County

COVER	1978 ACRES	1978 % OF TOTAL	1985 ACRES	1985 % OF TOTAL	Change ACRES	Change % OF TOTAL	+/-
Range	275,316	(53.58)	251,479	(48.94)	23,837	(4.64)	loss
Wheat	112,325	(21.86)	107,417	(20.90)	4,908	(0.96)	loss
Crop	118,985	(23.16)	149,451	(29.09)	30,466	(5.91)	gain
Bare	7,212	(1.40)	5,49	(1.07)	1,721	(0.33)	loss

TOTAL ACRES: 513,837.821

Table 2.

INTERSPERSION INDICES *		JUXTAPOSITION INDICES *	
Wallace	1978 = 0.29 1985 = 0.32	Wallace	1978 = 0.2725 1985 = 0.2379
Gove	1978 = 0.37 1985 = 0.38	Gove	1978 = 0.2329 1985 = 0.2083

*Based on +/- 40 acre grid cell size

JUXTAPOSITION EDGE QUALITY RATING

Range/Range = .45	Wheat/Wheat = .10
Range/Wheat = .35	All other combinations = 0
Range/Crop = .05	
Range/Bare = .05	

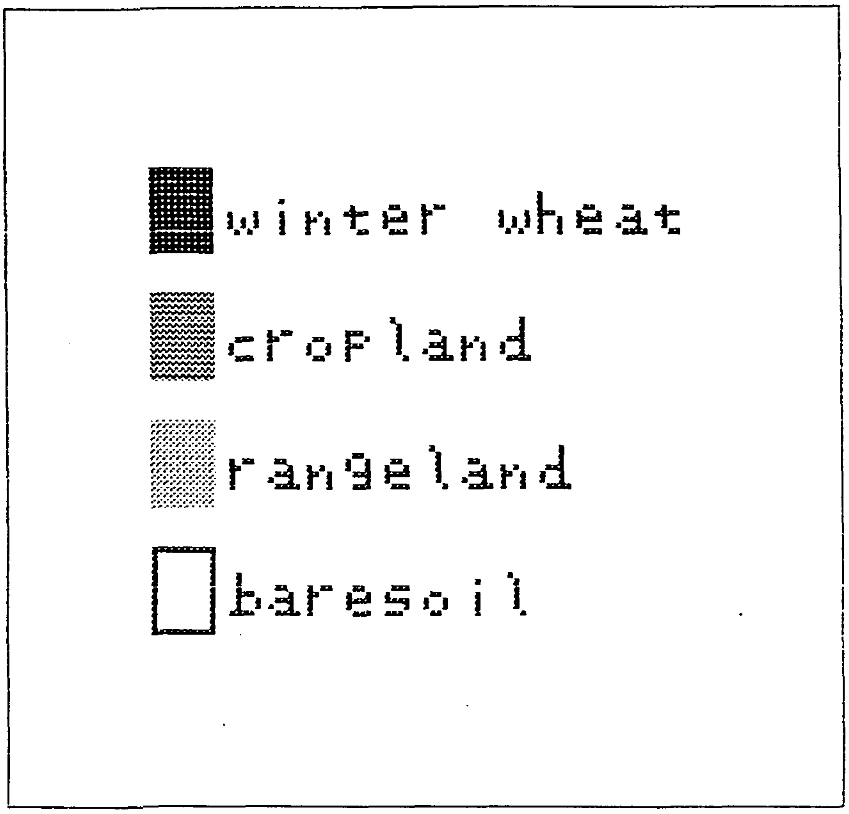

Figure 2: Cover type patterns for final classified maps.

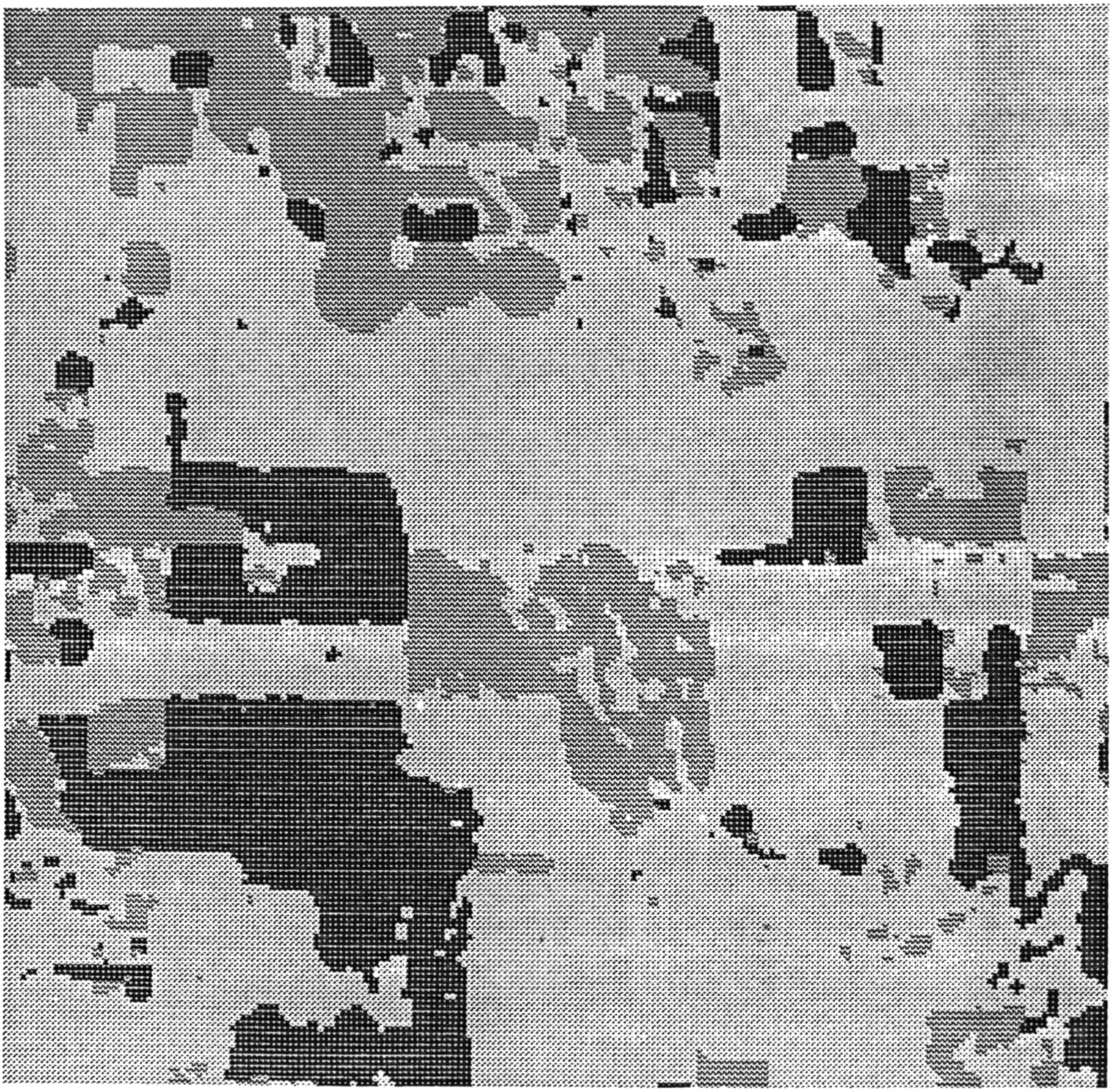

Figure 3: Wallace County, 1978

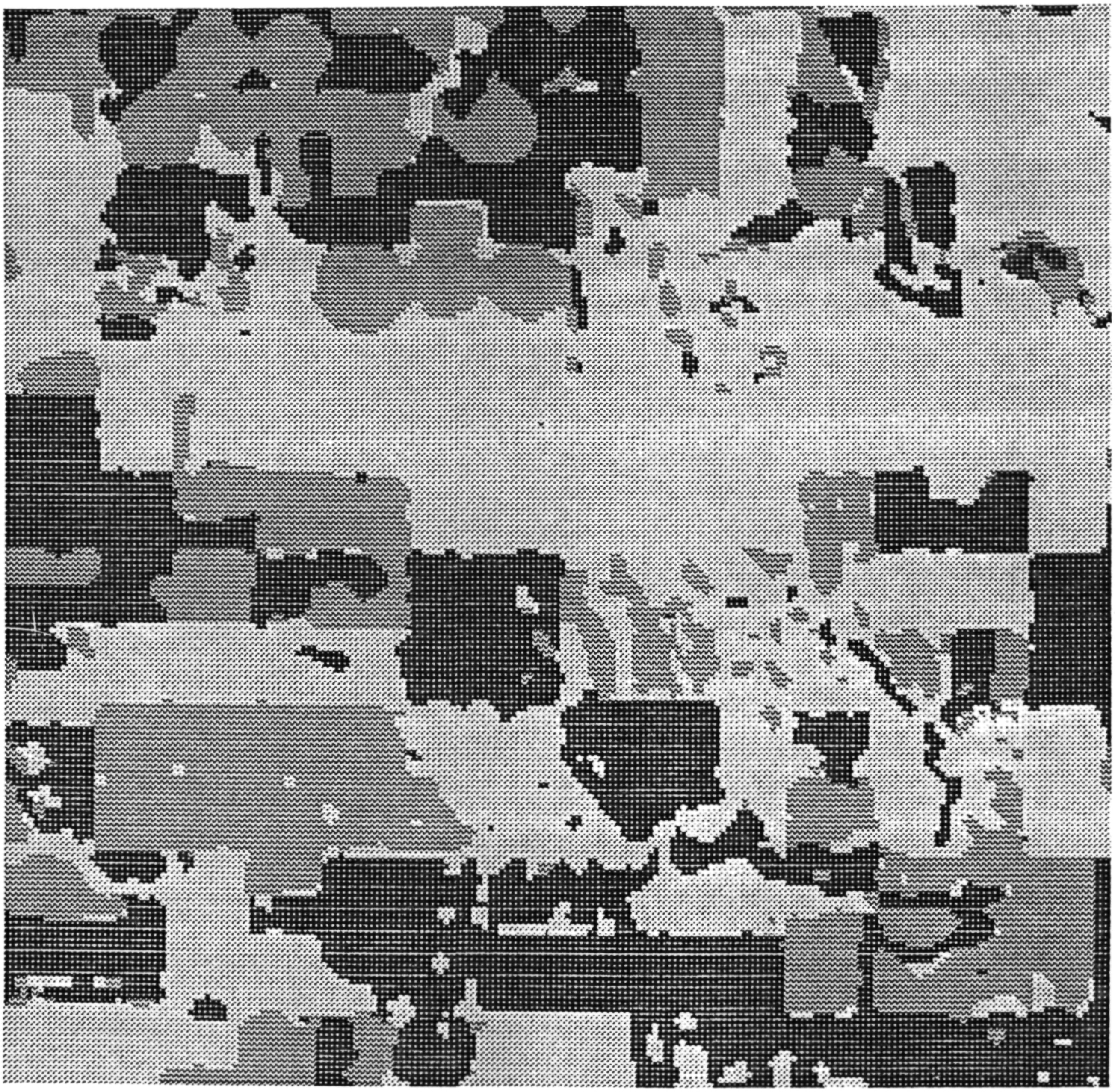

Figure 4. Wallace County, 1985.

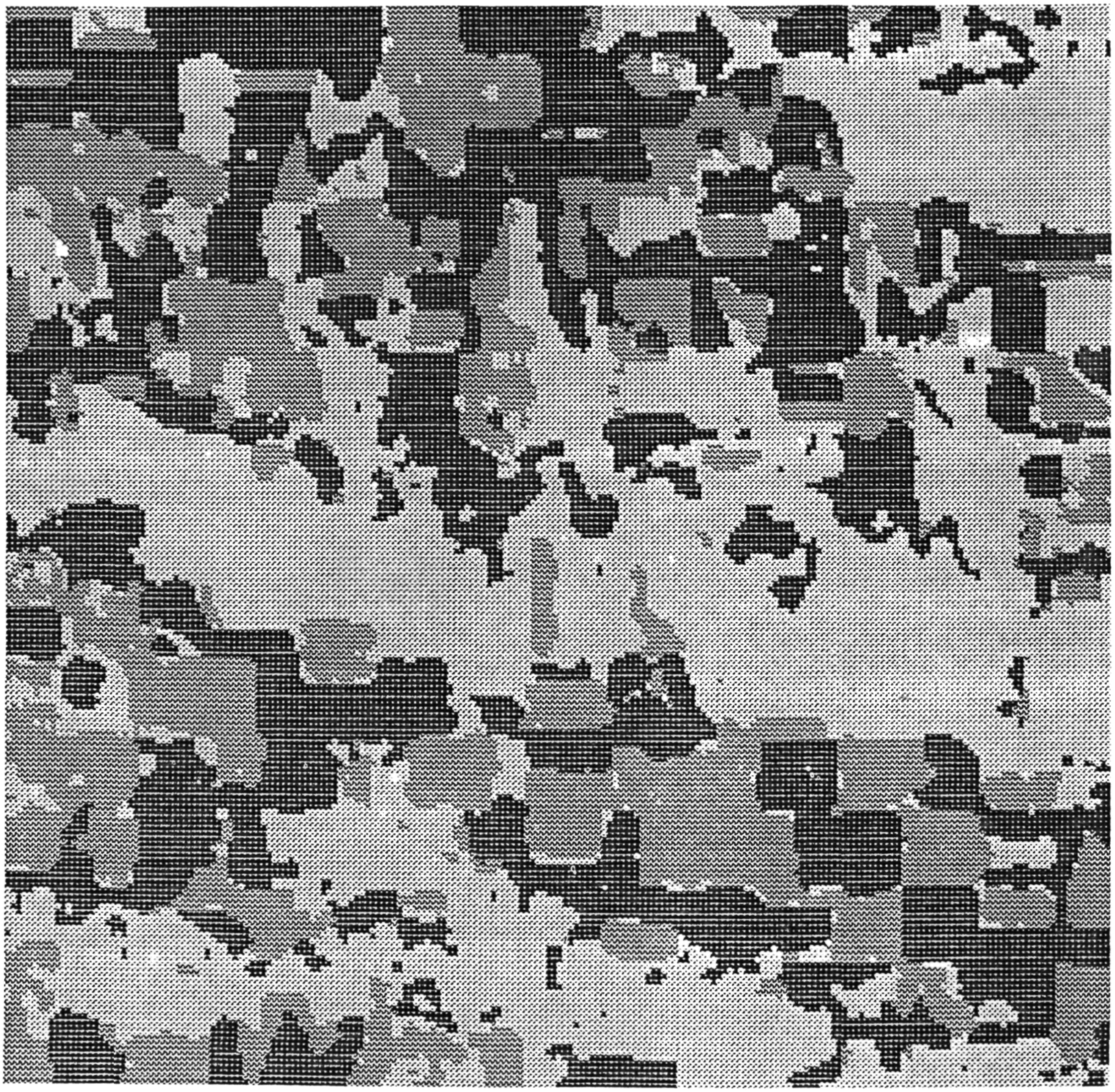

Figure 5. Gove County, 1978

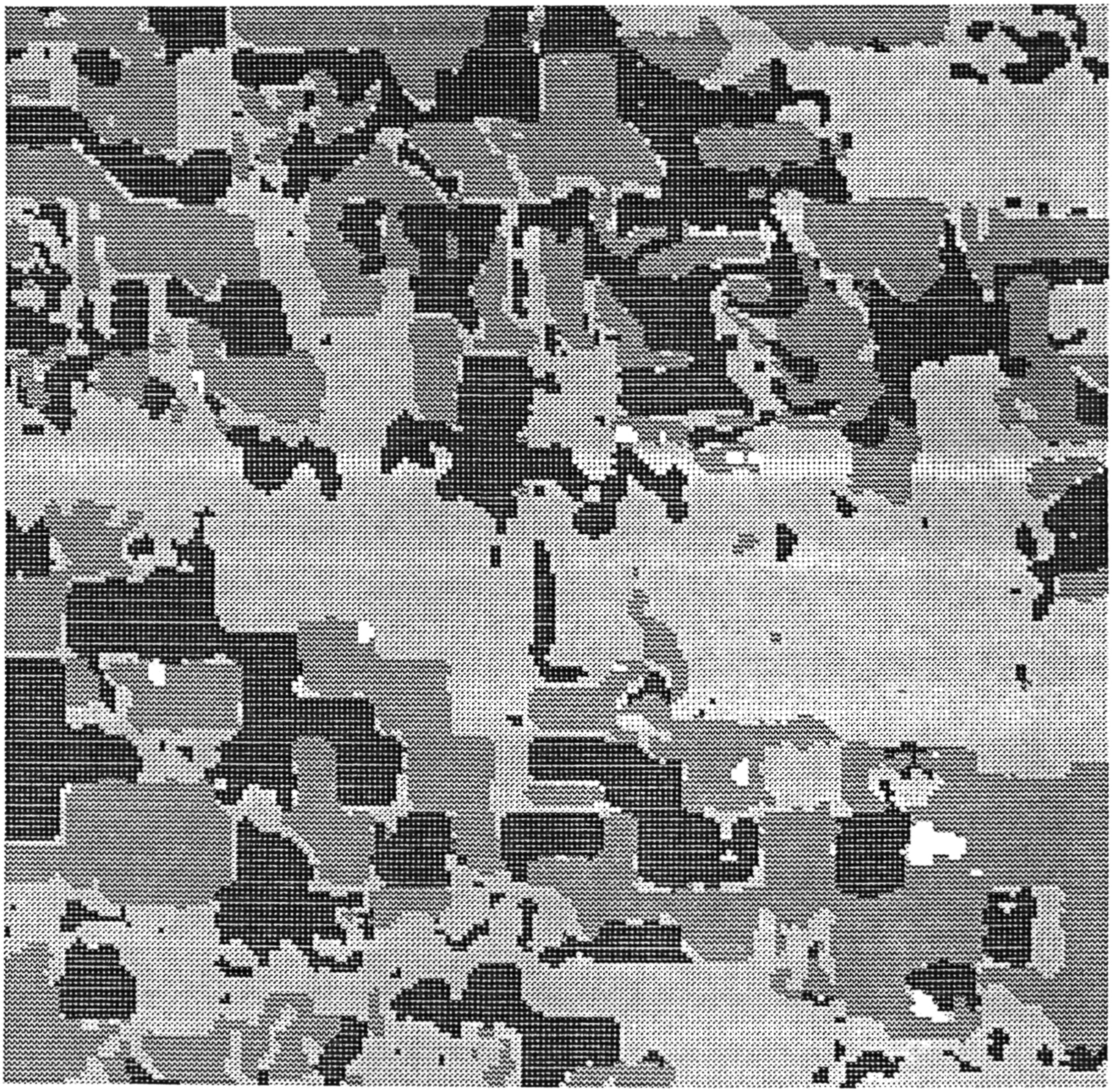

Figure 6. Gove County, 1985.

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MERGING REMOTELY SENSED DATA WITH ANCILLARY DATA: A GEOGRAPHIC INFORMATION SYSTEMS APPROACH TO RESOURCES MANAGEMENT

James W. Merchant
Jerry L. Whistler

INTRODUCTION

Computer-based geographic information systems (GIS) are powerful tools for integrating and analyzing data obtained from such disparate sources as remote sensing, soils surveys, land surveys, land ownership maps, water-sampling stations, topographic maps, and the census. In such systems, all types of geographically-referenced data are spatially registered so that multiple themes of data can be compared and analyzed in concert (Figure 1). Virtually any data that are, or can be, mapped (i.e., are geographically referenced) can be digitized and stored in the computer. Once stored, these data can be automatically extracted, reconfigured, updated, analyzed, and mapped in a format and at a scale designed to meet a specific need. Therefore the data can be used for many types of decision-making. A GIS provides water resource managers with a capability to analyze complex spatial interrelationships in a timely, efficient and cost-effective manner. It is important to note, however, that GIS technology also fosters better decision-making since it can enable the resource manager to conduct unique, and otherwise often infeasible, analytic tasks (Ozanich and Roberts, 1985).

There is a direct relationship between the quality and effectiveness of decision-making and the quality of data and analytical tools available to decision-makers. Environmental management and policy decisions must be based upon examination and analysis of the interplay of many different

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ANALYSIS PROCEDURE USING GEO-CODED DATA

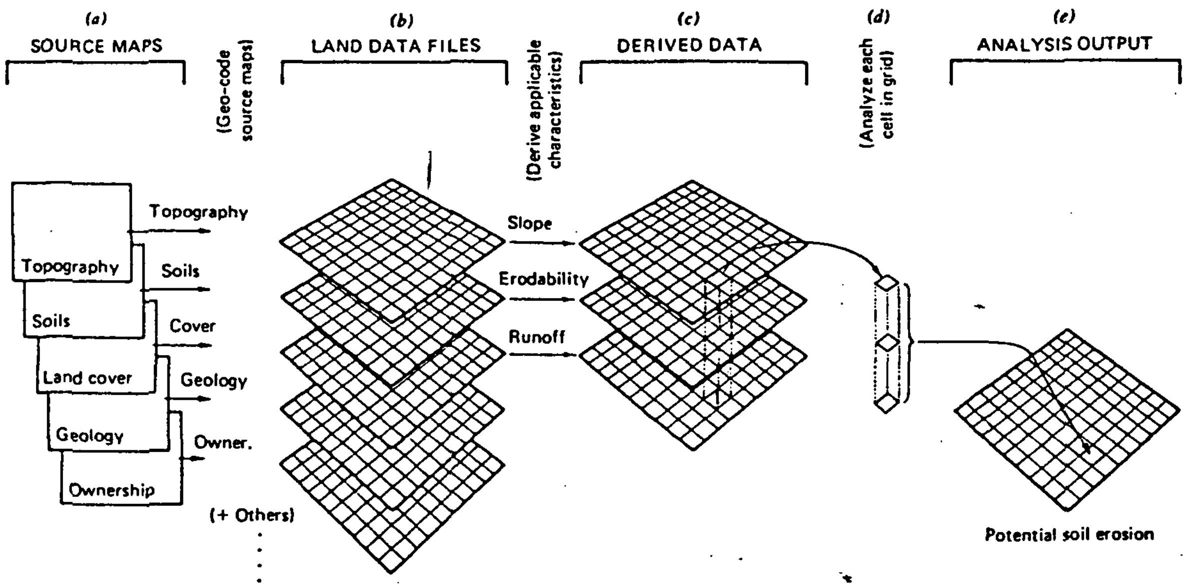


Figure 1. Geographic data are spatially registered within a geographic information system so that multiple themes of data can be compared and analyzed. Derived variables can be created from the original thematic maps and this information used to model environmental interactions.

factors which may bear upon a particular issue. Decisions concerning protection of water quality, for example, must be based upon evaluation of a spectrum of institutional, political, economic and environmental data. Automated geographic information systems (GIS) are potentially powerful tools which can enable natural resource managers to deal more effectively with such complex issues.

Establishment of a GIS has, in the past, been an expensive and technically demanding proposition beyond the resources available to many state agencies and local-level jurisdictions (e.g., counties, soil conservation districts, groundwater management districts, wildlife refuges, parks). Such entities, however, have a particularly great need for GIS technology. It is typical in these jurisdictions for land management to reside in the hands of a very few trained professionals, and for these individuals to be responsible for sometimes vast areas.

In recent years, the development of powerful, inexpensive computers and accompanying advances in software, data storage, display and hardcopy peripherals, have made it possible to fabricate geographic information systems suitable for use by these jurisdictions. If such systems were in widespread use by resource managers trained in GIS applications, significant positive impacts on natural resources and environmental issues of state and national concern would almost certainly result.

Users require assistance not only in acquiring GIS technology (i.e., hardware and software) but in learning to use such technology as an effective tool for decision-making (Tomlinson, 1982). Because a GIS presents the resource manager with so many <u>new</u> opportunities and alternatives for manipulating, analyzing, and displaying geographically-referenced data, many important uses of the system will not be immediately apparent to either the novice user or the GIS specialist (Tomlinson, 1982). They can only be discovered or developed as the resource manager becomes intimately familiar with this new tool. He or she must have the opportunity to interact with the system, to examine spatial interrelationships between data, and to experiment with, and observe the outcomes of applying, various models, assumptions and alternative management decisions (see Ozanich and Roberts, 1985). The resource manager possesses unique knowledge which must be brought to bear upon decision-making fostered by the geographic information system. The process of learning to use the system is one of trial, of error, of hypothesis-testing, and of experimentation. Results of data analysis must be evaluated within the context of the specialized knowledge of the decision-maker (e.g., the resource manger).

Resources management professionals should be involved in identifying the information components of the geographic information system, must aid in the design of strategies, models and algorithms for analyzing data, and must have access to such systems in order to gain experience in using them for routine decision-making (see Tomlinson, 1982). Such utilization is essential if resource managers are to better define mechanisms and methods for employing GIS capabilities in management activities. Feedback stemming from "hands on" experience will aid in "fine-tuning" system design, in more accurately establishing cost-benefit relationships and in better defining applications.

HARVEY COUNTY PROTOTYPE PROJECT

A prototype geographic information system is being established in Harvey County, Kansas to enable water resources managers in state, district, and county agencies to more effectively address issues pertaining to groundwater and surface water quality protection. Although designed for water resources management, resource managers in other fields would find the same GIS useful for applications ranging from urban planning and land appraisal to soil-erosion hazard assessment and wildlife habitat evaluation.

The project has four principal objectives:

1. to provide water-resources managers, administrators and policymakers with a "hands-on" capability to test and evaluate GIS technology in a real-world situation;
2. to build, via system utilization, a group of knowledgeable GIS users;
3. to generate suggestions for system design and software modifications, and for effective application of the system as a decision-making tool; and
4. to provide a mechanism for establishing firm cost-benefit relationships.

The project will, in a broader context, also serve to help guide Kansas policymakers in making informed decisions regarding future GIS utilization, implementation, integration and institutionalization on a statewide basis.

The principal participants in the prototype project include the:

1. University of Kansas Applied Remote Sensing (KARS) Program - responsible for GIS construction, software development, training and tech-

nology transfer, and coordination with the Kansas Commission on Applied Remote Sensing (KCARS);

2. Kansas Geological Survey (KGS) - responsible for identifying and accessing data, developing models and algorithms for data analysis pertaining to geohydrology and water quality, and coordination with other Kansas agencies involved in water resources management; and
3. Kansas Department of Health and Environment (KDHE) - responsible for identifying and facilitating access to source data, developing conceptual models and algorithms for data analysis pertaining to potential legislation and regulatory functions, and state-federal project coordination.

Other agencies contributing to the project are the U.S. Environmental Protection Agency (EPA) and the U.S. Soil Conservation Service (SCS).

Project Background and Scope

Ground water receives more public, media, planning, regulatory, management and legislative attention in Kansas than does any other natural resource occurring in the state. Ground water provides approximately 80 percent of Kansas' water supplies, and is regionally much more important, supplying nearly 98 percent of western Kansas' water. Although ground water depletion, stemming primarily from pumping for agricultural uses, has been a subject of concern for well over a decade, more recent concern has tended to focus upon man-induced degradation of groundwater quality. Approximately eight percent of those Kansas public water supplies which are drawn from ground water contain concentrations of pollutants which exceed State/Primary drinking-water standards. Such pollution may stem from natural circumstances and/or may be related to agricultural (e.g., pesticide applications), industrial (e.g., from oil-field brines) or municipal (e.g., sewage disposal) sources. The potential exists for additional contamination as man's activities change, become more intense, and cover a greater portion of the area overlying the aquifers. Land-use planning and management of these activities is an important approach to groundwater quality protection, an approach that can be greatly aided through use of GIS technology.

The prototype GIS developed for Harvey County was designed to assist water managers in (1) assessing and monitoring groundwater use, (2) evaluating the complex spatial interrelationships between physical and cultural phenomena that impact groundwater quality and supply, and (3) developing, forecasting, and assessing the outcomes of applying alternative management and regulatory options. The project encompasses ten major tasks. They are as follows:

1. Define KDHE needs for, and potential applications of, a geographic information system;
2. Establish contacts with other agencies (e.g., EPA, SCS, Kansas Water Office, Kansas Commission on Applied Remote Sensing, and Kansas Water Data Committee);
3. Identify types of information required by water managers for decisions concerning groundwater protection (e.g., for establishing environmental performance zoning);
4. Identify existing data-analysis models/algorithms that can be used to process data and display desired information (e.g., DRASTIC - Aller, et al., 1985);

5. Modify existing models or develop new models to address specific KDHE requirements;
6. Establish and test prototype GIS for an area that possesses a variety of existing and potential groundwater problems;
7. Assist KDHE and allied agencies in evaluation of GIS;
8. Recommend options for future development, implementation, integration, and institutionalization; and
9. Provide technical assistance, training, and technology transfer.

Study Area

The study area for which the GIS is constructed includes all of Harvey County, and those portions of the 7.5-minute topographic quadrangles that extend from Harvey County into the adjacent easternmost townships of Reno County, and the contiguous northernmost townships of Sedgwick County, Kansas (Figure 2). This 800-square mile region includes a portion of a major aquifer (the Equus Beds) that, in terms of groundwater resources, probably supplies the largest number of people in Kansas for an area of equivalent size. The water is used for both irrigation and municipal purposes. The well field (public water supply) for the City of Wichita (population 400,000) and a major portion of the Equus Beds Groundwater Management District (EBGMD) are included within the study site. A region of sand dunes lies in the northwestern part of the study area. A section of the alluvial aquifer of the Arkansas River is in the southwest, while limestone aquifers yielding supplies of water adequate for only domestic or stock purposes are in the east. Oil has been produced since the 1930's from the Burrton and

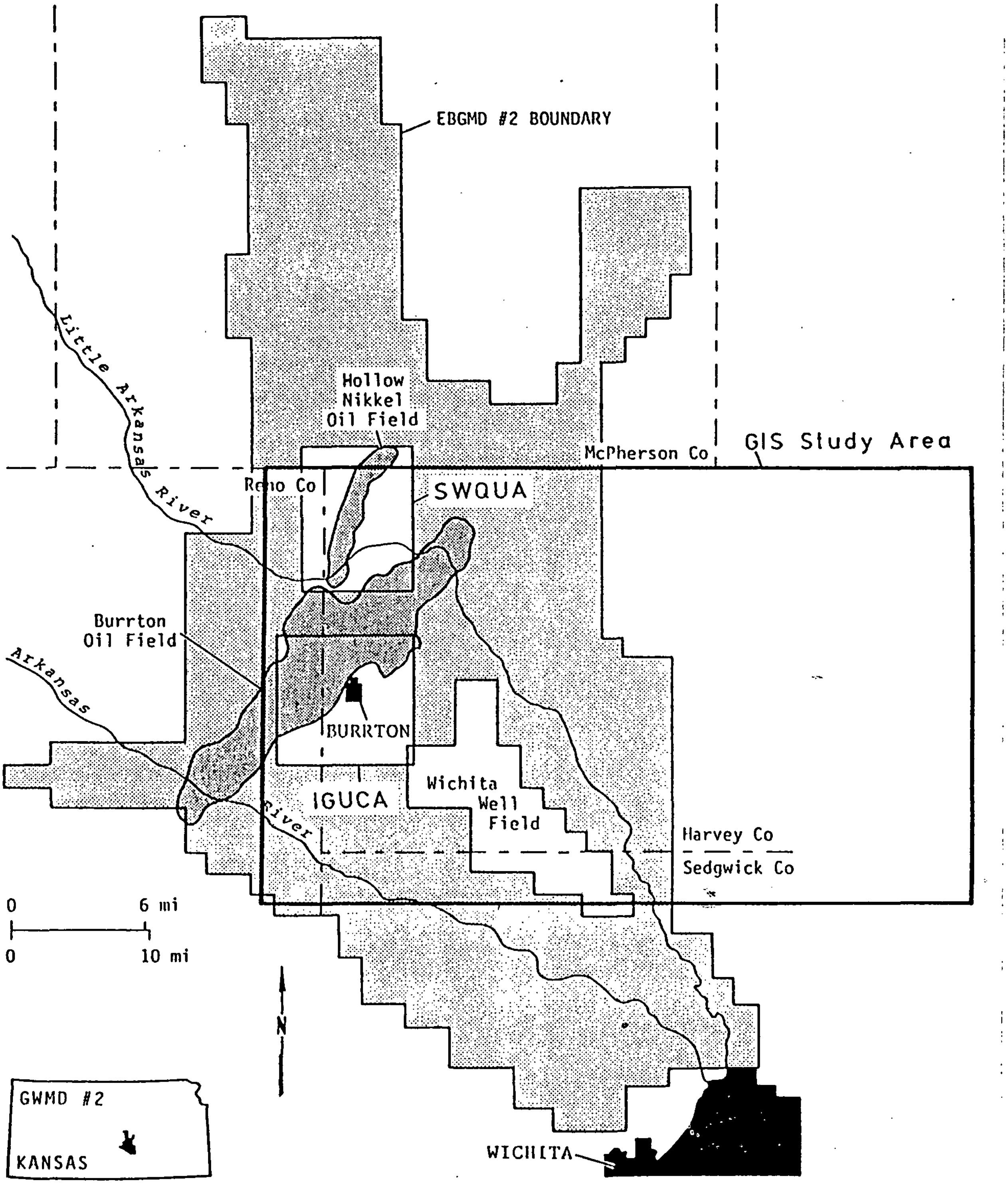


Figure 2. GIS study area and important relevant features. The Equus Bed aquifer is approximately bounded by the Equus Beds Groundwater Management District (EBGMD #2).

other, smaller, oil fields. Oil-field brine has polluted portions of the aquifer around the town of Burrton and in the northwest corner of Harvey County. An Intensive Groundwater Use Control Area (IGUCA) and a Special Water Quality Use Area (SWQUA) have been designated by the Division of Water Resources of the State Board of Agriculture at the request of the EBGMD (Whittemore et al., 1985).

The Equus Beds aquifer and Arkansas River alluvium consist mainly of unconsolidated deposits of Pleistocene age. The deposits are mostly sands and gravels, but also contain clay lenses interbedded with silt, sand and gravel. The saturated thickness ranges from a few feet at the aquifer edge to over 300 feet in areas where ancient channels exist in the subsurface. The depth to ground water ranges from less than 10 feet to 60 feet. The entire aquifer is believed to be hydrologically connected as an unconfined system, with the discontinuous clay layers acting as local aquitards. Ground water flow is generally to the southeast in the area north of the Arkansas River.

PROJECT RESULTS

Geographic Information System

The GIS package selected for the prototype study is the ERDAS (Earth Resources Data Analysis System) operating on an IBM PC/AT. The ERDAS system includes powerful software that allows automated mapping, overlaying of multiple data sets, and spatial modeling and analysis, as well as additional graphics operations. It also includes a "software tool kit" that allows software developed for specific purposes to be integrated into the system.

The ERDAS GIS used for this project was selected over other GIS packages because it is a well-supported, user-friendly, and highly flexible stand-alone system having a high performance/cost ratio. Other important features of the system are its modularity and portability because it operates on an IBM PC/AT microcomputer. The present hardware components being used include items obtained both through Earth Resources Data Analysis Systems, Inc. and other vendors, and consists of the IBM PC/AT microcomputer, monochrome monitor, 512 x 512 pixel color graphics monitor, 20 and 70 megabyte Winchester hard disks, one-half-inch 1600 bpi tape drive, a Calcomp 36 by 48 inch digitizing tablet, an Anadex 200 cps line printer, and a Tektronix 4696 color graphics printer-plotter. The ERDAS system uses a raster mode for data base storage, analysis, and information display. Menu-driven software that allows different graphics display and analysis options also allows positioning, selection, and modification of data directly on the graphics monitor through a joy-stick pointing device.

Digital Map Data Base

A wide variety of geographically-referenced data, including both natural (such as hydrogeology) and anthropogenic features (for example, land use), have been used in the overall project. The specific data files included in the digital map base which related to the hydrogeology of the study area included topography, aquifer characteristics (geology, saturated thickness, recharge, hydraulic conductivity, porosity, and hydraulic head), unsaturated zone properties (soil type, geology of unsaturated zone underneath soils, and thickness), surface hydrography, and well information (location and water use). Maps of other hydrogeologic data (for example, water quality) and maps depicting different anthropogenic activities (such as land use, transportation networks, waste-disposal sites, oil/gas fields) are also included in the data base as reference to existing or potential sources of groundwater contamination. These data were obtained from a variety of sources and existed originally in different formats and scales as indicated in Table 1. The construction of the data bases for the GIS thus involved different methods of transforming and transferring the information to the IBM PC/AT in a form usable by the ERDAS software.

Definitions, Concepts and Procedures for Constructing Digital Maps. Any data that can be mapped can be stored and manipulated in a computer-compatible format. This includes point, line, and areal data and extends to tabular data for which only legal descriptions exist defining their location. The digital data bases comprising a GIS must be referenced to one another as well as to some superordinate coordinate system such as the State Plane, the Universal Transverse Mercator or latitude and longitude.

Two issues have to be considered when constructing and subsequently maintaining a GIS data base. First, in order to provide accurate spatial control, a common base map to which all data will be referenced and transferred is necessary. Second, to allow flexibility in the analysis or display of an area, or any portion of it, the base map should serve as a logical building block from which larger areas can be constructed.

The use of USGS 7.5-minute topographic quadrangles ("topo quads") provide a good solution to these issues. The topo quads offer excellent spatial control. Further, each individual quad covers an area (~58 square

TABLE 1

HARVEY COUNTY PROTOTYPE GIS

CHARACTERISTICS OF SOURCE DATA

File	Data Source	Format	Scale	Date of Information
Generalized Well Yields	KGS-USGS	Map M-4A	1:500,000	1967 - Revised 1975
Specific Yield for Source	KDHE	Tabular	NA	Variable[1]
Elevation of Water Table	KGS-USGS	Digital	Variable	1980
Depth to Water	KGS-USGS	Digital-Derived[4]	Variable	1980
Annual Recharge	KGS-USGS	Map	≈1:50,000	1980
Quality (Brine Pollution)	KGS Report	Map	≈1:70,000	1983
Storage Coefficient (Hydraulic Conductivity)	KGS-USGS	Map	≈1:50,000	1980
Public Water Supply Wells	KDHE	Tabular	NA	Variable[2]
Publicly Owned Wastewater-Treatment Plants	KDHE	Tabular	NA	Variable[2]
Landfills/Dumps	KDHE	Tabular	NA	Variable[2]
Hazardous Waste Generators, Storage, Disposal Sites	KDHE	Tabular	NA	Variable[2]
Industrial Lagoons	KDHE	Tabular	NA	Variable[2]
Agricultural Feedlots	KDHE	Tabular	NA	Variable[2]
Oil/Gas Fields	KGS	Map M-17	1:500,000	1982
Land Use	USGS/ASCS	Aerial Photography	1:58,000	May 1985
Soil Series	SCS - County Soil Survey	May	1:20,000	Variable[5]
Elevation	USGS	Digital	1:250,000	1955 - Revised '66 & '69
Surface Hydrography	KGS	Digital	1:24,000	Variable[3]
Geology	KGS	Map M-1	1:500,000	1964
Transportation Routes (U.S. Highways/Railways)	KGS	Digital	1:24,000	Variable[3]

Table 1 (Continued)

CHARACTERISTICS OF SOURCE DATA

File	Data Source	Format	Scale	Date of Information
Public Land Survey (Township-Range-Section)	KGS	Digital	1:24,000	Variable[3]
County Boundaries	KGS	Digital	1:24,000	Variable[3]
Wichita Water Field Boundary		(Included on Public Wells Map)		
Slope		Derived from Soils Data	1:20,000	Variable[5]

Variable[1] - Date based on monitored wells.

Variable[2] - Date based on issuance of permit.

Variable[3] - Date based on last revision of quadrangle.

Variable[4] - Derived from contoured points of elevation of land surface and water table at wells.

Variable[5] - Harvey County 1969, Reno County 1969, Sedgwick County 1975

ASCS - Agricultural Stabilization and Conservation Service

KDHE - Kansas Department of Health and Environment

KGS - Kansas Geological Survey

USGS - United States Geological Survey

SCS - United States Soil Conservation Service

NA - Not Applicable

miles) large enough for the analysis of many localized problems. The development of the map data base around the relatively small area of the topo quad areal unit results in the practical benefits of 1) allowing rapid construction of prototype areas, 2) providing a uniform mapping standard which is universally recognized and accepted and, 3) speeding computational times during model development.

The use of topo quads also proves to be functional. Their scale allows detailed mapping (where such detail exists), and they are of a physical size (17" x 22") that an individual can easily interpret and transfer data. The use of quads also simplifies the organization and management of data files within the computer system. Fifteen quadrangles cover the Harvey County study area, consequently 15 subdirectories reside on the hard disk. Under each subdirectory are the individual files for that quad.

Other scales, referencing systems and areal units (e.g., counties, states) could, of course, be used to build the map data base. The final selection of these variables, however, must be made with forethought to the ultimate use and objectives of the GIS. Compatibility and uniformity of map data with outside agencies is an important goal. Compatibility and uniformity within an agency is a fundamental requirement.

<u>General Map Properties</u>. An orthogonal map projection based on latitude and longitude was chosen for construction of the maps. An orthogonal projection was judged to be satisfactory given the small size of the study area (< .6 degree in longitude and < .4 degree in latitude). The unit of measure chosen for representing distances was feet. The conversion of latitude/longitude coordinates to feet was based on a standard reference

table for converting geographic distances (i.e., degrees) to feet (U.S. Coast and Geodetic Survey). Table 2 gives the conversion factors used for Harvey County. Using these conversion factors, and a grid-cell size of 165 x 165 feet, one 7.5 minute topographic quad area was calculated to be 218 grid-cells in longitude (east-west) and 276 grid-cells in latitude (north-south). The area of one grid-cell is .625 acre. Figure 3 illustrates the resulting array representing one 7.5 minute area.

There are two basic types of maps contained in the data base. The first type identifies specific features on or below the landscape at a nominal or ordinal level (GEOLOGY and ERODIBLE). Most of these maps contain legends which identify a feature with a specific code number (e.g., Highly Erodible has the code of '1'). However, some maps of this type identify the same feature with unique codes. For instance, the map of public wells (PUBLICW) identifies each well with a unique code number. Since the number of wells varies depending on the quadrangle being displayed or analyzed, a legend was not built for these maps.

The second basic type of map is one which quantifies the map variable on either an interval or ratio scale (ELEVATN and DEPTH). Generally, the code number on this type of map can be directly interpreted as representing the actual value of the variable. There are exceptions, however, in which values have been grouped into ranges (SSLOPE) or have fractional values and/or limited areal extent (BRINE). The map code numbers on these maps do **not** represent actual values. Instead, these maps have legends identifying what values the code number does represent.

Table 2.

Conversion of Geographic Units to Feet and Meters
(U.S. Coast and Geodetic Survey)

GEOGRAPHIC TABLES
(units in **bold** used for Harvey County)

Lengths of Degrees of the Parallel (east-west)

Latitude		Statute Miles	Feet	Meters
°	'			
37	00	55.311	292,042.1	89,014
38	**00**	**54.579**	**288,177.1**	**87,835**
39	00	53.829	284,217.1	86,629

Lengths of Degrees of the Meridian (north-south)

Latitude	Statute Miles	Feet	Meters
°			
37 - 38	68.962	364,119.4	110,984.4
38 - 39	**68.974**	**364,182.7**	**111,003.7**

7.5 minutes	=	.125 degrees	=	1/8 degree
7.5 minutes (longitude)	=	288,177.1 / 8	=	36,022.1 feet
7.5 minutes (latitude)	=	364,182.7 / 8	=	45,522.8 feet

Given: (from Table 1)

7.5 minutes (longitude) = 36,022.1 feet
7.5 minutes (latitude) = 45,522.8 feet

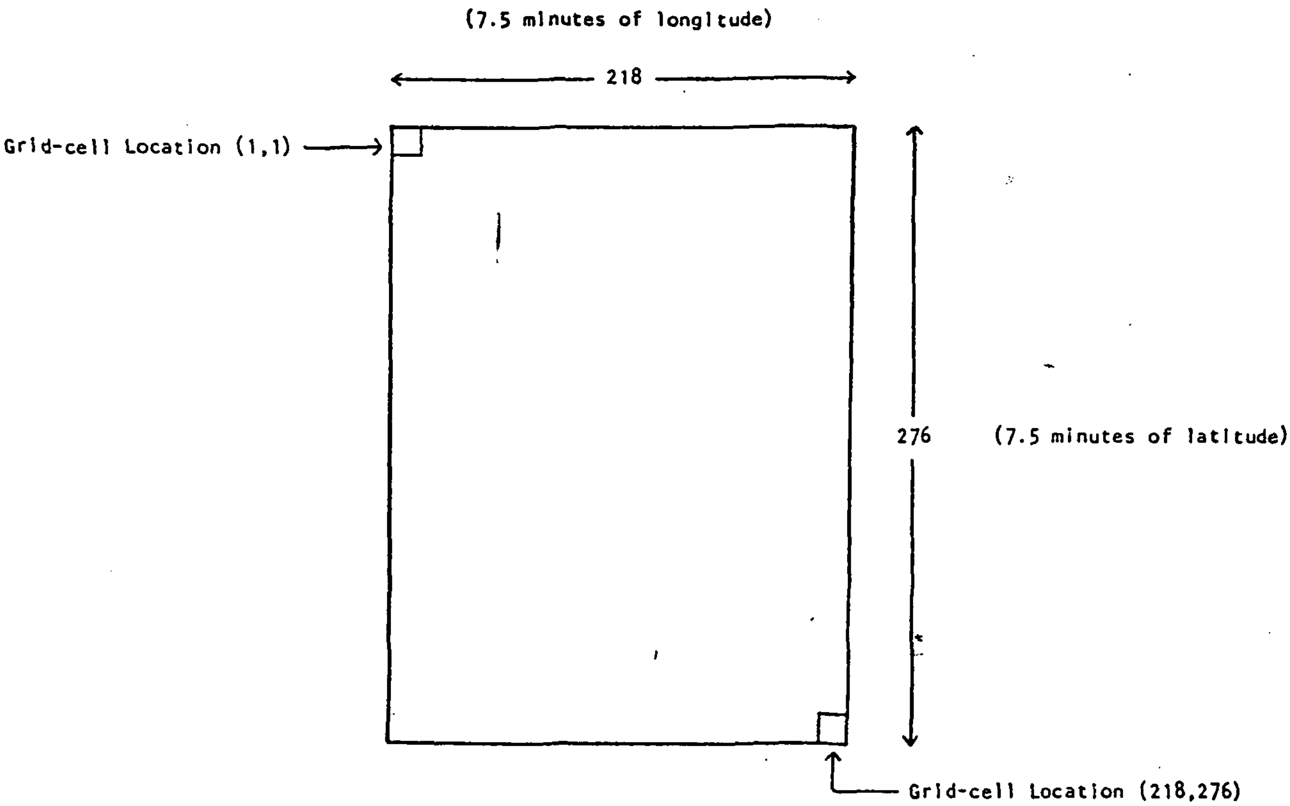
and

1 Grid-cell = 165 feet

Then

X dimension of map array = 36,022.1 / 165 = 218.32
= **218**

Y dimension of map array = 45,422.8 / 165 = 275.89
= **276**



Total number of grid-cells = 218 x 276 = 60,168 grid-cells

Area of one grid-cell = .625 acres

Total number of acres per 7.5 minute quadrangle = 37,605 acres

Figure 3. Dimensions in grid-cell units for one 7.5 minute topographic quadrangle.

The chart in Figure 4 outlines the basic steps involved in creating digital map data. The following sections will more fully define these terms and steps.

Interpretation and Mapping. Many times data to be placed into a GIS either have not yet been mapped (land use) or do not exist in map form (KDHE permit files). The process of transforming these types of data into usable spatial information requires interpretation. The interpretation and mapping of either type of data requires the use of base maps for spatial control on to which information will be transferred. When mapping information about surface objects for which no data exist, aerial photography is necessary. If a more precise location is needed for data located only by legal description, then aerial photography may be a necessary ancillary source of information.

If aerial photography is available, the procedures for mapping both cases are basically identical. Mapping tabular data is slightly different in that the interpreter knows what feature is being looked for and knows, within a quarter-quarter-quarter section, where to look.

A Bausch and Lomb zoom-transfer scope aided the interpretation and mapping process in Harvey County. This instrument allows the interpreter to mount an aerial transparency for viewing, while simultaneously allowing a view of the base map. A transparent mylar overlay is placed over the base map, and an accurate transfer of point locations and boundaries from the aerial photo is made directly upon the overlay.

Should a zoom-transfer scope not be available, a practical alternative would be to obtain aerial photography, at the same nominal scale as the base

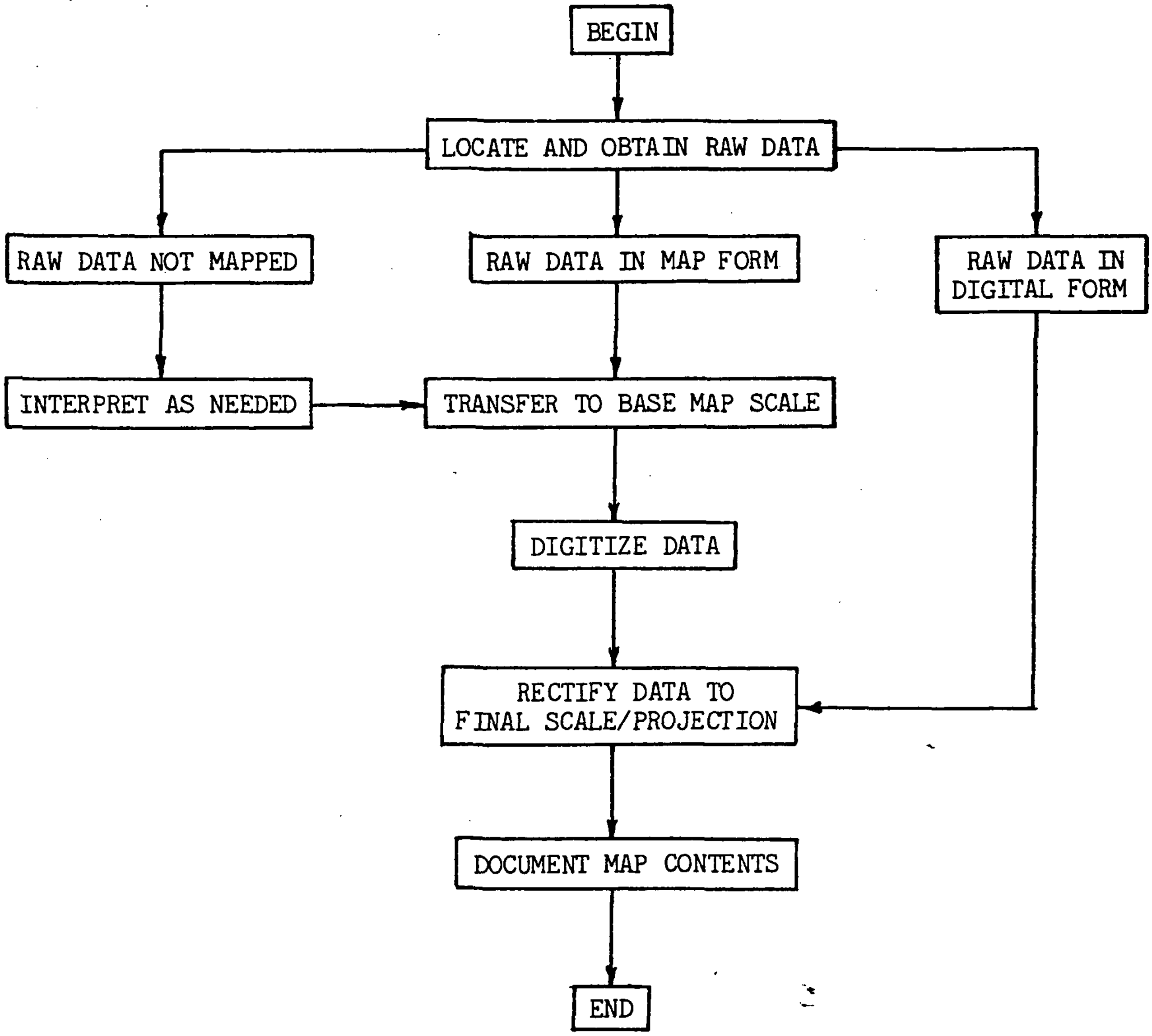


Figure 4. Flowchart of basic steps required to construct digital maps.

map, over which a piece of mylar could be placed (read 'nominal scale' as approximate). The interpreter would then use the technique of 'similar squares' to transfer the air photo information to the mylar. The transfer of data involves three (3) steps:

1) trace the section lines and any unique cultural and/or physical features from the base map to the mylar;
2) place the mylar over the aerial photo and visually determine the relative amount of difference in scale between them, and;
3) use the visual information to determine how large of an area can reasonably be transferred to the mylar before having to readjust the mylar-to-photo registration (usually about 4 sections when using 1:24,000 scale photography).

The method of similar squares was also employed with data that appeared on existing maps, but were in differing scales (recharge, soils, geology, oil/gas fields). Data were transferred to overlays for digitization.

Digitization. The data transferred to the mylar overlays is digitized. The process of converting data from their original format (e.g., a map format) to a numerical (digital) format that can be used in computer processing is called digitization. A digitizer tablet and cursor are the instruments used to carry out the digitizing procedure. The tablet sets up an electronic cartesian coordinate system that measures distance. The cursor is used by the operator to identify and enter the location to be recorded by pushing a key on the cursor.

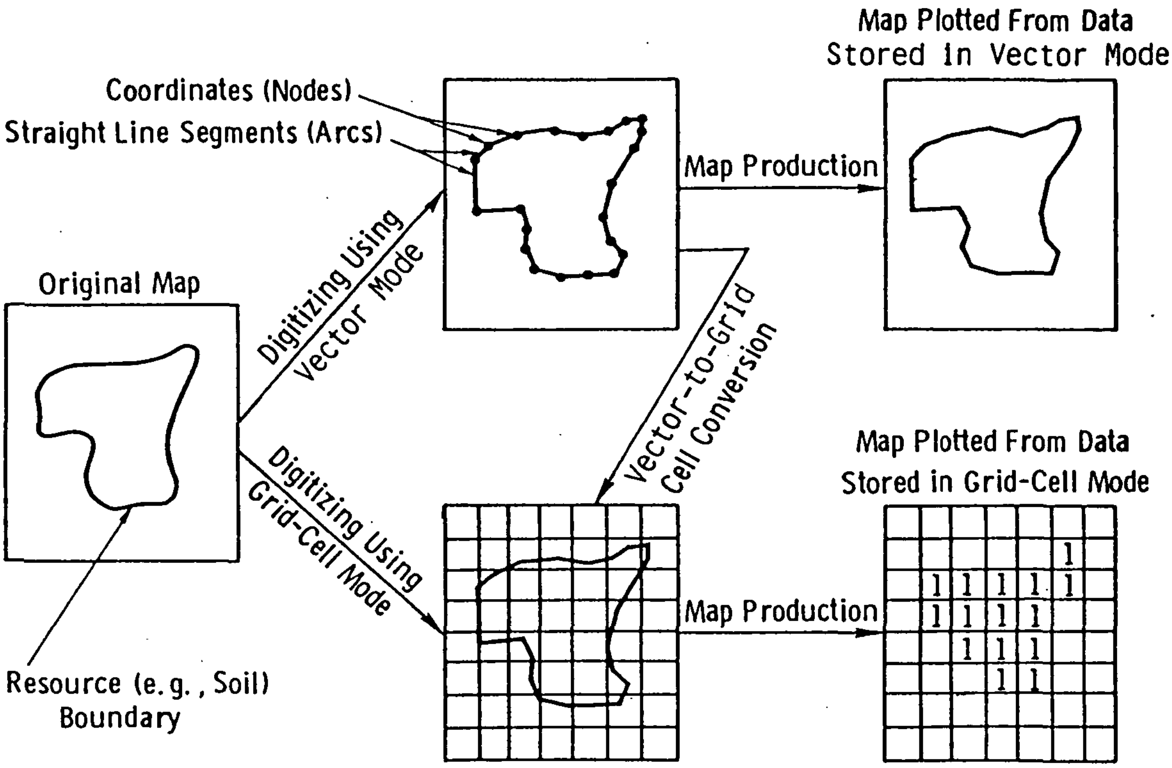
The default units of measure for the tablet are normally inches. Many tablets allow rescaling of the default units to user supplied units (e.g., State Plane , UTM). It is not important that the tablet provide for rescaling to the user defined units. Most digitizing software converts the tablet output into the user-desired units of measure.

Data are recorded in a vector format during digitizing. A vector format represents the continuous forms of lines and boundaries as a series of nodes and arcs (Figure 5). The vector data are then converted to a grid-cell format via rasterization (described below).

The vector data are archived as original source materials as the vector-to-raster conversion coarsens the resolution of the data to a degree. The degree of coarseness is dependent on the size of the raster grid cell: thus, flexibility in selecting a finer (or coarser) grid cell at a later date for the data base is retained.

Rectification. If the referencing system used for digitizing was in inches, or not otherwise the final reference system, it will require rectification. In addition, digital data obtained from other agencies (e.g., the Kansas Geological Survey and the Defense Mapping Agency) will most likely require rectification. Rectification is the process of fitting two maps, which are of the same area but depicted using different mapping units or projections, onto a common reference base map. Data available in a digital format from the KGS were ground-surface, bedrock, and water-table elevations, and surface hydrography.

The rectification process is initiated by locating the coordinates of three or more known points common to each map. From these coordinates, a transform matrix is constructed. The transform matrix provides the coefficients and constant for a quadratic equation. This equation is used to



ADAPTED FROM: Energy and Resource Management Techniques for Northwest Colorado: An Introduction to the Colorado Resource Information System, Denver: Colorado Department of Natural Resources, 1981.

Figure 5. Digital geographic data bases can be constructed using either vector or grid-cell digitizing techniques.

remap the coordinates of the original data to the coordinate system of the base map.

Rasterization. Spatial data digitized in vector mode must be converted to the grid-cell mode used by ERDAS by a process known as rasterization (Figure 5). The grid cells (rasters) within a bounded area are now used to represent the area of a feature (e.g., soils, geologic units) rather than vectors (boundaries). The map is represented in terms of a simple two dimensional matrix (i.e., array) of values.

Selecting the map grid-cell size early in the planning phase of GIS construction is imperative. The size of the grid cell determines the amount of detail that can be displayed and analyzed. Cell size also affects the storage requirements for the data base. An inverse relationship exists between these two facets of grid-cell size. Decreasing the cell size by half will result in a fourfold increase in the storage space required for a map. The grid-cell size selected for the Harvey County map data base was 165 x 165 feet (.625 acre). This cell size retains much of the original vector information. One map for one quad requires 60 K bytes of disk space at this resolution.

Derivation of Map Layers. Finally, certain data bases which will be needed for the DRASTIC and capture-zone modeling programs did not exist as such (depth to ground water, saturated thickness of aquifer). These were derived using digitized data bases and computer programs. For example, the file for depth to ground water was generated by computer subtraction of water-table elevation from ground-surface elevation at observation wells. The results were processed using the SURFACE II program developed by the Kansas

Geological Survey (Sampson, 1978) to generate contours of depth to ground water. Then the SURFACE II grid file was converted into a format acceptable for use in the ERDAS system.

Evaluation

Geographic information systems are designed to combine various data sets for an analysis to address a specific resource problem. The usual result of the analysis is a map and summary statistics for use by resource managers and planners. Those who use these output products, however, are often unaware of the accuracy, reliability, validity and precision of the original source data used to create the map (Vitek, et al., 1984). Often, the manager presented a computer generated map perceives it as representing an absolute environmental reality. Although the maps are most certainly a useful tool, GIS users must be aware of inherent and operational errors that occur in them. Inherent and operational errors are discussed in the context of this project.

Inherent errors are errors resident in the original source data. Operational errors occur converting, and subsequently manipulating, the original source data with the GIS. The sources of possible inherent and operational error are listed in Table 3 (Burrough, 1986). A few examples of these **possible** errors follow. Reference to the prototype data base is made when appropriate:

1. Age of the data - Water Well Records. Many of these records are over ten years old. Two question concerning these wells might be: are they still pumping, and at what rate?

Table 3.

Sources of potential inherent and operational errors in geographic information systems.

1. Age of data
2. Areal coverage - partial or complete
3. Map scale
4. Density of observations
5. Relevance
6. Format
7. Accessibility
8. Cost
9. Positional accuracy
10. Accuracy of content - qualitative and quantitative
11. Variation in data
    a. data entry or output faults
    b. observer bias
    c. natural variation
12. Numerical errors in the computer
    a. hardware limitations
    b. software limitations
13. Faults arising through topological analysis
    a. misuse of logic
    b. error propogation in map overlays

(after Burrough, 1986)

2. Areal coverage - Depth to Water Table. This map was created by the interpolation of point data (observation wells) into a surface. A lack of observation wells in the eastern part of Harvey County has postponed the completion of this map layer until additional depth information is available.
3. Map scale - Geology. This map was compiled and produced at a much smaller scale (1:500,000) than the base map used for data registration and digitization (1:24,000). Boundaries are generalized in some locations and positional accuracy at a 1:500,000 scale is thus coarse in some areas.
4. Density of observations - Annual Recharge. There are some data for which only very limited information is available. In these instances, interpolating a surface is not practical, or would produce grossly misleading precision and accuracy. Interpolation of point data into surface data is valid only when a sufficient number of observations exist to derive it.
5. Relevance - Slope. Not all data required for an analysis exist, or are too expensive to create. A surrogate may be found that can provide good information. The Slope map was created from a regrouping of soils data according to their slope class. Photogrammetric methods were used by SCS to determine slope, and are therefore very accurate. [Note: the data base includes digital elevation data. It was too coarse (+ 7 meter vertical resolution), however, to generate high-quality slope information in this study area.]

6. Format - Digital maps from outside sources. The magnetic medium (e.g., tapes, floppy disks), density of written information (e.g., double density, 1600 bits per inch), and data encoding standard used (e.g., ASCII, binary) are of considerable importance in determining whether a possible data source can be used. The current ERDAS configuration has no physical (equipment) limitations for accepting outside data. Personnel may be needed to help read and reformat the data to the ERDAS format.
7. Accessibility - No problem encountered. Not all data may be readily accessible. Data may exist in-house, within another agency inside, or outside, the state. Bureaucratic obstacles may render the data practically non-existent.
8. Cost - No problem encountered. While USGS digital data is available, its cost may delay its acquisition until funds are obtained.
9. Positional accuracy - Brine Pollution. The original map from which this map was created appeared as an uncontrolled (spatially), photo-reproduced map in a published paper (Whittemore et al., 1985).
10. Accuracy of content - No problem encountered. This error refers to the mislabeling of features (e.g., an area on a land use map may be wrongly labeled 'Residential' instead of 'Commercial').
11. Numerical errors in the computer - Elevation and Brine Concentration. The numeric representation of GIS values using ERDAS is limited to positive integer numbers with a range of 1 to 32,000. No negative or fractional values may be represented. In practice this

has not proved to be a limitation. No negative values have occurred in the data base, and fractional numbers have been represented as integers using a scaling factor based on powers of 10.

12. Errors resulting from rasterizing vector maps - All Maps. The representation of map information by grid-cells means that the smallest feature being displayed will always be as large as the grid-cell. In addition, the boundaries for objects will be displaced by up to + 1/2 the grid-cell size used.

13. Errors associated with digitizing - All Maps. Positional inaccuracies will always be present, no matter the original source. The digitizing process, whether by line scanners or human beings, introduces deviation away from the original source map (and even the best original source maps are not perfect). Theoretically accurate known points (e.g., quadrangle corners) may be established, and the digitized data rectified to these known points. Relative positional accuracy is then obtained.

14. Errors in analysis (Modeling errors). The most clear example of an error in analysis is that a mistake has been made in either the mathematical or logical representation of the relationship between two (or more) of the map variables used in the analysis. A more subtle and detailed analysis of error examines the **error propogation.** This error occurs when data are sampled and standard errors of the estimate (standard deviation) are large. The sampling error is carried into subsequent arithmetical overlays.

Users must be aware of potential error and procedures that can lead to invalid or unreliable results being generated with a GIS (for a more thorough examination, see Burrough, 1986). Many of these errors can be avoided by care in data entry and awareness of the limitations of less precise data sets. The review was intended to allow GIS users to construct accurate data bases and better understand and assess the results of GIS-based analyses.

SUMMARY AND CONCLUSIONS

The following significant results have been achieved:

1. A multifaceted digital geographic data base has been compiled for Harvey County, Kansas. The data are comprised of information derived from a variety of source materials (tabular, digital, and map), registered to one another and latitude/longitude. Each data layer may be displayed at any scale, reconfigured, remapped or analyzed in concert with other layers as required.
2. It has been demonstrated that data can be entered into the GIS via a number of different mechanisms including:
   (a) direct digitization of maps (e.g., soils);
   (b) geo-referencing and digitization of tabular files (e.g., KDHE files);
   (c) reading and reformatting existing digital data to the ERDAS format (e.g., KGS digital line graphs); and,

(d) computation of derived variables via use of KGS SURFACE II software and transferral of results to ERDAS (e.g., depth to groundwater).

3. Existing models for spatial data analysis addressing groundwater issues have been identified (e.g., DeVitis and Ford, 1984) and two models selected for automation on the GIS (e.g., DRASTIC and time-related capture zones).

4. The GIS has been demonstrated for representatives of KDHE, SCS, the Department of Revenue, the Kansas Water Office, EPA, USGS, the National Water Well Association, the Iowa Geological Survey, the Nebraska Department of Environmental Control, the Missouri Department of Conservation, the Kansas Water Data Committee, and the Kansas Commission on Applied Remote Sensing. These demonstrations have fostered a significantly improved understanding of the nature and value of GIS technology, and have provided valuable feedback regarding improvements which might be made in the prototype system.

The ERDAS geographic information system provides an effective means to store, display, and analyze data used in managing and protecting water resources. The microcomputer operation allows comprehensive treatment of areas on the order of counties, with the advantages of portability, modularity, and lower cost than larger systems. The system will allow the integration of additional programs that have specific applications to water resource planning.

Once files of hydrogeologic data are in digital form in the GIS, automated procedures will allow much faster processing than manual methods for such methodologies as DRASTIC and capture areas. Results from these methodologies can be easily recomputed to incorporate revised or additional data and to determine the sensitivity of the resultant map areas to estimated errors in the hydrogeologic data.

Representatives of KDHE, the U.S. Environmental Protection Agency, and the Kansas Geological Survey were actively involved in this project. The interagency, interdisciplinary activity greatly assisted in the development of analytical models and new applications of the GIS to water resource protection and management. The advantages we have identified in handling geographically-referenced data in a digital format have been demonstrated to and enthusiastically received by other federal and state agencies in Kansas, including the Kansas Water Data Committee, an interagency committee involved in coordinating data acquisition, storage, and processing related to water resources. In addition to continuing the development and refinement of models such as capture zones and contaminant plumes in the GIS, we will assist KDHE in the adoption and maintenance of the system as a tool for resource management.

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