Implementing LESA on a Geographic Information System—A Case Study

T. H. Lee Williams
Department of Geography, University of Kansas, Lawrence, KS 66045

ABSTRACT: The USDA Soil Conservation Service has developed the agricultural Land Evaluation and Site Assessment (LESA) system to determine the quality of land for agricultural uses and to assess agricultural land areas for their economic viability. The system is implemented manually on a site-by-site basis. However, many possible uses of LESA involve area-wide evaluations or are concerned with modeling the potential effect of changes such as rezoning, and are difficult to perform using the manual approach. A study was carried out to evaluate the feasibility of implementing LESA on a computer-based Geographic Information System (GIS). The study demonstrated that the GIS approach extends the utility of LESA into area-wide modeling and allows a more flexible site analysis. Furthermore, the recent advances in microcomputer hardware and software now make possible the development of an affordable county-level computer-based LESA system.

INTRODUCTION

THE U.S. DEPARTMENT OF AGRICULTURE Soil Conservation Service (SCS) has developed the agricultural Land Evaluation and Site Assessment (LESA) system to determine the quality of land for agricultural uses and to assess sites for their agricultural economic viability (SCS, 1983; Wright *et al.*, 1983; Dunsford *et al.*, 1983). The LESA system was designed to assist farmland protection policies and is developed at the governmental level at which it will be used (state, county, township, or town). Many of the data inputs to the LESA model are derived from remote sensing imagery (e.g., land use and surface hydrology), but many are drawn from other map and tabular sources (e.g., zoning, sewer lines, soils data). Integration of the many varied data sources for a particular site is therefore a tedious and inefficient manual process. A demonstration study was carried out to evaluate the feasibility of implementing LESA on a Geographic Information System (GIS).

There is no clear definition or agreement between cartographers and remote sensing researchers about what the term GIS actually covers. Cartographers have developed and researched digital geographic data bases as a means of automating map production and storing maps in a digital form. Their work has emphasized the efficient encoding, storage, retrieval, and display of the digital cartographic data. Each map element or theme in the data base, e.g., contour lines or hydrology, is independently retrievable, and a selected set of themes may be simultaneously displayed on a CRT screen or printed on a paper map product. The digital data are processed in a multiple-independent form in which the various themes are functionally separate. Remote sensing researchers, however, view the digital data base as a mechanism which will allow the map themes (land use, elevation) to be overlayed and combined in various ways to simulate a particular resource management analysis procedure. For example, soils, land use, and hydrology information may be used in concert to locate areas of potential soil erosion (Campbell, 1979). This use of the digital data base involves multiple-related *analysis* of the data base map themes, as distinct from the multiple-independent use of the data base as a map *storage* and retrieval device. Both approaches are included in the common definition of a GIS, although it is the former use of the digital data base that is of concern in this study.

The techniques used for analyzing the multi-theme data in a GIS involve application of arithmetic and logical operations on the data base themes in a structured procedure termed "cartographic modeling" (Tomlin and Berry, 1979). While the basic analysis functions and general modelling procedures have been available for a number of years, GIS techniques in the resource management field have been limited largely to national and regional programs. However, powerful microcomputers are now available at a cost within the reach of local (i.e., county level) programs. The advances in hardware and software have brought powerful 16-bit, 1 megabyte microcomputers, 10 megabyte disks which can handle county-level data bases, and digitizing tables into the $7,000 price range. GIS and image processing software is now available for microcomputers at prices starting around $1,000. It is apparent, there-

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fore, that more county-level GIS programs will develop in the next few years.

The work reported here presents a case study in which a GIS was used to automate and facilitate a county-level LESA model. The choice of LESA for a county-level demonstration is appropriate as LESA represents a national program that is mainly implemented at the county level. The study does not introduce new ideas on database design or natural resource models, but presents a practical example of using GIS technology to automate a tedious manual process.

LESA

The LESA system consists of two parts, land evaluation (LE) and site assessment (SA):

> - *Land Evaluation.* In agricultural land evaluation, soils of a given area are rated and placed into groups ranging from the best to the worst suited for a stated agricultural use, i.e., cropland, forest land, or rangeland. A relative value is determined for each group: the best group is assigned a value of 100 and all other groups are assigned lower values. The land evaluation is based on data from the National Cooperative Soil Survey.
> - *Site Assessment.* Site assessment identifies important factors other than soils that contribute to the quality of a site for agricultural use. Each factor selected is stratified into a range of possible values in accordance with local needs and objectives. This process provides a rational, consistent, sound basis for making land-use decisions.
>
> (SCS, 1983, pp. 600-1)

The SA factors and LE are combined to give a LESA score for the site under consideration. The score is scaled to give values between 0 and 300, with high scores corresponding to areas of high agricultural value. The LESA scheme is implemented manually: the LE and SA scores are derived and compiled for each site individually using a worksheet. In order to compare several sites or search for possible alternate sites, the LESA score must be compiled separately for each site. The scheme is appropriate for use in a reactive mode, i.e., responding to a request for consideration of a specific site. However, many potential uses of LESA involve proactive area-wide evaluations (to identify regions of low or high value) or modeling the effect of changing conditions (e.g., the impact of rezoning on agricultural value), which are time-consuming and awkward using the manual approach. A study of the typical SA factors and the scheme for combining the SA scores and LE scores shows that the scheme is well-suited to a GIS approach. Most of the SA factors are derived from raw data available in map or spatially-defined form, and the factors are derived from the raw data using simple spatial algorithms.

STUDY AREA

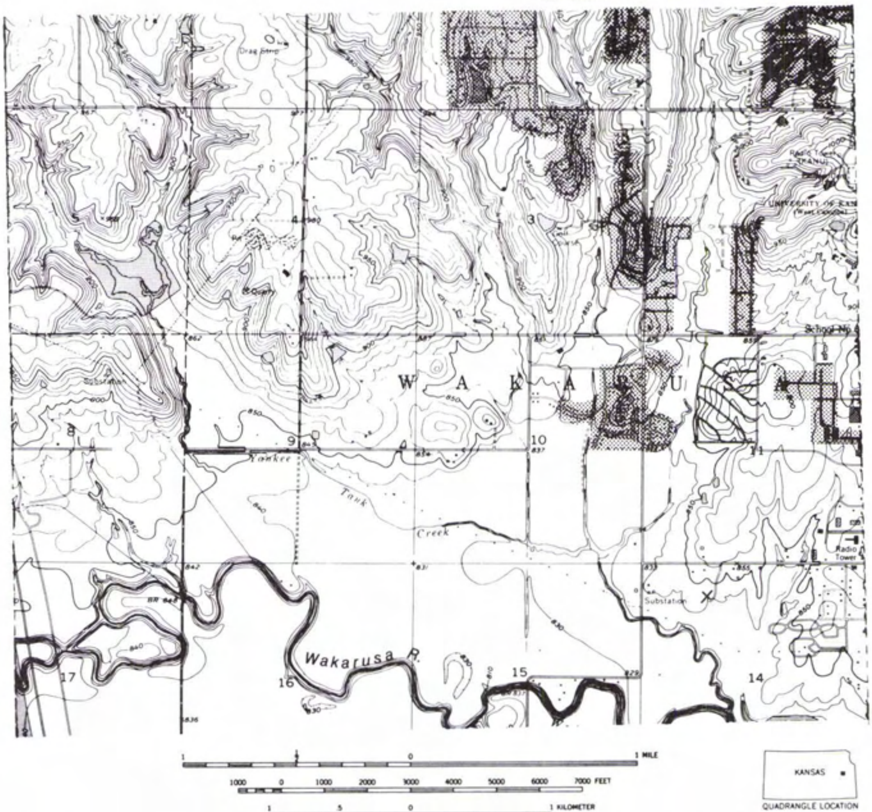
Douglas County in northeastern Kansas, the home of the University of Kansas, is experiencing many of the development pressures that threaten agricultural land throughout the U.S. In the past 15 years it has lost 40,131 acres of productive land (13 percent of its total area) to Clinton Lake and Park, rural residential development, and industrial expansion. The number of rural dwellings increased 12 percent in three years and 32 percent in the past decade. The city of Lawrence is among the fastest growing cities in the U.S., and the rural townships have already passed their projected population for the year 2000. The newest industrial development is full and another 400 acre industrial park is planned (Lawrence Journal-World, 1982; University Daily Kansan, 1981). At the time of this study, Douglas County was developing the LESA scheme and was therefore a suitable choice as a study area.

A 6 by 5-km area between Lawrence and Clinton Lake was chosen for the study (Figure 1). The area is experiencing development pressure from Lawrence due to the Clinton development. It also includes all the major physiographic types (floodplain, bluffs, and rolling uplands) and land uses (urban, cropland, pasture, etc.) found in Douglas County.

LESA DATA BASE DESIGN

Some design considerations for the data base are (1) will it be vector-based, raster-based, or a hybrid vector-raster system? (2) to what coordinate system will the data base be referenced? and, (3) what will be the minimum mapping unit (for a vector system) or grid cell size (for a raster system)?

A vector-based system explicitly records the boundary of each area unit as a string of x,y coordinates, and provides efficient storage for the data (Monmonier, 1982). It is favored in GIS systems that emphasize digital map storage and retrieval. Comparison or 'overlay' of different themes (e.g., land use versus soils data) is, however, difficult as the areal units do not usually match (e.g., a given land use will cross several soil boundaries). The vector-based system is not favored, therefore, in GIS systems where map overlay analysis is required, unless exact polygon boundaries need to be preserved. The raster-based system divides the study area into uniform cells. Each cell is encoded with an attribute value for each theme (e.g., a land-use value). Overlaying different themes is a simple process of comparing attribute values for each grid cell. The raster system is, however, a relatively inefficient method of storing spatial data. The trade-off between the vector and raster systems is, therefore, one of data storage versus the ease of overlay analysis. Hybrid data structures use a combination of raster and vector representations in order to preserve the data storage efficiency of a vector database and the theme overlay capabilities of a raster system. One hybrid approach encodes and stores the data in vector format, but displays and analyzes the data in raster



Base map reduced from USGS Lawrence West, 1:24,000, 1950 (photorevised 1978)

FIG. 1. 7½′ topographic map of the 6 by 5-km study area on the west side of Lawrence in northeastern Kansas. Note the Wakarusa river and its floodplain in the lower portion of the study area and the new developments (shown with an overlay dot pattern) in the eastern portion of the area.

format. Rapid vector/raster conversion is achieved using custom software routines and the standard screen painting routines available on microcomputers. Another approach uses a true hybrid data structure that contains elements of both vector and raster structures. This 'vaster' approach has been proposed for very large databases where the map data are digitized using raster flatbed or drum scanners (Peuquet, 1983). A hybrid structure is superior to either the vector or raster approach, and is the system of choice for microcomputers. However, the decreasing cost of mass storage devices makes the data storage limitations of a raster system less critical for moderate data bases of reasonable resolution, such as county-sized areas of about 1000 by 1000 cells. A raster-based system already available at the University of Kansas was adopted for the county-level LESA case study discussed here.

The second design consideration involves the choice of coordinate system to which the data base will be referenced. Although there are many potential options, two options were considered to be feasible: the Universal Transverse Mercator (UTM) and the Township-Range-Section (TRS) systems. The TRS system matches the pattern of land holdings (i.e., it is a cadastral system) and is familiar to the public and land resource agency personnel, but the systematic adjustments and random errors in the section boundaries make it unsuitable for geodetic purposes. The UTM grid is preferred by cartographers for its geodetic fidelity, but the coordinate system does not correspond to any pattern of land use and, hence, grid cells will be more likely to fall across land feature boundaries than those of the TRS system. However, as many data sources are available for a GIS in digital grid form (e.g., Landsat) and are easily referenced to the UTM grid (e.g., USGS and Defense Mapping Agency digital elevation data), the UTM scheme was selected.

The choice of grid cell size in a raster system is a trade-off between the large data volumes associated with small cells and the loss of detail incurred by the use of large cells. The particular considerations for this study are the minimum parcel size that will be considered by the LESA scheme, the errors in distance measurement (± 1 cell width) acceptable in the LESA scheme, and the minimum mapping units of the source maps. The minimum parcel sizes will relate to residential parcels, which are zoned to be a minimum of 5 acres for rural areas, 3 acres for designated suburban growth areas, and 2 acres for designated rural growth areas. The distance criteria for the LESA SA factors are in units of $^1/_8$ mile. The limiting factor, therefore, is the 2-acre rural parcel, and a cell size of 100 by 100 metres (2.5 acres) was selected. (Note that a hybrid data structure allows variable cell-size, limited only by the x,y precision of the vector data input.) For an average midwestern county size of 30 by 30 miles, this corresponds to a 480 by 480 cell array for the county, which is a convenient size relative to the 512 by 512 CRT displays commonly available.

LESA COMPONENTS

The national LESA handbook (SCS, 1983) describes in detail the design and uses of a LESA scheme. The general outline and procedures are fixed, but the details of a particular scheme (e.g., SA factors, relative weights for each factor) are designed by local working groups formed within the jurisdiction being considered (state, county, township, city). At the time of this study, Douglas County was in the process of defining the LESA factors and weights, but the process was not completed. The factors and weights finally used in the study were a combination of those defined by the county working group, supplemented by typical values derived by the author from the national LESA handbook.

LAND EVALUATION (LE)

The Douglas County Soil Survey was used to identify eight soil productivity groupings. Each group was then rated according to the yield of an indicator crop (grain sorghum was selected for Douglas County), taking into account the economic costs associated with the crop, e.g., necessary soil improvements. The outcome is a relative value rating for each group, with the highest group set to a value of 100 and the others prorated. Figure 2 shows the soil survey and relative value (LE) maps for the study area.

SITE ASSESSMENT (SA)

The SA rating incorporates physical, economic, social, and cultural factors in an assessment of the suitability of the site for agriculture, based on factors other than soil productivity. Table 1 shows the SA factors determined for Douglas County. Each factor is quantized and assigned values on a scale of 10 to 0, where a value of 10 indicates high suitability for agriculture, and 0 indicates low suitability. The quantization and value ratings for Factor 1, "Percent of Land in Agriculture within $1^1/_2$ miles," are shown in Figure 3.

Each factor (i) is assigned a relative weight (W_i), which indicates its importance relative to the other SA factors (see Table 1). The SA rating (SA_j) for a site (j) is then given by

$$SA_j = \Sigma_i W_i V_{ij} \qquad (1)$$

where V_{ij} is the value for factor i on site j. The values of W_i are adjusted (scaled) so that the maximum possible SA rating for a site is 200 (Table 1).

The LESA rating for a site is then given by

$$LESA_j = LE_j + SA_j = LE_j + \Sigma_i W_i V_{ij} \qquad (2)$$

A maximum possible SA rating of 200 and maximum LE value of 100 gives an SA:LE relative weight of 2:1, which was found to be reasonable in LESA test cases (SCS, 1983, pp. 601-12). The ratio can be adjusted for specific purposes by rescaling the LA rating or the LA factor weights.

PROCEDURE

SOURCE DATA

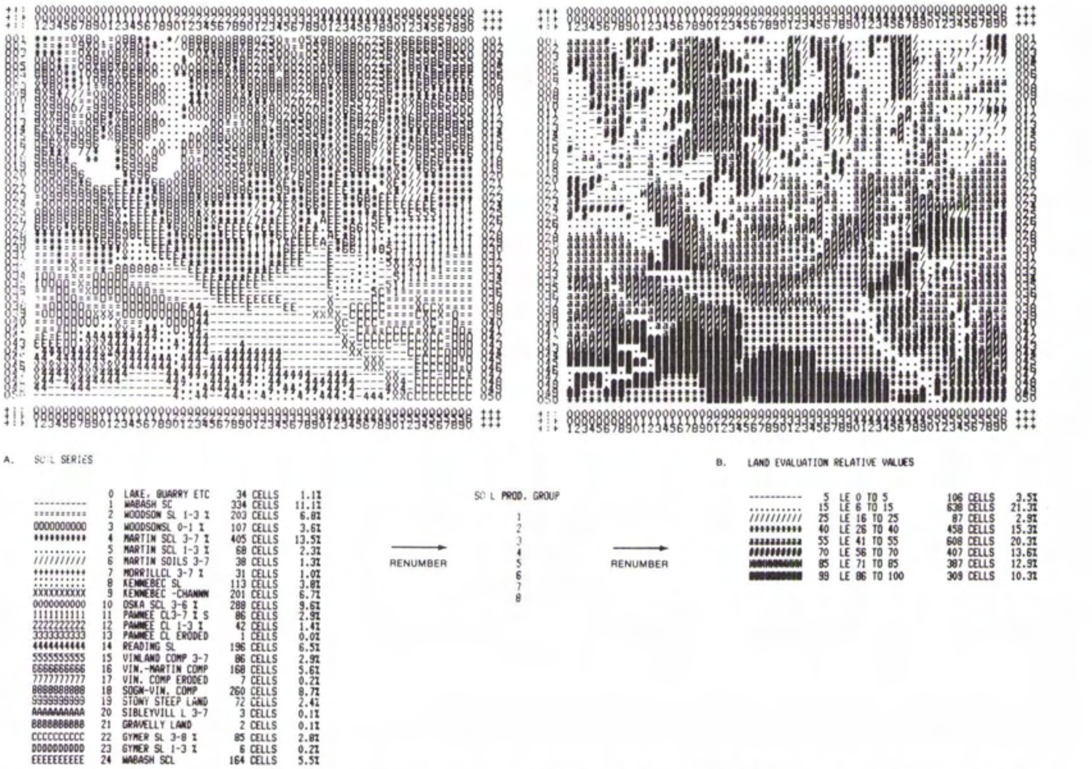
Table 1 lists the source data from which each SA factor is derived. Note that one factor has no source identified because the data were not available in a spatially-defined form. Factor 5, "Agrivestment in area," includes onsite investments (e.g., barns, conservation measures) and the agricultural support system (e.g., farm equipment suppliers, grain dealers). It is perhaps feasible to derive an estimate of the agricultural support system for a study area, but the onsite investments would have to be assessed on a site-by-site basis. A complete site inventory for the study area is infeasible. It is apparent, therefore, that there is at least one factor that will not be incorporated into the data base. It is likely that other study areas will have similar factors that may not be included because of availability, cost, or rate of change of the data. The approach taken in this study was to compute a partial LESA score based on all available factors, and to add in the remaining factor for a particular site when it is selected for study.

The data were coded onto transparent grid overlays on the source maps, and entered to the data base using run-length encoding (Wehde *et al.*, 1980).

MANIPULATION

The Map Analysis Package (MAP) developed at Yale University (Tomlin and Berry, 1979) is used in GIS courses at the University of Kansas. As much of the database construction for this project was carried out in a GIS course, MAP was adopted for the project. MAP allows a wide range of arithmetic and logical operations to be applied to single or multiple map themes. Five basic operations are used singly or in combination to generate the LE and SA ratings in this study:

- Renumber. Assigns new values to the categories of a map. It is used to combine map categories and



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A.    SOIL SERIES

               0  LAKE, QUARRY ETC     34 CELLS    1.1%
----------     1  WABASH SC           334 CELLS   11.1%
::::::::::     2  WOODSON SL 1-3 %    203 CELLS    6.8%
0000000000     3  WOODSONSL 0-1 %     107 CELLS    3.6%
**********     4  MARTIN SCL 3-7 %    405 CELLS   13.5%
..........     5  MARTIN SCL 1-3 %     68 CELLS    2.3%
//////////     6  MARTIN SOILS 3-7     38 CELLS    1.3%
++++++++++     7  MORRILLCL 3-7 %      31 CELLS    1.0%
::::::::::     8  KENNEBEC SL         113 CELLS    3.8%
XXXXXXXXXX     9  KENNEBEC -CHANNN    201 CELLS    6.7%
0000000000    10  OSKA SCL 3-6 %      288 CELLS    9.6%
1111111111    11  PAWNEE CL3-7 % S     86 CELLS    2.9%
2222222222    12  PAWNEE CL 1-3 %      42 CELLS    1.4%
3333333333    13  PAWNEE CL ERODED      1 CELLS    0.0%
4444444444    14  READING SL          196 CELLS    6.5%
5555555555    15  VINLAND COMP 3-7     86 CELLS    2.9%
6666666666    16  VIN.-MARTIN COMP    168 CELLS    5.6%
7777777777    17  VIN. COMP ERODED      7 CELLS    0.2%
8888888888    18  SOGN-VIN. COMP      260 CELLS    8.7%
9999999999    19  STONY STEEP LAND     72 CELLS    2.4%
AAAAAAAAAA    20  SIBLEYVILL L 3-7      3 CELLS    0.1%
BBBBBBBBBB    21  GRAVELLY LAND         2 CELLS    0.1%
CCCCCCCCCC    22  GYMER SL 3-8 %       85 CELLS    2.8%
DDDDDDDDDD    23  GYMER SL 1-3 %        6 CELLS    0.2%
EEEEEEEEEE    24  WABASH SCL          164 CELLS    5.5%
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RENUMBER →

```
SOIL PROD. GROUP

       1
       2
       3
       4
       5
       6
       7
       8
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RENUMBER →

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B.    LAND EVALUATION RELATIVE VALUES

----------     5  LE 0 TO 5        106 CELLS    3.5%
..........    15  LE 6 TO 15       638 CELLS   21.3%
//////////    25  LE 16 TO 25       87 CELLS    2.9%
**********    40  LE 26 TO 40      458 CELLS   15.3%
aaaaaaaaaa    55  LE 41 TO 55      608 CELLS   20.3%
##########    70  LE 56 TO 70      407 CELLS   13.6%
██████████    85  LE 71 TO 85      387 CELLS   12.9%
██████████    99  LE 86 TO 100     309 CELLS   10.3%
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FIG. 2. The soil series (a) are grouped into eight soil productivity units which are then renumbered to show the land evaluation (LE) relative values (b), which can vary between 0 and 100.

rescale measurements. Figure 2 demonstrates how the LE relative value ratings are derived—map categories (soil types) are combined into new categories (productivity groups) and the categories rescaled (to show the relative value of each group). The renumbering function is used for all the SA factors to rescale or combine categories.

- Neighborhood. Computes the average value of all cells that lie within a specified radius of a site, or counts the values for the four adjacent grid cells. Figure 3 shows how SA factor 1, "Percent of Land in Agriculture within 1½ miles of Site," is derived from the land-use map. The neighborhood functions are used in SA factors 1, 2, 4, 6, 7, 9, and 13 (Table 1).
- Intersection. Identifies cells with a specified set of values on two or more source maps (logical AND). It is used in SA factor 9 to locate sites that are both non-farmland and have poor soils.
- Distance. Computes the geographic distance from a cell to a line network, area, or point. Figure 4 shows how SA factor 20, "Distance from Central Water," is derived from the source map of water lines. The distance function was used in SA factors 18 to 21.
- Arithmetic. Computes arithmetic combinations of two or more maps on a cell-by-cell basis. The SA factor maps were multiplied by their relative weights and summed, to give the overall SA rating, which was added to the LE map to give the LESA scores (Figure 5).

Note that the scores are incomplete as they do not contain Factor 5, which is not in the data base. As discussed earlier, this factor would be evaluated and added to the LESA score of an individual site to give its final value.

RESULTS

As expected, location and acquisition of the source data and the entering of the data were the most time- and personnel-intensive parts of the study. Several of the source data items were not available in a standard form. For example, the utilities maps (water, sewage) were available on single maps within the city limits, but outside the city were available only on several different maps and tabular listings that had to be combined onto a common base before they could be coded. The mechanism of manually encoding the data is also inefficient but is suitable for such a small study area. The use of an electronic digitizer is recommended for encoding county-size areas. The initial construction of a geographic data base is personnel-intensive. County agencies will probably opt to contract the database construction, but will perform the necessary periodic updates in-house.

The final partial LESA map (Figure 5) corresponds well to the study area map in Figure 1. As expected, the Wakarusa floodplain had the highest scores,

TABLE 1. THE PRELIMINARY SITE ASSESSMENT FACTORS FOR DOUGLAS COUNTY, THEIR RELATIVE WEIGHTS, AND SOURCE MAPS

Site Assessment Factor	Source Map	Relative Weight
Land Use/Agricultural		
1) Percent of area in agric. within 1½ miles	Land use	10
2) Land in agriculture adjacent to site	Land use	7
Agricultural Economic Viability		
3) Farm size	Parcel size	2
4) Average parcel size within 1 mile	Parcel size	4
5) Agrivestment in area	—	3
Land Use Regulations		
6) Percent of area zones agric. within 1½ miles	Zoning	8
7) Zoning of the site and adjacent to it	Zoning	6
Alternative Locations		
8) Availability of land zoned for proposed use	Zoning	6
9) Availability of non-farmland or less productive land as an alternative site within area	Zoning/Soils	6
10) Need for additional urban land	Land use/City lim.	8
Compatibility of the Proposed Use		
11) Compatibility of proposed use with surrounding area	Land use	7
12) Unique topographic, historic or ground cover features or unique scenic qualities	Unique areas	3
13) Adjacent to land with unique topographic, historic or groundcover features or unique scenic qualities	Unique areas	2
14) Site subject to flooding or in a drainage course	Surface hydrology	8
15) Suitability of soils for on-site waste disposal	Soils	5
Compatibility with Adopted Master Plans		
16) Compatibility with an adopted comprehensive plan	Master plan	5
17) Within a designated growth area	Growth area	5
Urban Infrastructure		
18) Distance from city limits	City limits	6
19) Distance from transportation	Transportation	5
20) Distance from central water	Water lines	4
21) Distance from sewage lines	Sewer lines	4
		114
	Scale by $\frac{200}{(114 \times 10)} = 0.175$	

while the urban Lawrence area and new developments in the northeast have the lowest scores. The undeveloped dissected bluffs and upland areas in the northwest show intermediate values. Note that the variations in LESA scores follow closely the ridges, slopes, and valleys in this area.

DISCUSSION

The LESA map gives an area-wide view of agricultural value, and identifies the location and size of regions of relatively low or high value. Unfortunately, the LESA scheme has not been completed or adopted by Douglas County, and therefore the results of this study cannot be critically evaluated. However, the national LESA handbook (SCS, 1983) discusses extensively the uses of the LESA scheme, and provides a suitable framework for a general evaluation of the potential uses of the digital LESA database.

The digital data base format allows rapid manipulation of all components of the LESA scheme, including the factors to be used, factor quantization and scores, factor weights, and the relative LE:SA weighting. This flexibility is central to the utility and application of the LESA scheme as it allows modeling of the effects of changing parameters and assessing the effects of specific actions, e.g., the installation of a new sewer line. The design and re-

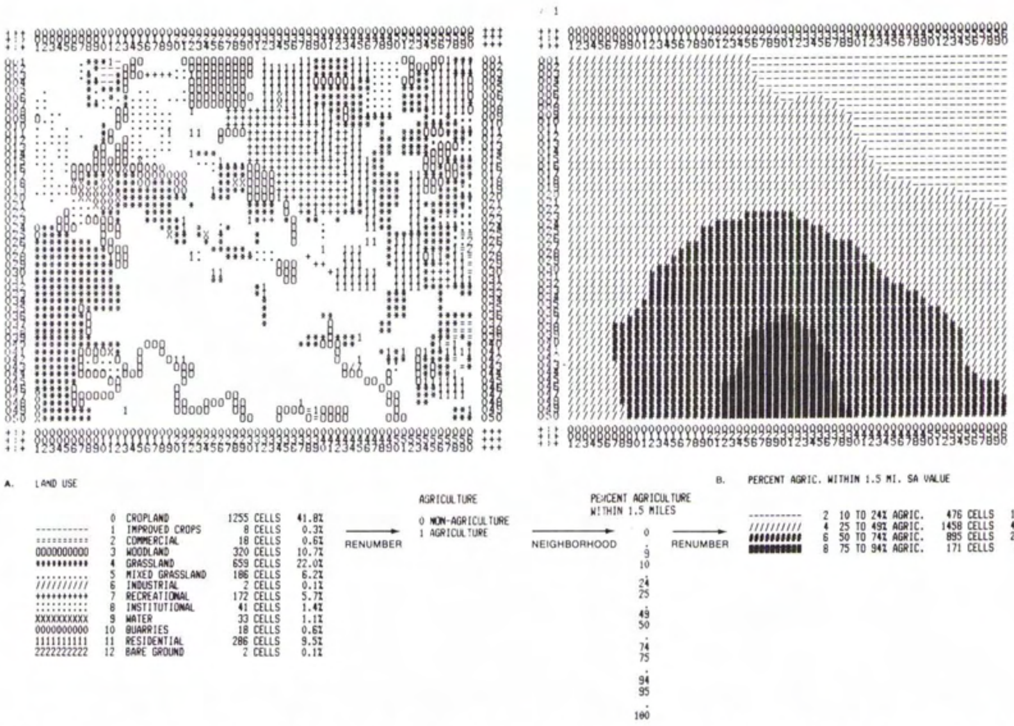

FIG. 3. The land-use map (a) is renumbered to give a binary agriculture/non-agriculture map. A neighborhood operation on this map produces a map showing the percent of agriculture within 1.5 miles of each site, and the map is then renumbered to give the site assessment (SA) Factor 1 map (b), which has possible values between 0 and 10.

finement of the original scheme parameters (e.g., the LE:SA weighting) are based on field tests of various parameter combinations (SCS, 1983, pp. 602-13), which is a time-consuming process using the manual LESA scheme. The scheme is also use-specific (e.g., cropland to residential use conversion),

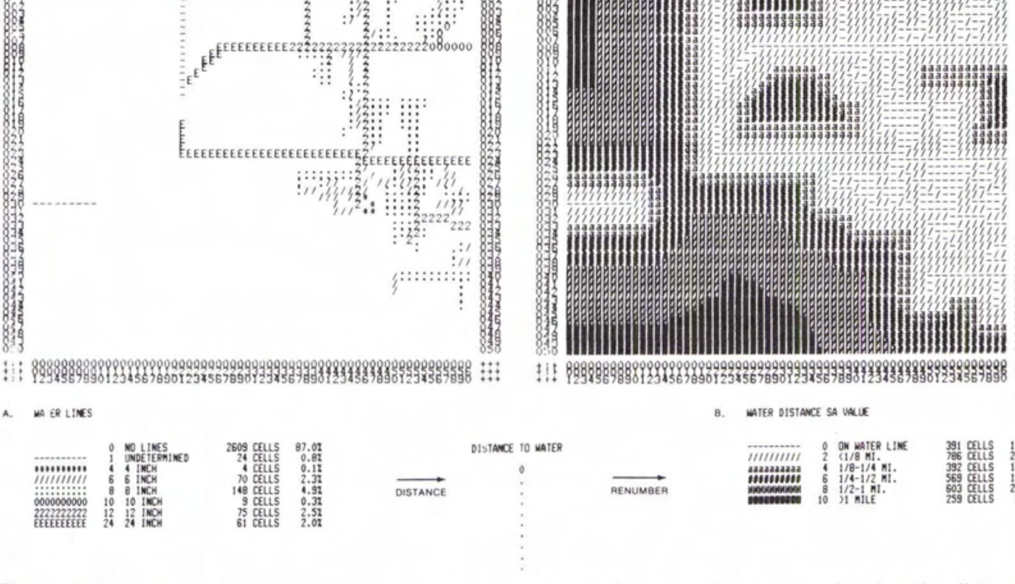

FIG. 4. A distance operation is applied to the water lines map (a) to produce a map showing the distance from each site to the nearest water line. The distance map is renumbered to give the site assessment (SA) Factor 20 map (b), which has possible values between 0 and 10.

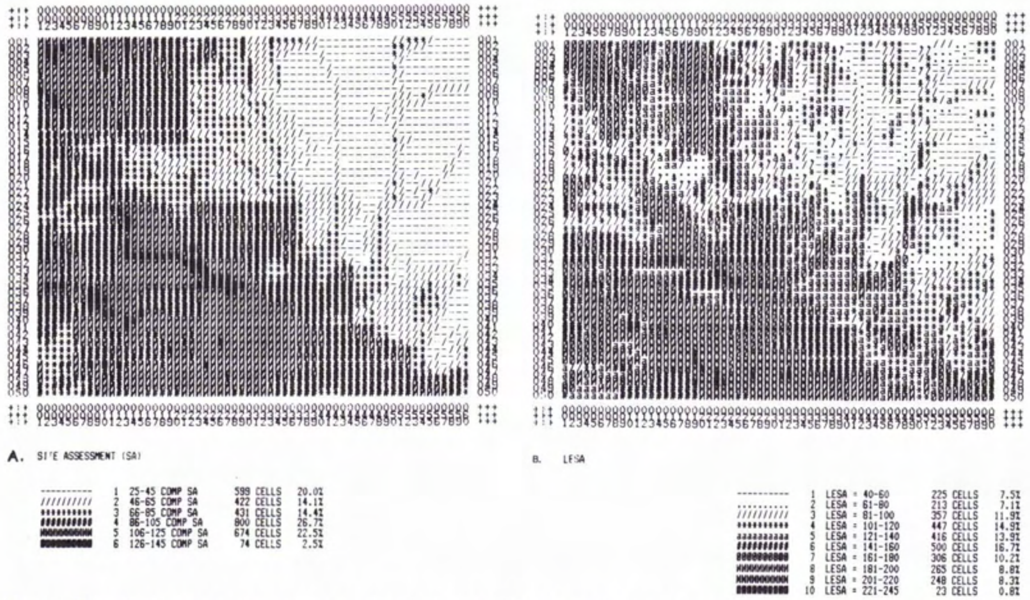

FIG. 5. The final site assessment (SA) rating map (a) is produced from a weighted linear combination of the individual SA factor maps, using Equation 1. It is added to the land evaluation (LE) relative value map (Figure 2b) to give the final LESA map (b).

and several versions of the scheme are required to represent the range of proposed uses.

Many of the potential applications cited for the LESA scheme involve the use of selected parts of the scheme (e.g., the LE ratings), which is easily accomplished using the stored LE and SA factor maps. Agricultural value assessment and the size of a site to meet income requirements can be derived from the LE value ratings (SCS, 1983, pp. 603-5, 6). The acquisition of development rights involves both the complete LESA rating and individual SA factors (e.g., distance to city, flooding, scenic easements, and adjacent land use) (SCS, 1983, pp. 603-6, 9). The relative LE:SA weighting is also adjusted for different development situations (SCS, 1983, pp. 603-7).

The LESA map in Figure 5 was derived from a cell-by-cell (100-metre area) analysis, whereas in practice the LESA scheme is applied to complete sites which are generally more than one cell in size. The LESA rating for a site can be computed as the average of the individual cell values, up to a site size of 100 acres (SCS, 1983, pp. 601-26). Alternately, the rating for an extended (multi-cell) site can be derived directly from the database.

A significant limitation of the scheme is related to the linear arithmetic structure of the LESA rating (Equation 2) where each factor is evaluated independently and the results added (SCS, 1983, pp. 602-13). The linear combination of factors does not account for interrelationships between factors. For example, Factor 15 rates the soils for septic tank suitability, but the importance of the factor is in practice related to the availability of a central sewage system (Factor 21). The relationships between factors can be expressed as simple arithmetic formulae or as complex symbolic decision rules. Expert system models that allow both arithmetic and symbolic reasoning are now being applied to remote sensing and natural resource problems (Mooneyham, 1983; Tinney *et al.*, 1983). Expert system techniques are being used in ongoing work at the University of Kansas to refine the LESA scheme (DeMers, 1985).

MICROCOMPUTER IMPLEMENTATION

For convenience, the test study was conducted using the University of Kansas mainframe computer. It is likely, however, that any implementation of an automated LESA system at the county level would use a microcomputer system. The question arises, therefore, as to whether and at what cost a microcomputer system has sufficient central processor size and mass-storage capabilities to handle a county-level data base, and whether appropriate GIS and image processing software is available for such microcomputers. The answer to each of these questions is encouraging: 16-bit microcomputers with one megabyte central processors are available for around \$3,000; 10-megabyte hard disks are available for around \$2,000; suitable digitizing tables cost around \$2,000; and GIS software packages are available at prices that start at \$1,000.

A county data base with a 100-metre grid cell for a 1000 square mile county (typical of the mid-west) is 509 by 509 cells in size, or 259,081 cells. If each attribute value for a cell is coded into one byte (thus allowing 2^8 or 256 possible values), each map theme (e.g., land use) will use 253K bytes of storage. A 10-megabyte disk could hold 39 map themes, which is more than adequate for the LESA scheme. Note that a more complex raster data base structure would allow more efficient use of space by encoding certain map themes in few bits per cell. For example, the city boundary theme (used in Factor 18, Table 1) could be encoded in 1-bit form (i.e., 0 = outside city, 1 = inside city), thus using 253K ÷ 8 = 32K bytes of storage. Also note that a hybrid vector/raster database structure would be considerably more efficient in data storage.

A one-megabyte computer is easily large enough to hold both a complex GIS program and two full map themes in core simultaneously. As all GIS operations can be broken down into sequences of operations on two map themes, the input/output problems associated with large data sets on small microcomputers (64K to 127K in size) will not be experienced with the larger microcomputers. The display screen resolution on microcomputers is also improving rapidly, and the cost of 512 by 512 multicolor displays is dropping rapidly. Systems with limited display sizes can still be useful, as a full county will usually be displayed to view general patterns rather than specific detail about any one area. Therefore, the effect of the resolution limitations of lower-cost microcomputers ($3,000) can be minimized by displaying a sampled version of the county (e.g., selecting every third cell on every third row will give a 170 by 170 display) to view general county-wide patterns, and zooming in to smaller areas at full resolution. Reasonable quality hard-copy output can be effectively produced on matrix printers costing about $500.

A few vendors currently are advertising image processing and GIS software for microcomputers. The effective operating speed of the hardware/software package is of concern in most GIS applications, due to their computation-intensive nature. However, LESA uses a simple linear arithmetic algorithm, which allows recomputation of the LESA scores to be performed by recomputation of only the affected part(s) of the model. Thus, once the initial LESA model is obtained, subsequent operations will not require rapid data processing or data transfer capabilities.

It is apparent from this short discussion that existing hardware and software are available to implement the LESA scheme at the county level on a microcomputer. The market is also changing rapidly, and improved capabilities at a lower cost are being introduced frequently. However, one should look for a hardware/software package that is appropriate to the intended use and requires minimal development.

CONCLUSION

The case study demonstrated that a GIS approach to implementing the LESA scheme provides a flexible framework within which many of the design considerations and applications of LESA can be performed more easily than in the manual approach. Most of the site assessment factors can be implemented, although some factors may be either unavailable in spatial form or change too rapidly to be entered into the database. The digital LESA scheme computes, therefore, a near-complete LESA score, with any additional factors added later on a site-by-site basis. A preliminary evaluation of available microcomputer hardware and software indicates that a microcomputer-based implementation at the county level could be accomplished at around $9,000 hardware/software cost. No estimate was made of the cost of database development.

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