

Abstract. This paper reviews an approach to knowledge acquisition for incorporating dynamic factor interaction heuristics into the static, linear Land Evaluation and Site Assessment (LESA) model. Links are provided to illustrate the outcome of the new LESA model within a geographic information system (GIS), and comparisons are made with a previous GIS automation of LESA to evaluate the validity of the model and its applicability within the study area. General comparisons are made between the time required to develop LESA using the traditional LESA development construct, and that required for the new methodology. Results indicate improvements in both development time and the validity of the final outcome of an automated LESA system constructed under the knowledge acquisition methodology.

Knowledge Acquisition for GIS Automation of the SCS LESA Model: An Empirical Study

Michael N. DeMers
Department of Geography
The Ohio State University
Columbus, Ohio 43210

Problems involving planning are among the most difficult to simulate with a computer. In particular, the complex interactions of factors are so integral to the knowledge of the expert, and often so qualitatively defined, that they are impossible to extract. Yet this is precisely the task that confronts the knowledge engineer within a knowledge domain such as planning for land use. Since planning requires its practitioners to operate in an uncertain environment, where facts are incomplete and the motives and goals themselves vague, devices must be developed for guidance. To simplify the process, checklists of the most important factors involved in specific task-oriented planning are constructed as a regular feature. By enumerating all of the factors which might have an impact on the planned environment, such lists provide a framework for planning

and a guide to decision-making. Such a framework was constructed by the United States Department of Agriculture Soil Conservation Service in the development of their Land Evaluation and Site Assessment (LESA) system, a model designed to aid local planners in protecting important agricultural lands (SCS 1983).

LESA is a two-part design consisting of a land evaluation subsystem, which evaluates and weighs the physical capabilities of the agricultural resource base, and a site assessment subsystem, which lists and weighs the socio-economic factors more closely tied to the local conditions and concerns of the regional officials. Together, these factors are scored based on their conditional compliance, then added and prorated to produce a final LESA value from zero to 300. Typically, the Land Evaluation portion of the model is

with the particular task of incorporating factor interaction into the linear LESA model. Further, based on the Williams' (1985) database, the newly acquired LESA model is incorporated into a GIS and compared to his original GIS automation of LESA to discern changes in model validity. Finally, development time is tabulated for the knowledge acquisition process, approximations are made for the original development process proposed by the Soil Conservation Service, and some comparisons are made between the two.

LESA Model for Douglas County, Kansas

In 1983 the Lawrence-Douglas County Planning Commission (1983), in cooperation with the regional SCS officials, began development of a LESA system for the area. Initially, SCS personnel developed the land evaluation portion of the model using the methods prescribed in the LESA handbook (SCS 1983), based on the county soil survey (Dickey et al. 1977). Once completed, the selection of appropriate site assessment factors and factor weights began. This process took place through lengthy discussion and debate, because no strict guidelines defined specifically how these factors and weights were to be decided. A non-formal LESA system was developed, but not implemented at that time.

Research conducted by Williams et al. (1983) and later refined (Williams 1985) resulted in a database of LESA factor scores and evaluative data for a 6 by 5 km rectangular area in southwest Lawrence, Kansas, for research in spatial modeling of the LESA system. This study region was encoded into a raster-based GIS with a cell resolution of 100 meters, thereby including 300 cells per map layer. The database was constructed from the early efforts of the Lawrence-Douglas County Planning

Commission to develop LESA for implementation. The area encompassed by this digital database borders a developed portion of the city, and includes an area designated as an urban growth area. Planners in Lawrence were interested in low LESA scores for this region because they wish development to take place there rather than in other, more agriculturally viable portions.

Review of LESA Knowledge Acquisition Process

Using the suggested list of factors developed by the Soil Conservation Service (Table 2), a formalized, structured interview process was developed with a three-part structure. First, this preliminary factor checklist was discussed with three planners in the area to determine if each should be included for use in Douglas County. Other potential factors were discussed as well, and the suggested weight of the land evaluation portion of the model was debated, thus producing a preliminary set of LESA factors for Douglas County (Table 3). Following these initial discussions, each participant was asked to give a

suggested weight to each factor to be brought back to the group in subsequent meetings for more discussion. The planners continued weighing in private and returning for discussion until they were no longer willing to adjust their weight assignments. Phase two concluded when the weights were averaged. This iterative weighing process is based on the Delphi technique and group decision-making theory used frequently in technological forecasting research (Jain et al. 1977).

Phase three of the acquisition process modified the weights to account for factor interaction. This procedure is also borrowed from the technological forecasting techniques, and is based on the Kane Simulation Model (KSIM) (Kane 1978). A detailed discourse of the application of KSIM to the LESA system can be found elsewhere (DeMers 1985); however, a brief discussion is still warranted. KSIM is based on a cross-impact matrix, where each of the pre-selected factors is compared to every other factor on a pair-wise basis. The comparison rates the impact of one factor on each of the others on a +10 to -10 scale, where

Table 2. Commonly used site assessment factors.

- 1) Percent area in agriculture within one mile
- 2) Land in agriculture adjacent to site
- 3) Size of site or farm (based on needed size unit to permit feasible farm operation)
- 4) Agricultural support system/services
- 5) Land use regulations
- 6) Availability of alternative site within area of consideration
- 7) Need for additional urban land
- 8) Compatibility with comprehensive plan
- 9) Distance to city or urban built-up area
- 10) Central water distribution system with available capacity
- 11) Central sewerage with available capacity
- 12) Investment for urban development
- 13) Transportation
- 14) Compatibility of proposed use with surrounding area
- 15) Environment factors (flood plains, wetland, historical area, open space, vegetation)

Table 3. Preliminary LESA site assessment factors for Douglas County
(+ = modifications to existing factors, ** = new factors added).

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| <ul style="list-style-type: none"> + 1) Percent area in agriculture within 1.5 miles 2) Land in agriculture adjacent to site 3) Size of site or farm (based on size for feasible operation) ** 4) Average size of land parcels within 1 mile of site 5) Agricultural support system/services ** 6) Agrivestment in real property improvements within 2 miles ** 7) Percent of land zoned agriculture within 1.5 miles of site ** 8) Zoning of site and adjacent to it ** 9) Availability of land zoned for proposed use ** 10) Availability of non-farmland or less productive land as an alternative site within area of consideration 11) Need for additional urban land 12) Compatibility of proposed use with surrounding area ** 13) Does the property have unique topographic, historic or ground-cover features or unique scenic qualities? ** 14) Is the property adjacent to land with unique topographic, historic or ground-cover features or scenic qualities? ** 15) Land subject to flooding or in a drainage course ** 16) Suitability of soils for on-site waste disposal + 17) Compatibility with an adopted comprehensive plan ** 18) Within a designated growth area + 19) Distance from city limits + 20) Transportation accessibility + 21) Central water distribution system with available capacity (municipal system) + 22) Central sanitary sewerage system with available capacity (municipal or established sewer benefit district) |
|--|

+10 indicates that an increase in one factor will have an extremely positive impact on another, and -10 shows an extremely negative impact.

Once this matrix is complete, the KSIM iteratively calculates a sigmoid (S-shaped) growth curve for each impacted variable, based on known starting values for all factors. For this procedure, it was necessary to select a sample site to determine initial values for all given factors. The site (W 1/2, Sect. 27, T 12 S, R 19 E) was selected as one with which the planners were familiar. KSIM then calculated the change in each factor with time, and graphically displayed the results. These results were then presented to the planners, who decided upon potential changes in selected factor weights so as to produce the desired planning results.

To operationalize LESA within a GIS, however, it was necessary to merge the results of KSIM with the linear model. Although attempts to use simulation for expert systems development do exist (Cuena 1988), there is no theory supporting an attempt at merging the results of a dynamic model with a static, linear planning model such as LESA. One must be guided by logic and insights derived from the models themselves. It is conceivable to combine the changing KSIM values one set at a time, as each periodic value is calculated, thus creating a dynamic LESA model. However, since LESA is a static, linear model and KSIM a dynamic, curvilinear model, it was felt that this combination would be artificial and meaningless.

LESA is meant to include total impacts in an evaluation of any given parcel. Logically, then, any combination of original LESA weights with the cross-impact matrix should look at totals. Upon acceptance of the KSIM model results, the LESA weights were adjusted by the values in the cross-impact matrix according to the following formula.

$$FW = (30/\sum W_i) \cdot FW_i \\ [(\sum KR \cdot -.01 \cdot F_{wn}) + F_{wn}]$$

in which:

KR = cross-impact row values, and
F_{wn} = initial LESA factor weights

These computations effectively combine the dynamics of the KSIM model with the static LESA values, and also reduce the multiplicative effects of similar factors. The completed computations produce a set of LESA factor weights that now incorporate these factor interactions and that can be modeled by a GIS (Table 4).

GIS Automation

The techniques necessary for GIS automation of the LESA system have already been developed by Williams (1985), using a preliminary modification of the proposed LESA values and weights developed by the Lawrence-Douglas County planning staff. Employing the identical database and established techniques for automation of the LESA model, the numerical results of the knowledge acquisition strategy were incorporated into the spatial model. The software used was a microcomputer implementation of the Map Analysis Package (pMAP). Although other versions and implementations of this software are available, this software was selected because little or no modification of the original algorithms used by Williams was known to exist with this particular package. This

allows comparative examination of GIS implementations to take place between the two while maintaining constant computational conditions.

A perusal of the digital database produced by Williams shows a number of factors with no corresponding map name (Table 4). This apparent discrepancy is due to the inability of the planning community to define these terms in a form amenable to GIS implementation. As such, the Williams database does not include available data layers for the following factors: agricultural support systems, agrivestment, availability of land zoned for the proposed use, need for additional urban land, compatibility with the surrounding area, compatibility with comprehensive plan, and within a designated growth area. Conversely, the newly developed LESA scheme omits "suitability of the soils for on-site sewerage" as a site assessment factor. Further, the new database consists of disaggregated factors. "Size of site and size of farm" have been created by decomposing "size of site or farm," and "zoning of site and zoning of land adjacent to site" were created by decomposing "zoning of site and adjacent to it."

These disparities are symptomatic of the difficulties involved in designing GIS databases with linguistically based variables, and cause difficulties in comparative evaluations among such databases. In order to make comparisons between the two LESA systems, it is necessary to use only those factors common to both. This required only minor adjustment of the original database, prorating the LESA scores to account for the exclusion of the factor "suitability of soils for on-site sewerage." Adjustments also had to be made to the new database to account for the two disaggregated factors. In this case, the weights of the two separate, disaggregated factors were reaggregated to match their original counterparts. The final adjustment was to prorate the factor weight totals to correspond

Table 4. Comparative GIS LESA factors and weights.

| Factor | Map Layer | Williams | DeMers |
|---|-----------|----------|---------------|
| 1. Percent area in agriculture within 1.5 miles of site | PROPAG | 10 | 7.81 |
| 2. Land in agriculture adjacent to site | ADJAG | 7 | 13.67 |
| 3. Size of farm or size of site | FARMVI | 2 | 1.29 1.60 |
| 4. Average parcel size within 1 mile of site | AVSIZE | 4 | 1.77 |
| 5a. Agricultural support system | — | — | — |
| 5b. Agrivestment within 1 mile | — | 3 | 6.88 |
| 6. Percent land zoned agriculture within 1.5 miles of site | PROPAGZ | 8 | 6.89 |
| 7. Zoning of site and adjacent to site | ADJAGZ | 6 | 10.38 6.89 |
| 8. Availability of land zoned for proposed use | — | 6 | 8.27 |
| 9. Availability of non-farmland as an alternative site | PROPALT | 6 | 7.18 |
| 10. Need for additional urban land | — | 8 | 7.14 |
| 11. Compatibility of the proposed use with surrounding area | — | 7 | 25.75 |
| 12. Unique topographic, historic or scenic qualities | ENVIR | 3 | 4.99 |
| 13. Adjacent to land with unique qualities | UNADJ | 2 | 4.36 |
| 14. Site subject to flooding or in drainage course | FLOODMAP | 8 | 1.84 |
| 15. Suitability of soils for on-site waste disposal | SEPTANK | 5 | — |
| 16. Compatibility with an adopted master plan | — | 5 | 31.38 |
| 17. Within a designated growth area | — | 5 | 29.72 |
| 18. Distance from city | DCITY | 6 | 40.55 |
| 19. Transportation accessibility | TDIST | 5 | 5.08 |
| 20. Central water system availability | WDIST | 4 | 26.62 |
| 21. Central sewerage system availability | SDIST | 4 | 29.36 |
| 22. Land evaluation | LE | 100 | 8.63 |

to a maximum possible LESA score of 300.

Methods of Analysis

Since production of a new LESA knowledge acquisition system or of a finalized LESA model, in itself, does not indicate whether or not it is an

improved system, comparisons are necessary for its evaluation. An important portion of this research is a determination of the effectiveness of the new knowledge acquisition model and the subsequent LESA scheme as compared to the original. Paramount among the seven criteria listed by Nutt (1981) as indicators of

the success of a decision-making strategy are savings in time and the validity of the results. Accurate results indicate a decision-making system's worth. One method for determining the validity of results is suggested by the remote sensing literature, which states that there is generally one best prescribed method for determining the validity of results. This requires that the data be

field tested or ground truthed (Lillesand and Kiefer 1979). In order to ground truth planning decisions, it is generally necessary to wait years for the results and impacts of those planning decisions to be realized. One other method would be to develop a database of past physical, economic, and social parameters, run the LESA system based on those data, and correlate the results of the derived

suitability ratings with past planning decisions.

To determine the accuracy of both systems, a number of test sites were established which have been previously evaluated and on which decisions have been made (DeMers 1985, 1986). This required the development of a database of historical information rather than current information. Each system was then used to base planning decisions for the test parcels of land. Finally, the LESA values on these test parcels were compared to established permit acquisitions to determine the likelihood that these permits would have been allowed using the two LESA systems. Results of this previous research indicated that, at least in these selected sites, the LESA system developed under the knowledge acquisition process produced values coincident with the wishes of the planners (Luckey and DeMers 1987). Building on those results, the present research utilizes scores produced through GIS computation and evaluates them for compliance with the stated wishes of the Lawrence-Douglas County Planners to promote growth and development in the entire study region, thereby avoiding such development elsewhere. Average LESA scores for each system are compared, while the number of scores fitting into each category of LESA are tabulated and analyzed. Furthermore, the digital databases themselves are examined to determine the spatial properties of the LESA categories for each model and the cartographic databases cross-tabulated to determine the spatial nature of the differences.

Since speed is also a practical virtue, an analysis of the time involved in system development and maintenance is undertaken. This analysis includes only the time for developing a workable LESA system under each development process. Comparison is made between the time necessary to develop the LESA

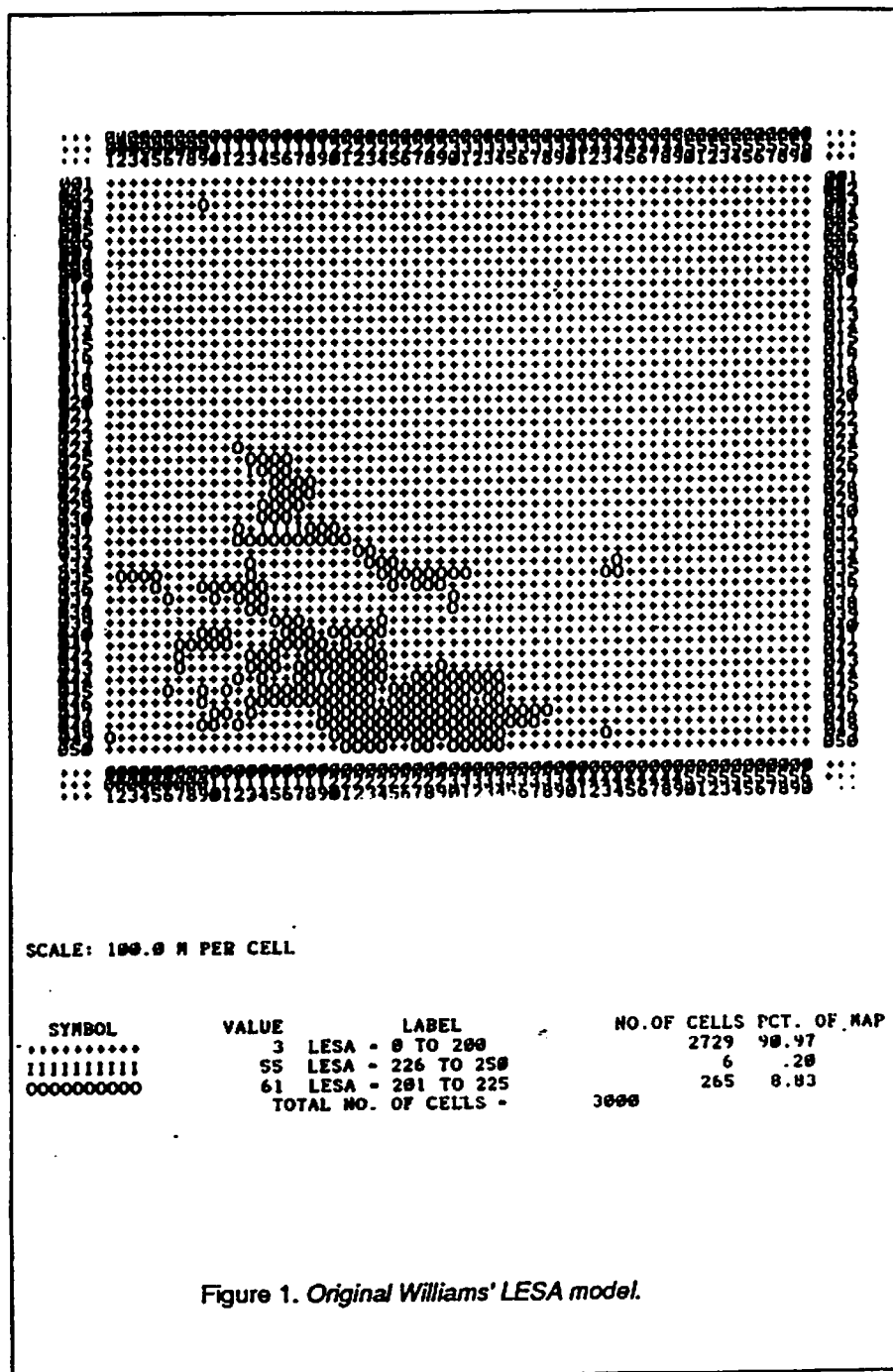


Figure 1. Original Williams' LESA model.

factors and weights utilizing the knowledge acquisition procedures and the unstructured approach used in the original development. The initial development time was estimated by the planners, while the knowledge acquisition development time was logged during the process. This differential in methodology for establishing development times results in some disparity of results; however, the planners stated that their estimate was accurate at least to a degree of magnitude necessary for comparison.

Results

Williams' original GIS LESA model (Fig. 1) showed a range of values of from 41 to 237, resulting in 265 cells (8.83 percent of the study area) requiring moderate protection efforts, and six percent cells (0.20 percent of the study area) requiring high protection efforts. These latter two categories run counter to the wishes of the planners in Douglas County for this particular study area. However, for comparative study, the removal of the "suitability of soils for on-site waste disposal" produces somewhat different results.

The modified Williams' GIS LESA model (Fig. 2), accounting for removal of the map layer SEPTANK, showed a range of slightly lower values of from 28 to 224. This resulted in 159 cells (5.30 percent of the study area) requiring moderate protection efforts. No cells in the modified LESA model showed protection efforts higher than this. Similarly, with the new GIS LESA resulting from the knowledge acquisition strategy (Fig. 3), no protection efforts higher than moderate resulted. In contrast to the modified Williams model, however, the new model showed still fewer cells in the moderate protection efforts class, with only 16 cells (0.53 percent) fitting into this category. Furthermore, the new model shows a range of values of from nine to 216,

considerably lower than those of the modified Williams model. This shows that the new approach conforms much more closely to the wishes of the planners than the modified Williams model for this study area.

Interestingly, there is no spatial correspondence among the moderate protection values between the two models. In the case of the modified Williams model, all of the moder-

ate protection effort values appear in the southwest quadrant, ranging from columns 1 through 35 and rows 26 through 50. No single factor can explain this distribution, yet two are worthy of note. A cross-tabulation with DLE (land evaluation) shows a high number of correspondences between the number of cells with the highest land evaluation scores (100) and moderate protection effort val-

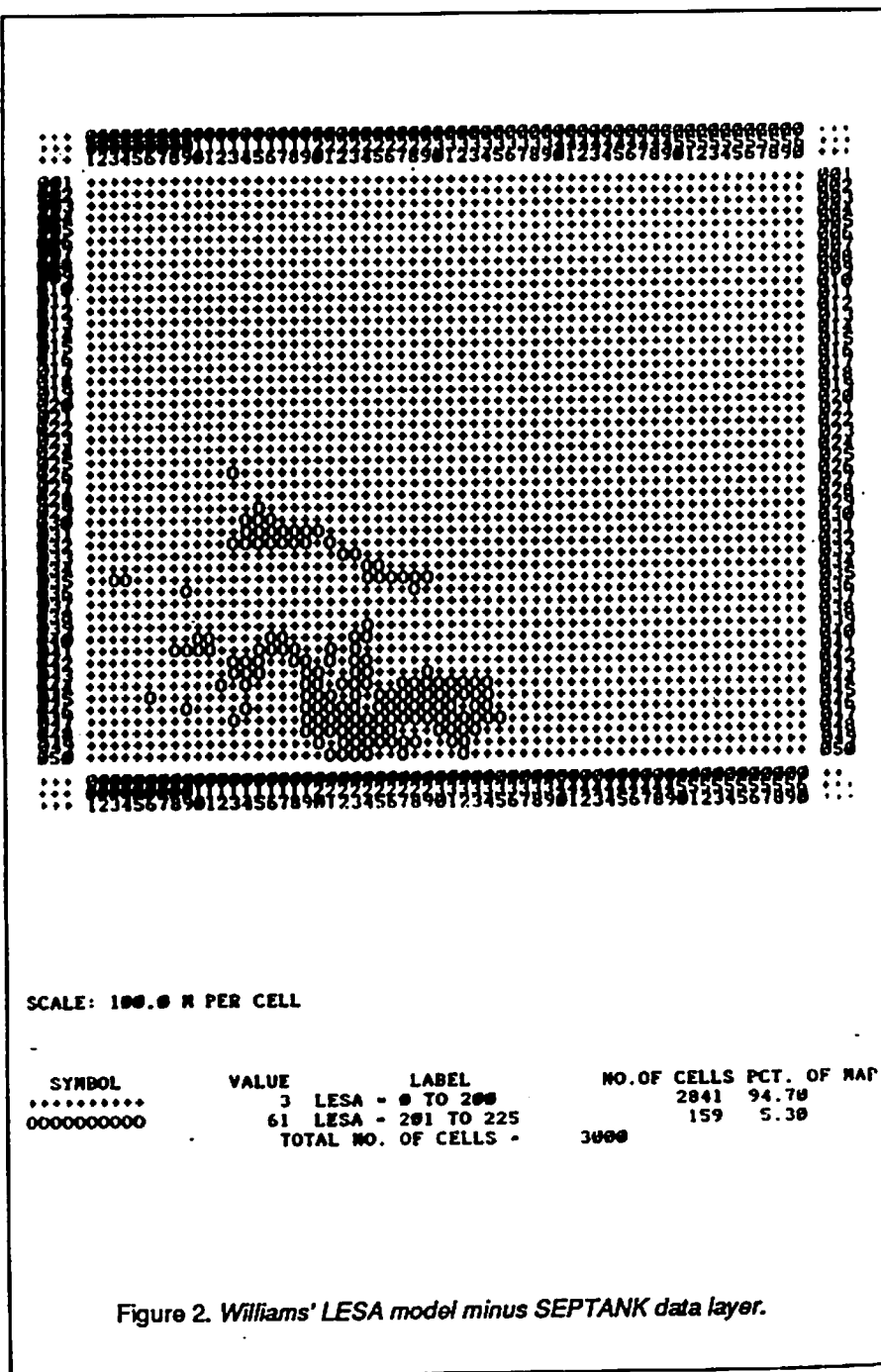


Figure 2. Williams' LESA model minus SEPTANK data layer.

ues. This is a function of the high weight of land evaluation in the Williams model. A similar correspondence does not occur in the new model, which shows two regional concentrations of moderate protection values. The far northwest quadrant, ranging from column 1 through 4 and rows 1 through 4, contains 14 of the 16 moderate protection values. The remaining two cells are located at row 49 column 10 and row 49 column

11. These two sets of locations seem to correspond most to DCITY (Fig. 4), which is the map layer indicating distance from the city, and an analysis using the pMAP spread function confirms this. Once again this is among the highest weighted factors for the model under consideration, and indicates a view by the planners that the closer one is to the city, the more likely there is to be development.

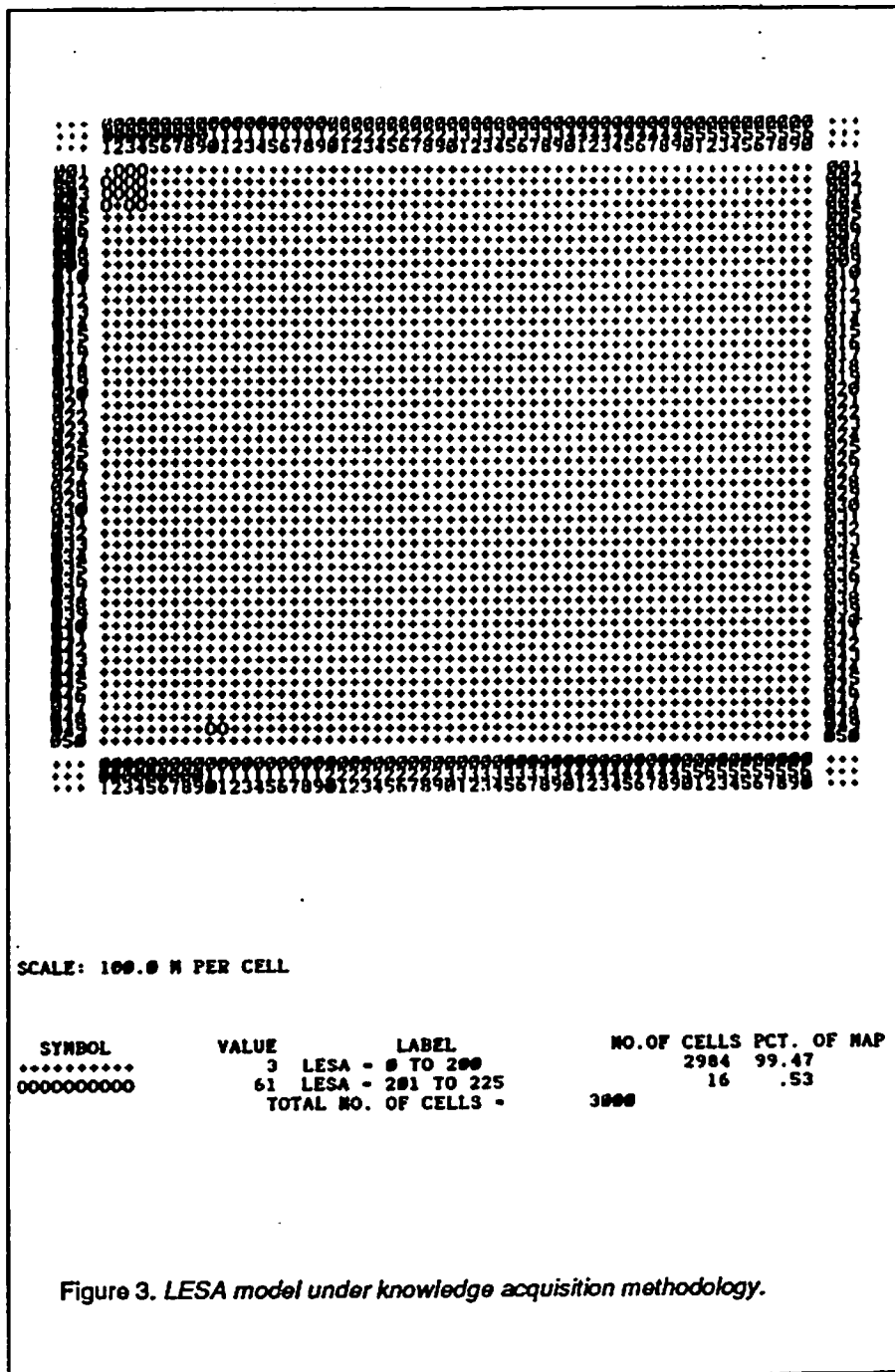
Considerable savings in develop-

ment time are achieved over the original approach suggested by the Soil Conservation Service. The LESA system proposed for use by the Douglas County planners involved a working group in the establishment of the land evaluation portion. One of the planners indicated that this involved an estimated 120 to 140 work-hours. Since this land evaluation portion was used in the development of the new system, time costs in this development will be considered equal between the two systems.

Site assessment for the proposed Douglas County system was designed as a rudimentary proposal by one planner and required approximately 12 work-hours. This is not normally the procedure for site assessment, development, and Douglas County had designated a 10-member working group for its establishment. Conversation with this planner indicated that this procedure would normally take several months of one-day-a-week meetings of eight hours each. This totals 80 work-hours each week for a minimum of 12 weeks, or a grand total of 960 work-hours. Tabulated time requirements for development of the new system indicates a substantial increase in time and cost efficiencies (Table 5).

The values for the old Douglas County LESA development system are estimates, and a comparison of development with three participants as opposed to development with 10 participants may not be valid. The larger the group of individuals, the more possibility there is for disagreement. Care must be taken in evaluating the differences in time required between the original system and the new iterative learning model.

Additionally, the use of large working groups enables all concerned citizens and organizations to have an input into the system, thus allowing their views to become part of the final outcome. As a research project, the current study does not recommend



that the original intent of the Soil Conservation Service of developing working groups be ignored, but rather that the structured approach to decision making espoused here might be adopted or modified to allow quicker development time. For example, some modification might be necessary to allow all participants to have a clear understanding of the outcomes derived.

Conclusions

Overall, the simulation knowledge acquisition approach to GIS LESA development offers some exciting improvements over its original counterpart. Notable enhancements include savings in time and a general correspondence between the wishes of the planners and the model results.

This latter should not be surprising, however, since it was precisely the wishes of the planners that were incorporated into the model. This poses a more fundamental question than the mutual correspondence of the model and the planner's wishes. Are the planners and local officials the ones who should be queried as to their wishes on such matters? Results of previous research indicate that they will ultimately have an impact on the model implementation no matter what methods are used in its creation (DeMers 1988).

Since this is so, one might ask why one should go through the trouble of developing such a scheme. The answer is that since the planners are to have such a strong impact on the model and on its implementation, then they should be made more familiar with the potential impact of their decisions upon the land use in their area. The knowledge acquisition process used here, I believe, provides this information in such a manner that the planners have an opportunity to act upon this new information prior to decision making.

As a prescription for GIS automation, however, the simulation methods used here for knowledge acquisition are incomplete. Much has yet to be learned about the subtle, context-dependent meanings of many of the terms used not only in the LESA model, but in land use planning and natural resource management in general. Few researchers have even recognized this problem much less addressed it. Before robust GIS models can be developed, all of the terms of the model must be defined.

Some GIS researchers have suggested that this is merely a "data dictionary" problem, implying that the problem is trivial and that one merely has to arbitrarily decide what the terms mean. However, as Robinson and others have shown (Robinson and Strahler 1984, Robinson and Frank 1985), the terms used in decision making are frequently vague, and often not entirely understood by

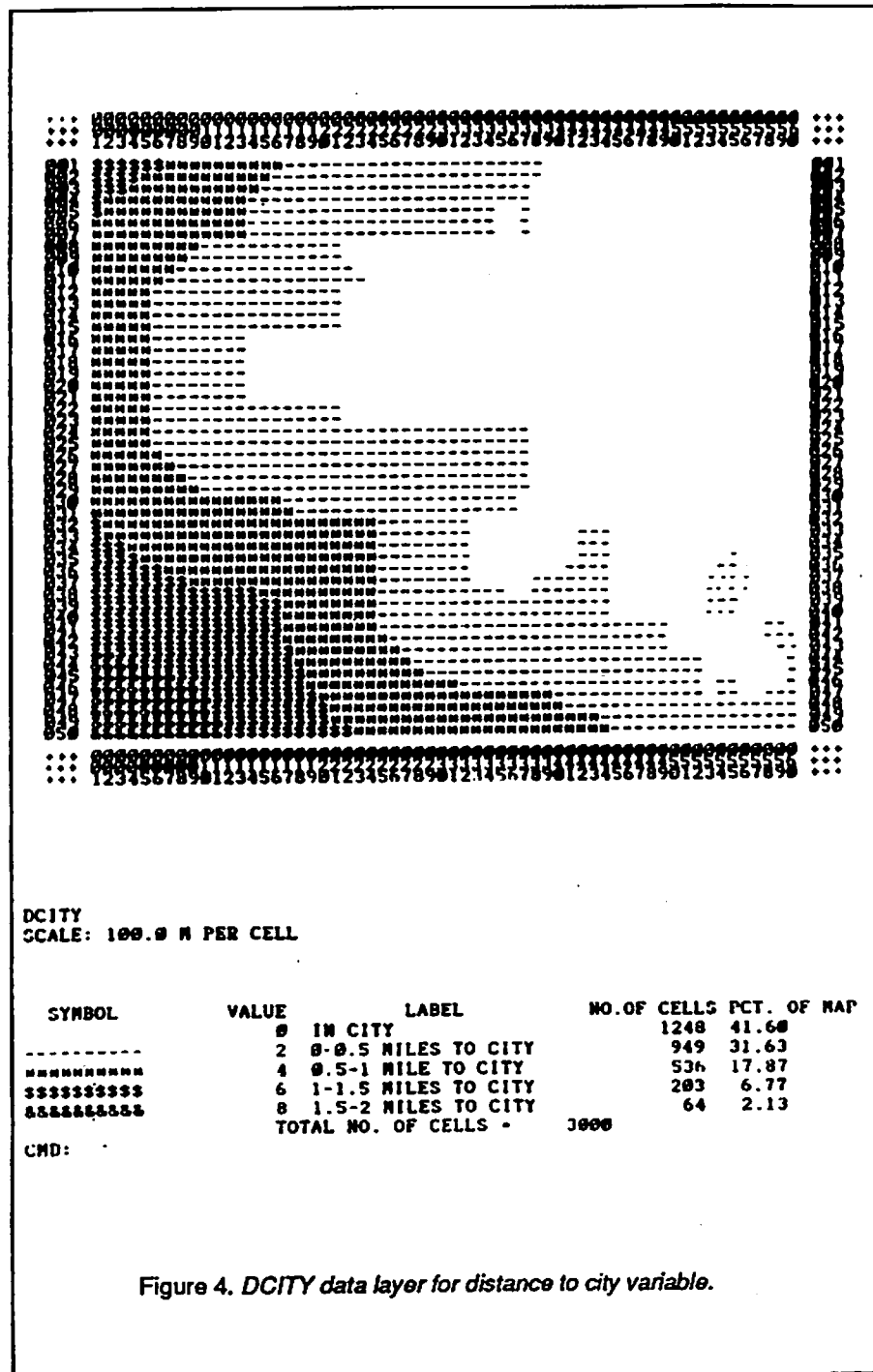


Figure 4. DCITY data layer for distance to city variable.

Table 5. Time requirements for system development.

| Model Portion | Time (work-hours) | |
|-----------------------|-------------------|-----------------|
| | Original System | New System |
| Land Evaluation | 120 - 140 | 120 - 140 |
| Factor Selection | — | 2.25 |
| Weight Determination | — | 13.50 |
| Cross Impact Matrix | — | 17.50 |
| Evaluation | — | 3.00 |
| Subsequent Meetings | — | 4.00 |
| Total Site Assessment | 960 | 40.25 |
| Total | 1080 - 1100 | 160.25 - 180.25 |

the decision makers themselves. Some techniques have been suggested to quantify these vagaries (Robinson and Wong 1986, Frank et al. 1986), yet much more research is needed to prevent the naive application of dangerously simple models to critical problems in land use planning and natural resource conservation and management.



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Michael N. DeMers is Assistant Professor of Geography at Ohio State University. DeMers received his bachelor's and master's degrees from the University of North Dakota and his Ph.D. from the University of Kansas. His current research efforts involve the development of both traditional and expert systems GIS models for range, forest, and agricultural land evaluation strategies, ecosystems and habitat assessment, and floral and faunal analysis and mapping.

Area in the vicinity of the La Selva Biological Station in northeastern Costa Rica. Image generated from a TIN model from ESRI's ARC/INFO. The data were digitized from 1:50000 topographic map sheets of that area. The data are part of the master Costa Rica database maintained by the Department of Geography at the Ohio State University. Image produced by J. S. Sandhu, a doctoral student in the GIS program at the Ohio State University, Department of Geography.

