173900-2-F

Final Report

A FUELWOOD PLANTATION SITE SELECTION PROCEDURE USING GEOGRAPHIC INFORMATION SYSTEM TECHNOLOGY — A Case Study In Support of the NASA Global Habitability Program

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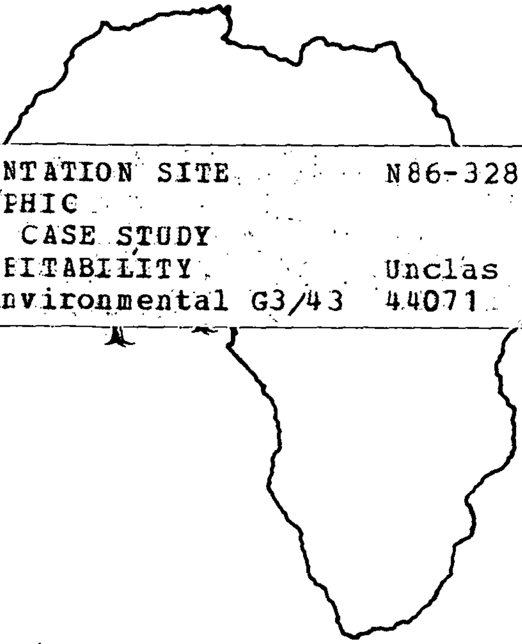
Applications Division

JULY 1985



(NASA-CR-179704) A FUELWOOD PLANTATION SITE SELECTION PROCEDURE USING GEOGRAPHIC INFORMATION SYSTEM TECHNOLOGY: A CASE STUDY IN SUPPORT OF THE NASA GLOBAL HABITABILITY PROGRAM Final Report, 1 Feb. (Environmental G3/43
N86-32828
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44071

NASA Headquarters
Code EE-8
Washington, DC 20546

ENVIRONMENTAL
RESEARCH INSTITUTE OF MICHIGAN
BOX 8618 • ANN ARBOR • MICHIGAN 48107

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. 173900-2-F	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle A FUELWOOD PLANTATION SITE SELECTION PROCEDURE USING GEOGRAPHIC INFORMATION SYSTEM TECHNOLOGY - A Case Study in Support of the NASA Global Habitability Program		5. Report Date JULY 1985
		6. Performing Organization Code
7. Author(s) N.E.G. ROLLER, J.E. COLWELL, A.N. SELLMAN		8. Performing Organization Report No. 173900-2-F
9. Performing Organization Name and Address Environmental Research Institute of Michigan Applications Division P.O. Box 8618 Ann Arbor, Michigan 48107		10. Work Unit No.
		11. Contract or Grant No. NASW-3852
12. Sponsoring Agency Name and Address NASA Headquarters Code EE-8 Washington, DC 20546 Attention: Alex Tuyahov		13. Type of Report and Period Covered FINAL REPORT 2/1/85 thru 6/30/85
		14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

This report describes a study undertaken in support of NASA's Global Habitability Program.

The study consisted of a demonstration of geographic information system (GIS) technology for site evaluation and selection. The objective was to locate potential fuelwood plantations within a 50 km radius of Nairobi, Kenya. A model was developed to evaluate site potential based on capability and suitability criteria and implemented using ERIM's GIS.

17. Key Words GIS Fuelwood Model Kenya	18. Distribution Statement

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
UNCLASSIFIED	UNCLASSIFIED		

PREFACE

The Environmental Research Institute of Michigan (ERIM), operating under the guidance of NASA on applied research and science areas directly stemming from the Global Habitability Program, has been working cooperatively with World Bank staff to demonstrate practical applications of contemporary data collection and analysis systems for natural resource planning purposes. Our activities have been designed to support the Bank's participation in the Global Resource Information Database (GRID) Project with NASA and the United Nations Environment Program. As a result, ERIM's work has centered upon the contemporary technologies of remote sensing and geographic information systems and their appropriateness for project design, implementation and evaluation. More specifically, ERIM has been working with the Office of Environmental and Scientific Affairs to demonstrate data analysis and modeling techniques appropriate for planning and selecting sites for fuelwood plantations that are also located near urban (high) demand centers.

This report describes the work done in collaboration with the Bank, using personnel and equipment at ERIM. It is promising to note, however, that the Office of Environmental and Scientific Affairs has recently secured an image processing and geographic information system and organized its staff in order to support program managers within the Bank to capitalize on the appropriate use of contemporary data analysis systems. This is a very positive sign, not so much for the act of staff reorganization and procurement of new equipment, but rather because of the realization within the Bank that project definition and planning is a process that needs to be constantly improved. We at ERIM are hopeful that the small collaborative effort we have just concluded may shed some light on ways to improve upon that process.

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1.0

INTRODUCTION

1.1 BACKGROUND

A major concern of countries in sub-Saharan Africa is the heavy reliance of their populations on rapidly dwindling fuelwood supplies to meet household energy demands. Between 70 and 90 percent of the total energy used in these countries comes from increasingly scarce, ecologically fragile, and costly supplies of fuelwood.

Rapid urbanization is compounding the supply shortfall caused by this general demand for fuelwood. The urban proportion of the population of sub-Saharan Africa increased from 11 percent of the total in 1960 to 21 percent in 1980; and, a further increase of the urban proportion to 37 percent of the total population is projected for the year 2000. Thus, by the year 2000 approximately 234 million persons in this region are expected to be dwelling in urban areas, a three-fold increase over the 1980 level of 74 million. As a result of this increase, urban energy demand has become a much larger fraction of total energy demand in many of the region's countries. In Sudan, for example, the consumption of fuelwood and charcoal accounts for as much as 40 percent of total energy demand; in Zambia the urban share is 54 percent.

Serious fuelwood shortages and rising prices already afflict many of the towns and cities in this region. The growing scarcity of fuelwood has caused the land in the vicinity of many African urban centers to be stripped of any vegetation that can be used as fuel. This removal has put in motion a downward ecological spiral of soil erosion that many feel will ultimately lead to desertification. At the same time, prices for fuelwood in urban centers have risen because of the need to bring in wood from greater distances.

Wood can only be transported economically in most developing countries over short distances. This is partly a function of the type of transportation available. In the poorest areas donkey-drawn carts, bicycles and human beings are used to move the wood to market. Elsewhere light trucks are replacing these more traditional forms of transportation. Moreover, the road surface is also important; studies show that the cost of transporting fuelwood on unpaved roads can reach nearly twice the cost of transport on paved roads. Thus, the proximity of sources of fuelwood to urban centers is an important factor affecting its price and availability.

One proposed solution to meeting fuelwood demand is the development of peri-urban fuelwood plantations. Ideally, such plantations would be located near urban centers and adjacent to efficient transportation. In locating such plantations, however, planners must also consider the value of this land for other important uses, such as those of producing food or providing shelter. Thus, a methodology is needed for objectively locating and identifying those sites whose best use would be for fuelwood plantations given other, and often competing economic, environmental, and social needs.

1.2 OBJECTIVES

The goal of this study was to demonstrate a methodology that may prove useful at the initial stages of World bank projects whose objective is to identify the most suitable sites for peri-urban fuelwood plantations. This methodology is structured around the use of a geographic information system (GIS). The GIS provides an efficient means of storing, accessing, manipulating and displaying spatial data relevant to the site location and evaluation process. The main benefits of this methodology are to (1) help synthesize and focus all of the knowledge associated with how to select sites for fuelwood plantations into an integrated, objective strategy; (2) place the site selection procedure on a quantitative basis; (3) improve the quality of data analysis; and, (4) reduce the possibility that a promising site may be overlooked. At the very least this methodology provides an objective means of separating a study region into zones of relative suitability for plantation development. Just by narrowing down the size of the area and number of specific locations that need to be seriously considered, this methodology can greatly reduce the time, improve the efficiency, and lower the costs of such projects.

To demonstrate the effectiveness of the GIS approach for fuelwood plantation site evaluation and selection, a demonstration project of some complexity was undertaken. This project was the identification and characterization of sites in the vicinity of Nairobi, Kenya that would be most suitable for the establishment of peri-urban fuelwood plantations.

1.3 STUDY AREA

The study area selected for this project was Nairobi and its vicinity (approximately a 50 km radius). The boundaries of the study area were established by defining a rectangle of 2° longitude by 2° of latitude roughly centered on Nairobi. The northern boundary is the equator (0°) and the southern boundary is 2° south latitude. The western boundary is 36° east longitude and the eastern boundary is 38° east longitude. The study area, as shown in Figure 1, is approximately 221 km on a side, and includes some 49,000 sq km.

1.4 APPROACH

The approach that was used in conducting this study is representative of that which is used in most GIS methodology related projects. It is summarized in the following steps:

(1) locate readily available existing resource data
(2) review available remote sensing data
(3) construct a spatial data base of resources

Kenya

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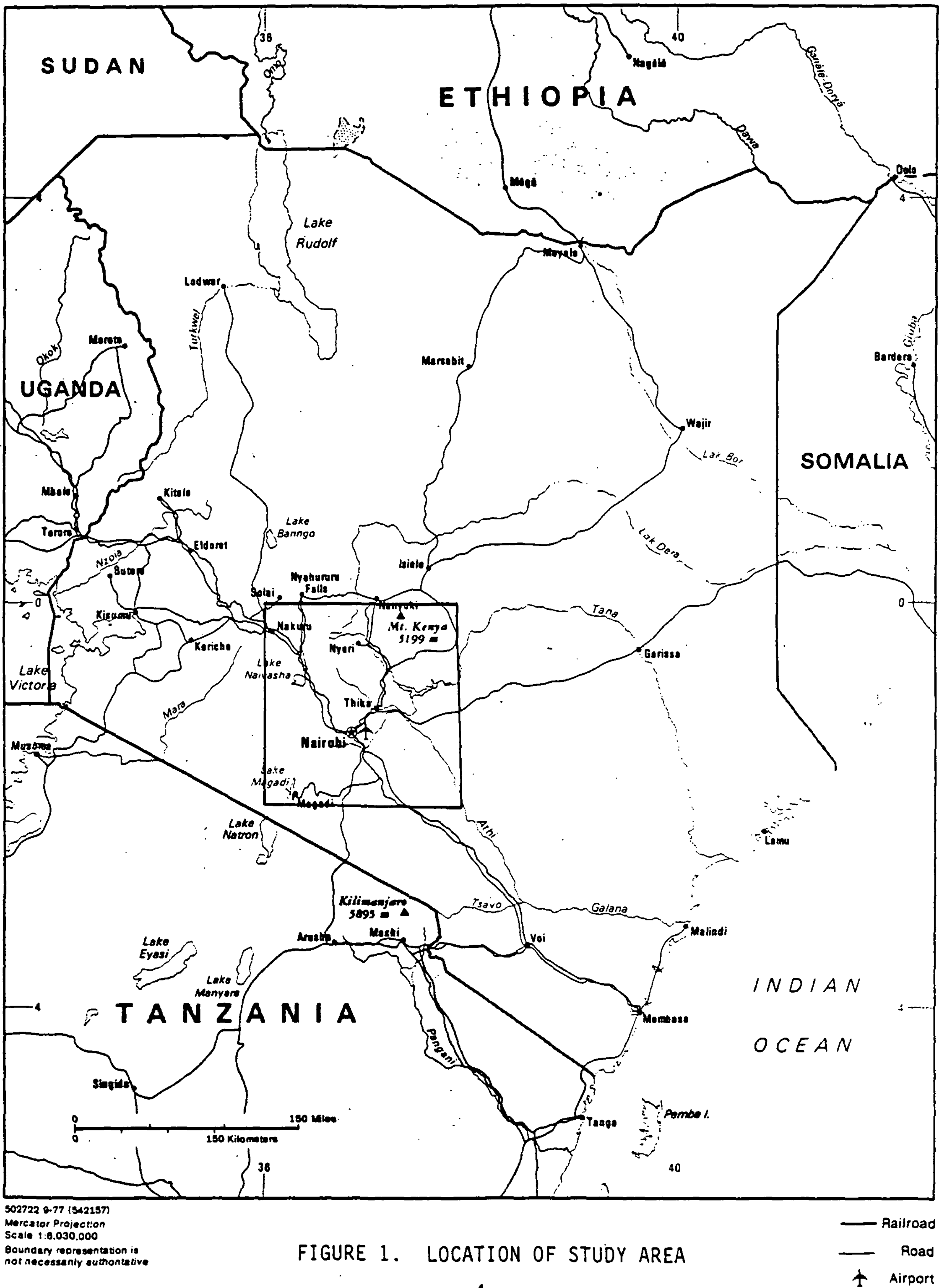

FIGURE 1. LOCATION OF STUDY AREA

(4) develop a model for site evaluation
(5) exercise the model on the data base
(6) evaluate the results, and
(7) suggest improvements to the methodology.

The remaining sections of the report discuss each one of these activities in detail.

2.0

DATA SOURCES

This study used data readily available in the U.S. because demonstration of specific GIS techniques and methodology were considered the most important aspect of the project. These data turned out, for the most part, to consist of maps in the National Atlas of Kenya (1970). In this Atlas there are a great variety of maps depicting the natural, cultural, and socio-economic conditions of Kenya.

The other source of data that was investigated were Landsat remote sensing data. A computer search of site coverage from the EROS Data Center indicated several useable frames of recent MSS* data and one frame of TM* data. Black and white negatives (bands 5 and 7 for MSS, and 4, 5, and 7 for TM) were ordered of enough scenes to put together a mosaic covering the study area.

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*MSS - multispectral scanner
TM - thematic mapper

3.0

DATA BASE CONSTRUCTION

The ERIM GIS stores data in a digital format on a cellular basis. Thus, the layers in the GIS can be visualized as a series of thematic maps of the study site, each with a cellular grid superimposed on it, and with a code describing the resource in each cell. Entering the data into the GIS consisted of converting the maps of the Atlas into digital files via a digitization process. The digitization process consisted of tracing the boundaries of resource classes on a map on a digitizing table, which subsequently created a computer file containing polygons showing the location of each resource class. Thus, each computer file polygon represents a polygon on the original map and is identified by the same resource class code. The computer file polygons are then converted into cells of an appropriate spatial resolution using another computer program. Each cell within a polygon bears the same resource class code as the polygon from which it was derived. In this way, each resource map selected from the Atlas is converted into a thematic layer in the GIS data base.

Because many of the analysis procedures in a GIS study require comparing the codes of the equivalent cell in different overlays, it is essential that the cells in the different layers be precisely registered. This is insured by transforming all the data maps into the same map projection and using the same cell size in the digitization process. For this study the UTM projection was used and the cell size was 200 m square.

A total of 14 resource maps were digitized, and eight were eventually used in the site selection procedure. All of the maps in the data base are listed in Table 1, while those used in the site selection demonstration are shown presented in Figure 2.

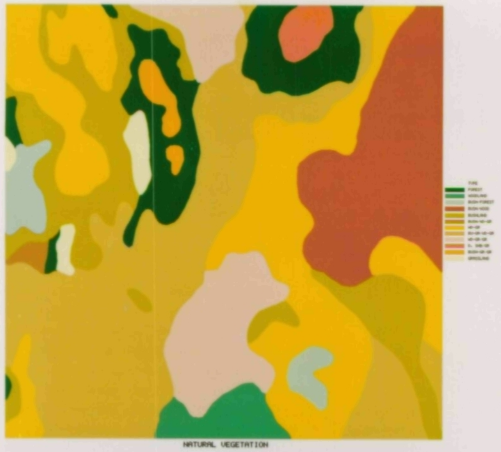
TABLE 1

RESOURCE MAPS OF KENYA STUDY AREA
(Source: National Atlas of Kenya, 1970)

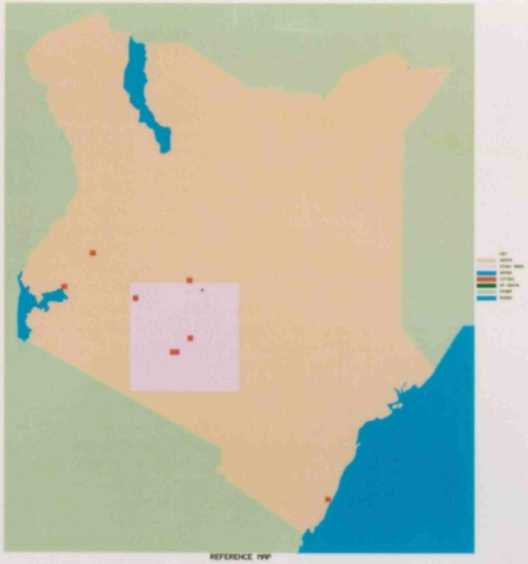
TITLE	MAY BE OBSERVED IN
1. Reference Map	Figure 2
2. Population Density	Figure 2
3. National Parks and Reserves	Figure 2
4. Land Divisions	
5. Transportation	Figure 2
6. Land Classification	
7. Ecological Potential	Figure 2
8. Vegetation	Figure 2
9. Forest Reserves	
10. Annual Rainfall	
11. Elevation	Figure 2
12. Soils	
13. Cultivated Land	Figure 2
14. Crop Combinations	

Figure 2

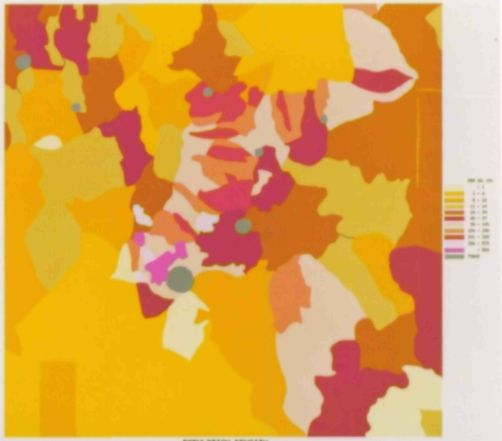
Resource Maps of Kenya Study Area



NATURAL VEGETATION



REFERENCE MAP



POPULATION DENSITY

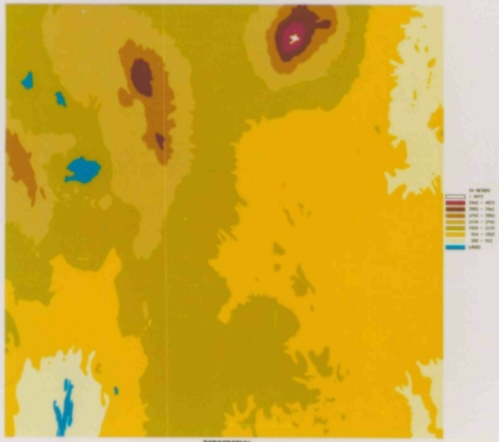
NATIONAL PARKS AND RESERVES

PERI-URBAN FUELWOOD PLANTATION SITE EVALUATION

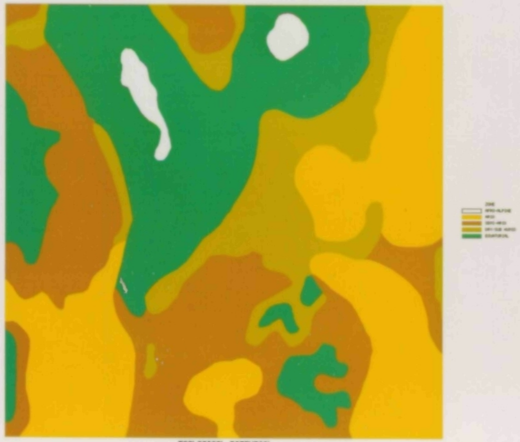
Nairobi, Kenya

World Bank/NASA/ERIM

TRANSPORTATION



TOPOGRAPHY



ECOLOGICAL POTENTIAL

LAND USE

4.0

MODEL DEVELOPMENT

Modeling is very useful because it forces one to synthesize and organize existing knowledge. It rapidly becomes clear in modeling what are assumptions, hard facts, and areas where nothing exists but educated guesses. Modeling also forces one to explain and quantify the interactions of the various components in a system. Furthermore, by expressing a model mathematically a language is provided with which it is possible to manipulate the elements of the model free from biases and interpretations. Another benefit is that mathematical models provide a common language in which professionals from many disciplines may communicate.

Modeling consists of the following activities. One, precisely defining the problem. Two, specifying the data analysis procedure. Three, writing equations to analyze the data. Four, writing computer programs to implement the data analysis procedure. And five, testing and analysis of the model's results. These steps were followed in this study.

The fuelwood plantation site selection and evaluation criteria used in this demonstration are contained in the model that was developed to evaluate the study area and select those sites most suitable for use as fuelwood plantations.

The role of the model in combination with the GIS was to quickly, completely, and quantitatively evaluate the terrain within the study area for its potential as a site for a peri-urban fuelwood plantation. This procedure results in a list of sites that are identified as candidate locations for plantations. Final site selection would then take place after a field visit and direct evaluation of all the candidate sites. Thus, the modeling/GIS methodology we have demonstrated is not considered to be a replacement for expert analysis; rather the methodology is designed to complement expert analysis and promote its more efficient use. The model, in effect, performs the tedious task of surveying and finding likely areas within the study area, while reserving the valuable time and experience of the expert for analyzing specific, high potential sites and making comparisons between such sites. Accordingly, the model developed for this study was designed to identify sites with the greatest potential and produce output products that would permit experts to become familiar with their resource characteristics. These products are listed in Table 2.

TABLE 2

OUTPUT PRODUCTS OF FUELWOOD PLANTATION SITING MODEL

1. Ranked list of sites
2. Potential rating for each site
3. Area of each site
4. Map of all sites

In constructing the model, it was decided that site potential was a combination of two basic factors, namely the capability of the site to support the right type and rate of plant growth, and the suitability of using that site for a plantation (given that there are other competing demands for its use, too). Thus, the basic site potential model consists of a combination of two submodels:

Site Potential = (Capability) (Suitability)

Each of these submodels will be discussed in detail.

The capability submodel, in turn, also consists of two components:

Capability = (Elimination Factors) (Ecological Potential)

The elimination factors are those terrain or cultural conditions that exist in an area that make it impossible or unreasonable to consider siting a plantation in that area. These factors were considered to be the current existance of forest, designation of the area as a national park or reserve, and, the presence of water (lakes).

$$\text{Elimination Factors} = (CF * NP * W)$$

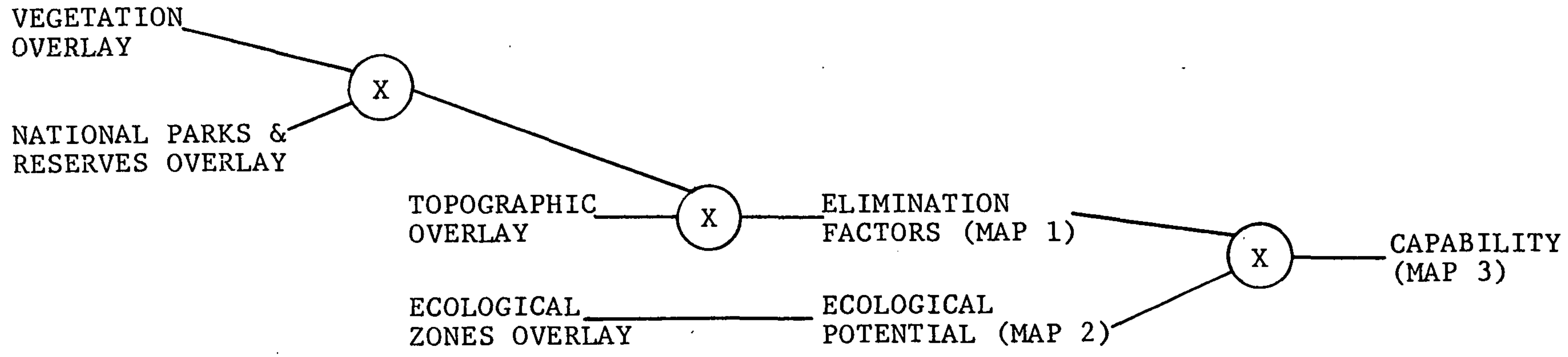
where CF = Current Forest
NP = National Parks and Reserves
W = Water

The ecological potential of an area to support the proper plants for a fuelwood plantation was derived from assigning ratings to the zones on the ecological potential map of the study area. Figure 3 shows a flow chart of the capability submodel. The codes of the categories in the resource overlays are shown at the bottom of the figure. Note also the key diagram, which references the derived intermediate results of the model to the maps shown in Figure 4.

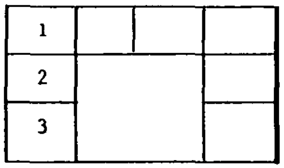
The other submodel, suitability, also has two components:

$$\text{Suitability Submodel} = (\text{Market}) \; (\text{Competing Land Uses})$$

The Market component is derived from a combination of factors; specifically, the distance of a site to a main road, and the demand for fuelwood on the site (which we have assumed is proportional to population density). The "distance to main road" overlay was derived from the original transportation overlay using an algorithm that computes the distance of a cell to the nearest main road. The demand factor was derived by rating cells on the basis of their population density; the greater the population density, the greater the demand. A



MAP KEY



VEGETATION	
FOREST	Ø
OTHER	1

NAT PARKS/RES	
NAT PARKS/RES	Ø
OTHER	1

TOPOGRAPHIC	
WATER	Ø
OTHER	1

ELIMINATION FACTORS	
ELIMINATE	Ø
CONSIDER	1

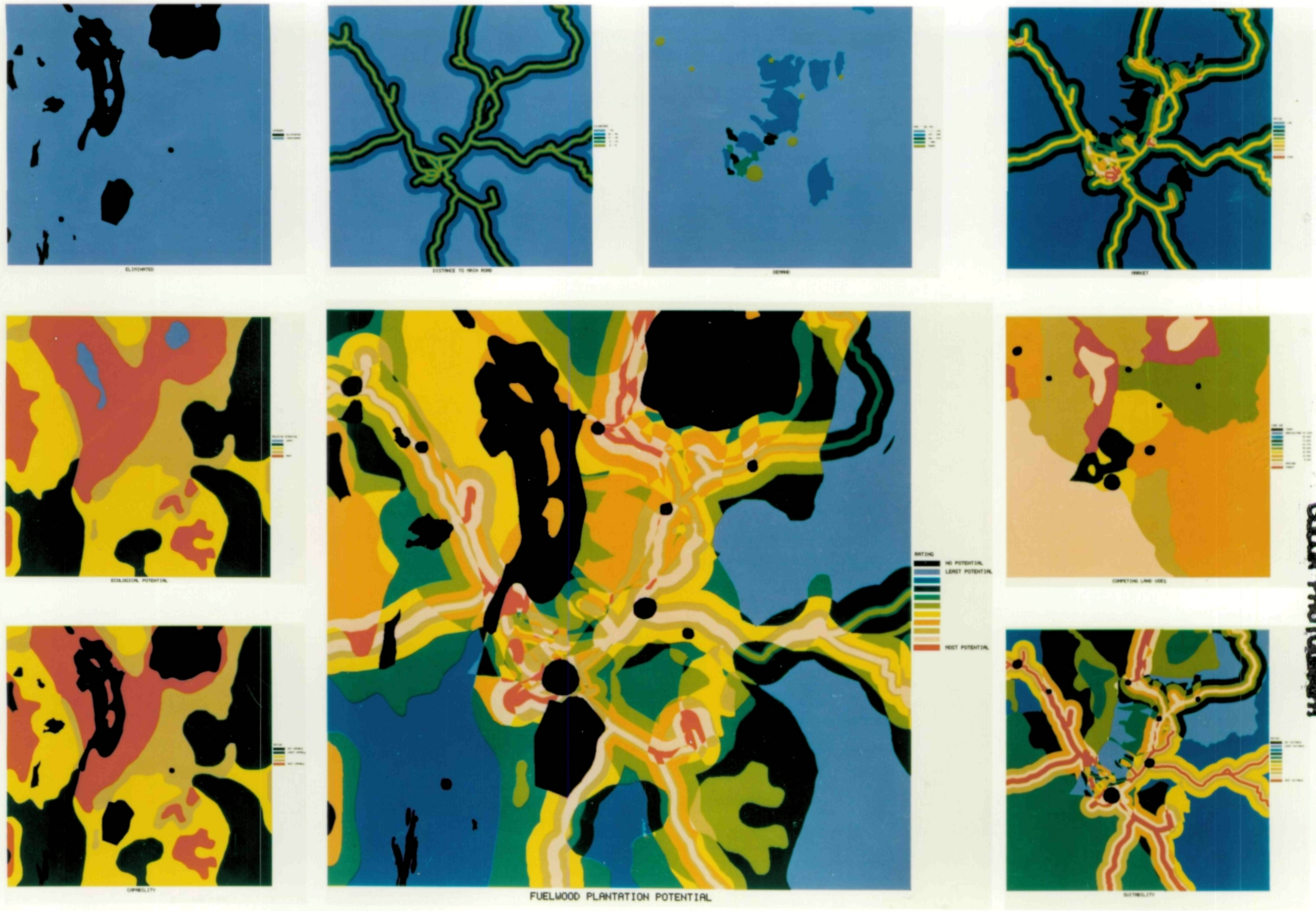
ECOLOGICAL POTENTIAL	
AFRO-ALPINE	Ø
ARID	3
SEMI-ARID	6
DRY/SUBHUMID	8
EQUATORIAL	10

CAPABILITY	
NONE	Ø
LOW	3
MEDIUM	6
MEDIUM-HIGH	8
HIGH	10

FIGURE 3. CAPABILITY SUBMODEL

Figure 4

Intermediate and Final Map Products for Fuelwood Plantation Study Project



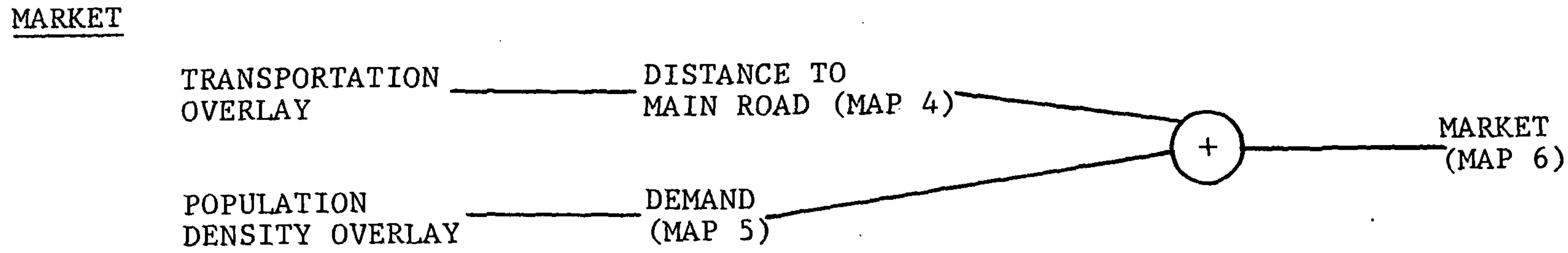
FUELWOOD PLANTATION SITING PROJECT

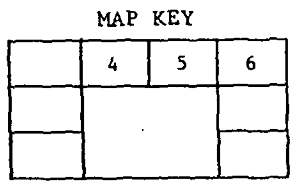
flow chart illustrating how the Market component is derived is shown in Figure 5.

The Competing Land Uses Component of the Suitability Submodel takes into account the fact that other uses may be a better, or at least a higher priority, use of a given piece of land; and, that it will be impossible, or at least not desirable, to convert land from these uses to fuelwood plantations. To perform this analysis, data from the cultivated land and population density resource overlays were merged and evaluated based upon the occurrence of various pairs of land uses. The evaluation logic was implemented using the procedure and the evaluation criteria shown in Figure 6.

The generation of the suitability submodel ratings were produced by combining the Market and Competing Land Uses Components using the procedure shown in Figure 7.

The final site potential overlay was produced by combining the Capability and Suitability submodel overlays using the methodology shown in Figure 8.





TRANSPORTATION	
RAILROADS	1
MAIN ROADS	2*
SECONDARY ROADS	3
TRAILS	4

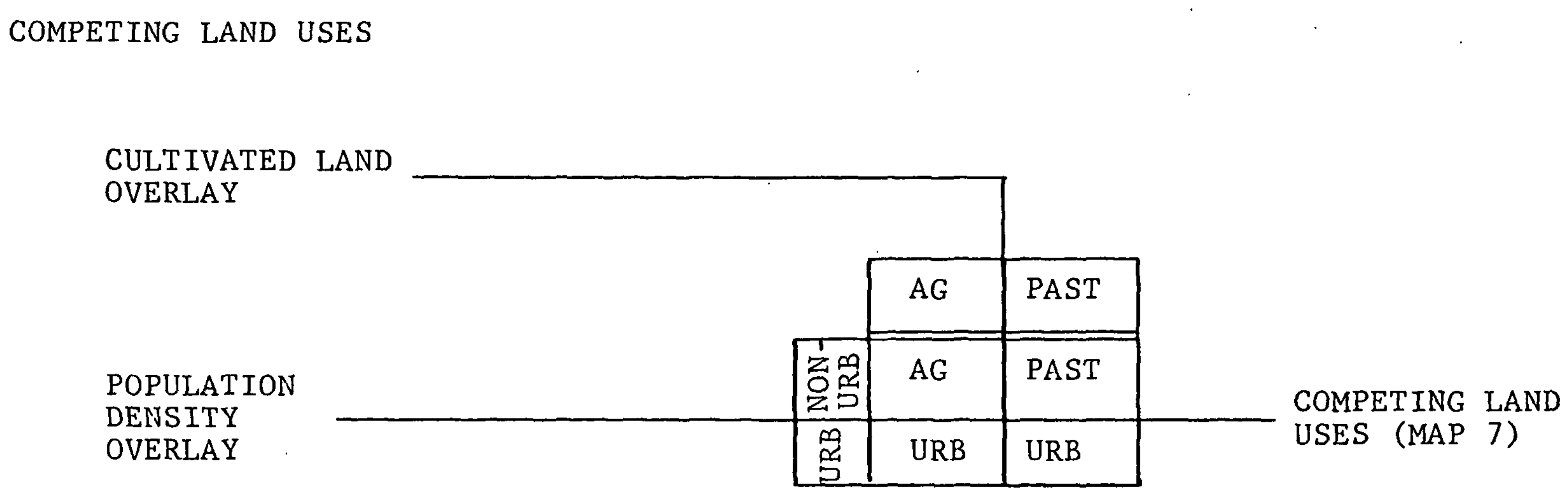
DISTANCE TO MAIN ROAD	
25 km	1
10 km	2
5 km	3
2 km	4
1 km	5

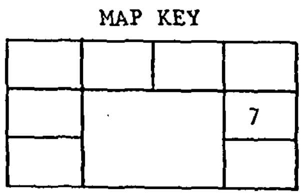
POPULATION DENSITY (1 sq km)	
< 1	1
1-4	2
4-10	3
11-19	4
20-39	5
40-97	6
98-193	7
194-290	8
291-385	9
386-579	10
580	11
> TOWNS	12

DEMAND	
<1-192	1
193-385	2
386-579	3
580-TOWNS	4
TOWNS	5

MARKET	
LOW	2
	3
	4
	5
	6
	7
	8
	9
HIGH	10

FIGURE 5. MARKET COMPONENT FLOW CHART





CULTIVATED LAND		
FOREST		1
PASTURE		2
AG %	3.8	3
	4.8	4
	7.8	5
	19.8	6
	21.2	7
	22.8	8
	28.9	9
	30.6	10
	41.9	11
	47.6	12
	53.1	13
	58.5	14
	79.0	15

POPULATION DENSITY (SQ KM)	
<1	1
1-4	2
4-10	3
11-19	4
20-39	5
40-97	6
98-193	7
194-290	8
291-385	9
386-579	10
>579	11
TOWNS	12

COMPETING LAND USES		
FOREST		10
PASTURE		9
AG	0-20	8
	20-40	7
	41-50	6
	51-60	5
	61-70	4
	71-80	3
	81-90	2
	91-100	1
TOWNS		0

FIGURE 6. COMPETING LAND USES COMPONENT

SUITABILITY

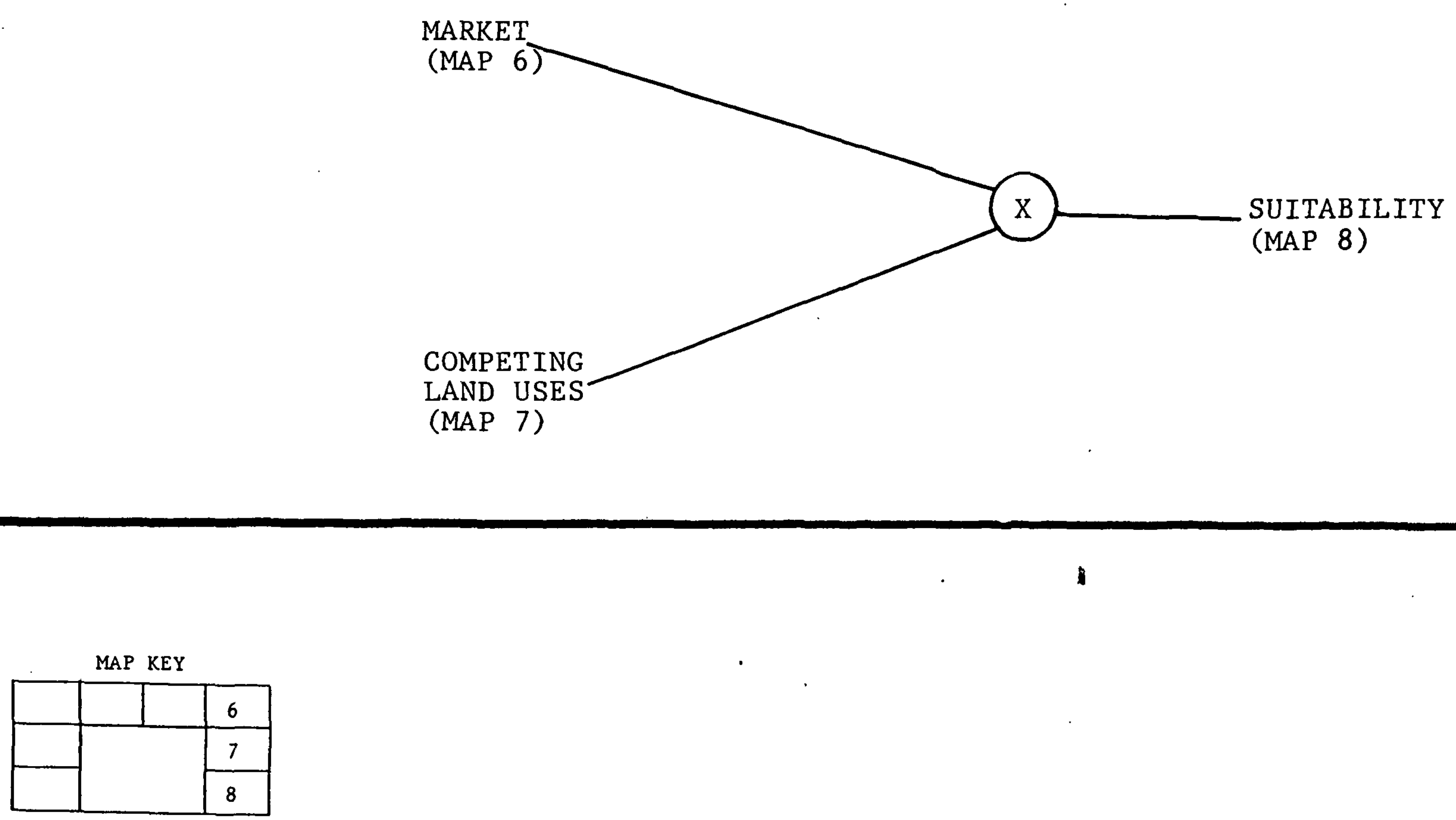
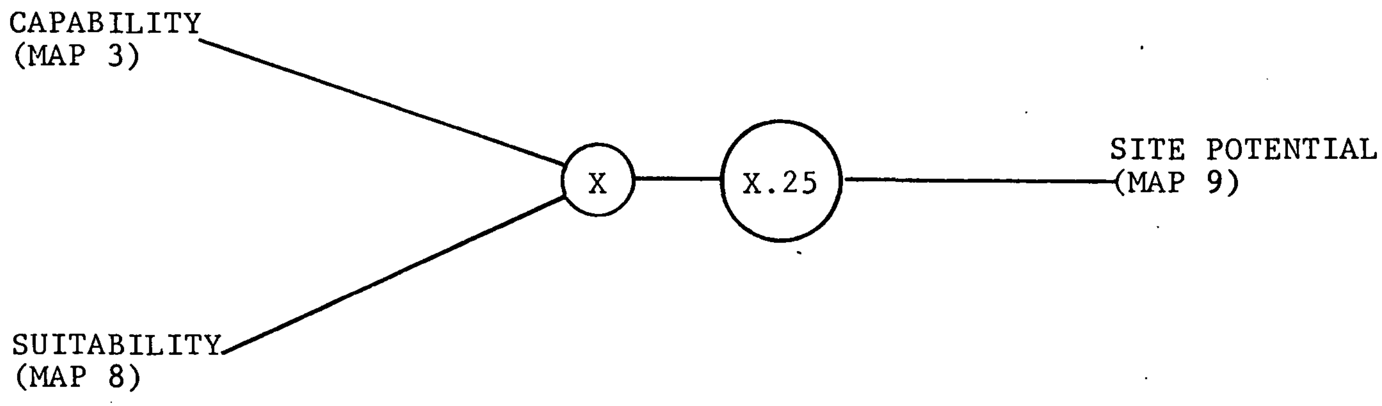
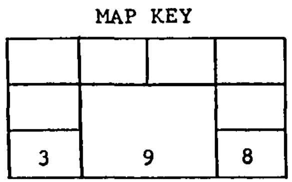


FIGURE 7. SUITABILITY SUBMODEL FLOW DIAGRAM

FINAL PRODUCTS

A. COMPONENTS





CAPABILITY	
NONE	Ø
LOW	3
MEDIUM	6
MEDIUM-HIGH	8
HIGH	1Ø

SUITABILITY	
LOW	Ø
HIGH	1ØØ

SITE POTENTIAL	
LOW	Ø
HIGH	25Ø

FIGURE 8. SITE POTENTIAL RATINGS FLOW DIAGRAM

5.0

MODEL OUTPUT

The output products for this study are of three types: Maps, site priority ratings, and area tables. These products are discussed in this section.

5.1 MAPS

The intermediate model component maps and final site potential output map are shown in Figure 4.

5.2 SITE PRIORITY RATINGS

A printout of the values of the data file of the site selection map provided information on the range and distribution of site potential ratings. Through an iterative process of threshold adjustment and map analysis, a set of levels was established for grouping the site potential ratings contained in the map into meaningful map categories. The top map category (highest potential) contained 1.5 percent of the scene, or approximately 741 sq km. Cells achieving potential values in this range were found to cluster together in several locations that were large enough to serve as plantation sites (areas greater than 200 sq km in size). An overlay showing the location of these sites, the transportation network, and the names of cities and towns was prepared to fit the site potential map (Figure 9).

5.3 AREA TABLES

The site potential rating (average site potential value of the cells included in the site) and the area for each candidate plantation site were tabulated. These data are presented in Table 3.

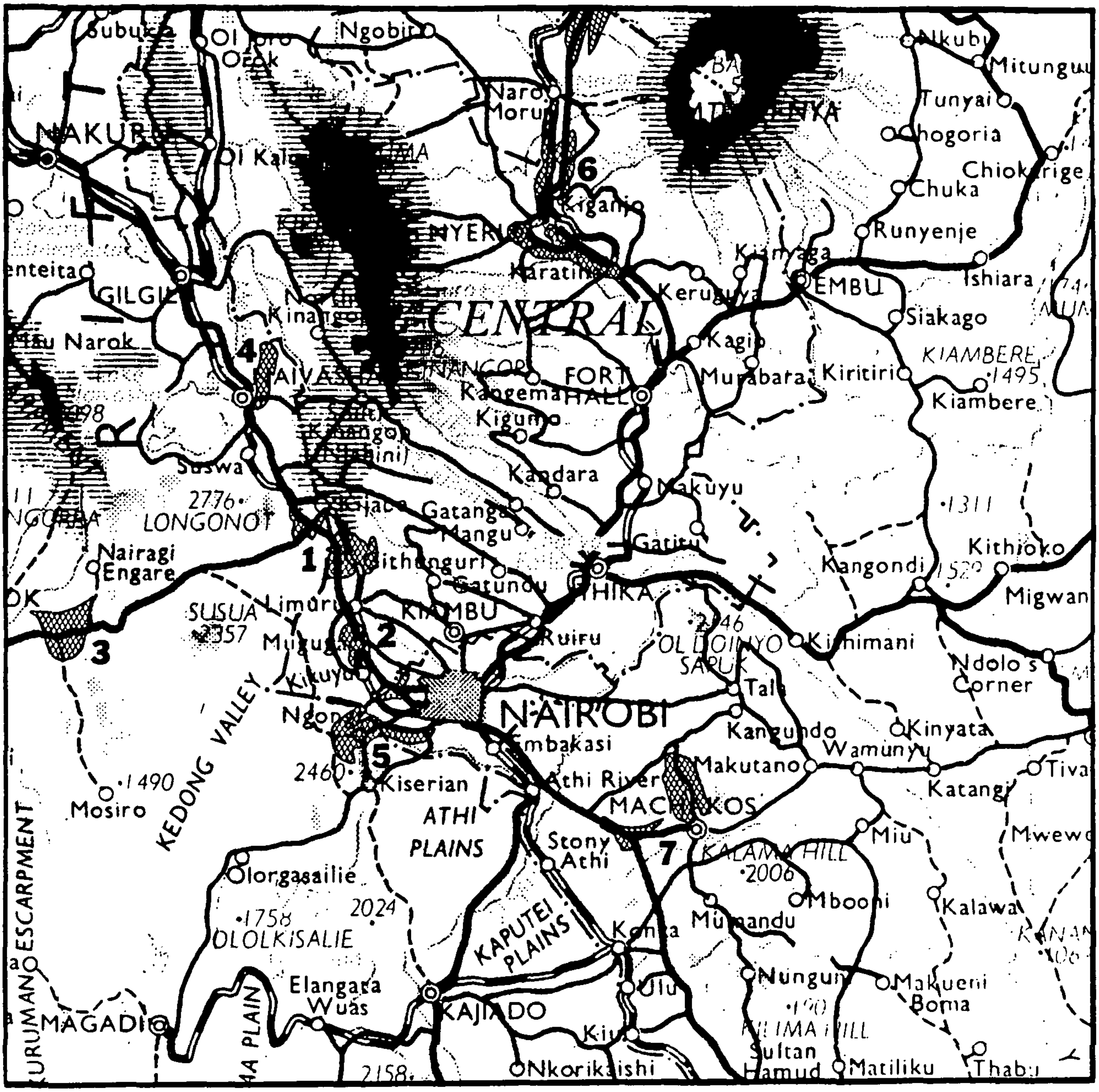


Figure 9. Location and Routing of Candidate Fuelwood Plantation Sites

TABLE 3

RANKING OF CANDIDATE FUELWOOD PLANTATION SITES

SITE	AVERAGE POTENTIAL*	AREA (HECTARES)
1	120	657.75
2	115	248.00
3	104	551.50
4	100	238.50
5	98	691.75
6	96	1338.50
7	91	672.50

*Scale 0 - 250

6.0
DISCUSSION

The model constructed for this project was intended to serve as an illustration of how resource relationships and site selection criteria can be formalized into mathematical equations, and implemented on a spatial data base using a computerized GIS. Given this objective, it was considered more important to develop a model that would demonstrate GIS capabilities than to construct a perfect model. For this reason, no claim is made that the results of this project are as good as the methodology is capable of, or that the model is complete and validated.

Rather, the project shows what can be done with rather limited time and funds. Thus, the model is fairly simple. It is characterized by the type of logic which is generally used in site evaluations of this type. The specific coefficients, however, are admittedly educated guesses, but are believed to be reasonable.

6.1 FINDINGS

There apparently are sites within the study area that are more suitable for use as fuelwood plantations than others. These sites have been identified using an objective, GIS methodology. The location of these sites was also accomplished in a timely fashion.

Furthermore, we believe the model has done an acceptable job of ranking the identified sites; but, even if the model has not ranked the candidate sites in exactly the proper order, the results are still valuable, however, because of the stratification of the study area it produced. Stratification is an important benefit because it helps solve the same basic problem that faces every expert who attempts to perform site evaluation: "Where do I begin?" Another problem faced by the expert, which this methodology solves, is the difficulty of considering every unit of the study area equally and objectively. Moreover, experts typically rely on only one or two key variables to perform most of their evaluation of sites. While this may be efficient, it may also not be as sophisticated as the algorithms that can be implemented using a GIS.

Another important aspect of using a GIS for site selection is that it forces the expert to codify existing knowledge, which leads to the identification of assumptions and even educated guesses in his site evaluation procedure. This information is useful in assessing the depth of the expert's judgement.

6.2 LIMITATIONS OF PRESENT PRODUCTS

During the course of this study several issues were identified which limit the usefulness of the present output products. Fortunately, all of these issues have known solutions.

The first issue noted was encountered during initial examination and comparison of the resource overlays. Inconsistencies in boundary location for the same resource category between maps was observed. To take one example, if you examine the forest category in several of the resource overlays (Figure 2), you will see that the boundaries of this category vary from map to map; and, moreover, that the boundaries vary in the amount of detail shown. Such differences can arise from many causes, including (1) the definition used by the preparer of the map for the category, (2) the data source used to prepare the map, and (3) whether actual, potential, or administrative boundaries are being shown.

Another issue we identified was that the level of spatial detail varied between maps. Some of the maps were obviously very generalized, and intended simply to show trends and relative conditions between large areas. Other maps apparently portrayed conditions much more closely to the way they occurred on the ground.

When maps with such differences in detail are combined, it is possible to generate co-occurrence categories with a high degree of unrealiability in the boundary regions. There is no way, however, to indicate that such data are potentially artifacts in the new co-occurrence map. Thus, a cascade of errors may occur if these data are used in additional data manipulations.

Another important issue is that much of the basic resource data are over fifteen years old. The publication date of the National Atlas is 1970. Therefore, the data used to prepare the maps in the Atlas had to be collected even earlier. Since there is evidence (remote sensing data, personal communications) that conditions have changed dramatically in this area during this period, there is obvious cause for concern regarding whether results based on the analysis of data so old are still valid.

Another concern associated with the quality of the input data is that its accuracy is unknown. Examination of the maps in the Atlas does not reveal whether the data are based on remote sensing, field work, some combination of the two, or expert opinion. Ideally, all of the data (maps) that are used to create a data base for analysis by a GIS are accurate to approximately the same level, typically 90%.

In addition to these data-related issues just mentioned, there are also model-related issues which cause concern. The most serious of these is that the model is not validated; i.e., it has never been tested and proven to produce correct results, given perfect input data. In fairness, however, it should be pointed out that model validation is difficult, and very few models are ever truly validated. It may even be the case that there does not exist a controlled situation in which the model could be tested.

Finally, it should be remembered that all of the coefficients in the model are strictly educated guesses. Very little guidance for setting coefficients was available, other than experience and common sense, and that is what was used in this study.

6.3 SOLUTIONS

All of the above issues have known solutions. The solutions vary, however, in their ease of implementation.

Initially, a consistent and well-defined resource classification system needs to be adopted. Having such a system will resolve inconsistent category boundaries between maps. In addition, a well-defined classification system can help improve map accuracy. This is especially true if the definitions are ones that are easily observable given the data gathering methods being used, such as remote sensing and field work.

Validating the model is also recommended. An effort at this may prove very valuable because it could uncover the need to include additional variables or modify existing ones. For example, one key variable in determining suitability could be land ownership. In some cases it may even be an overriding consideration. If this is true, the model must incorporate some measure of the influence of land ownership to produce realistic results. Tests to validate the model and determine its sensitivity could reveal this kind of knowledge, leading to development of an improved model.

Even if an effort cannot be mounted to fully validate the model, as a minimum it is recommended that an effort be made to examine the appropriateness of the coefficients used. One way of doing this could be through soliciting expert opinion, perhaps using an approach like the Delphi technique, in which experts reach a concensus regarding the best values for the coefficients.

Identifying sources of current data is also important. It may be that maps of the resources of interest showing current conditions are available. An effort should be made to contact sources in Kenya to determine what current data are available, their source and their accuracy. Typically, in projects such as this, some of the needed data are already available, while others are not. Knowing what is available and obtaining it can reduce costs and time by avoiding duplication of data collection, and provide a focus for what additional data should be collected.

One source of new data that should not be overlooked is remote sensing data. Remote sensing data has several important advantages for gathering natural resource condition data that can be very valuable to this type of project. These advantages are discussed in the next section of the report (Section 7.0).

7.0

ROLE OF REMOTE SENSING

Remote sensing data were not used directly in this study, but it is clear that they could be used to substantially improve the quality of the input data. The most obvious benefits remote sensing can provide are discussed here.

The primary benefit of incorporating remote sensing data into the study is that it would provide a way to obtain current maps of key resources. As an example, the forest category is one that could be interpreted from Landsat data. A Landsat derived forest cover map would have several advantages over the forest cover information used. These include: (1) current year information, (2) accurate boundaries, (3) consistent categorization, and (4) uniform level of spatial detail. Other categories for which improved maps could be produced include water (lakes), rangelands, and some types of agriculture.

Another useful type of information that remote sensing could provide is on the nature and location of changes over time. In preparing a response to a perceived need, such as planting fuelwood plantations, one needs to be sensitive to the fact that it is the future and not the present that our solution is supposed to serve. This means that trend information as well as current resource/demand distribution information is important. For example, if forest land is being cleared rapidly in one area, even though the land is shifting to a competing land use in this area, there may still be a good potential for reforestation. The reforestation potential may be good in such an area because, if this land has only been recently cleared, it probably has only marginally better value for other uses (or it would have been cleared before).

Also, in areas where population density has just started increasing (i.e., newly urbanizing areas) demand will undoubtedly become greater for fuelwood in the future. If this demand can be predicted (i.e., identify where the new urbanization is taking place), then fuelwood plantations can be established now before the value of the land for competing land uses becomes so high that establishment of plantations in the future is economically prohibited.

Other important changes that could be identified are those that take land out of consideration. An example of such a change was the creation of large reservoirs around Mt. Kenya that were observed in the Landsat data.

Another way in which remote sensing could assist in this particular study is to locate sites which were forested until recently, but which are now bare. These sites are very good candidates in many cases for reforestation. Detecting these sites could be done by comparing historical maps and current remote sensing data, or historical and current remote sensing data. In a pinch, this approach could even serve as a basic methodology for identifying candidate sites where there was neither time or funds for a more sophisticated approach.

8.0

CONCLUSIONS AND RECOMMENDATIONS

It has been ERIM's position throughout the period of collaboration with the World Bank that the appropriate use of a geographic information system offers a tremendous potential for assisting project planners to achieve specific goals. In our case we set out to demonstrate the use of a GIS to help locate fuelwood plantations near market centers. The specific example described here was a simplified version of what could be done, yet we are satisfied that the demonstration goal was suitably achieved.

A GIS is simply another tool available to planners, and should be viewed as a mechanism to augment well established planning practices and activities that will undoubtedly be pursued whether a GIS is available or not. Most siting decisions are extremely complex tasks and we certainly have not demonstrated here that the "best" decision is achieved by use of a GIS. What we have shown, however, is that a GIS is capable of treating multiple factors (e.g., physical setting, economic, cultural issues) in an equitable and uniform (objective) way to assist planners along their decision chain.

The challenge is still before us to select the most suitable parameters, ensure that one has or can gather the appropriate data, and define and defend the values which one attributes to each parameter. Each of these steps, in turn, has been introduced and discussed in this report.

The World Bank, like other lending institutions, faces many challenges when confronted with the task of assisting governments to meet their energy requirements. The rapid loss of timber throughout the developing world is especially difficult for populations already living at or near subsistence levels, since it forces adjustments in resource use among populations with little room to make (affordable) adjustments.

Yet the fuelwood shortages are already a fact of life in much of the developing world and this situation will not readily change in the near term. One option among many that may prove to be cost effective in certain instances is the development of plantations very near urban centers for the express purpose of producing fuelwood for cooking (prime need). In these cases, it is suggested that the methods demonstrated here would be very valuable to help decide where to locate these plantations. The process does facilitate communication among the community of experts (e.g., economists, foresters, sociologists, farm management personnel) that are needed to reach such a decision, it forces these same people to organize both existing and needed data in a consistent way, and it allows each expert an opportunity to realize "solutions", via the modeling processing, in a timely and cost effective way before the large and often irreversible expenditures of project implementation are formally underway. Once this stage is in motion, errors are only overcome at enormous, and generally unplanned, expense.

The Office of Environmental and Scientific Affairs, as mentioned previously, has procured a computer-based image processing system (for satellite data analysis) and GIS software so that Bank personnel can begin to test and evaluate the apparent opportunities (alleged by those outside the Bank) of these new data sets and analysis tools. This internal capacity is both a logical and appropriate step, since the Bank is now in a much better position to evaluate on its own schedule and terms whether or not contemporary tools of analysis like a GIS are in fact appropriate to the Bank's mission.

LITERATURE CITED

Survey of Kenya, 1970, National Atlas of Kenya, 3rd ed., Nairobi, Kenya.