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REPUBLIC OF KENYA

MINISTRY OF WATER DEVELOPMENT

THE STUDY
ON
THE NATIONAL WATER MASTER PLAN

SECTORAL REPORT
(S)

GIS-BASED ANALYSIS

JULY 1992

JAPAN INTERNATIONAL COOPERATION AGENCY

LIST OF REPORTS

EXECUTIVE SUMMARY

MAIN REPORT

1.	Vol.1	Water Resources Development and Use Plan towards 2010
2.	Vol.2	Master Action Plan towards 2000 Part 1 : National Water Master Action Plan
3.	Vol.3	Master Action Plan towards 2000 Part 2 : Action Plan by Province/District

SECTORAL REPORT

1.	A	Socio-economy
2.	B	Hydrology
3.	C	Groundwater Resources
4.	D	Domestic and Industrial Water Supply
5.	E	Agriculture and Irrigation
6.	F	Livestock, Wildlife and Fishery
7.	G	Flood Control Plan
8.	H	Dam Development Plan
9.	J	Dam Geology
10.	K	Topographic Survey of 11 Damsites
11.	L	Power Development Plan
12.	M	Integrated Water Resources Development Planning
13.	N	Environmental Conservation
14.	P	Laws and Institutions
15.	Q	Database
16.	R	Remote Sensing Analysis
17.	S	GIS-based Analysis

DATABOOK

1.	DB.1	Hydrological Data (Study Supporting Data)
2.	DB.2	Groundwater Data (Aquifer Test and Well Survey)
3.	DB.3	Groundwater Data (Study Supporting Data)
4.	DB.4	Topographic Survey Data
5.	DB.5	Inventory of Irrigation/Drainage Schemes
6.	DB.6	Project Sheet for Urban Water Supply

PREFACE

Administrative Division of Districts

In this Study, the original 41 districts were considered and various statistical data, particularly socio-economic information, were collected for these districts. During the progress of the Study, six districts were detached from the original ones and established as new districts. In the report, the data on these new districts are grouped together with the corresponding original districts as shown below.

	Original Districts	New Districts	Data included in:
1.	Machakos	Makueni	Machakos/Makueni
2.	Kisii	Nyamira	Kisii/Nyamira
3.	Kakamega	Vihiga	Kakamega/Vihiga
4.	Meru	Tharaka-Nithi	Meru/Tharaka-Nithi
5.	Kericho	Bomet	Kericho/Bomet
6.	South Nyanza	Migori	South Nyanza/Migori

(Note: The last three Districts were established very recently.
The report refers only to the names of the original 41 districts.)

The administrative boundary map used in this Study is the latest complete map set covering the whole country (41 Districts, 233 Divisions and 976 Locations), prepared in 1986 by the Survey of Kenya, Ministry of Land, Housing and Physical Planning.

Data and Information

The data and information contained in the report represent those collected in the 1990-1991 period from various documents and reports made available mostly from central government offices in Nairobi and/or those analyzed in this Study based on the collected data. Some of them may be different from those kept in files at some agencies and regional offices. Such discrepancies if any should be collated and adjusted as required in further detailed studies of the relevant development projects.

THE STUDY ON THE NATIONAL WATER MASTER PLAN

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

S1. INTRODUCTION

This sectoral report focuses on the application of the Geographic Information System (GIS) in the study on national water master plan (referred to as "the study" hereafter). A brief introduction to the GIS technology is given to explain the various tools for database management, analysis, and presentation. Then, the logical steps followed in the study for efficiently applying the GIS techniques are described. The advantages of using GIS in the analysis are explained next. Finally, some examples are presented to give an image of the types of data present in GIS.

S2. GEOGRAPHIC INFORMATION SYSTEM (GIS)

2.1 Basic Concepts of GIS

The Geographic Information System (GIS) is an efficient tool for spatial data management and analysis using computer. Spatial information, such as maps of landuse and soil types, can be digitally stored in the computer and analyzed using the GIS tools at speeds much higher than possible by other conventional methods. The data fall into several categories namely, maps, tables, and images. Maps can be input digitally into GIS through generic features such as points, lines and areas. The spatial relationship between these features is called topology. GIS can store the topology along with the maps to perform speedy operations later. Tabular data can be maintained as records in a relational database. Further, tabular data such as population which has meaning on a map can be linked to corresponding maps such as administrative boundaries. Images like aerial photographs and pictures produced by data from satellite borne sensors can also be digitally stored. These images can be spatially matched with the maps in the GIS. The different types of data are stored as layers in the database. GIS can assist in the integrated management of all the information in the data base. Queries on the database can be performed easily. Queries based on geographic situations - for example, population within 500 meters of a borehole - can also be easily made interactively. Thus GIS provides an advanced and integrated platform for analysis in the study.

2.2 GIS Techniques for Analysis

GIS is a set of software procedures that perform specific operations on the spatial database. These procedures serve as a tool box for the expert. The procedures can be combined and looped to perform complex operations on the database for obtaining desired results. Some typical possibilities are explained here.

2.2.1 Spatial queries

GIS provides a graphical interface to perform queries on the database. A particular record in a database can be looked up by entering its name or location on the computer terminal. Also, an area can be specified on the map, such as an area within 5km of a particular river, and the contents of the database like the area of a particular type of soil can be queried. These operations can be repeated automatically to classify a map. For example, a soil map can be classified based on soil characteristics such as depth and texture for its suitability for cultivation of rice. Thus GIS enhances the spatial queries of the database and assists in the edit and management of the database.

2.2.2 Spatial measurements

GIS can perform spatial measurements that include basic geometrical measures such as length, area, perimeter, volume and shape of features and more complex spatial measures such as spacing and compactness. Also, it is possible to ascertain from topological features various relationships between different places such as connectedness, adjacency and containment. For example, questions - such as are two cities connected by road, is a soil type near another area, or how many bore holes are in rocky geological zones - can be answered very quickly in the GIS.

2.2.3 Spatial analysis

GIS stores the various types of spatial information of the study - such as landuse, soil type, and basin boundaries - as separate layers. There are different layers for different types of information such as points, lines, and polygons and, different operations between layers are possible. For example, it possible to calculate the areas with a particular soil type and a given landuse by overlaying the layers for soil type and landuse. It is possible to repeat this process of polygon-overlay with several layers. Basically, the overlay of two layers becomes another new layer in the GIS database. In this new layer, each unit of area has the information of both layers it originally belonged to. So it possible to quickly identify areas suitable for a particular crop by overlaying layers for landuse, soil type, temperatures, rainfall, etc. Another important function is the line-in-polygon and point-in-polygon analysis. Here, it possible to classify - for example, the bore holes for groundwater (points) based on the geology (polygons) - by performing point-in-polygon operations between the two layers. Normally, such operations when performed manually are very cumbersome. The accuracy of results in the manual processes is very low compared with the GIS approach. In the manual approach the original layers are first approximated from polygons to regular shapes called grid cells. The boundaries of the grids must match for all the layers. Then overlays are created by loading values in each grid in a new layer by looking at the value for corresponding grids in all the layers. Of course decreasing the size of the grid cell would increase the accuracy but it would require a tremendous amount of labor. In the GIS approach the overlay yields new polygons that are not restricted by any grid, thus maintaining the geometric accuracy of the original information.

2.2.4 Spatial modeling

GIS also provides powerful tools for modeling spatial information. For example, it is possible to use elevation values obtained at random points on a piece of terrain and create contours for the terrain. The model can also be used to create thematic layers of the slopes and aspect of the terrain. The advantage with GIS is that these results of spatial modeling can be stored in the database and combined with other information for spatial operations. So for example, it possible to select areas with a particular landuse and slope less than 2 percent by overlaying the layers for landuse and slope. The layer for slope will be created from the spatial model. The spatial models can be also used for other interpolations such as querying the surface values on some terrain, the profile of a section on the surface, and the volume enclosed by an area on the surface. These operations will be very useful for many applications.

2.2.5 Enhanced presentation

GIS can provide high quality plots of maps and graphs from tabular information. Also the results from GIS can be exported for use with other desktop publishing tools. The surface models developed for different terrain can be viewed three-dimensionally from various angles. Further, other thematic information, such as landuse or results of land suitability analysis for crops, can be draped on the surfaces for better visual effect.

2.3 Computer Environment for GIS

The computer systems required for GIS include a main system to host the GIS software and the following tools: disk storage for managing the digital database; input devices for creating the database from paper, including digitizer boards and scanners; tape drives for importing digital information from other sources in the form of tapes; and output devices, such as printers, plotters, and film printers, for presentation purpose. Depending on the volume of data, load of input data, volume of data storage, the number of devices and power of the main machine must be decided. In this study the following hardware environment was used.

Main computer:	Sparc Station 1
GIS software:	ARC/INFO core module, TIN and NETWORK extensions
	MapInfo
Database software:	ORACLE
Digitizer:	GTCO, A0 size board with 16button mouse
Color Printer:	Canon Pixel EPO, A3 size
Electrostatic Plotter:	Hewlett Packard, A1 size, B&W

These core systems were networked with the host system for performing several other tasks such as report preparation, presentation, and simulation.

S3. GIS DATABASE DEVELOPMENT

In this study a GIS database was developed based on the requirements for the analysis and presentation. The GIS database was used by several experts in the study for different sectoral analyses and reports.

3.1 Basic Data

Several basic data were collected for this study. Some of the data were already available in the form of maps, reports, or database records. Since some data were not available or were old, new surveys were required to collect them. Some data could not be collected by a conventional survey. So remote sensing techniques were used to prepare those ones. The data fall into the following categories: socioeconomy, meteorology, natural resources, topograghy, water resources, groundwater, geology and geo-reference. The maps were of scales ranging from as small as 1:2,000,000 to as large as 1:250,000. A list of data created in the GIS database for this study is provided in Table S3.1. The data covered information such as socioeconomy, population, industry, meteorology, rainfall, temperature, humidity, forests, national parks, landuse, soil type, contours of topography, rivers, basin boundaries, administrative boundaries, cities, borehole locations, geology and landcover. The details on the surveys can be found in the respective sectoral reports.

3.2 Data Input, Check and Edit

GIS has various tools for creating a high quality data in the database. It is possible to input maps graphically using a digitizer. The maps can then be viewed on the computer terminal and edited. It possible to automatically input maps if the coordinates are available in the computer file. Tabular information can be automatically linked with maps and it is possible to graphically see the records of a table.

Data input was performed using digitizer for the maps that were available on paper. The geometric details, such as points, lines for rivers, and polygons for administrative boundaries, were input first. The topological information is automatically created by the GIS software. Then, the maps were checked by comparing proof plots with the original. The errors were edited interactively with GIS. The thematic information, such as administrative codes, was input interactively on the terminal using GIS software. The final map was again printed for checking against the original. One layer was created for each type of map or data listed in Table S3.1. Tabular information was input separately using database softwares. This information covered socioeconomy, population, industry and borehole. The tables were then linked with relevant maps, for example, the population information with the administrative boundaries, automatically in the GIS. The tabular information was then checked and edit interactively using GIS. Sample maps of administrative boundaries, location of cities and a table of socioeconomic information are shown in Appendix S.1.1 through S.1.3. The GIS approach was very advantageous for creating maps without errors. Without the GIS approach there is no graphic display available as maps for tabular information and it is very difficult to check the accuracy of their input. GIS provides a live link with the maps and the database. By selecting a particular location on the map the corresponding records from the tables can be viewed and edited.

The maps for boreholes were automatically created from the tables. The tables contained the latitude and longitude values for each borehole. These were used to generate the points for the borehole map. The other information on boreholes was then linked to the map.

3.3 Database for Kenya National Water Resources Master Plan

GIS has many tools to maintain the maps input as different layers in an integrated database where all the layers are registered to a single frame of reference. For example, the maps input from digitizers, scanned from papers and imported from computer files can all be registered to a common reference irrespective of the original scales and projections. In this study first the maps were registered to the latitude and longitude reference. Then they were transformed to the Universal Transverse Mercator (UTM) coordinates where the unit for measurement is meters. This was convenient to estimate areas and do other measurements. Thus an integrated database was created. Now it is possible to view information from all the layers simultaneously for any given location and perform many operations. These are discussed in detail in the next section.

3.3.1 Kenya map library

GIS can create a library of the database for enhancing the performance of the operation. With volumes of data, as in this study, for a database covering a vast area, each layer is very large and it is not always efficient to load the entire database for performing operations in a particular area. Library creates logical blocks called tiles in the GIS terminology that provides a spatial index for the database. The entire extent of Kenyan national boundary was split into tiles based on the 50 map sheets used in Kenya. Then, the layer information was loaded into these tiles. Thus it is possible to quickly access the contents of any tile and view all the layer information. The extent of each tile is roughly 1.5 degrees in longitude by 1.0 degree in latitude. This tiling was very convenient for checking input data and for presentation of results in the study.

S4. APPLICATION OF GIS IN ANALYSIS

GIS techniques were used for obtaining the best results in the spatial analyses in each sector. The role of GIS as an efficient tool for database management, spatial analysis, spatial modeling, and data visualization is evident from the applications in this study.

4.1 General Flow of Spatial Analysis Using GIS

The data required for spatial analysis were first input into the database. The detail of information, such as map scale, types and classification of attributes, were chosen to match the needs in the sectoral analysis. This is very important because otherwise the database will not be very useful. On the other hand, since the database was used only for this study, it is cost effective to avoid input of data in more detail than required in the sectoral analyses. There were many ways in which the analyses were performed. They are explained pictorially in Figure S4.1.

First, the tables from the database were extracted and analyses such as population forecasts were performed using some routines. Then the data were stored back in the database. The results were viewed spatially using maps. The Sectoral report on Socioeconomy is an example of this type of application.

Sectoral report on Hydrology is an example of another type of application. Here GIS tools were used for automatically calculating the areas of map features such as basin boundaries and administrative boundaries. Other analyses were performed elsewhere with these data and the results based on map features were stored back in the GIS database.

Other applications used GIS tools more extensively. For example, the analyses in the Agriculture and Irrigation sector, such as land suitability, were performed by combining information from different map layers. In the Groundwater sectoral analyses, the areas for drinking water availability with respect to quality constraints were automatically identified using GIS tools. First, contours and zones were created from points by spatial modeling tools in the GIS. Then, the new layers of information were combined with the basin and administrative boundaries to yield desired results. The details of these procedures are explained later.

Finally, while some analyses directly used the results from GIS operations, some others required information from experts for the preparation final maps. In these cases the results were stored back in the GIS as new layers for purposes of presentation. The sectoral report on Domestic and Industrial Water supply is one such example.

Thus GIS provided a consistent and integrated documentation of the all the data and results in the study.

4.2 Agriculture and Irrigation

In this study GIS tools were extensively used for analyses in the agriculture and irrigation sector. The detailed specifications for the analyses are available in the Sectoral report E. In this section the application of GIS tools is looked at.

4.2.1 Land suitability for crops

The land suitability for crops is determined by factors such as soil properties (depth, sodicity, fertility, etc.), slope, landuse, temperature, and humidity. At any particular location the suitability for the cultivation of a particular crop can be decided if these values are known. In the GIS terminology, first the map layer for each factor must be created. Then, these must be combined by the polygon-overlay tool. This will yield a new layer where each location has the information on all the factors in the original layers. Now, the criteria for each crop can be applied to select the areas suitable for that crop. The results yield a new layer where the areas suitable and not suitable are marked. Here, the slope information was not readily available. The elevation data from contours were modelled as Triangulated Irregular Network (TIN)s and the map was classified based on slope values. The GIS approach yielded results of very high accuracy since the shapes of areas in the original layers were maintained in the analysis. In typical manual approaches, the layers must be first approximated into grids where the size and location of each cell unit must match for every layer. This process and the subsequent overlay is also very difficult to perform and check against errors, especially as the size of the grids decreases. The procedure for the analysis is shown in Figure S4.2.

In this study, land suitability analysis was performed for 14 different crops. Land suitability was decided by the factors such as soil properties (depth, sodicity, fertility, etc.), temperature, humidity, and slope. The soil map used is shown in Appendix S.2.1. The soil was classified based on the criteria shown in Appendix S.2.2. This yielded 390 different soil types as shown in Appendix S.2.3. The agroecological zone map comprising of humidity and temperature informations is shown in Appendix S.2.4 and described in Appendix S.2.5. The areas for landuse control (such as forests and national parks) are shown in Appendix S.2.6 and S.2.7. First, the TIN model was developed from contours and a slope map layer was developed. The layers for soil, landuse, temperature, humidity, and slope were combined. Now, the criteria for soil properties, landuse, temperature, humidy and slope (see Appendix S.2.8) were applied to select the suitable areas for the different crops. The areas were ranked as highly suitable (S1), moderately suitable (S2), marginally suitable(S3) and unsuitable(NS). Now the results can be visually seen in the computer terminal as a map. By combining the result layer with the administrative boundaries the suitable area in each administrative district can be obtained as a table (see Appendix S.2.9). Similarly, by combining the result layer with the basin boundaries the suitable area in each basin can be obtained as a table. The maps produced in the analysis for the 14 different crops - namely, beans, coffee, cotton, culture, fodder, maize, potato, pyrethrm, rice, sisal, sorghm, sugarcane, tea, and wheat - are shown in Figures S4.3 through S4.16.

4.2.2 Irrigation potential

Land that can be irrigated with river water must be within an accessible distance from the rivers. Such areas around rivers can be automatically created with GIS tools. By performing the buffer operation with the rivers, a new layer can be created showing the area within the required distance from the rivers and outside it. This layer can be then combined with the layer showing the suitable areas for each crop. Then, the area that is suitable for cultivation and within the buffer can be selected to yield the results of irrigation suitability. When this layer is overlaid with administrative boundaries, the irrigation potential can be estimated for each administrative unit. The procedure for the analysis is shown in Figure S4.17.

In this study first the suitable areas for representative crops were identified as explained in Section 4.2.1. All these suitable areas were combined to get the overall cultivable areas. Here the areas marked S1, S2, S3 are all cultivable. The areas in the upland and lowland (based on slope information) were summarized separately. (For example, Paddy is a lowland crop, Maize is one of upland crops). The available areas around the rivers for irrigation were identified by creating a buffer of 2km around the rivers. The results are as shown in Figure S4.18. The buffer layer was combined by a polygon-overlay with the cultivable areas to yield the irrigation potential results. By combining the results with the administrative boundaries and basin boundaries, the area in each administrative district and basin respectively were obtained as a table. The maps produced in the irrigation potential analysis for upland and lowland crops are shown in Figures S4.19 and S4.20.

4.3 Groundwater Resources

Groundwater information from the borehole surveys were obtained in the form of tables for input into the GIS. There were more than 7000 records on boreholes which were spread all over Kenya. To perform easy checks on the data input, the records were geographically coded using the latitude and longitude information of each borehole. This was quickly registered as a layer with the other UTM based layers like basin boundaries. So it was possible to check, for example, the basin number, map sheet number in each bore hole by actually visually overlaying the basin map and map sheet boundaries in the display. Other rigorous checks for consistency were also performed on the data and these were spatially displayed for check by experts. The bore holes were classified based on the geology conditions at their location using GIS techniques. The point-in-polygon tool was used between the borehole layer and geology layer to obtain for each borehole the geology situation in its location.

4.3.1 Groundwater quality

The water quality information, such as levels of Sodium, Calcium, Chloride, and pH scale, was available in a table (see Appendix S.3.1). Usually experts would draw contours on the maps to identify areas of different levels of quality for each index like Sodium. But with data volumes, as in this study, it is quite difficult to draw contours manually. Here GIS tools were used to enhance the process. For example, to draw contours for levels of electrical conductivity , first the boreholes with electrical conductivity tests data were mapped out (see Appendix S.3.2). Then, a spatial model based on TIN was developed using the Sodium level at each point. Then contours were automatically developed after considering smoothing for errors and so on (see Appendix S.3.3). Water quality levels are not spatially continuously like elevation. The levels vary depending on the geological conditions as well. So it was required to perform the TIN model for homogeneous areas with respect to geology and then combine the results to get accurate contours representing the distribution of water quality levels. To achieve this, the boreholes were classified based on geology by performing the point-in-polygon operation with the geology layer.

After developing the layers for the contours for each water quality index, the land was classified based on acceptable levels of each index for drinking and irrigation purposes. The details of the levels can be seen in Sectoral Report C. Then, the suitable area for drinking water was obtained by combining the layers representing suitable areas with respect to each index through a polygon overlay operation in GIS. The results were then combined with administrative boundaries and basin boundaries to estimate the groundwater potential for each administrative unit and sub basin. The procedure can be pictorially explained as shown Figure S4.21. The map explaining the results of groundwater availability for drinking is shown in Figure S4.22.

Similar operations were performed for estimating the areas with suitable groundwater for irrigation. The criteria for identifying irrigable groundwater suitability with respect to each factor are shown in Appendix S.3.4. Here ranges classified as good and marginal are acceptable. The suitability maps for the different factors are shown in Appendix S.3.5. The overlay of these maps, that is, the map showing the areas with comprehensively suitable groundwater for irrigation is shown in Appendix S.3.6.

Then, the irrigation potential with groundwater was also estimated. For this purpose, the land suitability maps for the 14 different crops were combined by overlay to obtain the areas suitable in each administrative district comprehensively for all crops. Here the areas marked either S1, S2 or S3 for each crop are all suitable. The areas were classified as upland and lowland based on slope. (For example, Paddy is a lowland crop, Maize is an upland crop.) The results are shown Appendix S.3.7 and S.3.8. These results were combined by overlay with the groundwater suitability map for irrigation to yield the irrigation potential with groundwater. The maps of suitability are shown in Appendix S.3.9 and S.3.10.

4.4 Other Sectors

GIS database was used in some analyses in the sectoral reports from A through R. There is tremendous scope to apply GIS tools to other procedures for analysis in the study although they were not applied now. GIS was used to document the results of the analysis in all cases.

S5. SUMMARY OF APPLICATION OF GIS IN THE STUDY

5.1 Results of Master Plan in the GIS

The results of the Master Plan are discussed in sectoral reports A through R. The process by which these results were developed - namely, starting from data collection, database creation, spatial and statistical analysis, and expert evaluation for final presentation of results - is explained in Figure S5.1. Several details are omitted from this figure to focus on the flow of data for the analyses here. Basically, the future demand for water and the possible supply of water are balanced with alternatives such as development of new water resources or transfer schemes among other strategies. The important aspect here is to obtain these balances not only statistically but also temporally and spatially. The various data and results are marked on the side of the figure to indicate the corresponding sectoral reports. Then, the role of GIS in data manipulation is indicated using symbols where relevant. The details on the GIS tools have been explained earlier. The figure can easily convey the ability and advantage of GIS for integrating the different needs comprehensively such as for the master plan in this study. GIS is a powerful information management tool. The different types of information, such as maps, tables, procedures for analyses, and results of analyses can be maintained jointly by the GIS. The information which is spatial and non-spatial in nature can be integrated. Integration of such information provides a better platform for monitoring the overall progress of the study.
In this study the basic data and results of the sectoral analyses were all managed by GIS. They were used for developing the master plan which is the final output in the study.

5.2 Advantages of GIS for Explaining Results of the Master Plan

The study on Water Resources Master Plan focuses on providing balance between demand and supply of water resources over a vast area. The strategies in the study take into consideration the spatial parameters in the problem of matching the demand and supply. The results are better understood when presented on a map. With the GIS tools for database query, it possible to find out about a particular location information, such as the population forecast, the water demand, the available water for existing sources, and the strategies for new development. Also, it is possible look at the locations where new multi purpose projects are planned on the map. Thus GIS is very advantageous in decision making. The rank for a project in the study can be visualized on a map on the computer terminal and experts can query several underlying data and results of analysis that were the basis for arriving at such ranking. Thus it is possible to present the results of the study in an easily understandable fashion. Other results, such as the environmental impact analysis for proposed dam projects and land acquisition required for irrigation schemes, can also be visually shown on the map instead of just numbers such as total area or population affected.

5.3 Evaluation of Application of GIS in the Study

The application of GIS in the study was very cost effective from an overall perspective. There were many improvements in the quality of the results in the analysis. Much time required for conventional approaches based on manual operations was reduced drastically by the computerized approach in GIS. The time savings were useful for evaluating many alternatives in the water resources development. GIS improved the presentation of results. GIS provided an integrated database management approach that was essential in this comprehensive study.

GIS application had many difficulties as well. In developing countries like Kenya volumes of digital data must be input from paper. So the data preparation process is very expensive and time consuming compared with the manual approach of using paper maps in analyses. Input and management of digital data requires the knowledge of GIS contrary to the tracings done in the manual approach which can be done by ordinary persons at less costs. In this study, the input of data that are not required or not used in the analysis were not avoided in some cases. Such redundancy problems also concerns the detail of information. To efficiently handle such problems, it is required to first discuss the different requirements from the database perspective and then decide the data input strategy such as types of maps, attributes, date and scale of maps. Further, to efficiently use the GIS tools, the expert must study the capabilities of GIS and translate the manual approaches for analysis into GIS terminology. The examples in Groundwater analysis clearly explain this process. In such situations, a GIS expert is required in the project. Otherwise, the full potential of GIS may not be utilized in the analysis and it could make the data input less cost effective. Operating GIS tools also requires experience on computers. The procedures for analysis must be computerized as much as possible so that they can be linked to GIS. Then, it possible to show the changes in results when some parameters are alternated and thus evaluate alternatives in the decision making. Otherwise the results of the study stored in GIS will not be correct.

TABLES

Table S3.1 List of Data in the GIS Database for the Study

Data	Information on Data Scale, Number of sheets	Approach for Input into Database
Socioeconomy Population Industry	 Tables Tables	 Automatic data transfer after tabular input
Meteorology Rainfall Temperature Humidity	 1:5000000 1:5000000 1:5000000	 Digitizing
Natural Resources National Parks forests Landuse Soil	 1:2000000 1:2000000 1:1000000, 2 sheets 1:1000000, 2 sheets	 Digitizing
Topography Contours	 1:100000, 41 sheets	 Digitizing
Water Resources Rivers Basin Boundary	 1:2000000 1:2000000	 Digitizing
Georeference Cities Administrative boundary	 1:100000, 41 sheets 1:100000, 41 sheets	 Digitizing
Groundwater Borehole Water Quality	 Tables Tables	 Automatic data transfer
Geology	1:1000000, 2 sheets	Digitizing
Landcover	Remote sensed images LANDSAT (31 scenes) NOAA, SPOT	Image processing Raster to vector conversion

FIGURES

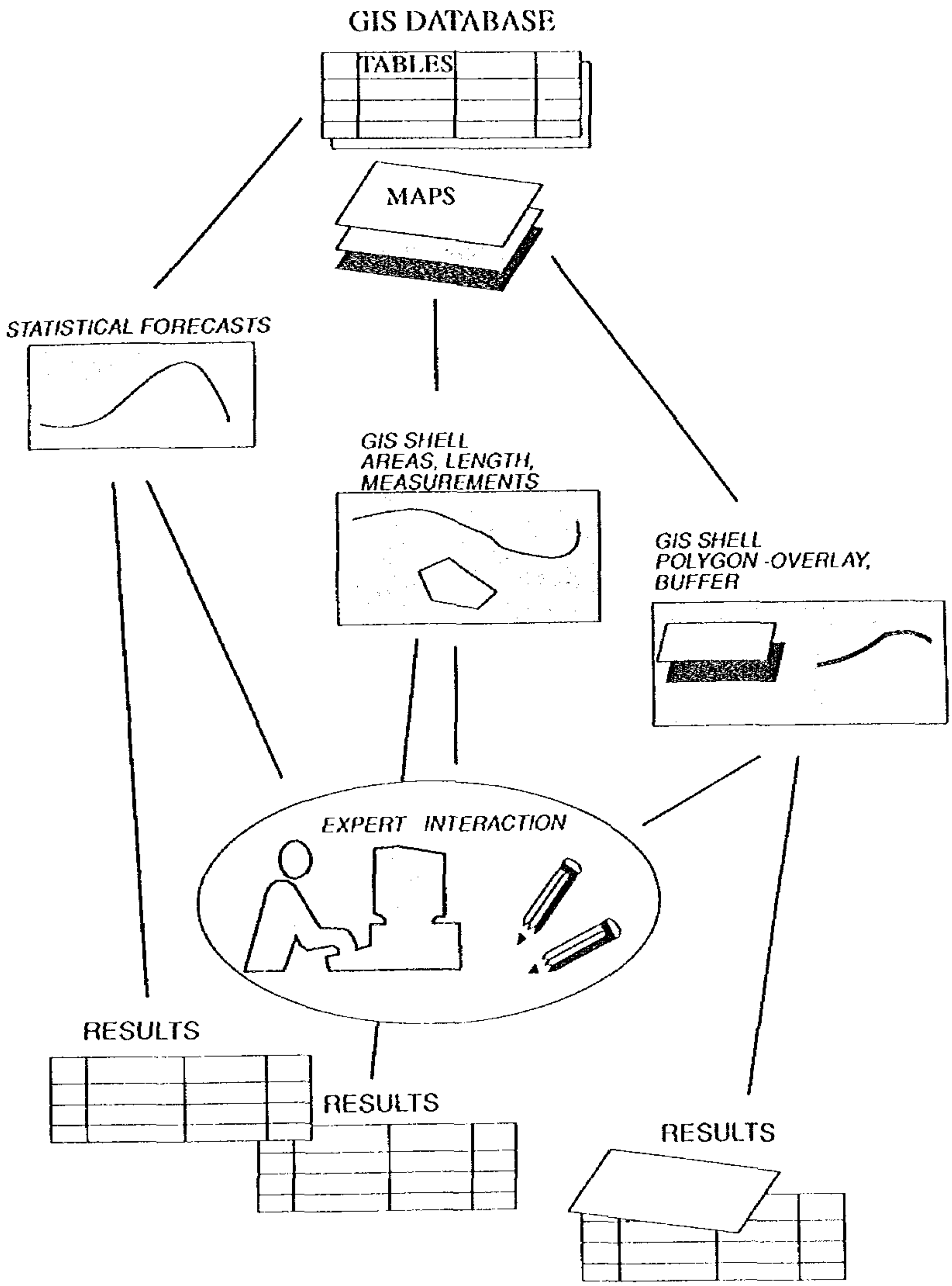

Figure S-4.1 Scenario of Application of GIS in Each Sector in the Study

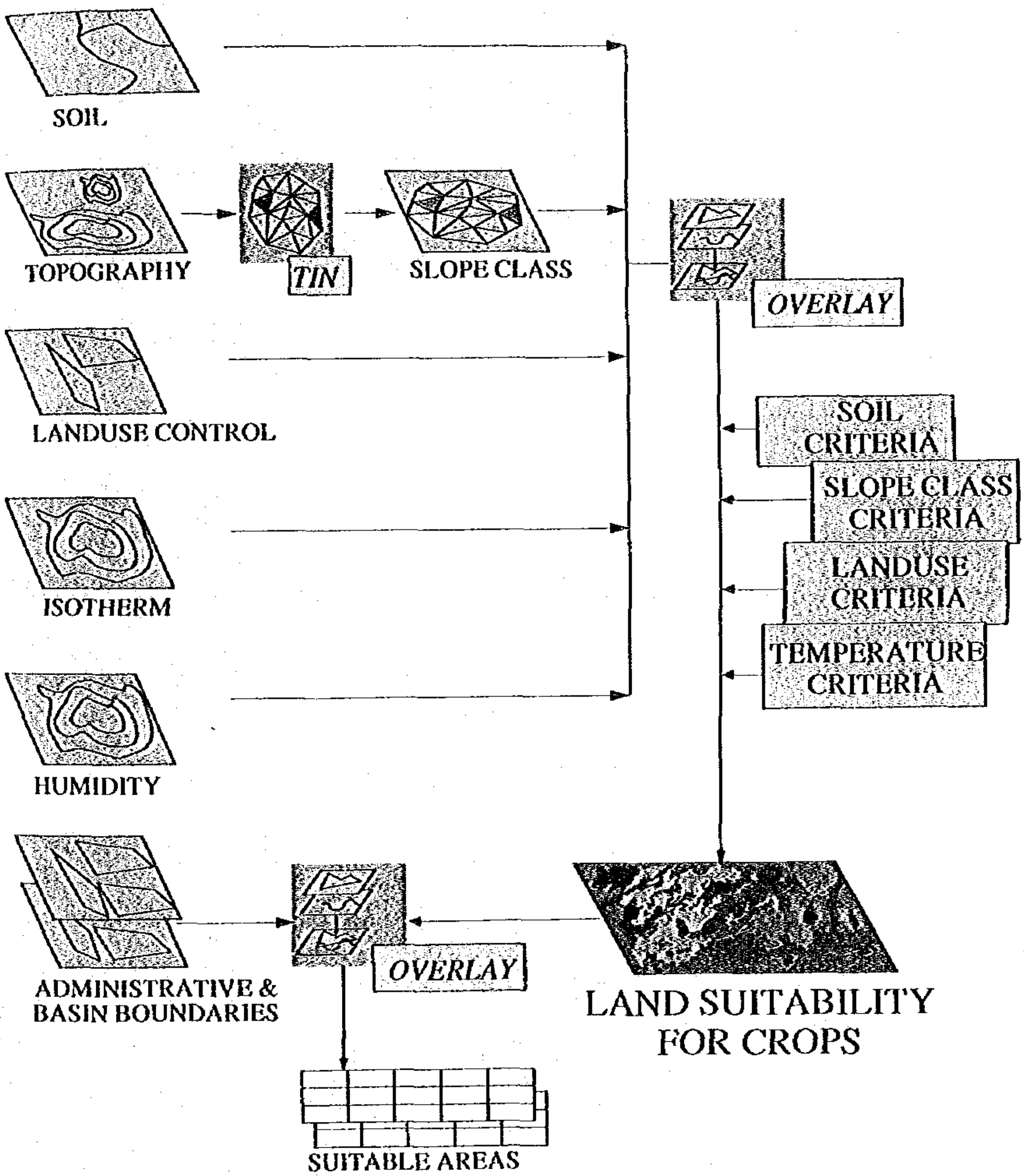

Figure S-4.2 GIS Based Procedure for Land Suitability Analysis

THE STUDY
ON
THE NATIONAL WATER MASTER PLAN

JAPAN INTERNATIONAL COOPERATION AGENCY

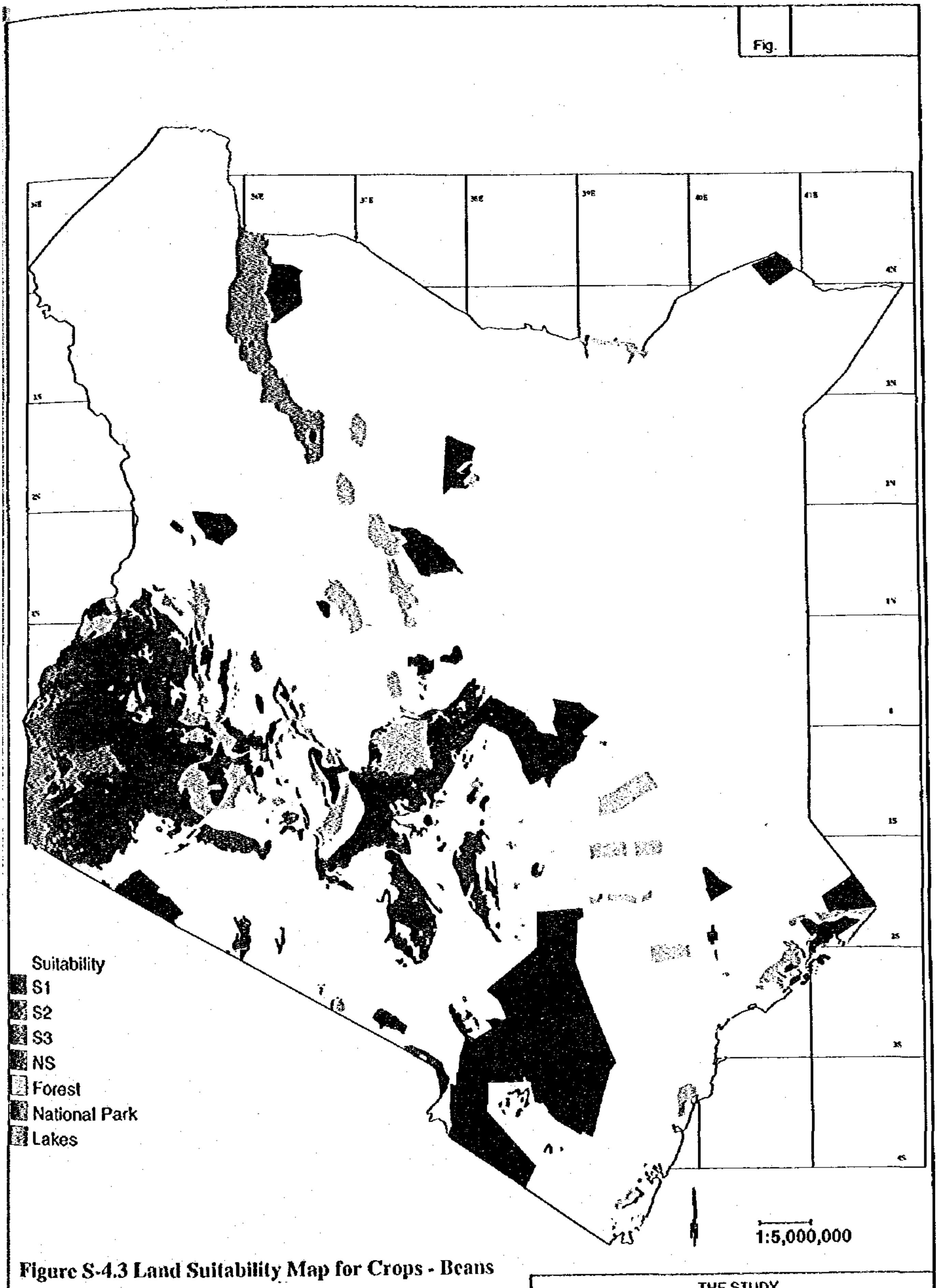

Figure S-4.3 Land Suitability Map for Crops - Beans

THE STUDY
ON
THE NATIONAL WATER MASTER PLAN

JAPAN INTERNATIONAL COOPERATION AGENCY

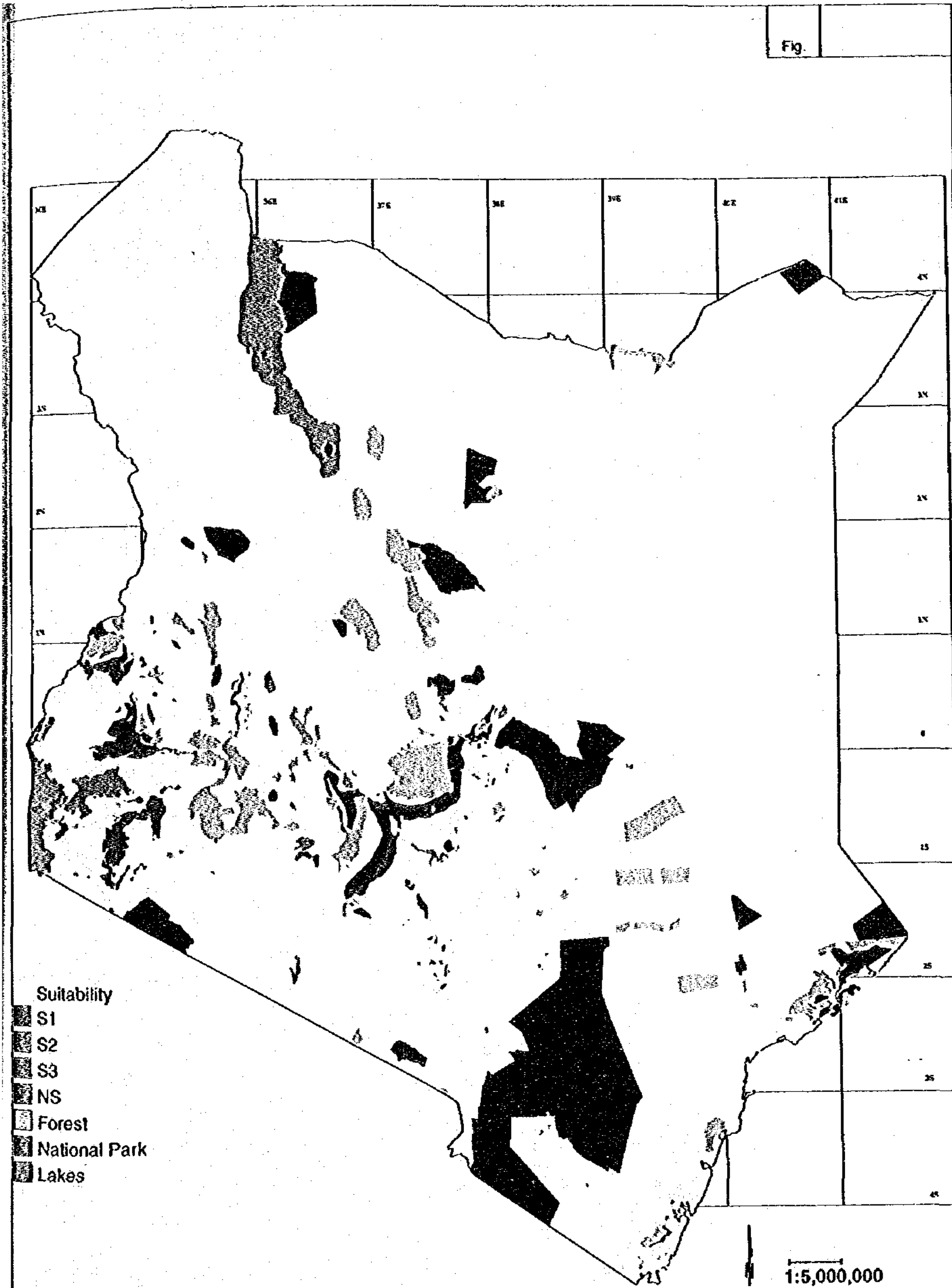

Figure S-4.4 Land Suitability Map for Crops - Coffee

THE STUDY
ON
THE NATIONAL WATER MASTER PLAN

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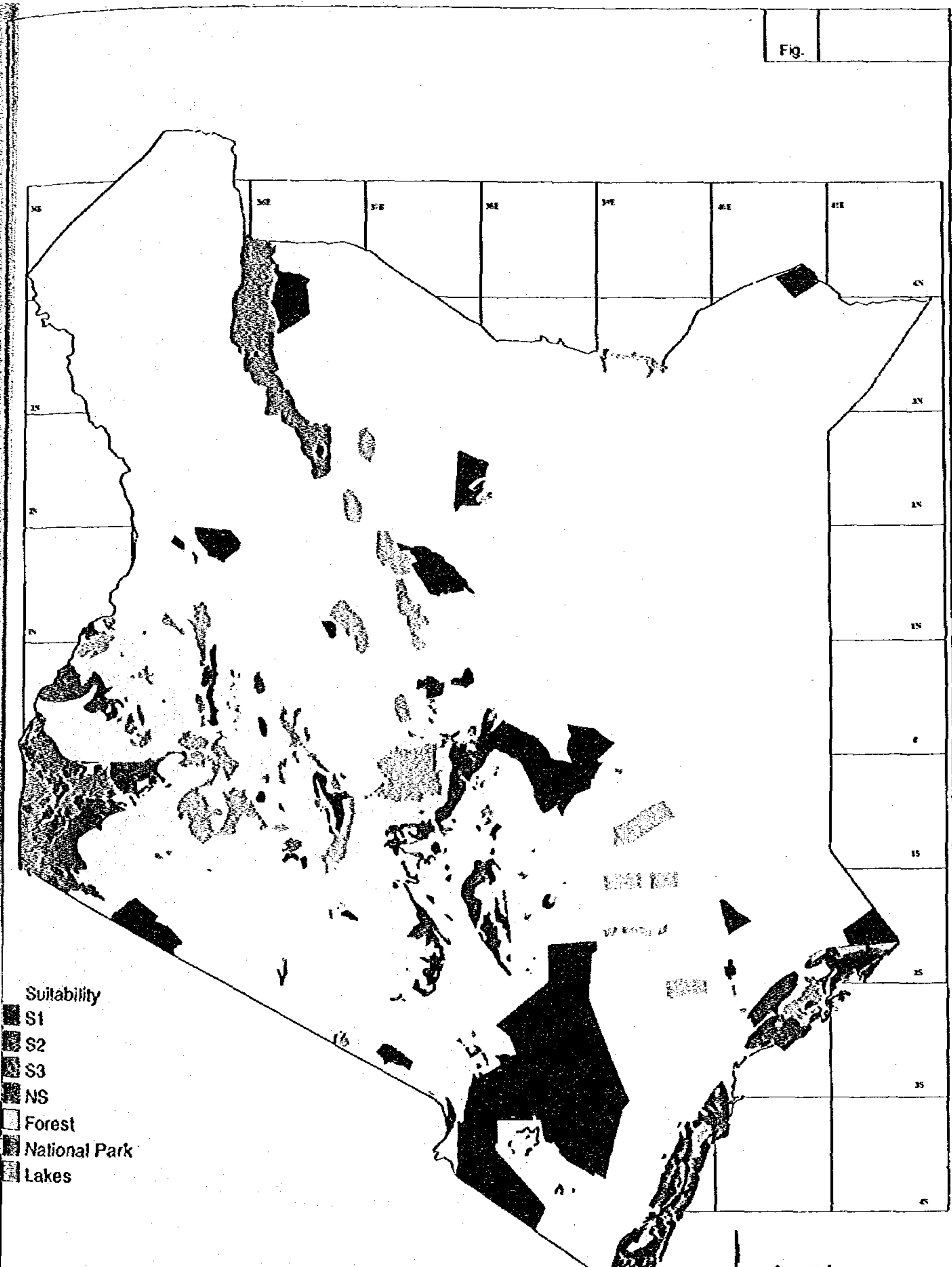

Figure S-4.5 Land Suitability Map for Crops - Cotton

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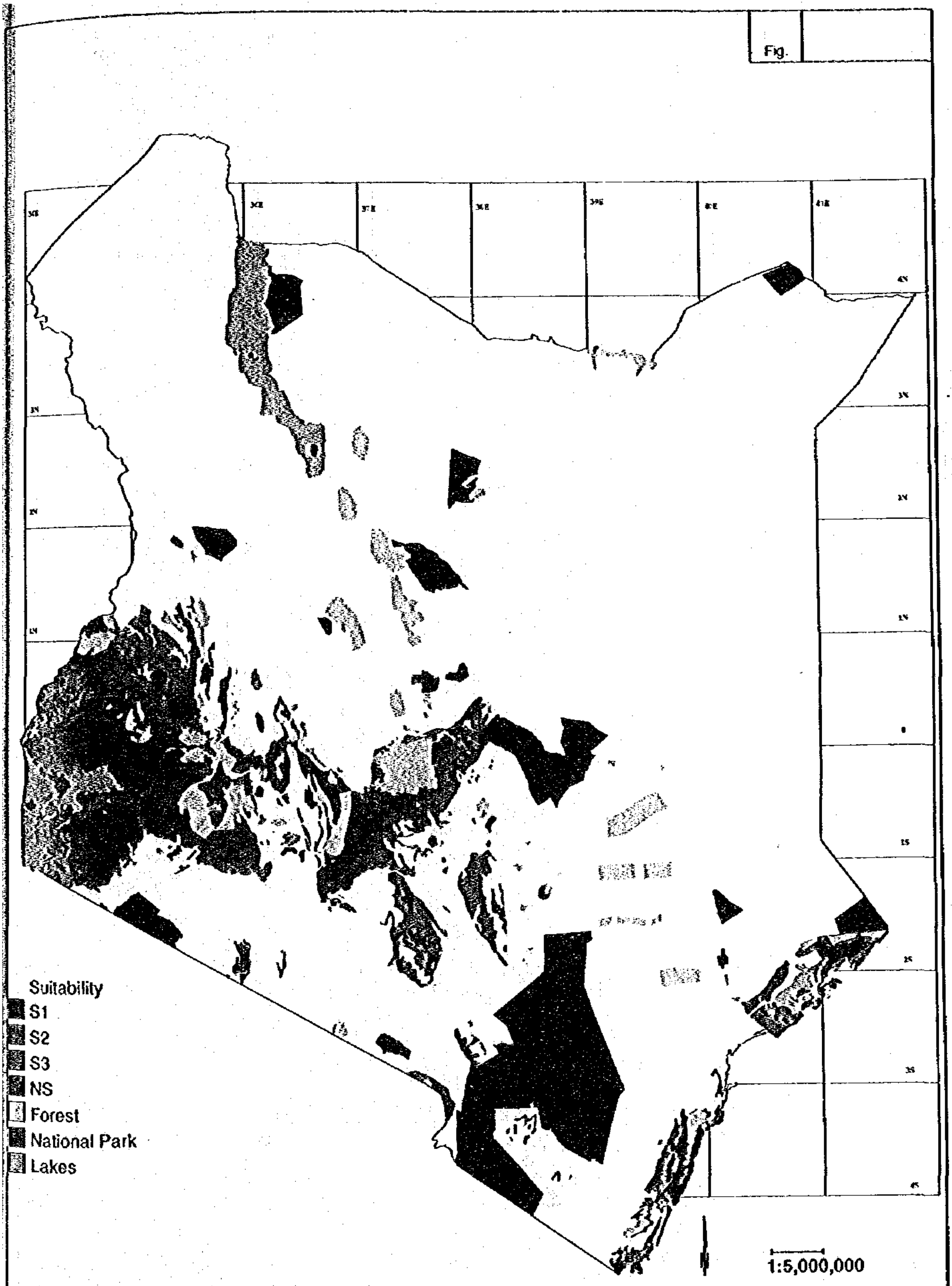

Figure S-4.6 Land Suitability Map for Crops - Culture

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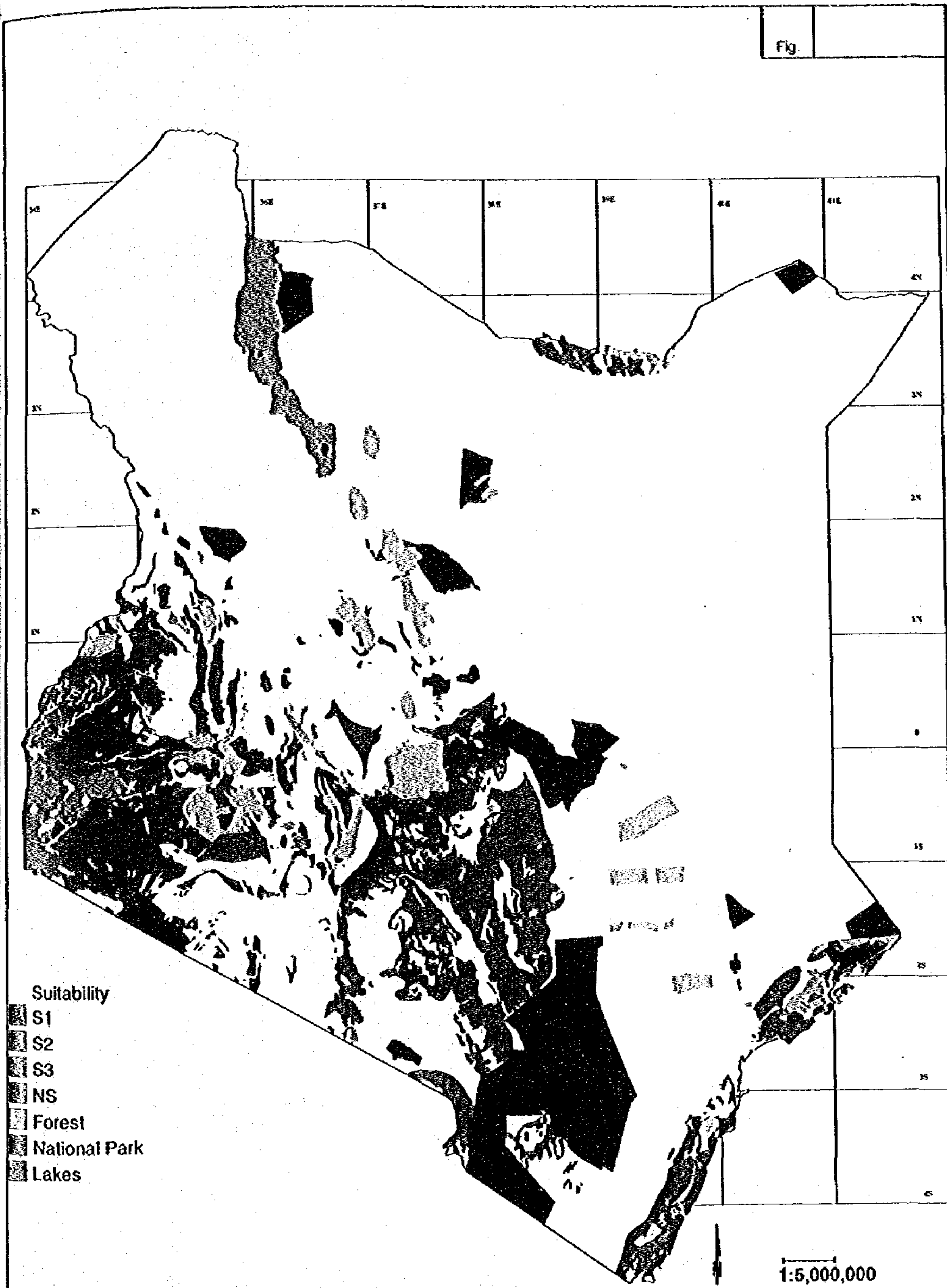

figure S-4.7 Land Suitability Map for Crops - Fodder

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Fig.

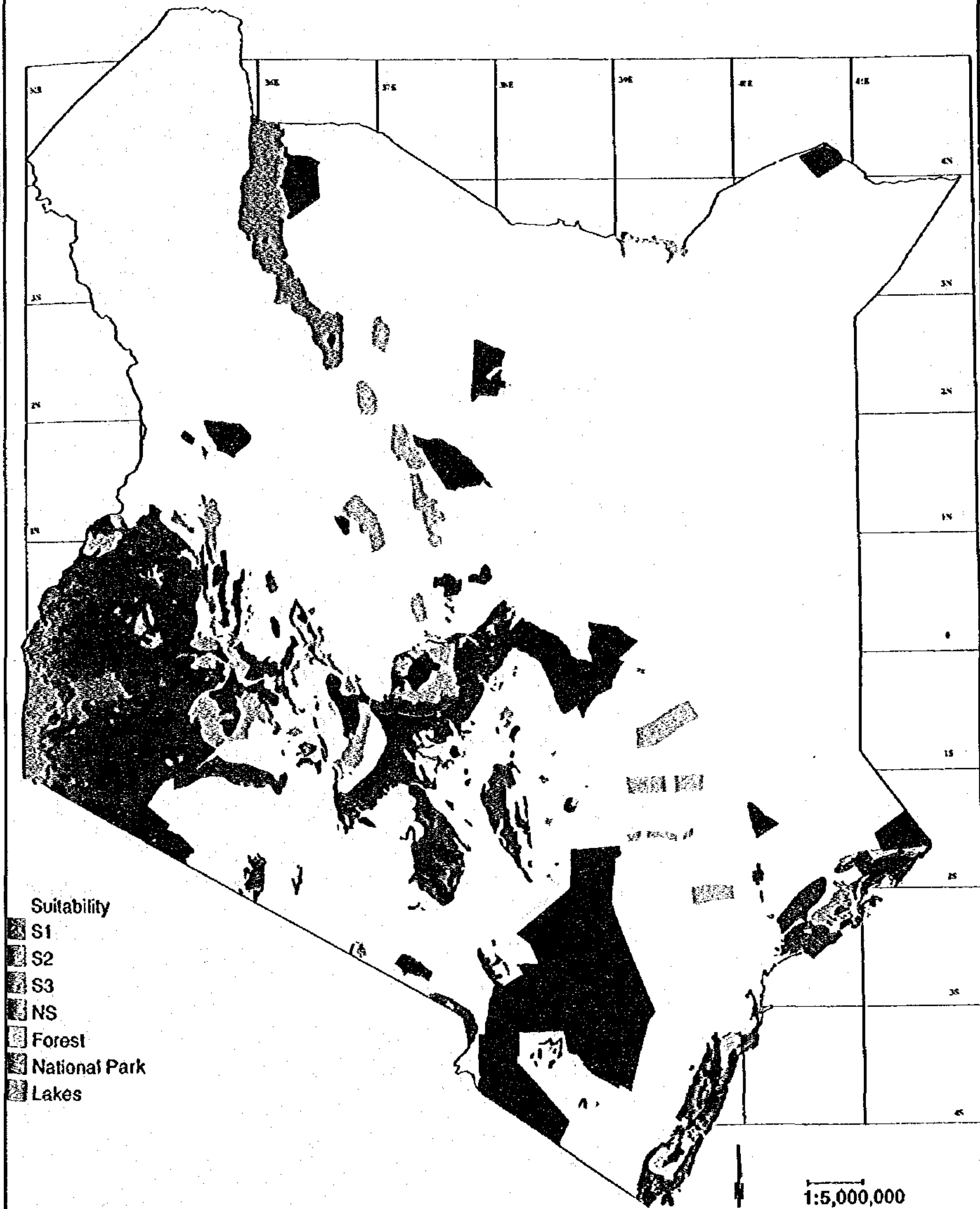

Figure S-4.8 Land Suitability Map for Crops - Maize

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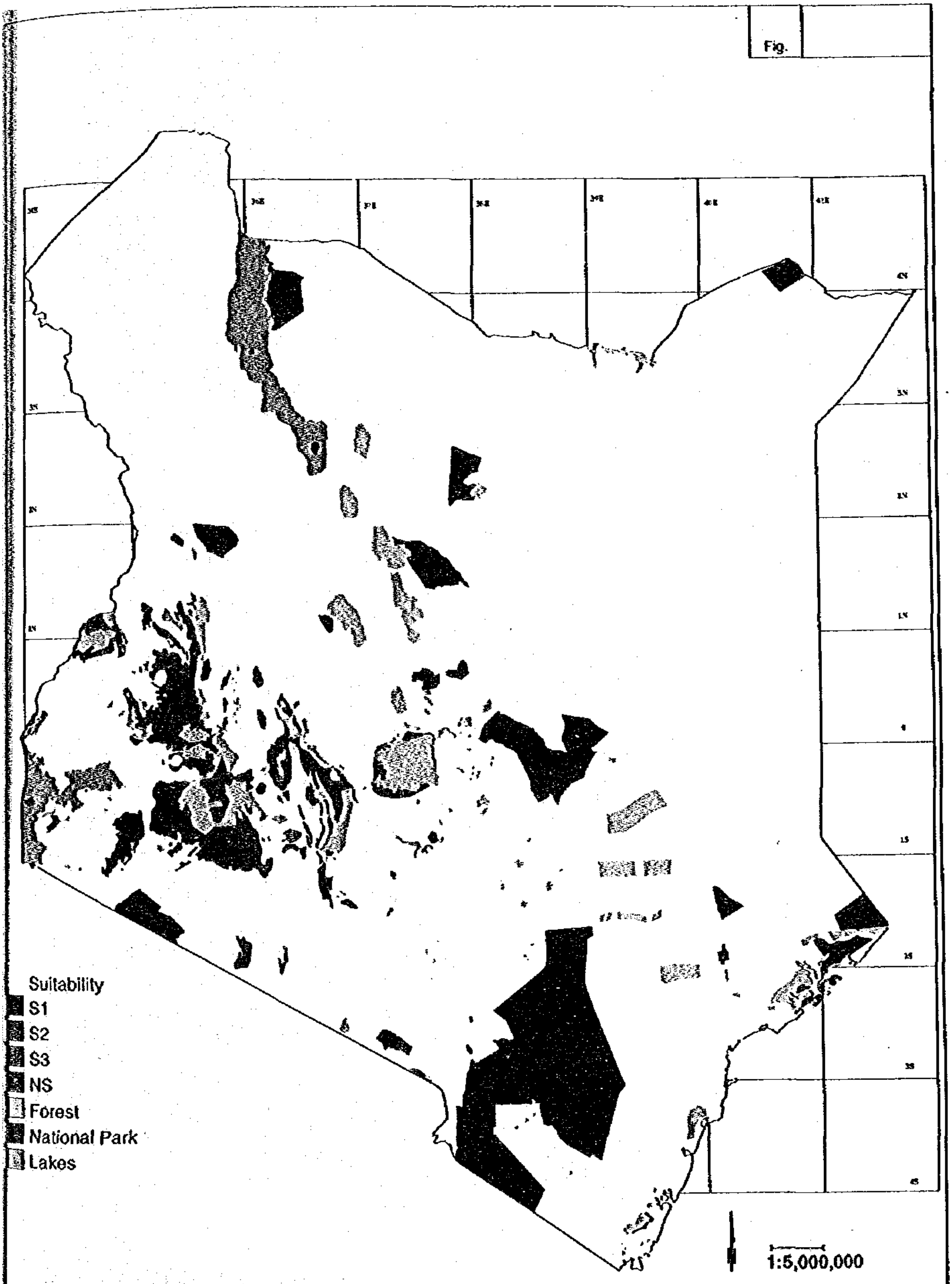

Figure S-4.9 Land Suitability Map for Crops - Potato

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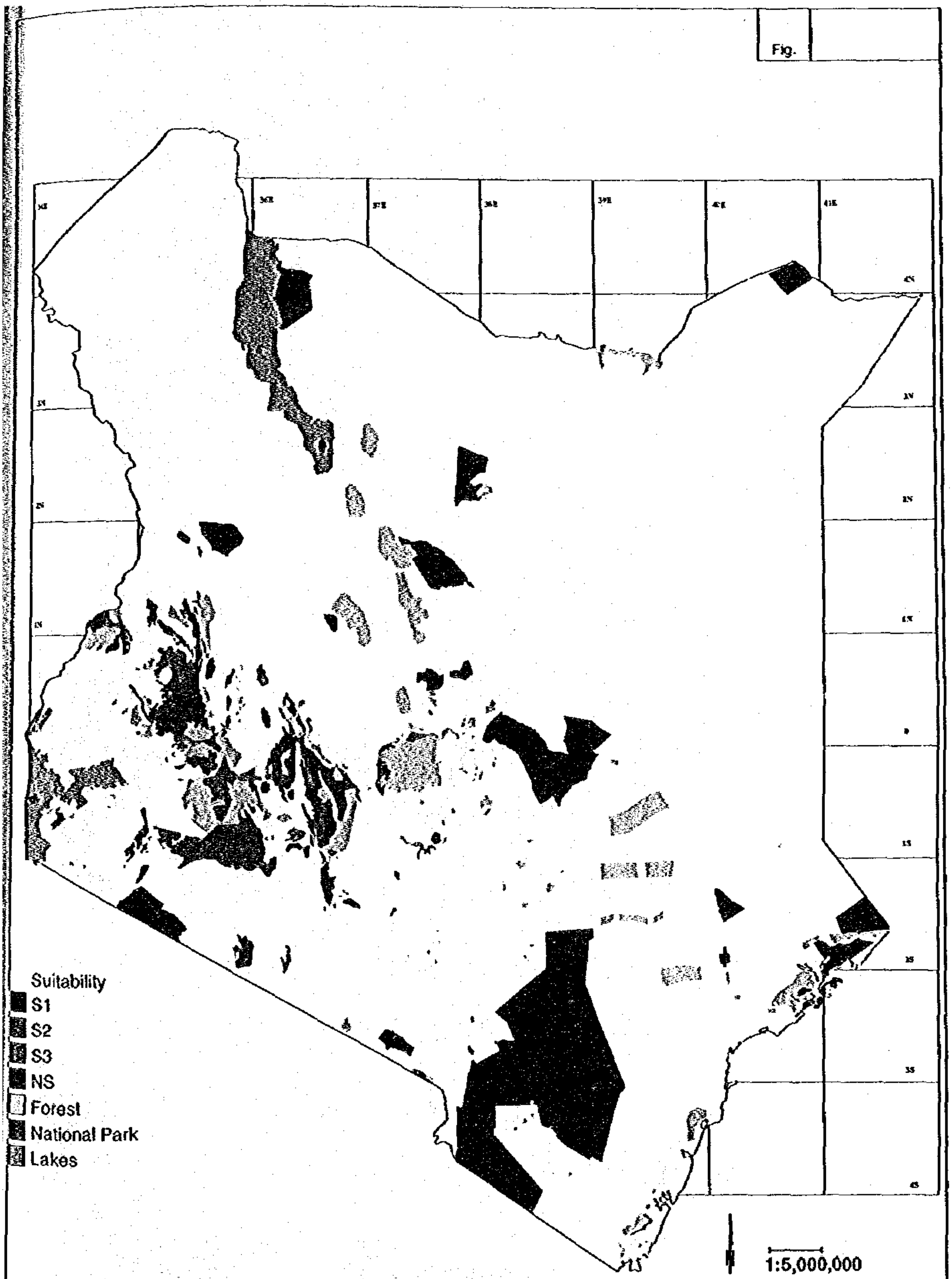

Figure S-4.10 Land Suitability Map for Crops - Pyrethrm

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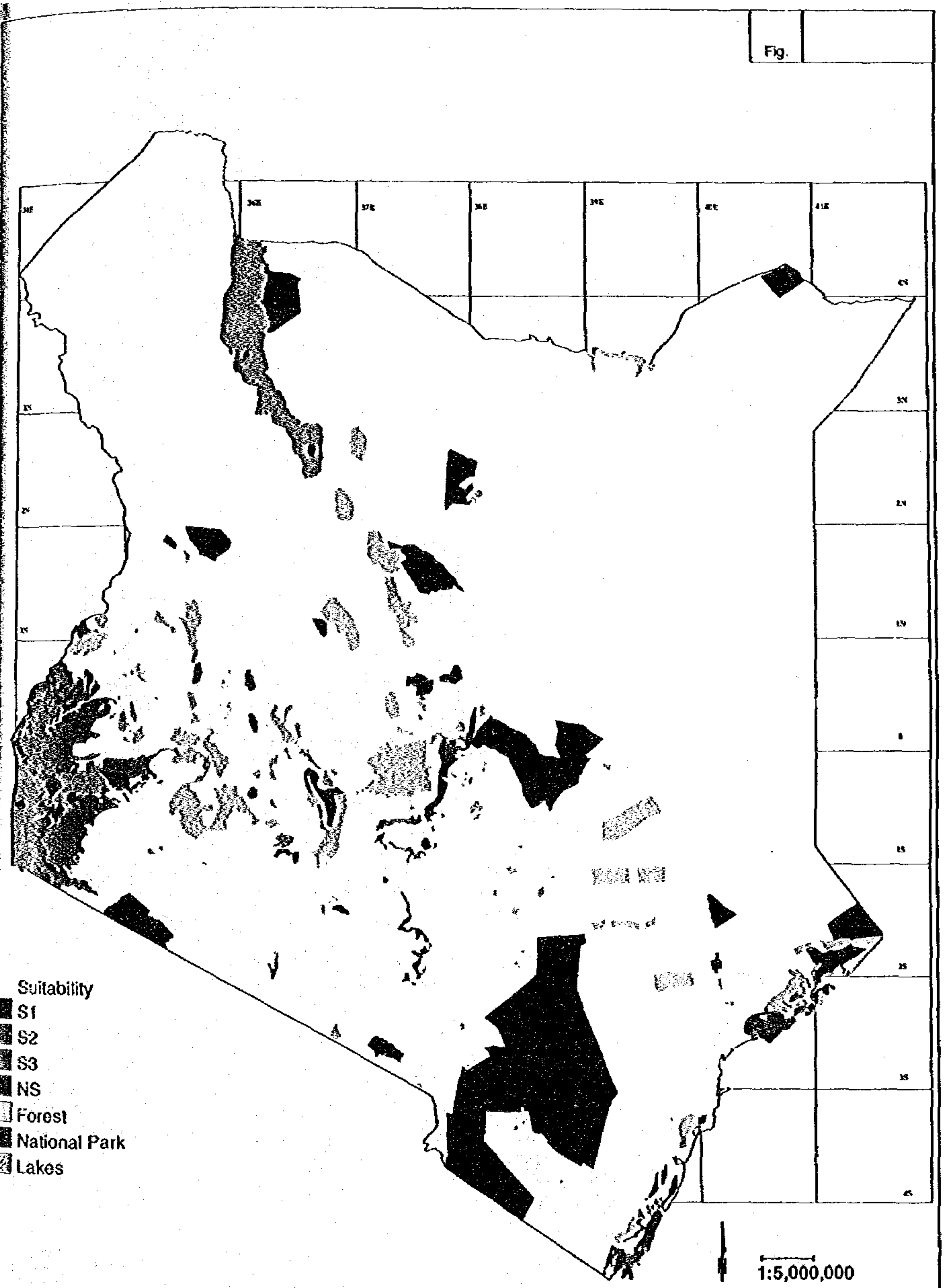

Figure S-4.11 Land Suitability Map for Crops - Rice

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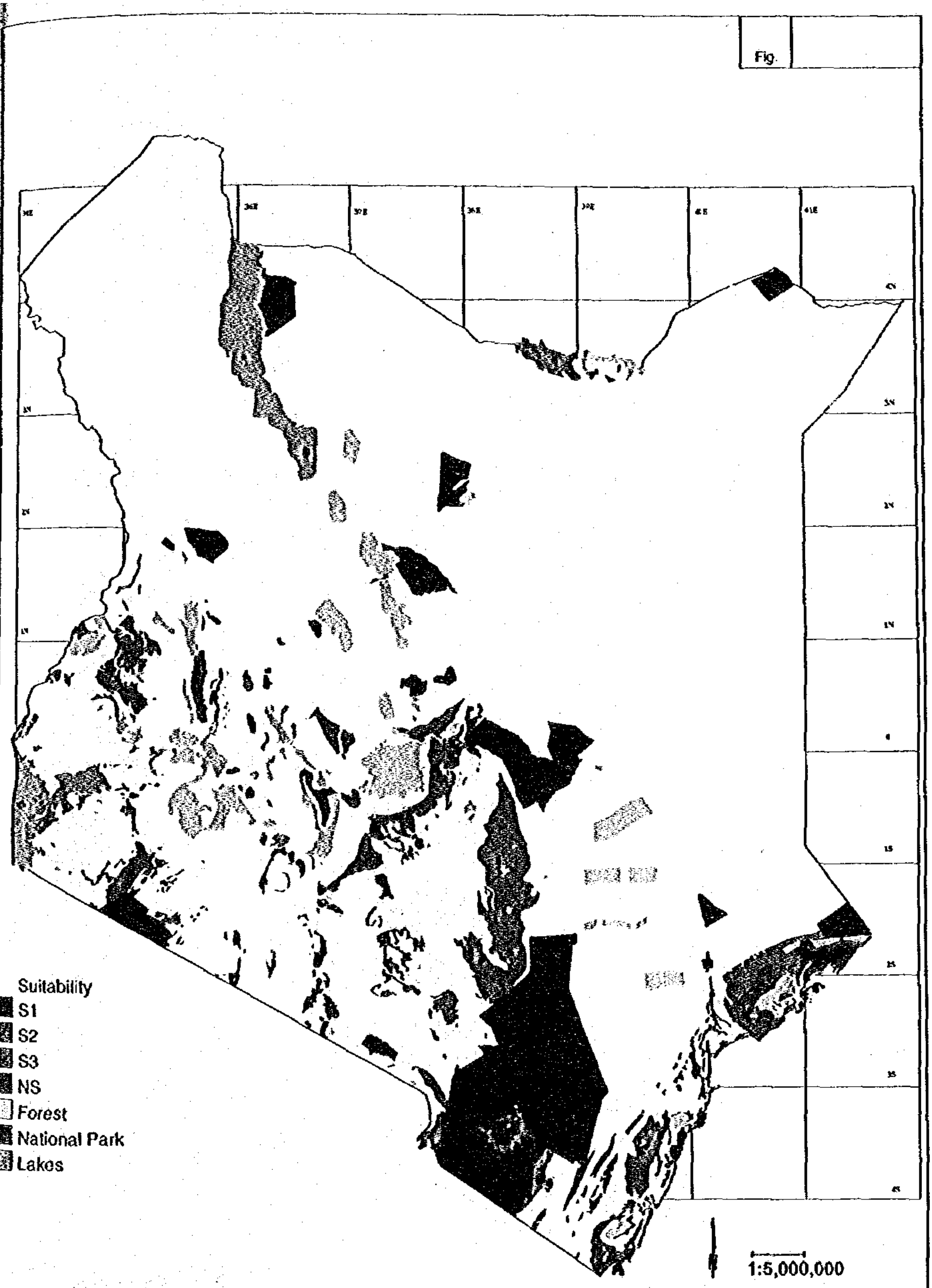

Figure S-4.12 Land Suitability Map for Crops - Sisal

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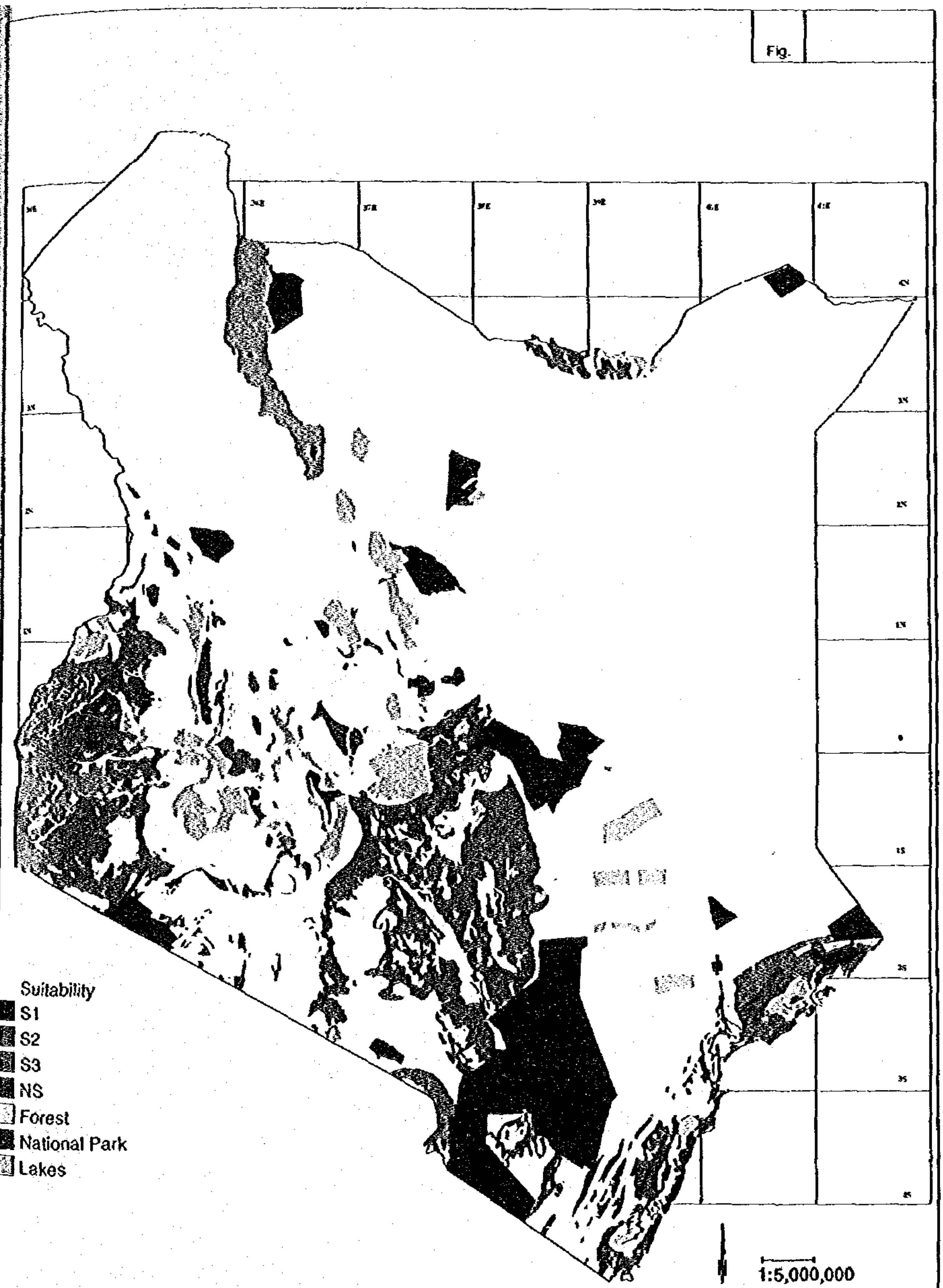

Figure S-4.13 Land Suitablility Map for Crops - Sorghm

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Fig.

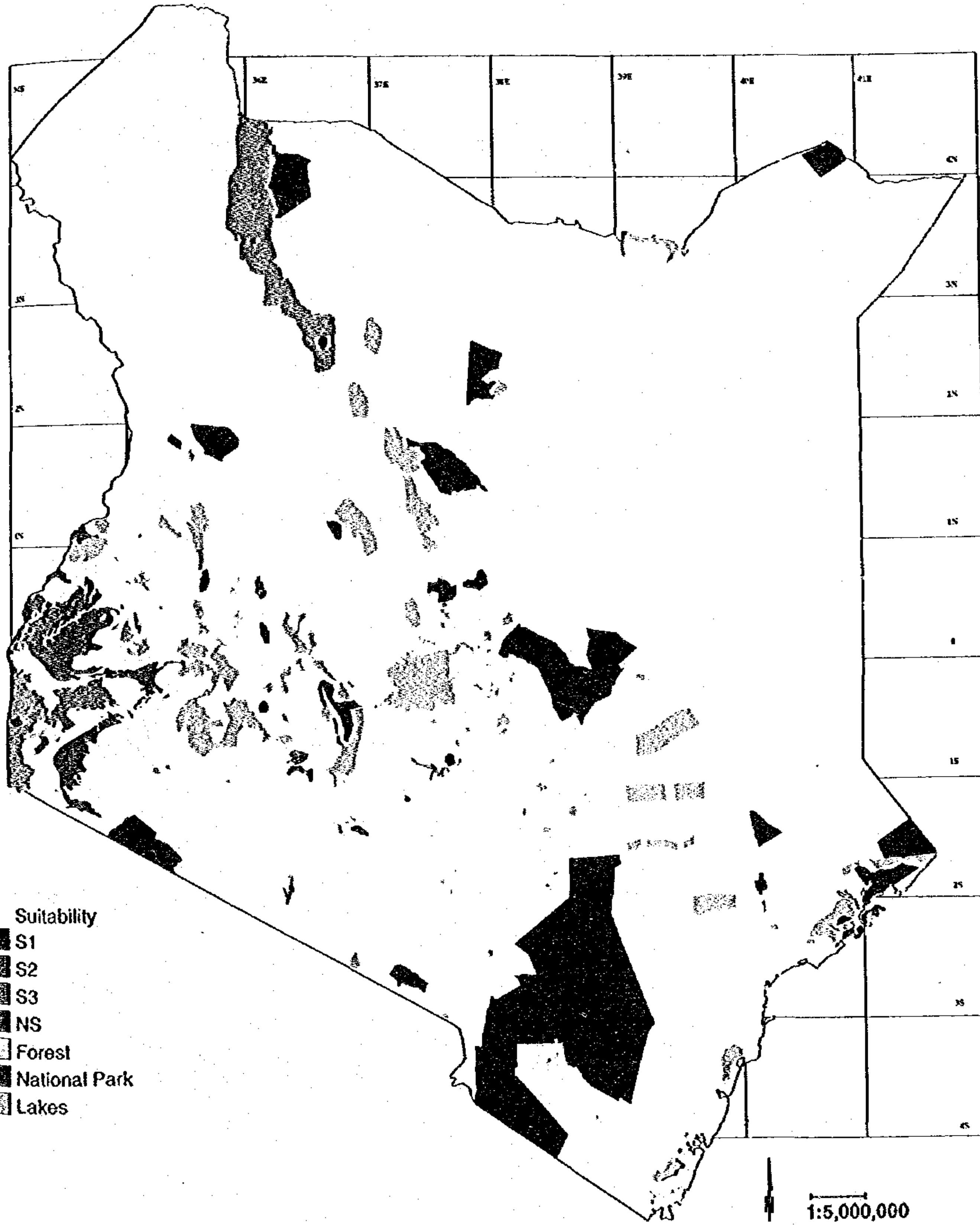

Figure S-4.14 Land Suitability for Maps - Sugarcane

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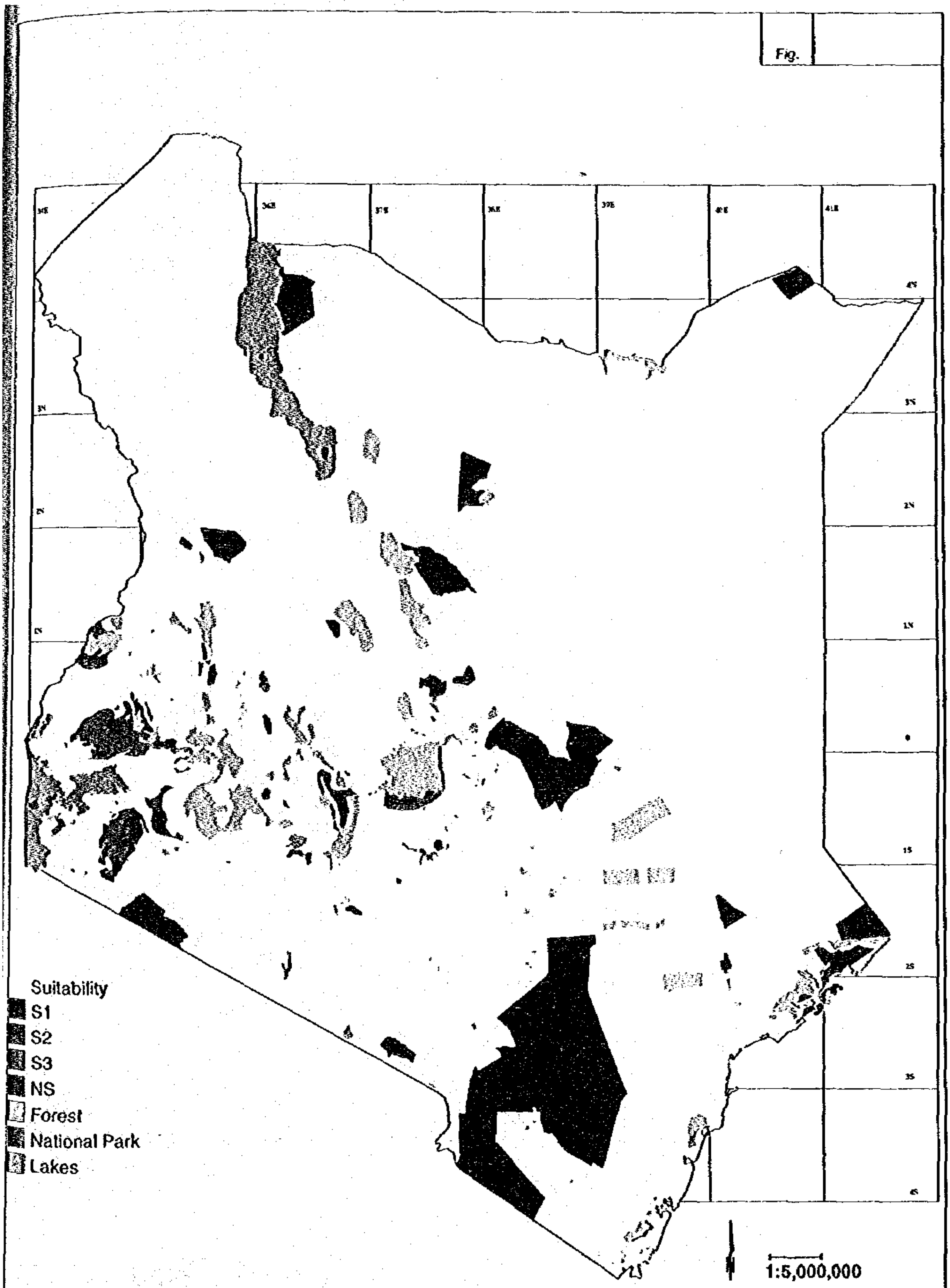

Figure S-4.15 Land Suitability Map for Crops - Tea

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Fig.

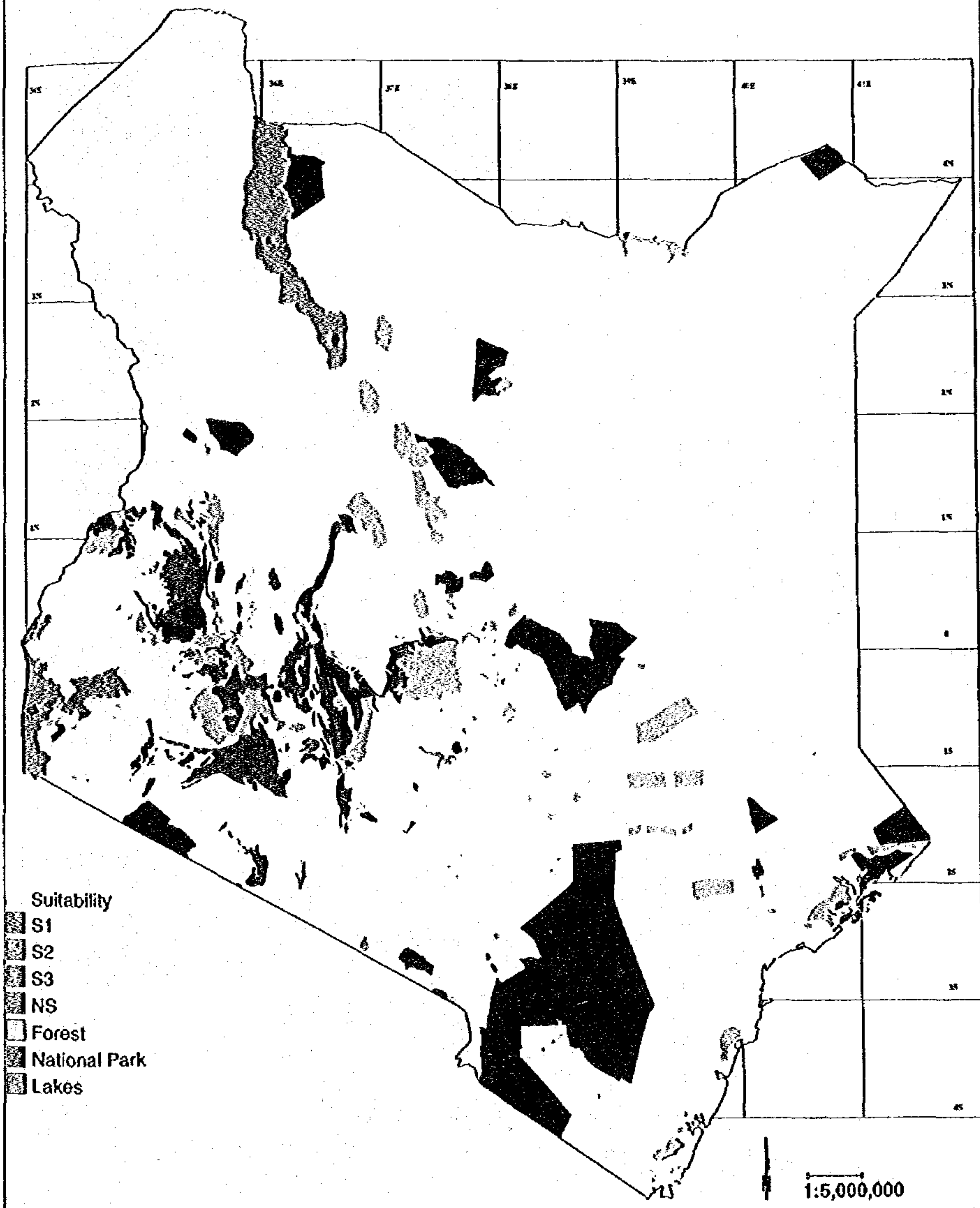

Figure S-4.16 Land Suitability Map for Crops - Wheat

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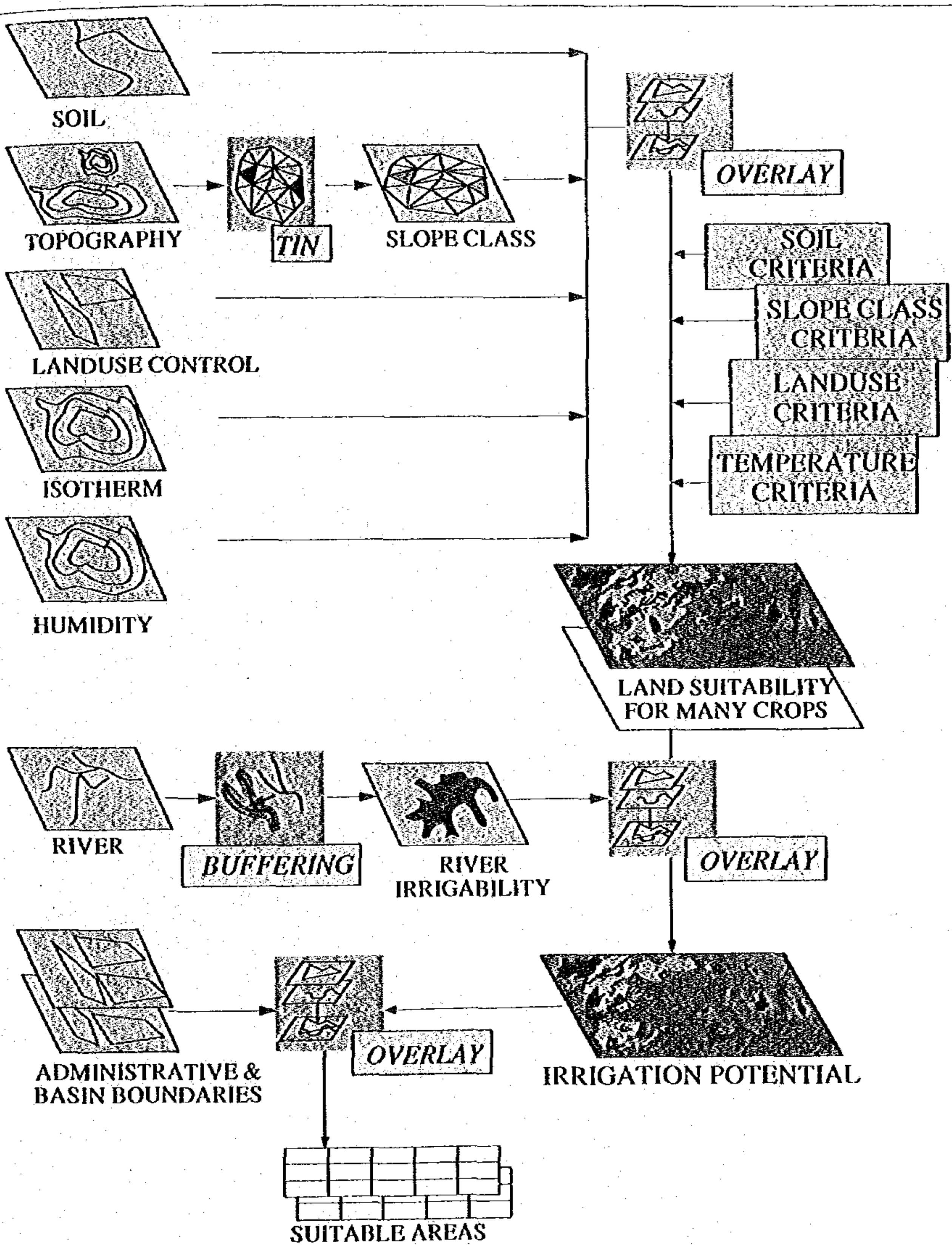

Figure S-4.17 GIS Based Procedure for Irrigation Potential Analysis

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Fig.

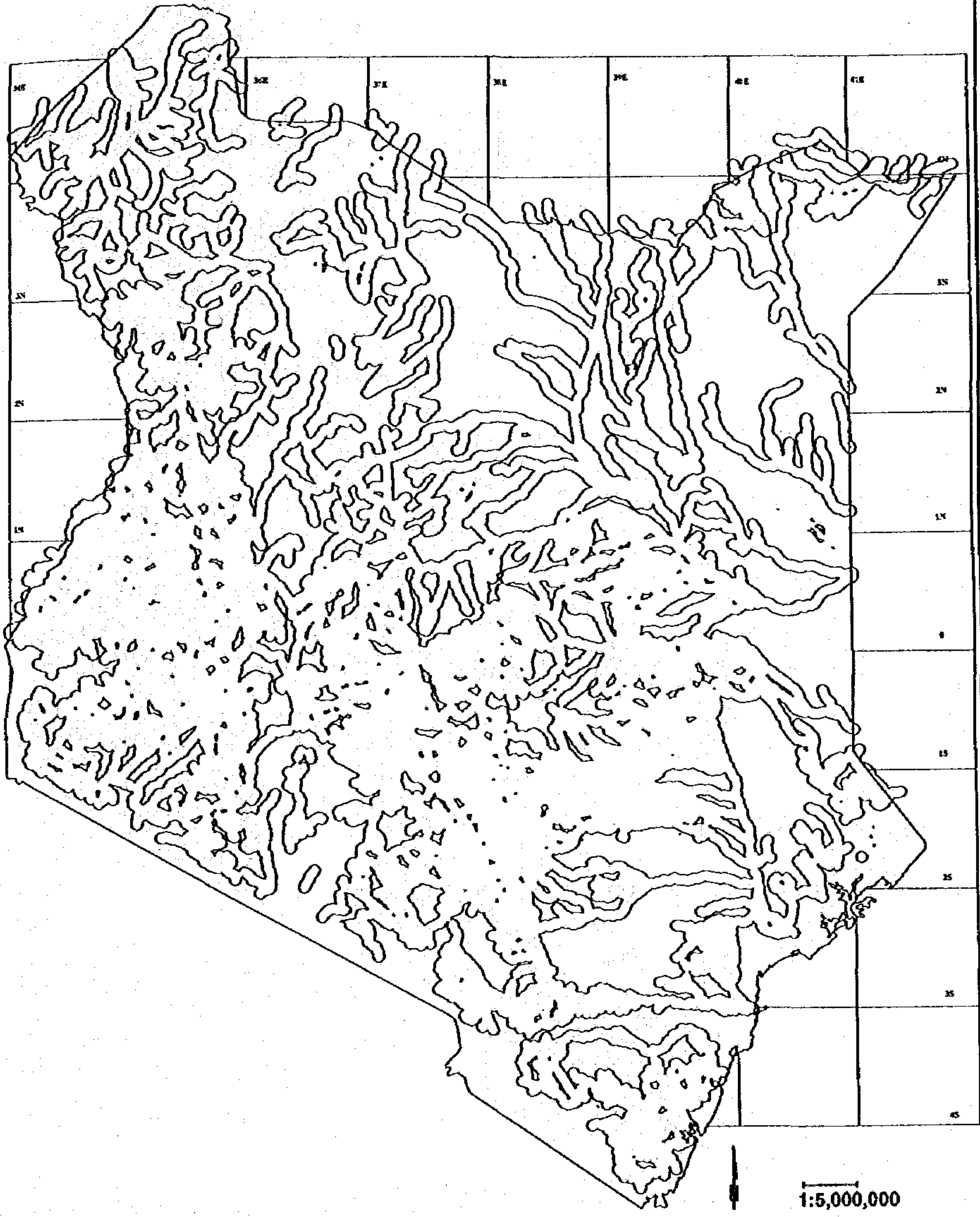

Figure S-4.18 Buffer Area around Rivers-for irrigation

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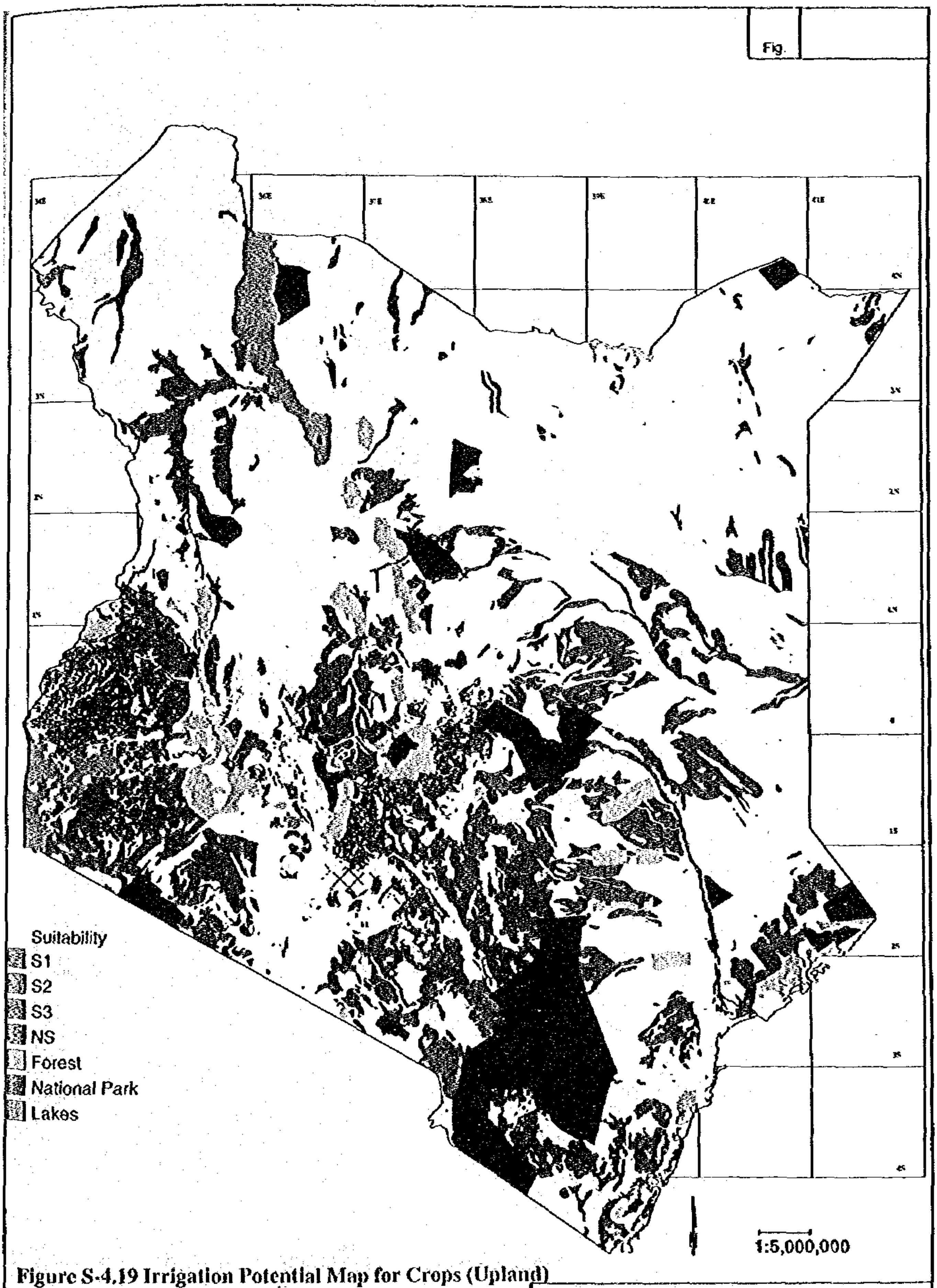

Figure S-4.19 Irrigation Potential Map for Crops (Upland)

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Fig.

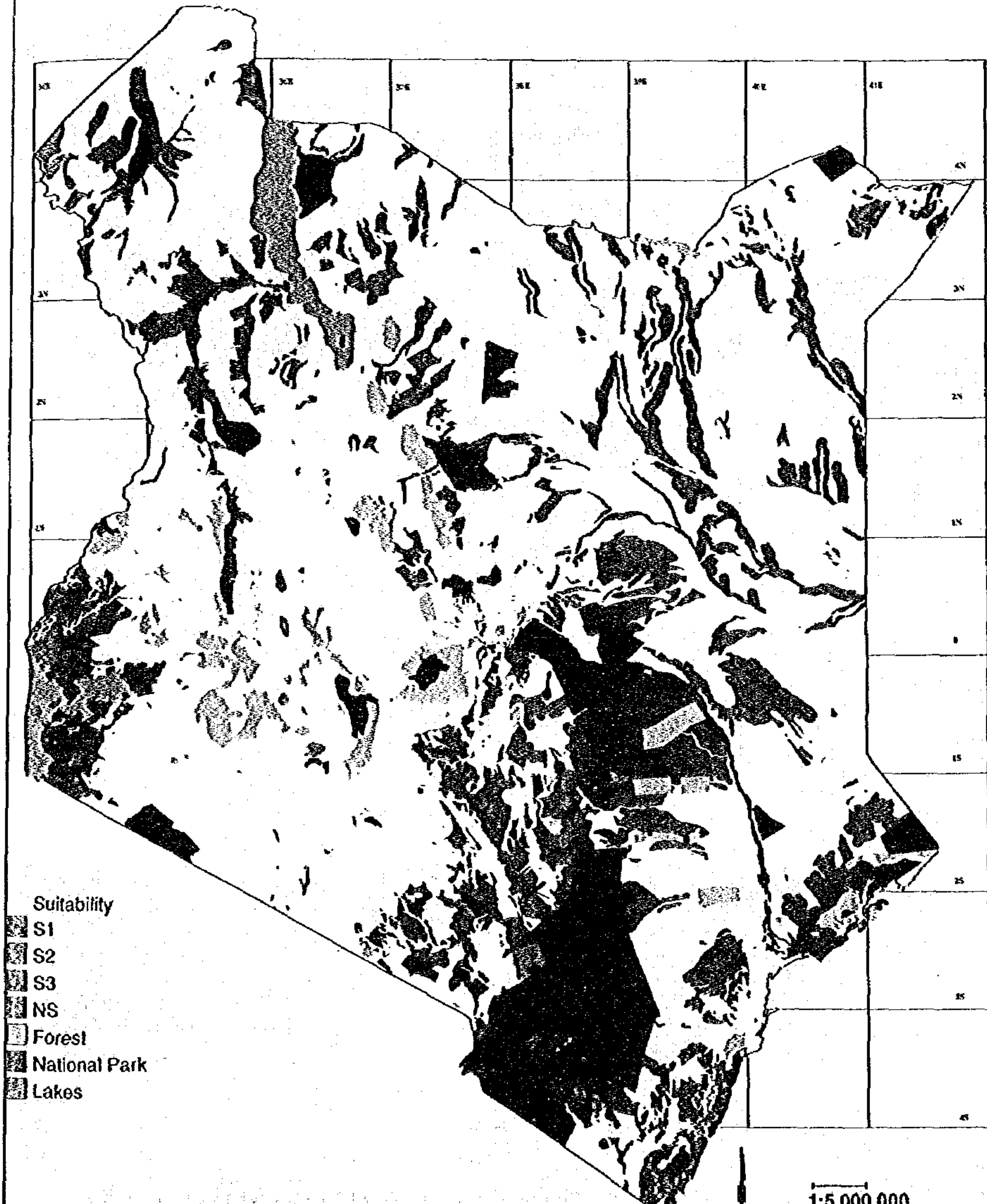

Figure S-4.20 Irrigation Potential Map for Crops (Lowland)

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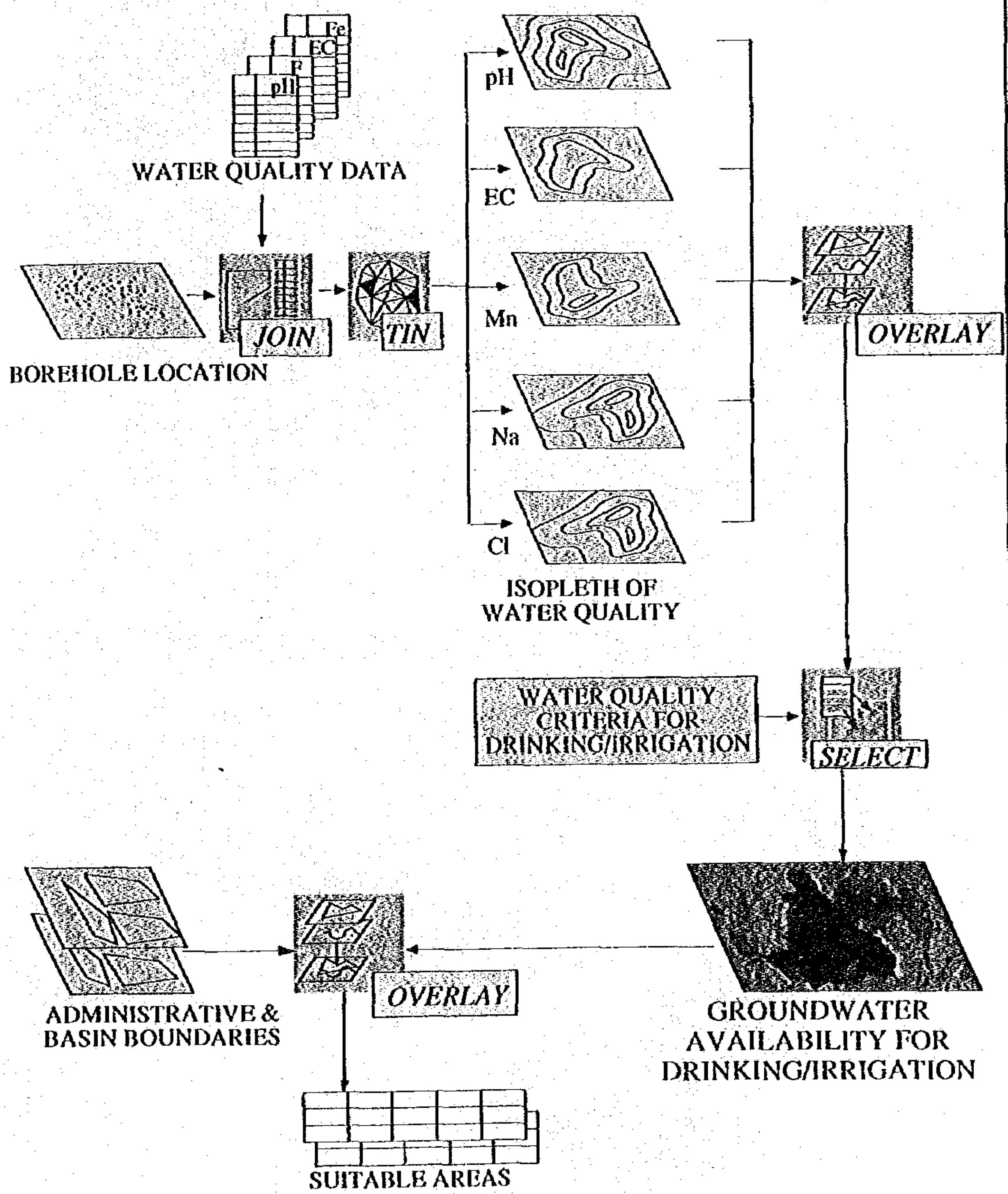

Figure S-4.21 GIS Based Procedure for Groundwater Potential Analysis

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Fig.

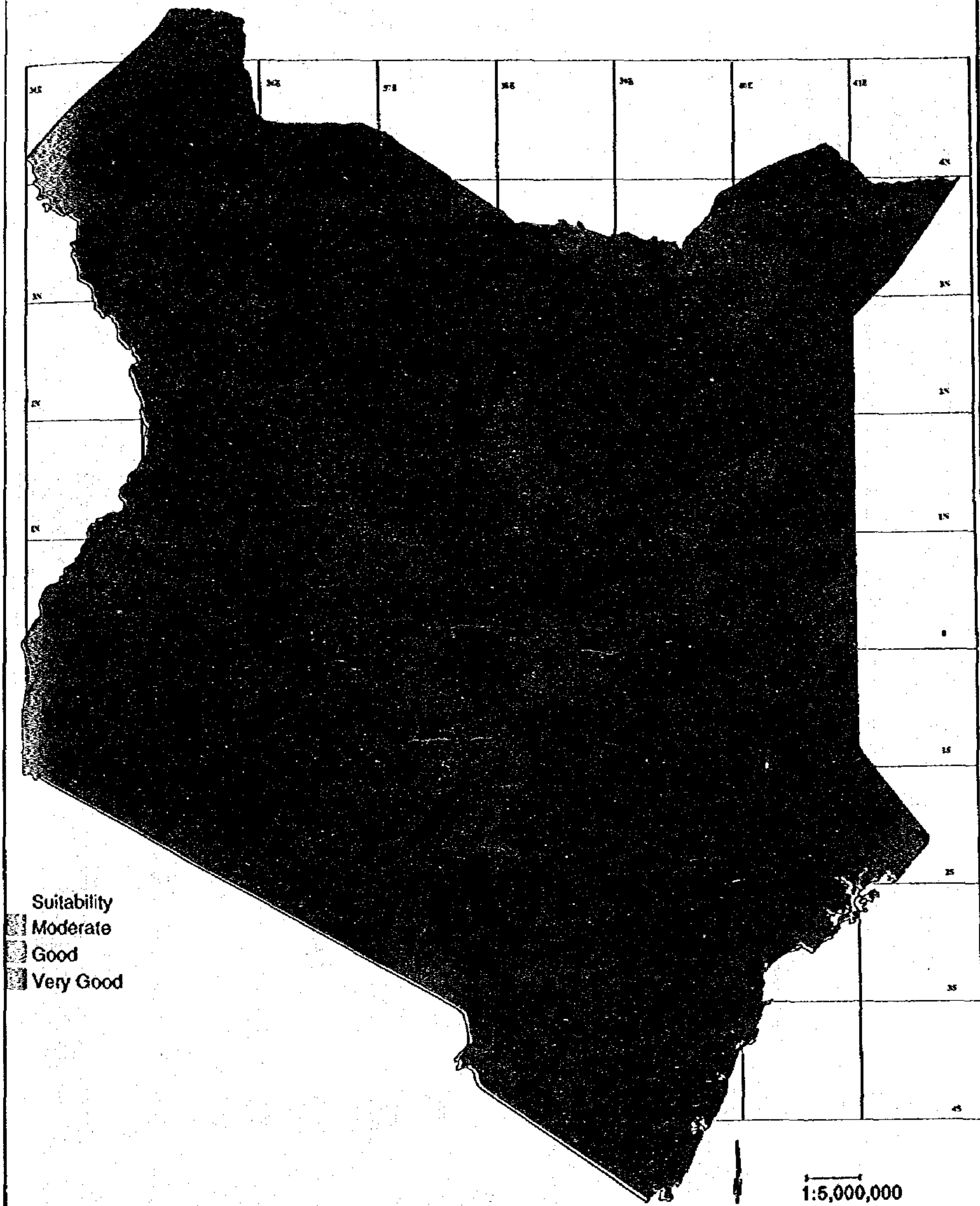

Figure S-4.22 Groundwater Potential for Drinking

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