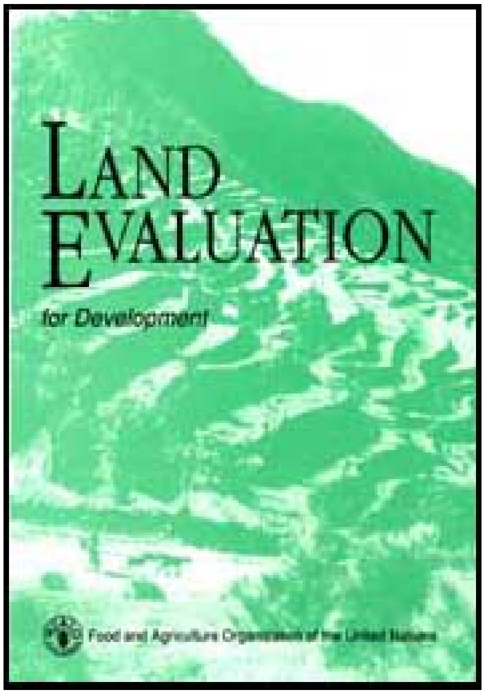

Land evaluation for development

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Foreword

Wise land use is an essential basis for a healthy and prosperous future for the human race. In many developing countries, land well-suited for the production of food is already in short supply. This is often obscured by the existence of vast areas with limited potential for production. Fuelwood, cash crops, timber for construction and grazing for livestock compete with food crops for space on the better quality land. The pressures which this competition engenders, coupled with unsuitable land-use practices, lead to degradation, erosion and, eventually, to complete destruction of the soil. Vast areas of the planet's best land resources have already been destroyed as a result of man's activities. Meanwhile the numbers of human beings and their domestic animals continue to multiply.

In 1976 the Food and Agriculture Organization of the United Nations (FAO) published *A Framework for Land Evaluation*. This publication synthesized international thinking on the best way to assess the potential uses of rural land as a prerequisite to sound land-use planning. The framework was just that - a framework of philosophy and principles upon which procedures for the sound evaluation of land potential could be developed. It attracted wide interest, and the methodology was tested and adopted in many countries.

FAO subsequently published a series of documents describing procedures for land evaluation for rainfed agriculture (1983), forestry (1984) and irrigated agriculture (1985). A further publication on land evaluation for extensive grazing is being prepared. Each makes use of extensive international experience and discussion, and is based on the original *Framework*.

The purpose of this publication is to increase awareness of the crucial need for reliable land evaluation in the context of land-use planning and rural development. Doubtless, the procedures will be improved but, in view of the need to increase food production in some areas of the world and protect remaining soil and land resources from further degradation, methods which have already proved successful should be more widely applied. They provide a practical and tested basis for safeguarding the world's land resources for future generations. FAO, in fulfillment of its international mandate, stands ready to assist all countries in whatever way it can in this important activity.

Edouard Saouma
Director-General
Food and Agriculture Organization
of the United Nations

The need for land evaluation

The nature of land

'Traditional systems of resource management and land husbandry are rapidly being abandoned; soil and environmental degradation are proceeding rapidly over large areas of the world. An alternative approach is essential.'

When populations were far smaller than today most societies were able to live in balance with their natural environment. As numbers expanded, man had a greater impact on the land through clearance for farming and in order to obtain fuel and construction material.

In most places this was a gradual process, and social groups were able to develop often complex systems for exploiting natural resources on a sustainable basis.

More recently, human populations have increased very rapidly, especially in developing countries, and demand for food and fuel has grown alarmingly. At the same time, changing economic and social conditions have undermined or destroyed traditional systems of land resource management.

Thus, not only is the land being cropped and grazed more intensively, with rest or fallow periods being drastically reduced or eliminated, but effective systems for maintaining fertility are no longer being applied. The result has been massive soil degradation on a world scale, through loss of plant nutrients and organic matter, erosion, buildup of salinity, and damage to soil structure.

Increasing demand for food, plus the fact that parts of the land most suited to crop production have been damaged or destroyed, has led to the expansion of cultivation and grazing into areas less suited to such uses, and ecologically more fragile. This has upset or destroyed natural ecosystems and modified or eliminated natural populations of flora and fauna.

Terraced rice fields

Land such as these terraced rice fields in Indonesia (left) is under intense pressure from the expansion of the human population. If land is not to be destroyed by these pressures, land evaluation studies must be carried out to ensure that maximum productivity is achieved, and can be sustained far into the future.

Much of the damage is irreversible, as when fertile topsoil has been stripped off to expose infertile subsoil or bare rock, or where plant or animal species have been wiped out. In other cases the damage can be economically irreversible, such as when millions of hectares become infertile due to the build-up of salinity.

There is an urgent need for a new approach. Traditional systems must be preserved and strengthened wherever possible, but it is clear that they alone are far from sufficient in view of the magnitude of the problem and the rate of destruction of the world's land resources.

How people or nations use their land depends on complex, interrelated factors which include the characteristics of the land itself, economic factors, social, legal, and political constraints, and the needs and objectives of the land users. In order to make rational decisions it is necessary to:

- collect the right information about the physical, social, and economic aspects of the land area in question; and

- asses the land's relative suitability for different uses in the light of the needs and objectives of the land user and the community.

This process is known technically as land suitability evaluation, or simply as land evaluation, and the basic methodology was set out in the 1976 FAO publication *A Framework For Land Evaluation* (Soil Bulletin 32).

Land evaluation is part of the process of land-use planning.

Food for the future

In 1982, the FAO study *Land Resources for Populations of the Future* concluded that, of 117 developing countries examined, no less than 64 would be unable to meet the food needs of their expanded populations in the year 2000 without the use of fertilizers, pesticides, improved seeds or improved conservation measures. In fact, of course, some agricultural inputs are being used in all these countries but large quantities of food still have to be imported.

The same study showed that if a modest increase in the level of agricultural inputs was projected, the situation improved significantly, with 28 of the 64 critical countries achieving self-sufficiency. At an optimistically high level of inputs, equivalent to that of Western Europe, a further 17 highly populated or exceptionally dry countries could become self-sufficient.

Decisions about land use need to be made at national level, provincial or district level, and at the level of the plot or farm. The basic process is the same, but the level of detail and map scale are quite different.

Successful land evaluation is necessarily a multi-disciplinary process and therefore the use of a standardized framework is essential to ensure logical, and, as far as possible, quantitative analysis of the suitability of the land for a wide range of possible land uses.

The nature of land

In the context of land evaluation, land is much more than the solid surface of the Earth. It includes the soils and rocks beneath, the atmosphere with its climates, the cyclic interchange of water between the sky, the ground, the rivers and the sea, and the whole mantle of living things, both plant and animal.

All of this is subject to the aims, abilities and stupidities of the human population. And a single change in any aspect of the land can precipitate a change in many others. Understanding the complexity of land, and the snowball effects of interacting changes that occur when balances are altered by development or disturbed by changing circumstances such as population growth, is essential to successful land evaluation.

It is impossible to foresee all the changes that may result from a single action. The art of land evaluation is to predict the most important changes, to decide whether these are desirable or acceptable, and thus to categorize the proposed action as a wise or an unwise use of land.

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How land is evaluated

> *'The essence of land evaluation is to compare or-match the requirements of each potential land use with the characteristics of each kind of land.'*

Land evaluation is part of the process of land-use planning. Each step is discussed separately in the pages that follow.

Once the objectives of the study have been established, the collection of basic data can begin. At this stage, there are two main aims: one is to catalogue the different types of land that exist in the study area; and the second is to identify the possible uses to which they might be put.

The essence of land evaluation is shell to compare or match the requirements of each potential land use with the characteristics of each kind of land. The result is a measure of the suitability of each kind of land use for each kind of land. These suitability assessments are then examined in the light of economic, social and environmental considerations in order to develop an actual plan for the use of land in the area. When this has been done, development can begin.

Land evaluation, strictly speaking, is only that part of the procedure that lies between stages two and six on the diagram below. Stage seven is a transitional step between land evaluation and land-use planning. The powerful interactions that occur between all the stages mean that the planning process must be approached as a whole. The requirements of the different kinds of use that are to be evaluated, for example, largely determine the range of basic data that must be collected before evaluation can begin. Later, the identification of suitable forms of land use provides the building blocks for land-use planning.

Ideas on how the land should be used are likely to exist before the formal planning process begins. These ideas, which often reflect the wishes of the local people, are usually included among the possible uses to be assessed in the evaluation and will thus influence the range of basic data that needs to be collected.

As the study proceeds, new ideas on the way the different types of land could be used will emerge. Not only will these need to be evaluated but, conceivably, additional basic data will need to be collected. The original objectives of the study may even need revising.

Thus, the overall procedure requires more than a simple passage through the flow chart. It is the norm rather than the exception that the procedure cycles backwards and forwards through the stages of the chart until the planners are satisfied that all important possible uses have been evaluated.

Figure

A wide range of specialist knowledge is needed to collect and analyse all the data relevant to land evaluation. The work is best undertaken by a multidisciplinary team that includes social and economic expertise as well as biophysical scientists. Ideally, such a team should work together throughout the study so that each member can influence the others with his or her special knowledge and viewpoint.

In practice it is not always possible to field the whole team at once. In this case, the physical aspects of land are usually studied and mapped first to provide a geographical framework into which the socio-economic dimensions are inserted later. A two-stage approach is obviously less well integrated and will take longer to complete.

The reliability of a land evaluation can be no greater than that of the data on which it is based. Ideally, fresh data should be obtained to answer all questions raised by the study, although time and expense usually prevent this being done as thoroughly as is possible. The one really important requirement is that the reliability of each data source is checked. Any shortcomings that are not subsequently made good should be highlighted in the evaluation report.

In order to be objective and, as far as possible, quantitative, land evaluation follows certain established procedures based on the concept of land 'qualities' and 'characteristics'. Land characteristics are single factors such as annual rainfall or soil texture/ which can be measured or estimated. Land qualities, on the other hand, are complex proper ties of the land such as moisture availability or fertility, produced by combination groups of land characteristics. Land suitability is rated for a given use by comparing the requirements of that use, which must of course first be identified, with the qualities of the land unit.

The evaluation process can be 'automated' and carried out quite rapidly once all the necessary data are available, by setting up a computerized data bank or geographical information system, and establishing rules or decision trees to carry out the matching process which produces the evaluation.

Land evaluation concepts	
land suitability is evaluated for specific types of land use	land use may be defined either at a general level (such as rainfed arable cropping) or as a particular crop at a specified level of inputs
evaluation includes a consideration of inputs and projected outputs	the level of material inputs is defined in the evaluation as are land improvements such as soil conservation or drainage and their overall impact is taken into account in predicting crop yields or outputs
land evaluation requires specialists of different disciplines	the land evaluation team must coordinate surveys and work in consultation with soil scientists, agroecologists, socioeconomists and planners

evaluation relates to the environmental and socio-economic conditions of the area	evaluation recommendations should relate to existing farming systems and to changes in land use which are technically feasible and socially and politically acceptable
suitability refers to use on a sustained basis	recommended land uses must not cause soil erosion but must conserve the land for long-term production
evaluation involves comparison of more than one land use	improving the productivity of land use systems may involve introduction of new crops, changes in land management or other innovations in the existing farming system

1. Defining objectives

> *'The most significant decisions at this stage relate to the levels of planning that the study must serve, because these determine the precision of evaluation and thus the intensity of every aspect of the investigation.'*

The definition of objectives is a critical step in the evaluation procedure. It largely determines how elaborate the study must be, how long it will take and how much it will cost. It also ensures that the investigations set off in the right direction, with a good chance of providing all the advice that the planner will need. The procedure allows for minor revision of the initial objectives in the course of a study but a major change at a late stage would be likely to involve repetition of field work at considerable cost.

The most significant decisions at this stage relate to the levels of planning that the must serve national, district, or individual farm because these determine the precision of evaluation required and thus the intensity of every aspect of the investigation. Any small increase in the intensity with which the study is carried out can represent a major increase in study duration and cost, so inappropriate detail must be avoided during the study. Often, the most efficient approach is to phase the study through successive stages of increasing detail.

Figure

A start might be made with a rapid overview of a whole region of possible interest before moving to more detailed investigation of smaller areas - each identified in the overview as having particular promise for the objectives in view. A third phase of very detailed investigations might be needed to allow planning of individual farms. Each phase requires its own defined objectives to meet the starting requirements of the next phase and, eventually, the most detailed needs of the study.

An overview of the study area, such as that shown below, is often the first stage in the planning process. This leads to a definition of the areas of promise that merit evaluation.

The objectives must establish the boundaries and thus the size of the study area. They must also provide a first selective list of the forms of land use to be evaluated, and indicate whether these evaluations need to be made in qualitative or quantitative form. The study team needs guidance on these issues because the choices must reflect the special interests of the planners and the aspirations of local people. Furthermore, as will be explained later, without this guidance the choice of land-use alternatives to be considered could be infinite.

In framing the objectives, the need for comparisons in land-use planning must be recognized. The prime objective of the study may be to establish the suitability of a particular kind of use, but this can be achieved most effectively by making comparisons with other feasible uses of the same land. For example, if major costly improvements such as new irrigation are planned, the objectives of the land evaluation should include comparison with existing unimproved uses of the land so that the advantages of the planned development can be truly assessed.

Where expensive improvements such as irrigation are required, as in this project in Tunisia, the objectives of the evaluation must include a comparison of existing unimproved uses with those of the improvements so that the real merit of the planned development can be assessed.

Environmental conservation is always an objective of land evaluation. It is assumed, therefore, that no form of land use will be judged 'suitable' unless it can be sustained on a long-term basis without significant detriment to the land.

Major stages in defining objectives

Evaluation for land-use planning can be carried out on different scales, such as national, provincial or farm level.

Objectives will be different at each of these levels, but the same approach is used to define objectives which in turn determine the 'best' land use for the area.

The major stages are to:

- identify relevant types of land use;
- carry out surveys to establish needs and wishes of the local land users and needs of the community as a whole;
- and rank objectives in order of priority.

2. Collecting the data

> *'The range of information that could be relevant to land evaluation is huge, and collecting data which are not essential can be costly in both time and money.'*

Reliable knowledge of land characteristics, and of the way these differ from place to place, is essential to good land evaluation. The kinds of data that may be needed are summarized in the box on the opposite page. In some parts of the world, much of this information is already available. Elsewhere, there is very little. Even if substantial local knowledge exists, however, some additional information will almost certainly need to be collected for any new evaluation study.

Figure

The range of data that could be relevant to land evaluation is huge, and collecting it can be costly, in both time and money. There are three main ways to minimize costs:

- focus on data that are essential to the evaluation;
- search out and make maxi mum use of existing data; and
- use new technology in data collection.

Selecting the right data is the most difficult of these economies, for it is not easy to know in advance which kinds of data will prove essential. If a need is not identified until late in the study, serious delays may ensue whilst the missing data are found.

Data selection is easier if the survey work can be phased through stages of increasing detail. A first examination of the entire area, aimed mainly at eliminating land areas that are irrelevant to the study, may well require very few kinds of data. This process can be very helpful in deciding what investigations and what data are essential for later stages. At any stage, opportunities to acquire additional data at reasonable cost should be accepted.

Seeking out existing data is not as easy as it sounds. Valuable data are often hidden in obscure archives and can be traced only by systematic enquiry. Once located, old data must be carefully compared with the present situation to establish their relevance and reliability. Satellite imagery, for example, sometimes reveals alarming inaccuracies in older maps. Despite these warnings, huge savings in time and money can be made by using earlier survey data in conjunction with such modern aids as remotely sensed imagery.

The new technology that is available for land evaluation consists mainly of the use of remote sensing and computers. Stereoscopic examination of paired, black and white, photographs obtained by conventional aerial photography - the best tested form of remote sensing - remains the mainstay for interpretation of landform, vegetation, land use, soils and geology, and for other purposes such as contouring.

Sources of data		
type of survey	**data source**	**range of data**
satellite	digital tapes, photographs, other imagery	water resources, vegetation, land use, infrastructure, landform, soils
aircraft	photographs (conventional, infra-red), radar imagery	landform, soils, vegetation, land use, farm boundaries, water resources, crops, infrastructure
ground	reports, questionnaires, maps	soil, climate, landform, vegetation, land use, population, social and economic data

While the newer forms of remotely sensed imagery (such as infra-red and radar) may not yet match the precision or stereoscopic capability of conventional air photography, they have other advantages. Each image sensed from space covers a comparatively large area - especially helpful in analysing and mapping landform. Satellites return at regular intervals to obtain new imagery of the same sites, so that libraries of sequential imagery can be built up showing the changes at a single site over time. Satellites can now record at up to seven different wavelengths simultaneously. Radar wavelengths are particularly useful in the humid tropics because they can obtain images of the Earth through dense cloud.

Computers can now be used to store and manipulate the huge amounts of data needed in land evaluation. Tough, portable, micro-computers are being increasingly used to record, store, interpret, test and communicate data at the survey site itself.

The main impact of these new technologies has been to save time and money, and to extend the range and depth of land evaluation, allowing data 011 a greater complexity of land-use alternatives to be collected than was possible in the past.

However, many kinds of data have to be collected in traditional ways. The soil surveyor must dig or drill holes to describe the sequence of soil 'horizons' with depth. The hydrogeologist may have to drill deeper holes to prove the existence of suspected groundwater whilst hydrologists set up gauges on streams to measure surface water flow. The meteorologist has to rely on systematic measurements of change in the weather at established weather stations. Agriculturalists, economists and sociologists observe people in action in farms, villages and markets and, by means of questionnaires and other enquiries, establish the patterns of their business. Foresters and livestock specialists make inventories and observe how their respective resources are exploited, propagated and conserved. These and other scientists collect the central core of basic data on land much as they have done for decades.

Aerial photographs are used to verify the accuracy of existing maps when collecting data to be used in land evaluation.

What data are needed?

Physical land resources

• climate
• land
• water resources

socio-economic issues

• human populations
• land tenure, other legal issues and constraints
• development objectives and policies

present land use

• major land uses and land use types
• vegetation types and distribution
• prevalent pests and diseases

• infrastructure

3. Identifying land uses

'The aim is to recognize and describe land utilization types that are either in existence or that could be developed.'

A plot of land can often be put to any one of several possible uses - but rarely with the same degree of success. One of the objectives of land evaluation is to inform this choice by assessing the suitability of each use for each land unit, and vice versa. The first step in this procedure, therefore, is to determine which forms of land use are worth considering.

In a reconnaissance study of a large area it may be sufficient to identify possible land uses in general terms, such as rainfed agriculture, irrigated agriculture, forestry and wildlife reserve, without further definition. Indeed, over a large area, the range of possible uses could be too large to handle if it were subdivided further. These sub-divisions are called major land-use types.

In more detailed studies, land use types have to be more carefully defined. Their definition must include details not only of the produce (or other objective) foreseen but also of the production method and the socioeconomic setting of production. These definitions are called land utilization types (LUTs).

The forms of land utilization that are to be evaluated, if not set out in the study objectives, need to be identified early on because this may have a bearing on the data that need to be collected. initially the descriptions can be fairly general: smallholder rainfed arable farming based on maize and cassava, improved village woodland, smallholder coffee farming and government nature reserve are typical examples.

As the work proceeds, the descriptions of the utilization types can be modified and elaborated in keeping with the overall precision of the study. Further utilization types may have to be added or substituted in the light of this new knowledge bearing in mind that such a change may require further data collection, possibly in areas where field work was thought to be completed.

Figure

Very intensive land evaluation studies could lead, by successive refinement, to the specification of utilization types that are virtually tailor made to each part of the study area. The final precise description of the farming systems concerned would then be a major part of the evaluation findings - tantamount to land-use planning. This is possible, however, only when quantitative agronomic studies are being made, and the relationships between land-use requirements and local land characteristics can be very closely examined. Normally, the aim is to recognize and describe land utilization types that are either in existence or that could be developed. Comparison of the present and future situations is important if development is planned. It is not possible to consider every form of use and management practice relevant to an area, so those that are chosen for evaluation are regarded as 'markers' against which the suitability of similar uses can eventually be judged.

Some forms of land use serve more than one objective simultaneously. In agroforestry, for example, trees are grown in close, mutually beneficial association with rainfed crops - the whole system providing fuelwood, shelter, erosion control and possibly fruits and / or timber, as well as arable crops.

Major land uses, such as those shown in the diagram right, are identified first More detailed studies will then elaborate on land use, in some cases specifying even the exact farming systems to be used on specific areas of land, and describing the socioeconomic setting of production.

Key
(1) rainfed agriculture (2) irrigated agriculture (3) forestry (4) fisheries (5) wildlife reserve (6) urban development (7) extensive grazing

Other forms of land utilization, such as farming systems that combine livestock husbandry and arable cropping, are even more complex. Different uses occupying the land sequentially, or one use extends seasonally or periodically to different areas of land. Extensive grazing, irrigated agriculture, forestry and some other major kinds of land use also give rise to complications.

A selection of headings for the criteria that are taken into account in defining land-utilization types are shown on the right. In the matching process, land-use types are formally characterized and their qualities are compared with the requirements of land users.

Land-use types	
Characterized by:	**'user requirements':**
product	*physical*
• output (crop)	• climate
	• land
production system	
• sequence of actions/practices	
• inputs	
social setting	*social*
• land tenure system, legal aspects	• rights and customs
• farm size	• managerial level
• labour intensity	
• managerial level	
economic setting	*economic*
• capital intensity	• capital requirements
• input/output factors	• availability of inputs
	• infrastructure

Major land uses

4. Identifying land units

> *'Land units, or land-mapping units, are areas with and qualities that differ sufficiently from those of other land units to affect their suitability for different land uses.'*

Land units are areas of land with specific characteristics. They are normally represented within a boundary on a map in order to create visually a geographical framework, but land units can also be stored invisibly in computer memory, in terms of location and description.

Any area of land, no matter how its boundaries are defined, can be regarded as a land unit for purposes of land evaluation, provided the characteristics of the land enclosed can be adequately described. However, land evaluation can be performed more easily and its findings are likely to be more valuable if the land units on which it is based have been defined and mapped for the purpose, using available and specially collected data.

Figure

An enormous number of characteristics is required to describe a single piece of land adequately. Comparatively few of these characteristics are especially important in relation to a particular kind of land use. Of those that are, not all change at the same rate or in the same place. Thus there is often a surprising amount of choice in deciding where boundaries should be drawn. A judgement therefore has to be made on where the most significant changes occur. The aim is to enclose areas that are as nearly homogeneous as possible.

The problems are more complicated if, as is usually the case, several alternative types of land use are to be considered. It may then be necessary to make compromises in positioning the boundaries.

Some land qualities used to identify land units

In practice, land units are often defined by superimposing maps of different aspects of the land - such as climate, soils, vegetation and landform - and then drawing boundaries that best reflect the most important distinctions in the separate maps. Aerial photographs and satellite imagery are, like maps, visual summaries of land surface characteristics and they, too, are often used to divide an area up into its initial units - units that may have to be revised in the light of information on climate and from 'ground truth'.

The intensity of the study - the scale of the mapping and the degree of detail desired - is important in determining which land characteristics should be used to define the boundaries. For example, in an overview of a large region, differences in climate will largely determine these boundaries because differences in other factors, such as soils, are likely to be too localized to be investigated and mapped individually on such a small scale. Information on the nature and influence of these other factors, which may well change with climate, can be included in the description of the land units but will not determine their boundaries.

In contrast, if the evaluation is focussed on a small area, even minor differences in soils may be represented by separate land units whilst macro-climate will be assumed to be uniform across the area and will not, therefore, affect the land boundaries. Knowledge of local climate will be just as important for practical interpretation of the soil differences but, in a detailed study, climatic information is generalized and confined to the land unit description. At intermediate scales (around 1:250,000) landform is likely' to be decisive in locating boundaries, with both soils and climate contributing only to the description.

Land units can be described in terms of their characteristics, their qualities or both. A land characteristic is a fairly simple attribute that can be measured or estimated - such as mean annual rainfall or a particular texture of the soil. A land quality, on the other hand, is a complex attribute that usually reflects the interaction of many land characteristics - such as susceptibility to flooding or erosion and ability to retain nutrients. Each land quality has a distinctive influence on the suitability of land for a specified kind of use. Land qualities are very helpful in 'matching' land units with land-use requirements. Some of the land qualities important in the evaluation of rainfed crops are illustrated on page 14. The characteristics and qualities that are important in relation to some other forms of land use are dealt with on pages 24-33.

Major land qualities that are important in rainfed agriculture are shown in the illustration, left. Each of these qualities can be further subdivided; thus, the radiation regime would include measurement of both total radiation and day length, and moisture availability would include total moisture, critical periods and drought hazards.

Key
(1) radiation regime (2) temperature regime (3) moisture availability (4) nutrient availability (5) rooting conditions (6) flood hazard (7) erosion hazard (8) excess salts (9) size of management units

Typical description of a land unit in an evaluation of suitability for rainfed agriculture

land quality	**land characteristic** (in growing season)	**value**
radiation regime	mean daily sunshine	6.5 hours
temperature regime	mean temperature	22°C
	mean temperature in coldest month	14.5°C
moisture availability	total rainfall	750 mm
	relative evapo-transpiration deficit	0.21
oxygen availability	soil drainage class	well drained

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5. Assessing suitability

> *'Suitability is a measure of how well the qualities of a land unit match the requirements of a particular form of land use.'*

Suitability is a measure of how well the qualities of a land unit match the requirements of a particular form of land use. Suitability is assessed for each relevant use and each land unit identified in the study.

Matching land use to land is the essence of land evaluation, and often influences all the other steps in the study. For example, early investigations may show that parts of an area are too dry to grow a desired crop; irrigation may therefore be needed. An additional land utilization type involving irrigation would then have to be recognized, and the increased relevance of slope and drainage might then lead to changes in the way land units were mapped. Needless to say, matching may suggest more subtle changes than these. The important point is that the systematic process of matching can really begin only after the most informative definitions of land uses and land units have been established.

The suitability classification aims to show the suitability of each land unit for each land use. In FAO's *Framework for Land Evaluation*, land is first classed as suitable (S) or not suitable (N). These suitability classes can then be further sub-divided, as required. In practice, three classes (S1, S2 and S3) are often used to distinguish land that is highly suitable, moderately suitable and marginally suitable for a particular use. Two classes of 'not suitable' can usefully distinguish land that is unsuitable for a particular use at present but which might be useable in future (N1), from land that offers no prospect of being so used (N2).

Figure

The process of suitability classification is often easier than it might appear. Although theoretically there are an almost unlimited number of land-use requirements and land qualities, in practice only a few have a major influence on suitability. These factors change from place to place and depend, of course, on the nature of the land use - and this means that a sharp eye must be kept open for unusual local factors or requirements.

Each land use has requirements and limitations that relate separately to its objectives, its management needs and to environmental issues. Different crops clearly have specific physiological requirements but land-use objectives such as recreation or watershed protection also have requirements related to soils and climate. Management requirements include factors such as workability of the land, access to markets and size of local land holdings. The environmental requirements of the land relate mainly to erosion and other forms of soil degradation but can also include pollution, increased salinity and waterlogging.

The requirements and limitations of each land use can usually be specified in terms of a limited number of land qualities, such as a growing period requirement, a moisture availability requirement or a water quality limitation. The FAO *Guidelines* for land evaluation for irrigated agriculture lists 32 such 'class-determining factors'. If suitability classes have been defined in terms of a range of values for each factor, the assessment is then relatively straightforward.

Of course, it is sometimes possible to change land qualities - swampy land can be drained, for example, or steep land terraced. If the suitability of the land for a particular use is assessed both with and without such improvements, then the evaluation will provide a measure of the value of the improvement itself.

The first step in classifying suitability is to decide which factors should be used to define each suitability class. Upper and lower limits for each relevant land characteristic or quality are then set for each class.

Local agronomic experiments are the best guide in this process. If these experiments cannot be carried out, class-determining limits must be based on the experience of local farms or on farms elsewhere. If no other information is available, estimates from first principles may have to be used to set the limits.

That done, the properties of each land unit are reviewed and compared to the class limits. Each land unit can then be assigned a suitability classification for each type of land use.

This stage is simplified if all the known information is first set out as a table that shows, for each land utilization type, the class rating of each class-determining factor together with any qualifying information or comment. The final assessment of suitability is usually based on one of three principles.

- **The limiting condition principle**: the most unfavourable quality determines the suitability classification.

- **The subjective assessment principle**: suitability classes are raised or lowered on the basis of judgements of the importance of different factors. Because subjective assessments are risky, the relevant factors are weighted, and account is taken of special limitations that may occur if two or more negative factors occur together.

- **The principle of arithmetic modelling**: the fact that each land quality has an independent influence on suitability means that land qualities can be assigned values and manipulated arithmetically to provide a numerical assessment of overall suitability.

In practice a combination of these approaches is often employed.

Maps above show the agro-climatic suitability for the rainfed production of two crops - sorghum and maize - in South America. This assessment was made on a very small scale, for half a continent, and shows only four suitability classes: very suitable, suitable, marginally suitable and not suitable. High altitude areas were first eliminated from the study area.

6. Identifying environmental and socio-economic issues

Before a land use can be recommended in a development plan, its environmental and socioeconomic implications must be evaluated further. Conservation interests are taken into account in the matching process because suitability is assessed 011 a sustained use basis. But the environmental effects the land use may have on other land systems must also be assessed.

Irrigation schemes, for example, change the pattern of water distribution in an area and can also change water quality. These changes may be significant or minor but can rarely be ignored. While drainage may protect an irrigation scheme from waterlogging and salinization, the output from the drainage system can produce these effects further downstream. If groundwater is used excessively for irrigation, other wells, pumps and natural springs may dry up, and saline water may enter the aquifer with highly detrimental effects. But such difficulties can be foreseen.

Forestry activities, whether they involve clearance, production or plantation are also likely to affect the environment - particularly in relation to soil erosion, the rate of which may increase dramatically as forest cover is removed. The soil that is eroded may be deposited a long way downstream, where it may be even more damaging to agricultural production, at least in the short term.

Changes in microclimate, moisture retention and run-off associated with large-scale forest felling or plantation are more difficult to assess. Local changes in vegetation and wildlife which can result from forestry, and the prospects for regeneration after felling should be evaluated as part of the matching process. But these changes need to be assessed in a regional context: will enough land still be devoted to wildlife, for example?

Figure

Soil erosion and degradation of soil fertility, leading to loss of vegetation and further erosion, are the principal environmental hazards associated with rainfed crops. Land utilization types that involve the build-up of humus and ground cover on the plains, and the use of tree crops and agroforestry on the steeper slopes, should contain these problems on a local scale. But the effects of runoff, sedimentation and pollution from the use of excessive fertilizer accumulate downstream, and must be kept within acceptable limits.

A number of other awkward questions may well arise. Could future population growth render current precautions inadequate? Could over-stocking lead to migrating livestock trampling down land around villages and waterholes, leading to soil damage and erosion?

Not all such problems are amenable to complete solution but a first defence is to be aware of a threat before it develops beyond control.

Cattle trampling and eroding soil near a water-hole may be an undesirable outcome of new land-utilization.

A new or improved land use can succeed only if it can be adapted to fit local social and economic conditions. Socio-economic investigations are therefore a vital part of land evaluation, starting with the initial formulation of the study's objectives. Attention needs to be given to markets (local, national and perhaps even international), population levels and growth rates, problems of land tenure, the availability of skilled and unskilled labour, transport of products and inputs, and the ease with which subsistence needs for such things as firewood, building materials and local grazing can be met. Local religions and cultures may be important, particularly if new techniques, such as irrigation, are being considered. Political circumstances cannot be ignored, and any analysis should take account of the needs of all members of the population, including minority groups.

In quantitative land evaluation, more detailed and expert economic studies are necessary. These can take several forms and more than one form of presentation may be required. The balance of advantage - that is, profit or loss - can be assessed by financial analysis in relation to the individual farmer (or the enterprise of which he is part) and by economic analysis in a broader national or community context. Furthermore, profitability can be measured simply in terms of gross margins; or in almost limitless complexity, using techniques of discounted cash flow analysis that offset initial capital expenditure against the resulting gains in future years.

The choice of the most appropriate approach is, in itself, a matter for expert guidance.

It is important to distinguish the economics of land evaluation from project cost/benefit analysis. The former is concerned with land use on individual land units and develops assessments which, when combined with other information, can greatly increase the precision possible in project analysis. In quantitative land evaluation, the range of each suitability class is frequently expressed in monetary cost/benefit terms. Of special interest is the value below which a particular use is not to be recommended - the separation between the suitable (S) and not suitable (N) classes - because this can be determined accurately only by an analysis of costs and benefits. This limit will normally be set at some low level of positive return below which the risks and effort involved do not seem justified.

The precise numerical findings of economic analysis need to be viewed with caution. They reflect the time-dependent nature of land suitability assessment - a change in one economic parameter (the global price of oil, for example) can invalidate economic-based class limits almost overnight. Their significance depends greatly on the baseline against which they are measured - profit per hectare, per caput or per enterprise, for example. There is no single measure of profitability.

People are the ultimate beneficiaries of land evaluation; population levels and growth rates, labour supplies, markets and subsistence requirements are vital inputs to successful evaluation

Most important, perhaps, numerical findings are based unavoidably on major assumptions about the future of such factors as population growth, market growth, project lifetime and inflation. These assumptions may or may not prove to be correct.

7. Identifying the most suitable land use

> *'The best land use has to be selected in the light of economic, social, and sometimes political factors.'*

Once evaluated, land units are rated according to their suitability for a range of uses, including the production of individual crops. The requirements of types of land use or crop are compared with the characteristics and qualities of each land unit. This matching process provides a measure of how successful any land use would be on a specific land unit.

Since land use normally involves the production of crops or products for consumption or sale, the matching process concentrates on soil and climatic factors, measuring the level of output that could be produced from a particular land unit using a given production system or level of inputs. In fact, the resulting suitability rating often represents average expected yield levels.

But the suitability-matching process does not take into account whether a potential market exists, or whether it would be necessary to transport products to that market. It is, as far as possible, a technical process which does not include off-farm or non-production factors such as the availability of credit, and does not make value judgements on the potential uses of the land. That is a separate and subsequent stage, at which environmental and social and economic issues are taken into account.

Figure

Furthermore, the evaluation process is carried out separately for each individual crop and land use, and results in an individual suitability rating. It does not, however, judge witch would be the 'better' land use between, say, oranges, which might be rated S1 and represent 80-100 percent of potential yields, or 30 tonnes/ha, and potatoes which might have a suitability rating of S2, or 60-80 percent of potential yield, or 20 tonnes/ha. Clearly, decisions about best or optimum land use must take into account the objectives of land users and the community, economic factors, input/ output relationships in terms of money, labour or produce, demand and other factors.

Typical land suitability assessment for subsistence farming

After: *Soils and Land Suitability for Arable Farming of South-East District, Botswana*, 1989. Government of Botswana/FAO project BOT/85/011, Field Document 3.

'Cultivation of land classified as S4 will not be economically profitable for a long time.

However, part of this land is used, and will be used for the specified system of production (improved traditional dryland farming) because:

- economic considerations are not significant, or only play a very minor part, as even very low yields are essential to bring total production up to subsistence level; and
- considerations such as employment justify crop production even at very low yields.

Land rated as N cannot provide an output or yield that would cover input costs.'

Therefore, once the land unit has been rated in terms of its suitability and potential for different crops or uses, the best use has to be selected in the light of economic, social, and sometimes political factors.

In general, this will entail:

- a review of objectives in order to select land uses which have the potential to produce the required outputs;
- an economic evaluation to compare input levels with expected output levels, establish which of the land uses would be economically viable, and whether the required inputs and infrastructure are available, or could be made so;
- a socio-political evaluation to establish whether potential land uses are socially, legally, and politically viable, and whether they could be made so; and
- an environmental impact assessment to establish the long-term effect of potential land uses and production systems on the land units for which they are proposed.

The result of the above procedure will often be a proposed modification of existing land uses and production systems, and may also indicate the need to modify the economic or legal environment, provide training, institutional or financial support and infrastructure as part of a proposed development plan.

These activities form the borderline between land evaluation and land use planing.

Land evaluation sequence

Farmers in Upper Volta using zebu cattle to work their land.

8. Planning land use

Tanzania: Land-use planning in practice

'Whilst land evaluation is focussed on the potential of individual land units for various uses, land planning must examine the relationships between uses.'

Land planning takes over from land evaluation after the latter has produced recommendations as to the most suitable land uses for the land units in the area. It is the job of planners to evaluate and discuss these recommendations with the beneficiaries and the authorities. Planners also decide how and where the plans can best be put into action to meet the social and economic needs of the community and ensure the environmental stability of the area as a whole. This kind of planning, to be successful, must be developed within the broader context of both the region and the nation itself. It must also include measures to encourage adoption of the land-use patterns proposed.

Whilst land evaluation is focussed on the potential of individual land units for various uses, land planning must examine the relationships between uses. For example, labour-intensive work may be suited to some areas, but it is not suitable to include in land planning if it draws labour away from other areas where it is needed. Similarly, it may matter little how well suited an area is to the growth of one particular product if the market for that product is limited.

The extent to which local demand should be met from local production needs careful consideration. A measure of self-sufficiency is always desirable, and in developing countries fuelwood, some building materials, essential livestock products and basic foods are nearly always produced locally in rural areas. But account must also be taken of outside markets, ease of communication and the social and nutritional implications of the choice between trade and self-sufficiency.

Figure

Food security is an important consideration in planning land use in developing countries. Food surpluses, and means of storing them, must be planned to carry the community through unfavourable circumstances. This requires some assessment of how well the planned land uses will meet the needs of future populations - in other words, an assessment of the future 'human carrying capacity' of the land.

To maximize food security the choice of land utilization types should aim to provide a variety of crops in order to guard against the ravages of selective pests and diseases, provide a balanced diet and, in the case of cash crops, cushion the effects of market changes. Similarly, thought must be given to the implications of exceptional meteorological conditions, as the potential of different types of land will change dramatically during particularly wet or dry seasons, and individual farmers should have access to alternative plots if their land is likely to be seasonally affected.

Although environmental hazards are examined before the detailed planning stage, the planner must ensure that all necessary precautions are included within the plan. The land-use pattern as a whole must be in keeping with the long-term conservation needs of the area, and local plans should include provision for safeguards such as wind breaks, contour terracing, adequate drainage, sensibly routed roads and control of pollution.

To be effective, a land-use planning authority needs to have a clearly established position in the organization of local or national government, with advisory access to the senior levels of the executive. The authority's planning proposals must be clear and attractively presented. The people who will be directly affected need to be convinced that the changes will be to their advantage. This may not be easy since in many development plans expenditure is required immediately while the benefits and rewards take time to materialize. Incentive schemes may well be needed during the period before benefits begin to be felt.

Tanzania: Land-use planning in practice

In 1976, the World Bank planned a Rural Integrated Development Project for the Tabora region of Tanzania. The importance of land use was recognized from the start. The project included a land-use component to survey land resources, develop a methodology of land-use planning at village level, and train local staff in using the new methodology.

Tabora, the largest of 20 regions in Tanzania, occupies 73,500 km^2 in the west of the country. Three-quarters of the region is wooded, mostly infested with tsetse fly, and only about one-eighth is ever cultivated. Thus, despite generally infertile soils and low, rather unreliable rainfall, there is ample land to feed foreseeable populations. However, the present population of about 1 million is increasing and is not evenly distributed. More than half of the population occupies less than one-fifth of the area in two north-eastern districts. There is local over-population and serious land shortage - a situation demanding land-use planning at both regional and village levels.

Data collection, using air photo interpretation and extensive ground checking, was completed in two years. Meanwhile, agro-economic studies were made at village level to establish a basis for land planning. The survey mapped and analyzed the nature and distribution of land units, soils and vegetation throughout the region and was sufficiently detailed to identify regional development priorities. Furthermore, the survey provided insights into the factors that determine land suitability, the potential of land for agricultural use and the need for conservation. These insights allowed simple procedures to be drawn up so that these factors could be easily dealt with during village-level planning.

One of the project's achievements was to develop a method of calculating human carrying capacity of different areas, based on the proportion of the land available for cultivation, the length of fallow required (which varies with soil fertility and farming practice) and the area of land that an average family must cultivate to meet its needs. The family's land requirements for livestock and fuelwood were calculated separately.

The carrying capacity assessments were used first to examine the viability of existing villages, and then to establish planning priorities with district authorities. Finally, the assessments were used in a systematic, detailed survey and planning of individual villages. A land-use planning handbook was prepared and planning teams were trained.

Map (Tanzania)

Applications of land evaluation

Choice in rainfed agriculture

Mauritius: Mapping agricultural suitability

> *'Recent droughts and famines, notably in the Sahel, are a reminder of how precarious our dependence on rainfall can be.'*

Arable land and permanent crops cover about 1500 million hectares of the Earth. Only about 15 percent of this area is irrigated, the remainder depends on rainfall. Recent droughts and famines, notably in the Sahel, are a reminder of how precarious this dependence on rainfall can be.

Reduced production due to moisture stress, however, is not confined to arid areas: it can occur wherever rainfall fails. Moisture availability is thus a land quality of special importance in land evaluation. It is a complex quality, reflecting the interaction of many characteristics of climate, soils, landform and hydrology. The balance between rainfall and evaporation is, of course, the primary determinant, but effects on plants are modified by the capacity of the soil to accept, store and release excess moisture to the roots. Topographical position and the presence of groundwater may modify the plants water supply.

Changes in any of these factors can alter moisture availability and, therefore, the suitability of land for a particular rainfed crop or farming system.

These factors change not only from place to place but also with the seasons and from year to year. Furthermore, different plants, and even different stages of growth of a single plant, respond to moisture stress in unique ways.

The FAO approach to land evaluation emphasizes the possibility of raising the suitability of a land unit for a particular use by good management. For example, even if irrigation water is not economically available, it may still be possible to improve moisture availability by water harvesting, through minimum tillage, better weed control, mulching and planting wind breaks to reduce evaporation. These techniques can raise productivity to make a previously unsuitable farming system suitable.

Many other land qualities are amenable to improvement by good management practice. Nutrient availability, for example, can be improved by the judicious use of mineral fertilizers, animal manure or garden compost. Erosion and flood hazards, soil workability and susceptibility to pests and diseases can also be controlled by improved management.

During the process of matching land and use, all these constraints are examined and the possibility of making improvements is considered. The selected management techniques are written into the definition of the Land Utilization Type (LUT), which is then evaluated on the assumption that these techniques are used.

If a new technique such as irrigation or terracing involves major investment or will induce major changes in the nature of the land, the evaluation can be approached in two ways: by recognizing and comparing the land use with and without the investment as two separate LUTs; or by defining a present suitability classification (without change) and a potential suitability classification (with change) for uses with the same end-product. In either case the advantage or otherwise of any major investment can be readily assessed. The choice is one of convenience in presentation (*see box opposite*) and illustrates the flexibility of the FAO approach.

Qualities to be examined when choosing land for rainfed agriculture

- radiation regime (total radiation, day length)
- temperature regime
- moisture availability (total moisture, critical periods, drought hazard)
- oxygen availability to roots (drainage conditions)
- nutrient availability
- nutrient retention capacity
- rooting conditions
- conditions affecting germination or establishment
- air humidity
- conditions for ripening
- flood hazard
- climatic hazards
- soil toxicities
- pests and diseases
- soil workability
- potential for mechanization
- conditions for land preparation or clearance
- conditions for storage and processing
- conditions affecting timing of production
- access within production unit
- size of potential management units
- location
- erosion hazard
- soil degradation hazard

Land uses and units within a region form a complex land system. Choosing which systems are worth evaluating is complicated by the range of crops that can be grown separately, in sequence or in mixed or intercropped systems.

Mauritius: Mapping agricultural suitability

The first comprehensive use of land evaluation as advocated in the FAO Guidelines was in a study of agricultural suitability on the island of Mauritius in the early 1970s. The main island of Mauritius, situated in the southwest Indian Ocean, has an area of 186,000 ha. At the time of the study, sugar and tea production accounted for about 95 percent of GNP. Land and water resources were under pressure from population growth and a better understanding of these resources was needed to form the basis of planning strategy. The evaluation study was seen as a first step in this direction.

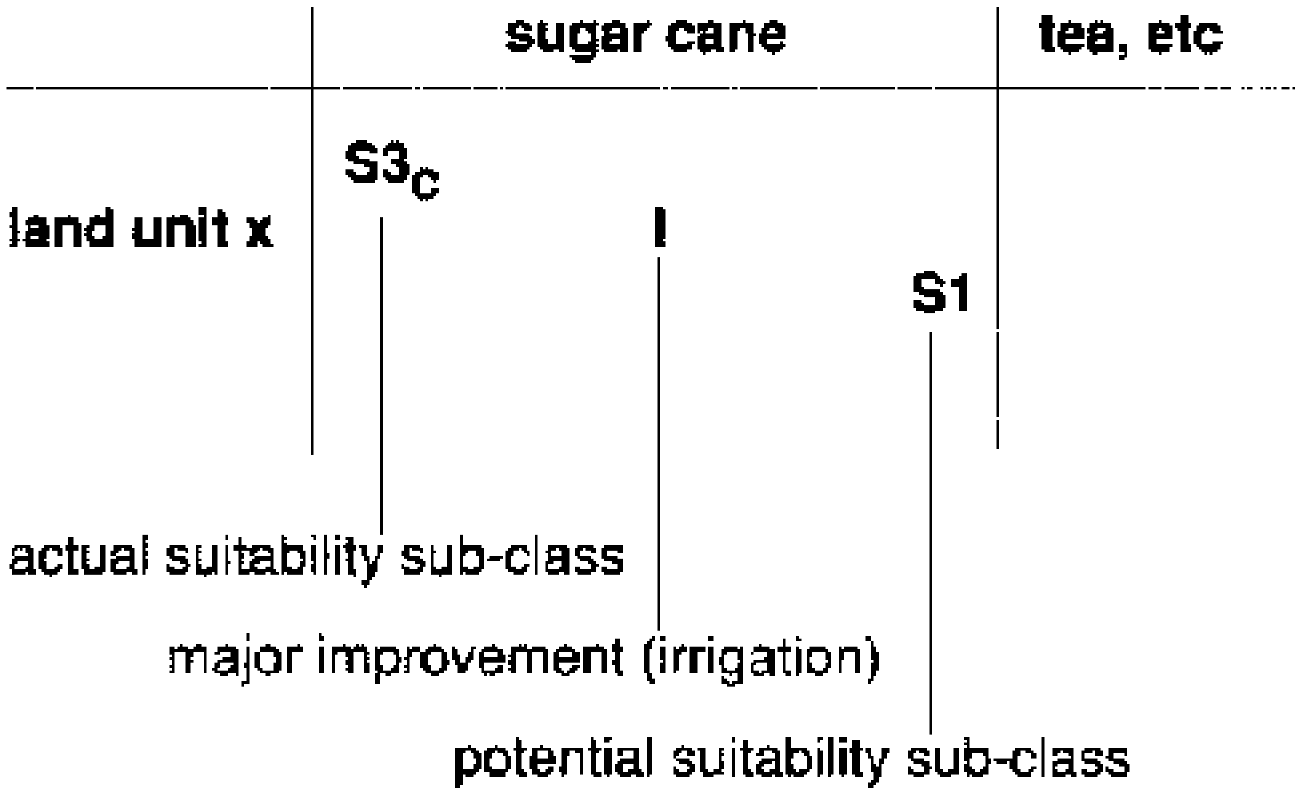
The land units of the island were depicted in colour on two map sheets at 1:50,000 scale. A key indicated the actual and potential suitability of each land unit for each of seven land utilization types. The types examined were sugar cane, food crops (large mechanized holdings), mixed cropping (smallholdings), paddy rice, tea, productive forestry (or livestock grazing), and conservation forestry/wildlife/recreation.

In some parts of the island, major improvements - particularly for the first three LUTs - could be achieved by irrigation (1), removing large rocks (R), terracing (T) or by a combination of these actions. Possible improvements were predicted by the difference between the potential and actual suitability class (with and without the improvement respectively) for the land use on a given land unit. This information was presented in one box of the tabular key as shown above right.

Numerous suitability sub-classes were defined, and lower case subscripts were used to reflect local constraints, and combinations of constraints, on individual land units (the 'c' of $S3_C$ in the example above indicates a climatic constraint - shortage of rainfall). Several 'conditionally suitable' classes were also defined to reflect situations where suitability was conditional on provision of adequate erosion/flood control measures or on the choice of certain crops and varieties adapted to special conditions.

Land suitability was assessed for each LUT in terms of five land qualities: availability of water; limiting super-humid climate; availability of plant nutrients; suitability of land for cultivation and erosion susceptibility. Tables of specifications relating these qualities to measurable land characteristics and to the requirements of the LUTs were prepared. The study yielded a concise but unusually comprehensive summary of the agricultural potential of the island.

Figure 1



Map (Mauritius)

What price irrigation?

Ethiopia: A cautionary tale

The amount of irrigated land in developing countries has increased by more than 50 million hectares over the past 25 years, and there is scope for a similar increase in the next quarter century. Where rainfall is inadequate or uncertain, notably in much of Africa, only irrigation can provide enough water for reliable higher crop yields. Careful land evaluation is especially important in planning irrigation, as without it irrigation can be costly, disruptive of life-styles and environmentally damaging.

Irrigated land utilization types are diverse and a wide range of crops can be grown, even including dry land and wetland crops within the same year. There are two main ways of dealing with the variations in water availability that occur: separate LUTs can be defined for specific cropping sequences and water requirements; or water availability can be used as a factor to determine the suitability class of a smaller number of LUTs.

Tunisian farm workers on newly irrigated land: without careful planning and evaluation, irrigation can lead to soil damage, erosion and the spread of vector-borne diseases.

Separate land utilization types may need to be recognized to distinguish alternative methods of irrigation. Surface irrigation, for example, often involves spending a great deal on land levelling and drainage. These preparations are less crucial for sprinkler irrigation but the costs of pipes, sprinklers and pumping equipment may be high.

Because of the investment involved, land evaluation for irrigation should always be carried out, so that the scheme's economic and financial feasibility can be analyzed. Estimates of capital investment and land development costs, for example, need to be defined as class-determining factors in evaluating the suitability of different methods of irrigation.

Quantified evaluation calls for detailed examination of the physical environment. Irrigation water is an erosion hazard even on gentle slopes, and water that cannot drain away will cause waterlogging and other detrimental effects. Thus the factors that bear directly on these hazards - topography, the physical characteristics of the soils and local hydrology - are especially important in relation to irrigation.

In the early stages of an investigation, the amount of water available for irrigation and the exact areas that can be supplied are likely to be uncertain. If this is the case, a suitability classification identifying 'provisionally irrigable land' can be carried out for the whole project area. This will help in the formulation of a project plan and will indicate the areas that are physically unsuitable for irrigation and can therefore be excluded from further investigation.

Ethiopia: A cautionary tale

Recent droughts in Ethiopia have led the government to give high priority to irrigation as a means of providing an assured food supply for resettled people. To this end, FAO was asked in 1985 to investigate the feasibility of controlling flow on the Kesem River, a tributary of the River Awash in the northern part of the Ethiopian Rift Valley. The aim was to provide irrigation in the Kesem area and generate hydroelectricity.

FAO commissioned consultants to investigate soil and land suitability for a variety of irrigated uses in an area of 22000 ha that might be commanded by such a dam. After a preliminary reconnaissance, intensive field work was carried out in the spring and summer of 1986. Subsurface characteristics were carefully investigated with 1900 auger borings to a depth of 3 metres or more. Sixty deep soil pits were dug and described, and some 1700 soil samples were analyzed - mainly to check for salinity and alkalinity. Soil infiltration and permeability measurements were also made in the field. The suitability of the land for a number of alternative irrigated land uses was then assessed. Finally, the information was described in a detailed report and portrayed on maps of soils, irrigation suitability, vegetation and land use at 1:20000 scale.

The findings of the study, however, were disappointing. Although most of the area was at least marginally suitable for some form of irrigated agriculture, the soil pattern was found to be complex, and soils wholly unsuited to irrigation because of salinity, alkalinity or poor internal drainage were widely scattered amongst the better soils. Large patches of uniform good quality soils that could be irrigated efficiently and economically were rare. Thus, although data appears promising on the availability of soils suited to uses other than irrigated agriculture in the area (*see illustration*), problems associated with efficient water delivery, drainage and management make it unlikely that the irrigation project can proceed as originally conceived.

Suitability of soils in the Kesem area for non-irrigated agricultural uses

The next stage - classifying the 'irrigable land' - involves more detailed investigation of the promising areas, and elimination of those that would be too costly to serve or drain, that would provide only marginal returns or that should be eliminated for other social or economic reasons.

Assessment of land suitability classification can also proceed in stages. The separate classes (S1, S2 and so on) in a simple qualitative comparison of land can be quantified in terms of a 'land productivity index' that reflects expected production - the best S1 land normally being given an index of 100, with lower land classes having smaller indices.

Economic considerations can be introduced next by relating the classes to 'net farm income' - values obtained by deducting all direct farm costs from the value of production on each class of land. This measure is appropriate for the classification of 'provisionally irrigable land'.

A more precise economic index - 'net incremental irrigation benefit' (NIIB) - is desirable for the final 'irrigable land' suitability classification. This is arrived at by estimating the net benefit on a unit area of land with and without the project, taking account not only of all the ordinary farm investment and operating costs and returns but also project investment, operating and maintenance costs. NIIB is therefore a measure, expressed in economic terms, of the potential increase in productivity on a specific class of land under the project plan.

The possibility of environmental degradation as a result of the introduction of irrigation is very real. Historical evidence of the collapse of civilizations from this cause underlines the need to look beyond mere economic yardsticks in predicting the suitability of land for irrigation. Apart from damage to soils, which may be difficult to reverse, the risk of spreading vector-borne diseases such as malaria, bilharzia and river blindness must also be considered. So, too, must a wide variety of socio-economic issues ranging from traditional attitudes, laws and customs to problems of labour supply and food preferences. Any of these can prejudice the success of new irrigation schemes.

What future for extensive grazing?

Kenya: Land suitability for nomadic grazing

Rangelands occupy more than one-third of the Earth's land surface and, although generally ill-suited to arable farming because of insufficient or unreliable rainfall, short growing season or excessively rugged terrain, they provide a livelihood for more than 25 million people engaged in two of mankind's oldest activities - livestock grazing and hunting. Demand for animal products continues to increase and there is a tendency for farmers to increase livestock numbers, sometimes beyond the viable carrying capacity of the land. In the drier range-lands the risk of desertification through overgrazing is increasing and in the wetter areas pressure from expanding human populations is leading to competition between pastoralist and arable farmer.

Well-planned livestock grazing and arable farming can be mutually supportive, and such an arrangement provides plant feed for the herds in critical seasons in exchange for animal proteins, manures and tractive power. In contrast, straight competition can be disastrous, leading only to erosion and the loss of farms and pastures. Such competition for land calls for careful planning and creates an important demand for land evaluation.

The financial return from extensive grazing is low. This fact has two important consequences for land evaluation. Firstly, it makes it difficult to justify large expenditures on data collection and analysis.

Secondly, it implies that land improvements requiring significant expenditure are unlikely to be feasible - particularly if the expenditure would be recurrent, as in repeated applications of fertilizer. These considerations greatly reduce the predictive value of land evaluation for extensive grazing as land must be mainly evaluated in its current condition, using the status of the existing vegetation as a general yardstick. The range of investigations should be sufficient, nevertheless, to detect changes already in progress or immediately foreseeable, and assess their likely effects.

Suitability of land for extensive grazing is normally measured in terms of the number of animals that can wisely be allowed to graze a land unit for all or part of a year the 'carrying capacity'. This depends mainly on the amount of feed and water that will be available to the animals on that land in all but exceptional years. Other factors that may enter the suitability analysis include biological hazards (toxic plants, pests and diseases), climatic hazards and practical issues such as access to grazing areas, ease of fencing and location.

'Grazing capacity' - a measure of the ability of land to meet just the feed requirements of a particular species during a particular part of the year - can be used in evaluation as a kind of 'super' land quality embracing the interacting effects of all the big-climatic factors in producing feedstuff. Since grazing capacity can be assessed by sampling existing vegetation in conjunction mainly with climatic data, the need for other aspects of basic data collection is reduced.

Distances which herds are moved in search of fresh grazing and water and in response to the seasons vary greatly with the kind of livestock husbandry being practiced. In communal grazing, possibly combined with agriculture, movement is limited and may be negligible. In ranching, movement is greater but still systematic between fenced paddocks. Nomadism extends erratically, as need dictates, over considerable distances while transhumant herdsmen may move their livestock hundreds of kilometres over traditional routes in pursuit of seasonally favourable conditions. These, together with hunting and recreation, represent the major kinds of grazing land use, but can be sub-divided for evaluation purposes in terms of kinds of animals and animal produce and by criteria such as labour intensity, capital input, knowledge and attitudes.

The mobility of livestock presents a special problem in land evaluation because it implies that the acceptability of a single land utilization type may depend on its suitability on each of several successive land units during specific periods of the year. An acceptable sequence and timing for the use of different land units may have to be recognized and assessed - creating problems that have to be faced anew in each location. A suitable grazing use will be one that provides a herd of desired size with adequate feed and water throughout most years, without placing any part of the land under excessive grazing pressure. Defining the desired size of herd is itself a complex socio-economic issue and the solution must take into account the needs and attitudes of local people.

Kenya: Land suitability for nomadic grazing

FAO is still developing definitive procedures for evaluating grazing land and research has been going on for some years. One study was undertaken on behalf of Unesco's Man and the Biosphere (MAB) programme in the Mount Kulal/Marsabit area of northern Kenya.

The study area, which covers 15630 km^2, is mainly populated by nomadic pastoralists. The Rendille tribe uses most of the area to keep camels, sheep and goats whilst smaller numbers of nomadic cattle-herders occupy discrete areas in the mountainous fringes. Annual rainfall is only 225mm over most of the plains, rising to 700mm on Mount Marsabit. The study, which followed a soil survey, aimed to contribute to the solution of environmental problems associated with desert encroachment and ecological degradation of arid lands.

Nomadic and semi-nomadic, small-scale, extensive grazing and browsing was recognized as a single land utilization type, although the differing requirements of camels, sheep, goats and cattle were recognized in parts of the analysis and in the final presentation. The land qualities invoked in assessing relative suitability for this land use were accessibility, resistance to erosion, moisture availability and salinity/sodicity of the soils.

Accessibility has special significance in an area that is partly mountainous, stony and subject to flooding, and where the single through-road and most tracks are likely to become impassable in wet periods. Susceptibility of land to erosion was judged to be important where herds gathered near villages and waterholes. Moisture availability and salinity both influence the essential production of vegetation for grazing.

A method was developed for rating each of these land qualities in terms of relevant land characteristics and then of combining their mutual effect to determine the suitability of different land areas for the nomadic grazing of camels, sheep and goats, or cattle (see table). The method involves rating the constraints imposed by different land characteristics as a series of indices of decreasing severity (1-5) and developing a conversion table in which the separate indices are combined to give a suitability classification.

The results of this investigation have been integrated into an area management plan aimed at improving the lifestyle of the pastoralists and protecting the natural environment. Only the Chalbi Desert was assessed unsuitable for all animal species. It was, however, found that the pastoralists sometimes use the areas assessed as unsuitable and that some highly suitable areas are avoided for social, religious and inter-tribal security reasons.

Map (Kenya)

Land suitability for extensive grazing in part of the Mount Kulal/Marsabit area

Choosing land for forestry

Land planning in the Philippines

Every year more than 25 million hectares of forest land are converted to other uses, even though fuelwood is in critically short supply in many parts of the world. Land evaluation has an essential role to play in deciding which areas should be preserved for production and conservation, where forest clearance is justified and where new forests should be planted or allowed to develop.

In the past, forestry was often assigned to the poorest classes of rocky, stony or steeply sloping land. While forestry may well be the best and even the only effective use of such land, future demand for fuelwood and timber will be met only if the specific growing requirements of the trees are taken into account. Furthermore, in deciding whether better quality land should be allocated to forestry, all the benefits of forestry must be considered.

The major benefits include the production of commercial timber, pulp and household items (including fuelwood and products as diverse as dyes, medicines, fibre, glues, mushrooms and honey), the protection of land and water resources, and the creation of resources for tourism. These major forestry land uses apply to natural forests and plantations.

These categories can then be subdivided into land utilization types defined by the nature of the products and expected benefits, and by the forms of management and investment planned. In detailed studies, examples of criteria that can be used to distinguish different forest land utilization types include the intended levels of labour, capital investment and technology for use in silviculture, harvesting and conservation (notably fire fighting).

Because forests nearly always serve more than one purpose, the multiple land utilization type is the norm in forestry. Mutually supportive combinations of forestry and agricultural cropping - known as agroforestry - often deserve consideration, especially in cases where forests are being reestablished or where risks of wind or water erosion are severe. Soil and water conservation are nearly always important objectives of forestry, and there is also growing appreciation of the importance of the preservation of genetic resources, both flora and fauna. This diversity of potential uses calls for wide-ranging consultation with users, policy makers and technical experts when formulating evaluation objectives and land utilization types.

The process of suitability assessment is essentially the same as that used for rainfed cropping. The data collection stage, however, may need to include established procedures of forest inventory, volume measurement and yield prediction to provide knowledge of existing forest stands and growth potential. Moreover, the evaluation must take account of the long time-scale involved in bringing a forest to maturity and harvest. This does not involve any change in principle because even arable cropping should be evaluated on a sustained basis, but it may be of relevance when assessing other pressures on the land over the long term.

Tree crops being planted on terraces on step land on the northern coast of Haiti... Demand for the products of trees and forests is now so high that land evaluation is often needed to select the most appropriate sites for new plantations.

Land planning in the Philippines

The Marakina Watershed Reservation in the Philippines occupies some 28000 ha and is the major source of water for Metro Manila, the national capital. The Reservation is drained by two major rivers, one of acceptable water quality, the other highly polluted. Due to its proximity to Manila, the area is subject to land speculation and a national highway passing through the watershed invites migration and re-settlement. Today, less than 30 percent of the Reservation is forested and there is tree regeneration in a further 11 percent. More than half of the Reservation was formerly forested, but is now cleared and has reverted to grassland.

In 1985, concern over the long-term future of the area as a water source for Manila led to it being chosen for a pilot study to test land-use planning activities destined for nation-wide use. An FAO Technical Cooperation team working with the Philippine Bureau of Forest Development undertook the study.

Types of data collected

big-physical

- precipitation
- bedrock; kind and depth
- mineral and coal deposits
- land form, slope, aspect, elevation
- soil depth, pH, drainage, texture, fertility, erosion evidence
- current land cover and land use
- timber volume by vegetation class
- herbage production by vegetation class
- wildlife; kind and distribution
- water table location
- water; quality and availability
- flooding hazard

economic

- access by kind
- timber haulage distance
- internal markets
- external markets
- distance to markets
- products
- product disposition
- disposable income
- total income

socio-cultural

- total population
- population structure
- tribal/cultural communities
- land ownership
- employment
- community services

The activities undertaken resembled a more detailed version of the flow chart on page 6. In establishing study objectives, 11 potential land uses were identified for investigation. These included protective forest, production forest and agroforestry, agricultural, residential and industrial use, settlement, fish farming, mineral exploitation, recreation and grazing.

The land uses were defined, and their characteristics and requirements specified. Land units were identified and mapped by overlaying maps of landform, soil and vegetation. The characteristics of each land unit, defined in biophysical, economic and socio-cultural terms (*see below*) were then matched with the requirements of the separate uses to develop suitability classifications for each land use. Three classes of diminishing land suitability (S1, S2 and S3) were recognized, and unsuitable land was categorized (N1 and N2) depending on whether or not constraints were likely to prove permanent.

Future land-use patterns in the Marakina watershed

The approach was found to be particularly satisfactory for guiding land-use planning in politically sensitive areas such as the Marakina Watershed. Future land use suggested by the suitability classification is illustrated above.

The difficulties related principally to defining appropriate economic and socio-cultural criteria, and securing the confidence and cooperation of local people in divulging information of this kind. A need to develop simple. yet comprehensive operational procedures for collecting field data was recognized. Subject to suitable adjustments in the light of this experience, the procedures were deemed suitable for nationwide application.

New land for settlers

Indonesia: Phased land-use planning for transmigration

Overcrowding in fertile areas of the developing world can be solved either by using existing land more intensively or by resettling people on new land. In both cases, careful land evaluation is required.

Unfortunately, many of the still unsettled areas are agriculturally poor and cannot support sustained arable cropping. This is obvious in places that are arid, cold or steeply sloping but less obvious in the tropical rain forest. However, lush rainforest vegetation is no guarantee of high soil fertility - more often the soil contains a limited volume of nutrients originating mainly in the vegetation itself. This supply of nutrients is irretrievably lost if the forest is felled. Usually less than 20 percent of this kind of land can sustain the unsophisticated arable cropping with limited fallow that typifies re-settlement.

In the past, much money and effort have been wasted by planning and even implementing resettlement schemes without first establishing the suitability of a chosen site. The distress suffered by unsuccessful settlers on these sites has been even more painful. To rely on chance when selecting a site is to accept odds of at least five to one against success.

The first task is to use land evaluation to identify suitable areas for resettlement. Very large areas - perhaps a whole nation - may have to be examined; however, if no national overview exists, the study can be planned to serve many purposes besides re-settlement. Many countries could benefit from such an overview, which can unify much scattered, uncorrelated information. Modern technology, especially satellite imagery, radar scanning (so useful in the cloud-covered humid tropics) and computerized data storage is on hand to assist. In the context of resettlement the aims of the overview should not be ambitious. Small-scale mapping (say 1:250000) will not yield more than broad indications of the likely quality of the soils but it will help eliminate huge areas by revealing unfavourable aspects of topography, existing land use, swamps and other factors. The areas remaining are worth further examination.

Two more stages of land evaluation are often desirable before detailed planning can begin. The first confirms the general suitability of the soils, examines alternative land-use possibilities and indicates where each alternative should be considered. The final step is a detailed land evaluation, particularly if the topography and soils are complex, so that optimum land-use patterns can be determined.

Land evaluation for resettlement concerns people who have moved from a familiar environment. If new conditions arc very different, their situation is correspondingly more difficult. They may lack experience of how their new land should be used or of the vagaries of local climate and soils - an unusual and precarious situation for farming families. Sometimes farmers used to growing paddy rice have been resettled in areas where only dry land cropping is possible. In such circumstances, land evaluators have a special responsibility to anticipate all the problems that may arise in relation to the land utilization types that they put forward.

Resettled farmers often have to learn new techniques: here a soil conservation expert teaches Thai farmers how to construct a waterway from bench terraces.

Indonesia: Phased land-use planning for transmigration

Transmigration - the movement of large numbers of families from the overcrowded islands of Java, Bali and Madura to new settlements on the sparsely populated 'outer' islands of the Indonesian archipelago - is a major element in the national development programme of the Indonesian government. Careful land selection and planning is crucial to the success of such schemes. Recognizing this, the UK government provided the services of a multi-disciplinary team from the Land Resources Development Centre to assist the Indonesian authorities in planning site selection for transmigration in central Sumatra. The work, carried out between 1976 and 1979, was conducted in four phases.

Phase I: rapid reconnaisance for site identification.
Phase II: semi-detailed studies for site verification and evaluation.
Phase III: agro-economic analysis for site development.
Phase IV: detailed physical planning of village units.

The initial reconnaissance examined an area of 18000 km^2 astride the Trans-Sumatra highway and eliminated land with steep topography or evidence of existing land use. Eight large sites proved worthy of more detailed study. Six of these were examined in Phase II which involved surveys at 1:40000 scale of soils, land use, drainage and slope associations. Land suitability was assessed for six defined land utilization types: villages and houselots; dryland arable farming with minor tree crops; tree crops; wetland arable farming; pastureland; and fuelwood and timber plantation.

The main constraint to settlement on all sites was found to be low soil fertility. High fertilizer inputs would be needed to maintain crop yields and, for this reason, none of the soils were more than marginally suitable for arable cropping. To minimize soil erosion, arable cropping was not recommended on slopes greater than 8 percent. It had been anticipated that the six sites would provide land for 60000 settler families, but the study concluded that only 31165 families could be accommodated. Details of the findings on land availability are shown in the table below.

Phase III work entailed the formulation and detailed economic appraisal of development plans for one of the sites (Kuamang Kuning). Four systems of smallholder arable cropping were examined (with and without treecrops, and with and without irrigation) together with the possibility of establishing a nucleus rubber/oil palm estate. The study provided valuable information applicable in principle to all the sites and showed that the prospects for a nucleus estate were favourable.

In Phase IV the detailed layout of village centres, houselots, family holdings and general infrastructure was worked out for two village units within Kuamang Kuning, taking account of land suitability, social environment, future development needs and infrastructure requirements. The project clearly demonstrated the advantages of a phased approach in which time-consuming detailed work is confined to areas where it will be of immediate value. The Phase I and II procedures have since been widely adopted, with minor modification, in transmigration planning. The Phase III and IV procedures provided valuable insights to general problems but have proved too elaborate to be accepted as standard.

Availability of land on possible settlement sites in Central Sumatra, Indonesia (ha)

possible settlement site	area examined	used land		unused land		
		already intensively used	only lightly used	suitable for mixed arable/tree crops	suitable for tree crops only	swampy or too steep for development
Alai Hilir	65900	9000	7180	22090	27630	-
Singkut	48500	6660	10450	24250	2340	4800
Kuamang Kuning	60000	-	3140	42860	14000	-
Kubang Ujo	41600	3170	560	15670	6400	15800
Hitam Ulu	81500	-	5950	52460	1460	21630
Sungai Tambangan	25300	6150	4170	7140	-	7840
TOTAL	322800	24980	31450	164470	51830	50070

Quantification and computers

Indonesia: Computerized land evaluation

Qualitative land evaluation may be adequate in the early stages of planning but a need often arises later to compare the relative suitability of alternative land uses on a precise numerical basis. Indeed, without quantitative economic assessment, it is scarcely possible to make meaningful comparisons between land uses that yield different products - grain crops and livestock, for example - or which differ greatly in their requirement for inputs. Only a monetary base can make a comparison between such different factors possible.

Quantitative suitability is measured by comparing output (crop yield, for example) with the sum of the inputs, all in monetary terms, for each class of land for each alternative use. Predicting yield is the first step. In principle, the problem is no different from that faced in qualitative evaluation and is approached in the same way. The method involves recording actual yields in comparable situations or calculating yield with arithmetic models that simulate the way in which yield is determined by the interaction of environmental factors.

Modern statistics provide refined means of extrapolating actual yield data and of verifying the reliability of the output. No comprehensive model yet exists that can manipulate raw environmental data and provide practical assessments at farm level but progress is being made and existing models can already address limited problems, such as the availability of moisture or the risk of soil erosion. Furthermore, summary models, notably the FAO approach to the evaluation of 'agro-ecological zones', that consider only selected environmental variables can provide reasonable assessments of productive capability.

Verification of results, by comparison with actual field experience, is important because it is easy to be misled by the apparent precision of numerical values. The conversion of yields into economic returns, of course, is also subject to uncertainties such as changes in future market prices and rates of inflation. Similar problems and assumptions are encountered in assessing the present and future costs of capital and recurrent inputs.

The increasing power of the microcomputer will make it possible to carry out basic land-evaluation analysis in the field, and thus to provide immediate answers to on-the-spot queries.

Nevertheless, quantification adds several new dimensions to land evaluation beyond the ability to compare unlike uses and products. For example, developments in modelling are soon likely to provide a systematic way of using available data more efficiently, by minimizing the effects of some of the inevitable shortcomings and gaps in raw data and thus economizing on survey resources. Most significantly, by expressing all input and output variables numerically, the way is opened for the application of computers.

Computers can assist land evaluation in the storage and retrieval of data, in the manipulation of data and in graphic representation. The use of computers in this field has progressed rapidly. In developing countries, for example, FAO teams have recently helped to develop computerized land evaluation systems based on the FAO framework in a number of countries (*see box*). This work is so recent that the systems have yet to be extensively tested but, in the context of data collection and retrieval alone, such systems can serve as, or make a major contribution to, a national geographical information system which is of great value in development planning.

Approaches differ by the extent to which mathematical modelling within the computer is used to derive and combine environmental data. The extent of modelling is not important if the approach itself is systematic and logical, and the findings are adequately validated by field observation. The computer allows stored data to be reproduced at will as maps, diagrams or tables. Imagery from satellites, aircraft or other sources can also be stored in digital form, and processed mathematically to enhance contrast and aid interpretation.

Computer science itself is developing fast. A negative aspect of this development is the temptation to abandon one system in favour of a more powerful one before the first has had a chance to fulfill its design purpose. There are few clearer examples of the better being the enemy of the merely good. This risk can be minimized by designing the computer system in a way that allows individual modules, serving separate purposes, to be updated periodically without discarding the system as a whole.

Indonesia: Computerized land evaluation

In 1983 an FAO team working with the Centre for Soil Research at Bogor in Indonesia developed and published the methodology of a land evaluation computer system (LECS) based upon the FAO *Framework*. In developing LECS a pragmatic approach was adopted with an eye to the kinds of data already available or readily obtainable for a regional study in Indonesia. The overall model is simple in relation to the complex land systems that it represents or, indeed, in relation to computer systems that are now being developed elsewhere, but it well illustrates the basic possibilities of computerized evaluation.

Using LECS, a standardized selection of basic physical and economic data relating to each land unit and to the requirements of each land utilization type is stored in the computer and then analysed in two stages. First, the potential productivity of each land unit is evaluated for each of 22 crops and 10 timber species, each at 3 levels of technology and management input. In parallel, the computer runs a soil degradation model, based on an adaptation of the Universal Soil Loss Equation, which estimates soil loss under each land use and compares this with a level of loss regarded as tolerable; this indicates the level of conservation measures required.

The second stage assesses potential productivity on an economic basis by predicting the effects of improved management at the three management levels. These are defined in terms of input resources, allowable cropping patterns and available management resources for conservation and land improvement. The conservation model selects options for conservation management and estimates their cost. The final output provides individual crop recommendations for each land unit on an economic basis.

LECS uses a simplified procedure to predict local crop yield, and thus land suitability, by assessing the local values of just 8 land qualities derived from 14 land characteristics. These qualities are chosen because they are the major environmental variables which affect crop yield.

A computerized system can be expected to be versatile in the way in which it presents findings. Thus, the first stage output of LECS, in addition to indicating the suitability of each crop on each land unit, can provide summaries of land units and their areas within each class and of areas affected by each crop constraint. The sensitivity of the classification to different constaints can even be assessed by deliberately changing a parameter and re-running the analysis. By changing the boundary values assigned to salinity, for example, the effect of introducing a salt-tolerant crop variety can be simulated.

LECS, as originally developed, did not consider irrigation or livestock, but there is no reason, in principle, why the requirements of these land uses should not be added to the data store. The data is arranged in modules that can be updated separately as need arises.

Basic physical data used in LECS

Land qualities

1. Temperature regime
2. Water regime
3. Nutrient retention
4. Nutrient availability
5. Salinity
6. Toxicity
7. Rooting conditions

Land characteristics

1. Average monthly temperature in growing season
2. Length of growing period (days)
3. Annual rainfall (mm/year)
4. Cation exchange capacity (me/100g)
5. pH*
6. Nitrogen (kg/ha)
7. Phosphorus (kg/ha)
8. Potassium (kg/ha)
9. Salinity (mmhos/cm)
10. pH *
11. pH *
12. Rooting depth (cm)
13. Drainage class (USDA, 1951)
14. Texture class (Sys and Riquier, 1979)

* different ranges of pH are established for different qualities

The increasing power of the micro-computer is highly significant. Machines and programmes are already available that promise an effective, easy to use, land evaluation capability on small, personal computers. These will allow great flexibility and speed in resolving land evaluation queries, even in remote field offices.

Computers will revolutionize land evaluation and land use planning - but will be for the better only if their output is geared closely to practical objectives and is continuously validated.

Getting help from FAO

Technical assistance

Whereas FAO can at times advise individuals on an ad-hoc basis, it is not equipped to do this on a large scale. Most technical assistance is provided through projects, following an official request for assistance from a government. The objectives of a project are set out in a project document which forms the basis of an agreement between FAO, the country concerned, and the funding agency.

Though FAO projects are normally established to solve technical problems or carry out technical programmes, all projects have the equally important objective of building or strengthening local institutions so they can tackle these problems for themselves.

Governments that wish to obtain any form of technical assistance from FAO should contact the FAO representative in their country or region, who can assist in the formulation of a programme and advise on funding.

Further information is available directly from: FAO, Via delle Terme di Caracalla, 00100 Rome, Italy.

Publications

FAO produces a range of technical literature in several languages covering soil and water management under the following headings:

- Soil Bulletins, a list of which appear on the right, and several of which, printed in bold, deal with aspects of land evaluation;
- Irrigation and Drainage Papers; and
- Conservation Guides.

In addition, FAO has produced, together with leading soil scientists throughout the world, the World Soil Map and its legend, and important project reports such as the series covering the original world-wide Agro-Ecological Zones Project, and the follow-up project on potential population-supporting capacities of lands in the developing world.

Over the years, FAO has carried out numerous land evaluation and land-use planning projects, for which technical reports are available.

FAO Soil Bulletins can be purchased locally through FAO sales agents or directly from: Distribution and Sales Section, FAO, Via delle Terme di Caracalla, 00100 Rome, Italy.

FAO Soil Bulletins

1. Soils of the arid zones of Chile
2. Survey of soil laboratories in 64 FAO member countries
3. Guide on general specialized equipment for soil laboratories
4. Guide to 60 soil water conservation practices
5. Selection of soil for cocoa
6. Aerial photo interpretation in soil survey
7. A practical manual of soil microbiology laboratory methods
8. Soil survey interpretation and its use
9. The preparation of soil survey reports
10. Physical and chemical methods of soil and water analysis
11. Soil fertility investigations on farmers' gelds
12. A study on the response of wheat to fertilizers
13. Land degradation
14. Improving soil fertility in Africa
15. Legislative principles of soil conservation
16. Effects of intensive fertilizer use on the human environment
17. Trace elements in soils and agriculture
18. Guide to the calibration of soil tests for fertilizer recommendations
19. Soil survey interpretation for engineering purposes
20. Fertilizer legislation
21. Calcareous soils
22. **Approaches to land evaluation**
23. Management properties of ferralsols
24. Shifting cultivation and soils conservation in Africa
25. Sandy soils
26. Planning and organization of fertilizer development in Africa
27. Organic materials as fertilizers
28. S.I. units and nomenclature in soil science
29. **Land evaluation in Europe**
30. Soil conservation in developing countries
31. Prognosis of salinity and alkalinity
32. **A framework for land evaluation**
33. Soil conservation and management in developing countries
34. Assessing soil degradation
35. Organic materials and soil productivity
36. Organic recycling in Asia
37. Improved use of plant nutrients

38/1. Soil and plant testing and analysis
38/2. Soil and plant testing as a basis of fertilizer recommendations

39. Guidelines for prognosis and monitoring of salinity and sodicity
40. China: recycling of organic wastes in agriculture
41. China: azolla propagation and small-scale biogas technology
42. Soil survey investigations for irrigation
43. Organic recycling in Africa

44. Watershed development with special reference to soil and water conservation
45. Organic material and soil productivity in the Near East
46. Blue-green algae for rice production - a manual for its promotion
47. Le recyclage des résidus agricoles organiques en Afrique
48. Micronutrients and the nutrient status of soils: a global study
49. Application of nitrogen-fixing systems in soil management
50. Keeping the land alive: soil erosion - its causes and cures
51. El reciclaje de material orgánicas en la agriculture de America Latina
52. Guidelines: land evaluation for rainfed agriculture
53. Improved production systems as an alternative to shifting cultivation
54. Tillage systems for soil and water conservation
55. Guidelines: land evaluation for irrigated agriculture
56. Soil management: compost production in tropical and subtropical environments
57. Soil and water conservation in semi-arid areas
58. Guidelines: land evaluation for extensive grazing
59. Nature and management of tropical peat soils
60. Soil conservation for small farmers in the humid tropics
61. Radioactive fallout in soils, crops and food
62. Management of gypsiferous soils
63. Micronutrient assessment at the country level: an international study

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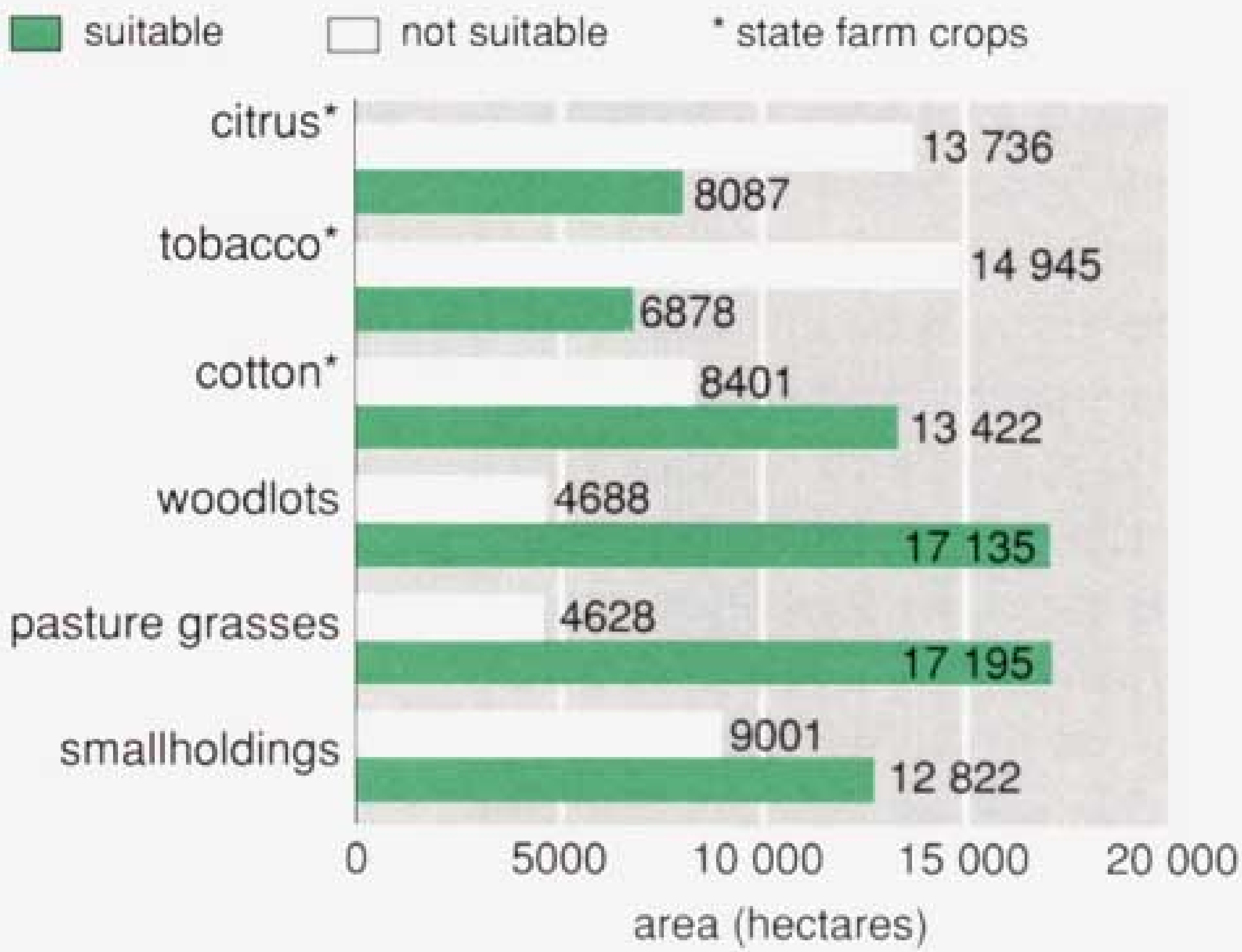
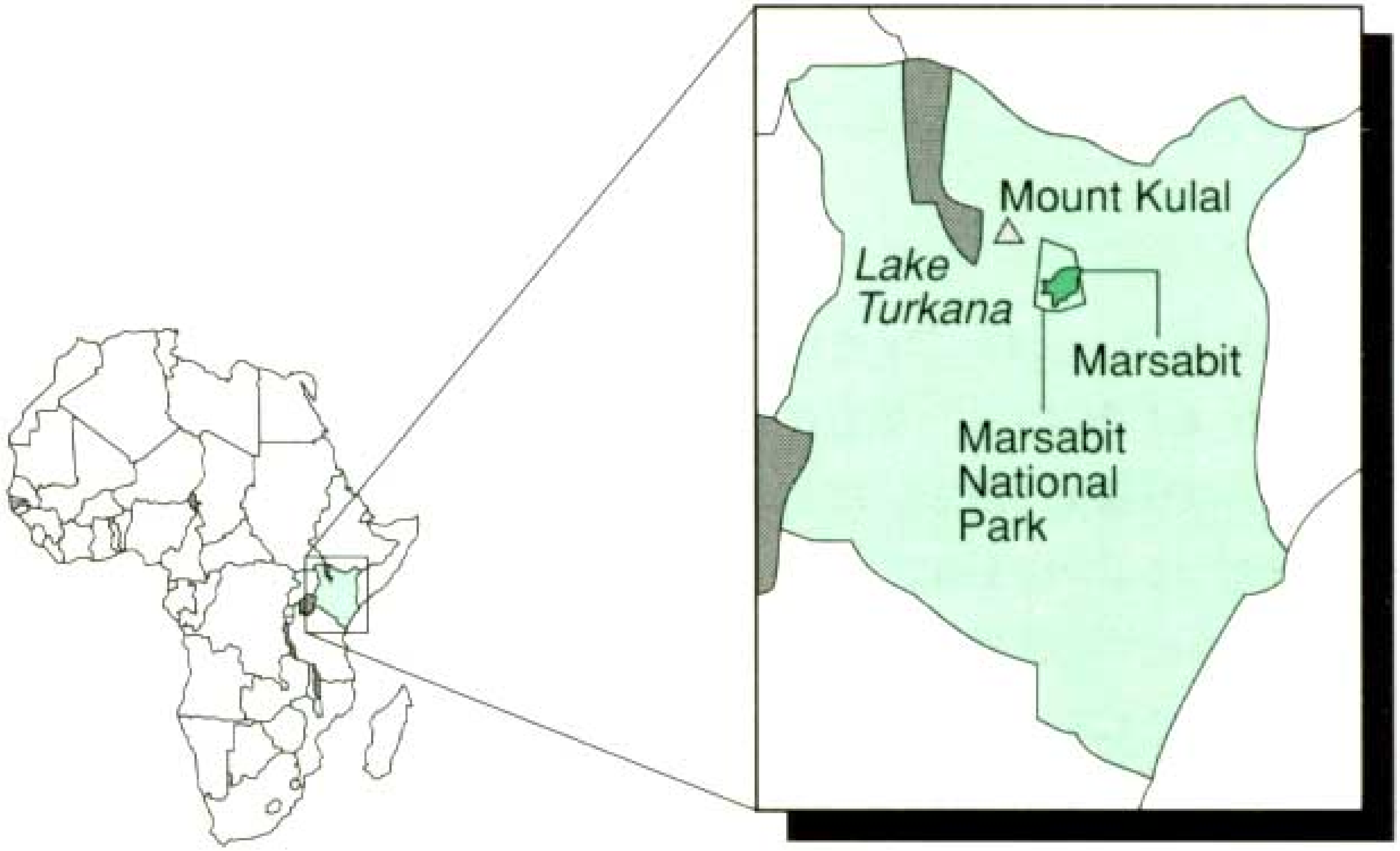
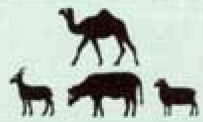
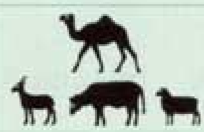
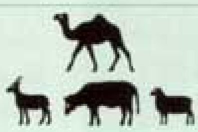
Contents - **Previous**


Mauritius
Port Louis
Mahebourg

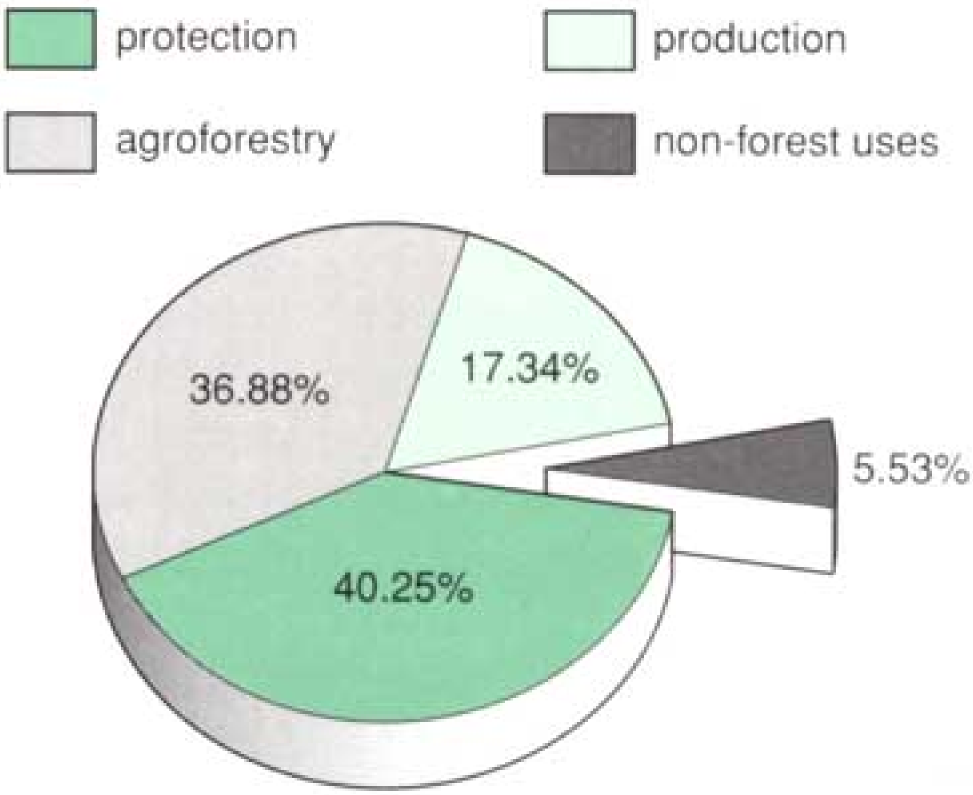
Suitability of soils in the Kesem area for non-irrigated agricultural uses

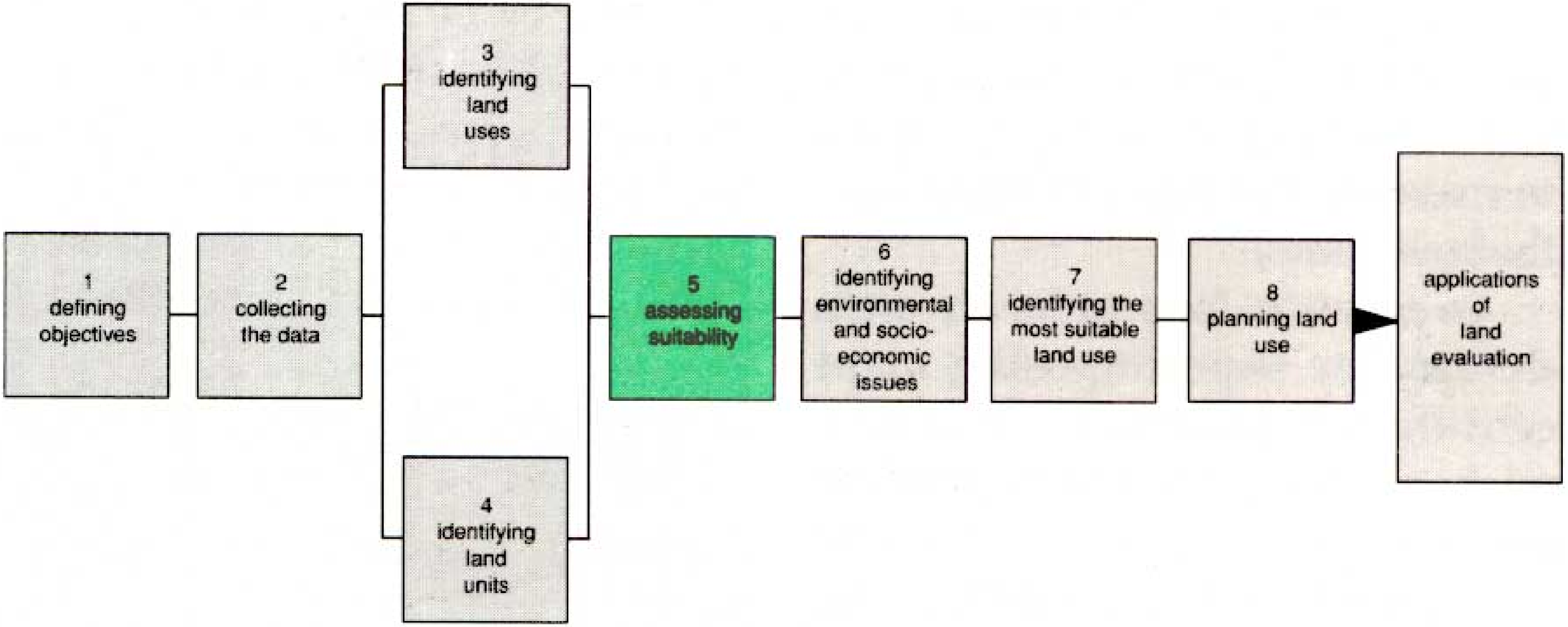



Mount Kulal
Lake Turkana
Marsabit
Marsabit National Park

physiographic unit	map unit	land suitability classification for extensive grazing				
		S1	S2	S3	N	remarks
mountains (volcanic)	MV1					too cold
uplands (volcanic)	UV1/2					too cold
sedementary plains	PsU1/2					
stepped plateaux 1	LsV1P					
stepped plateaux 2	LsV2					

Future land-use patterns in the Marakina watershed





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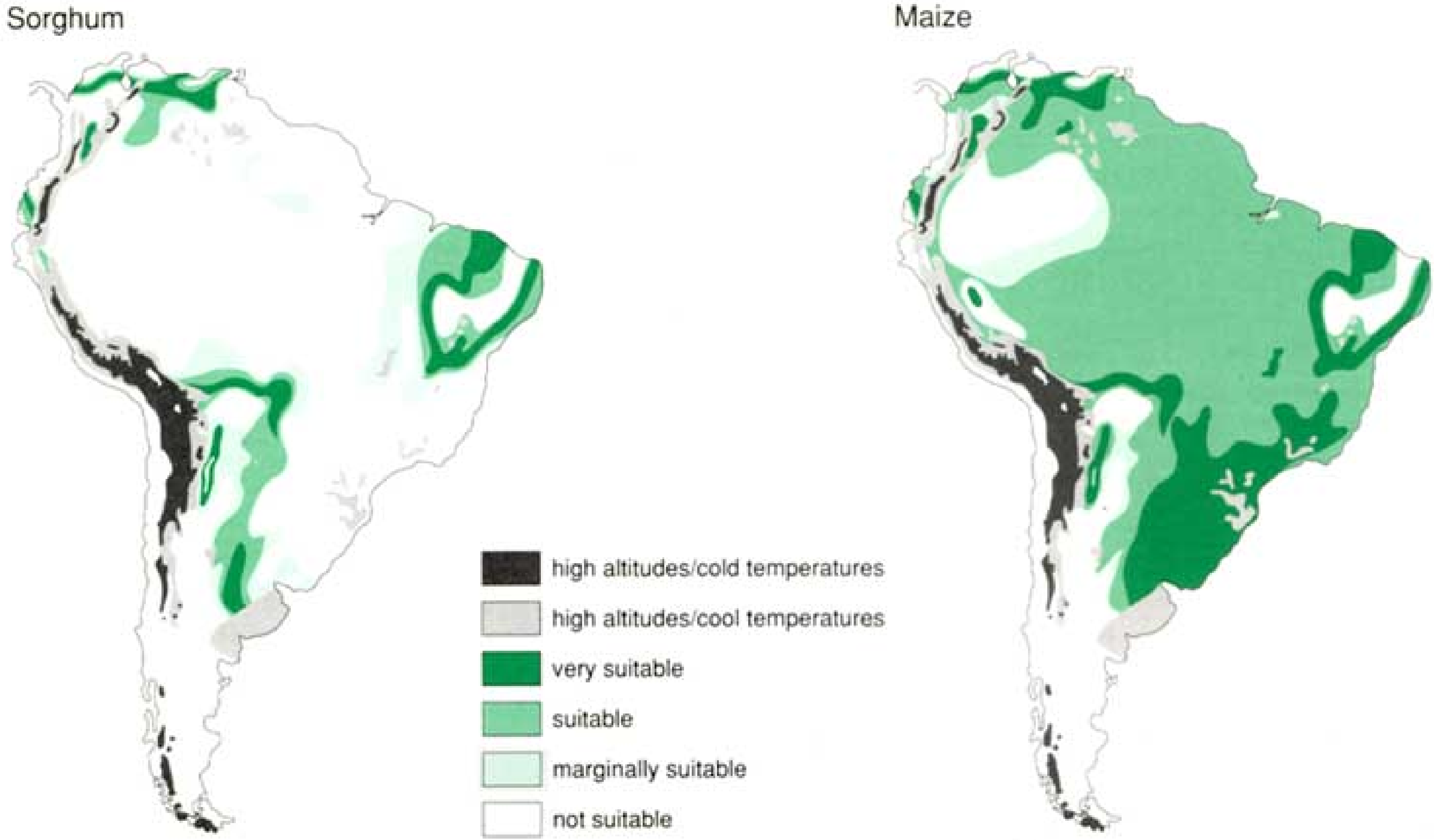
Sorghum
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high altitudes/cool temperatures
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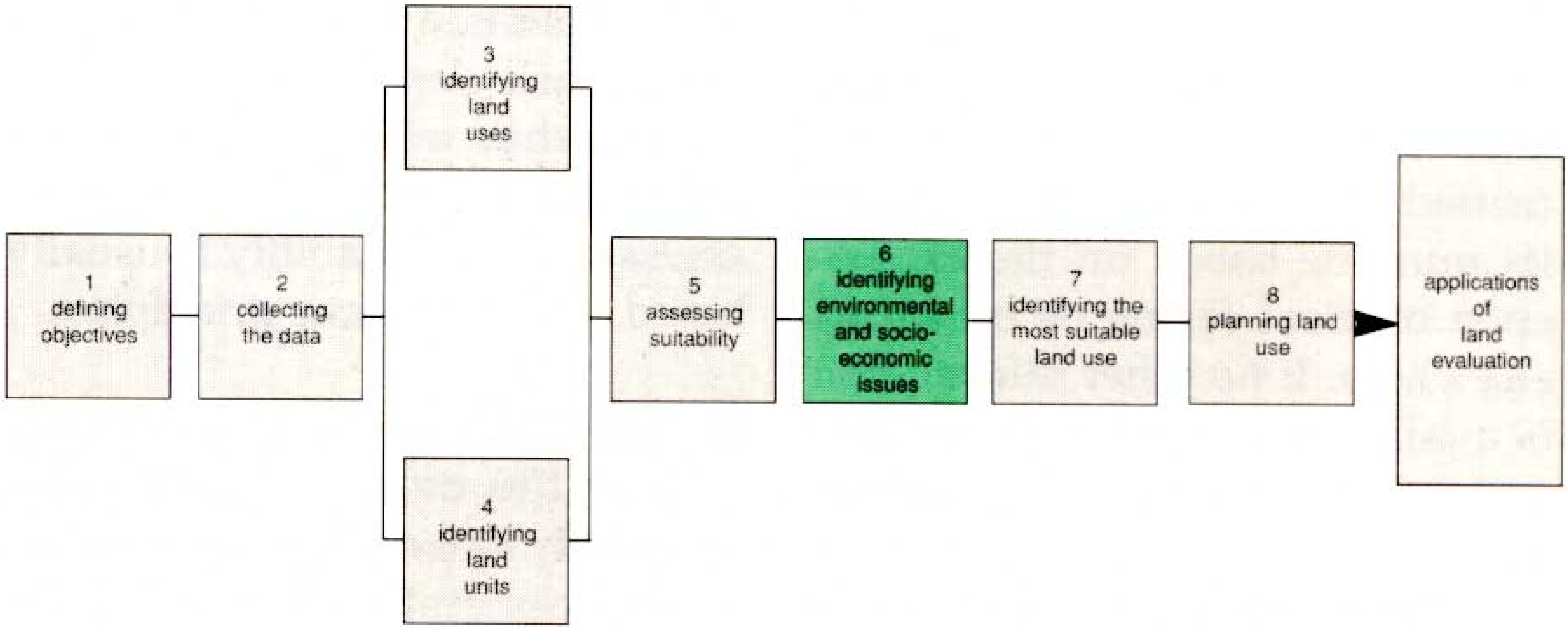
suitable
marginally suitable
not suitable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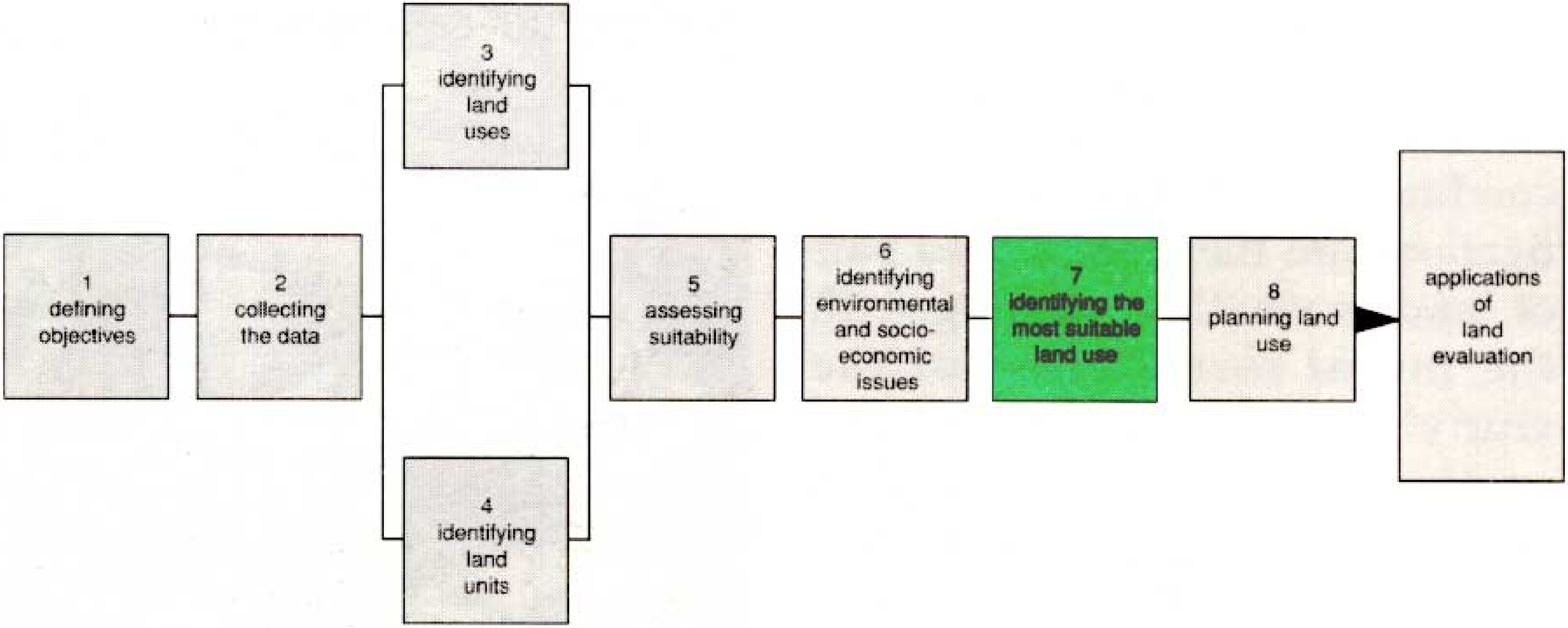

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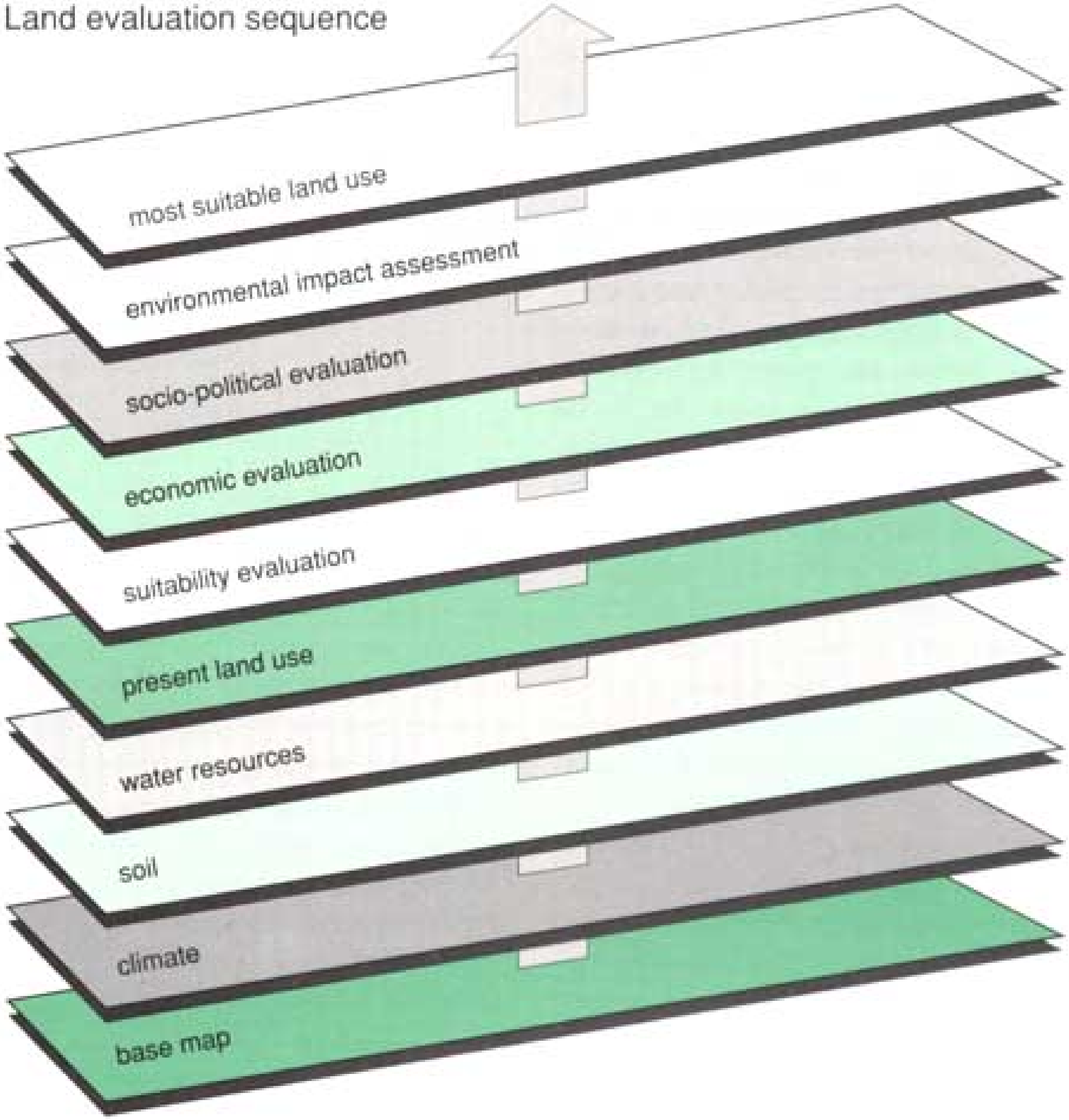
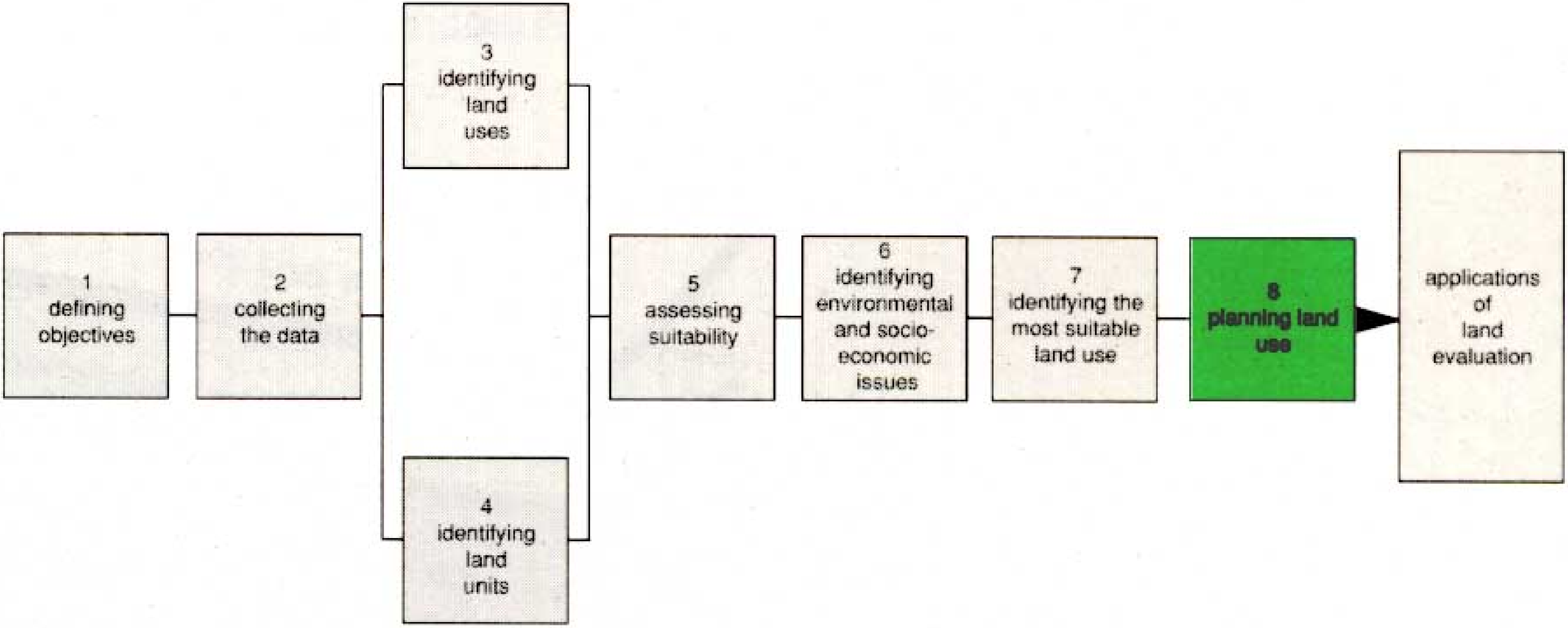
Land evaluation sequence

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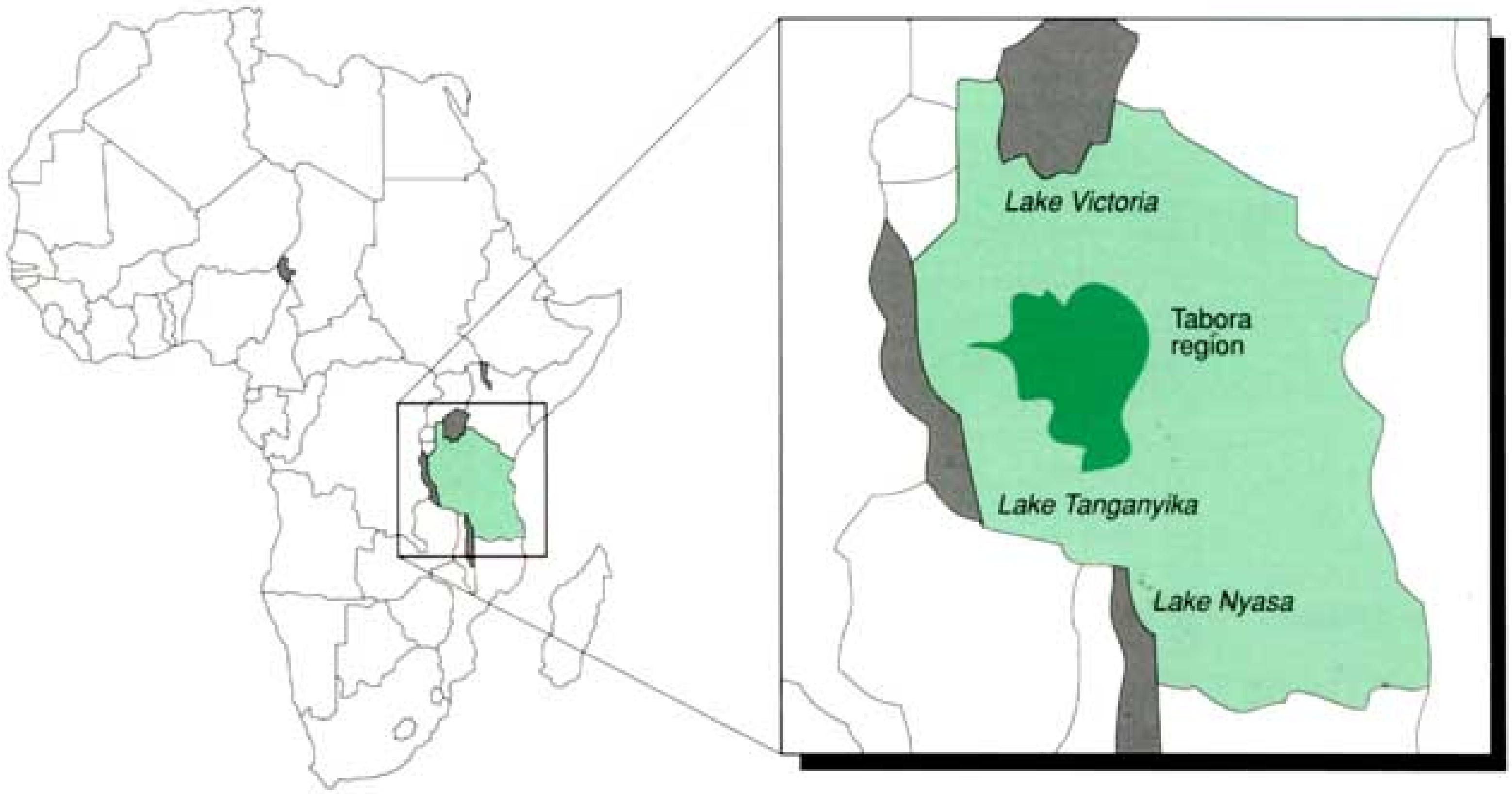
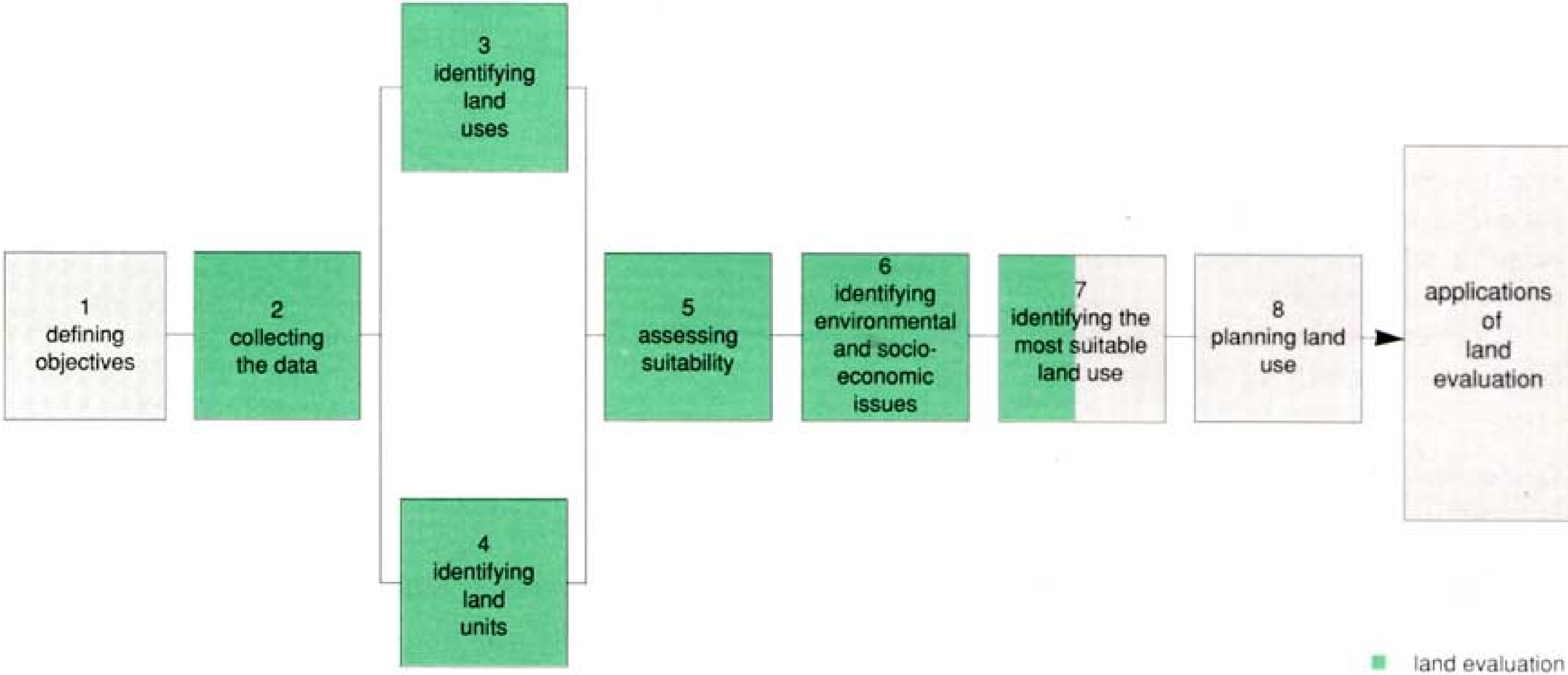

Lake Victoria
Tabora region
Lake Tanganyika
Lake Nyasa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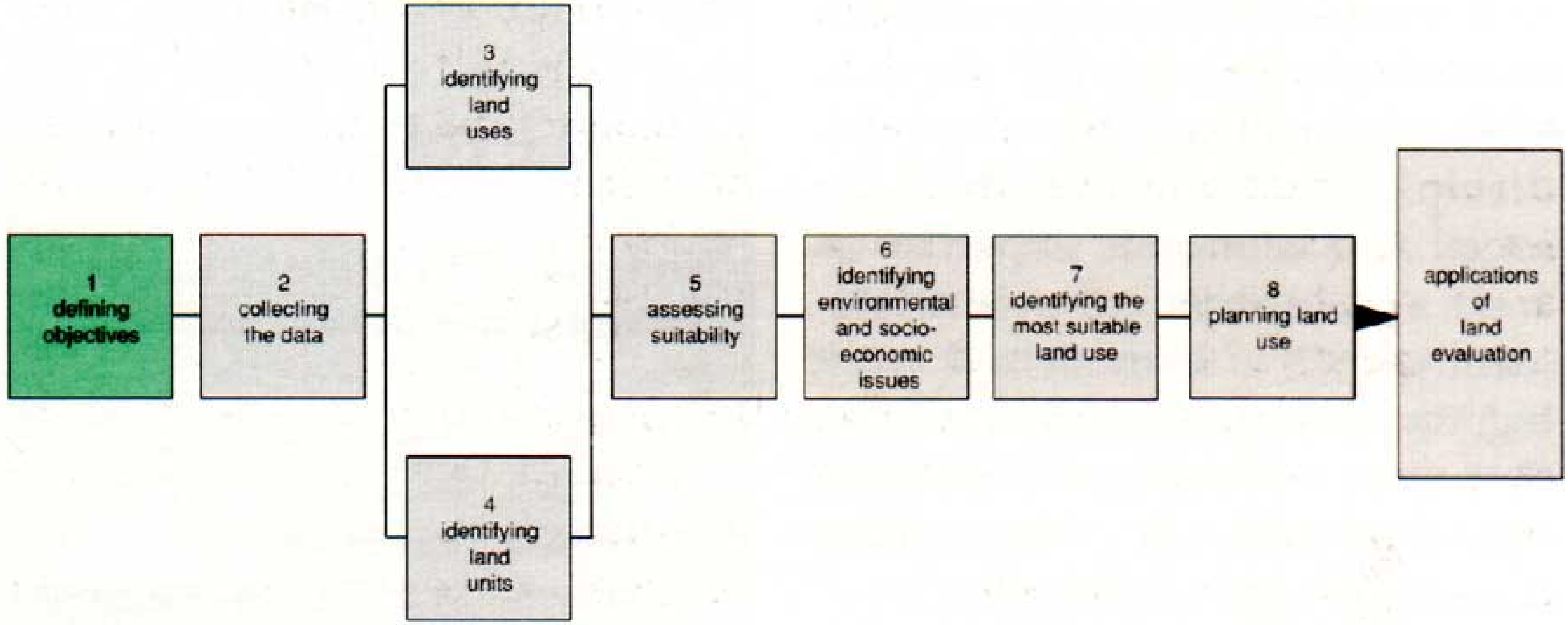

1 defining objectives
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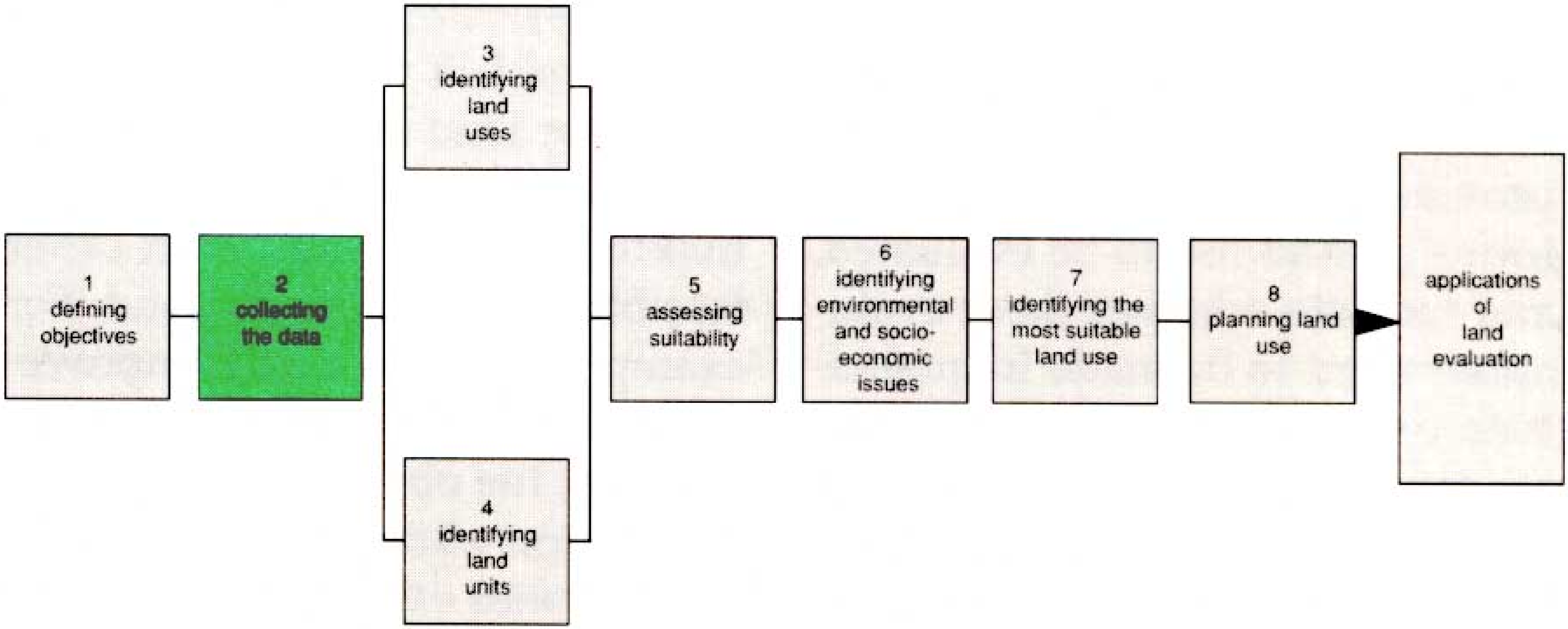
3 identifying land uses
4 identifying land units
5 assessing suitability
6 identifying environmental and socio-economic issues
7 identifying the most suitable land use
8 planning land use
applications of land evaluation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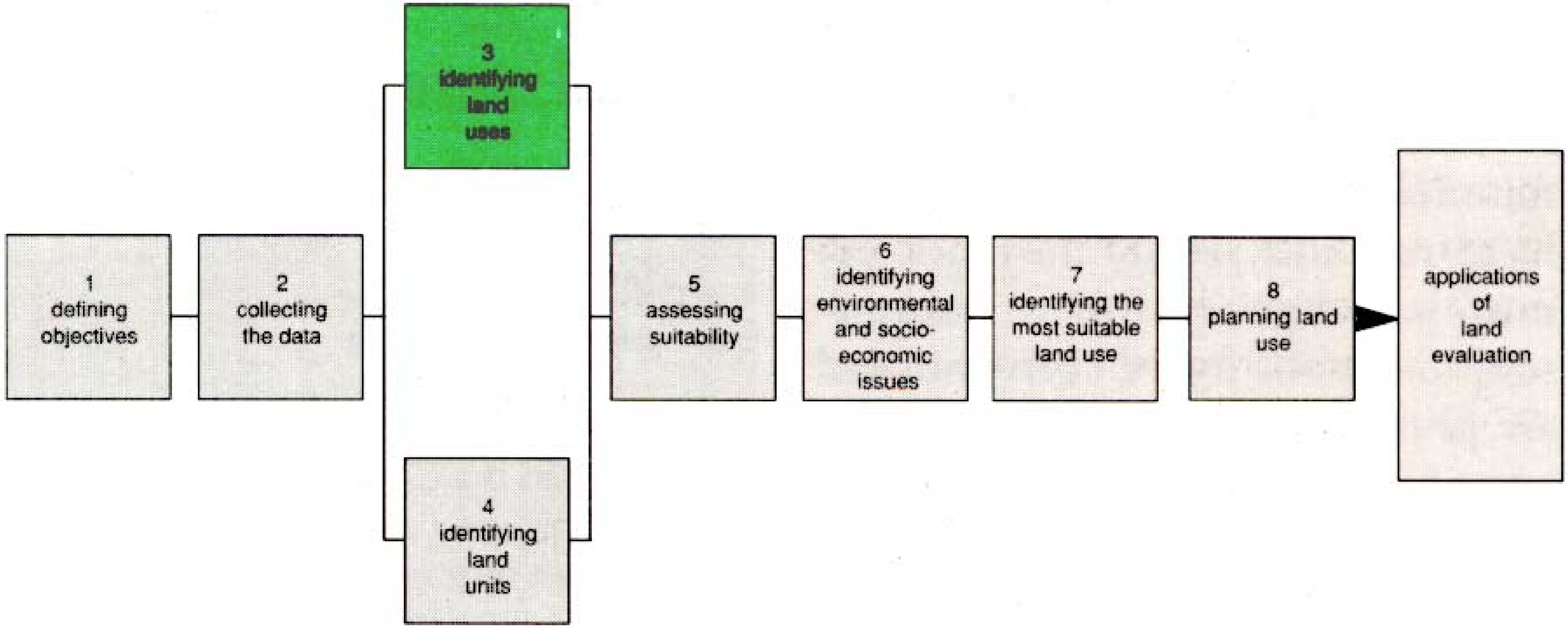
planning land
use
applications
of
land
evaluation


1 defining objectives
2 collecting the data
3 identifying land uses
4 identifying land units
5 assessing suitability
6 identifying environmental and socio-economic issues
7 identifying the most suitable land use
8 planning land use
applications of land evaluation

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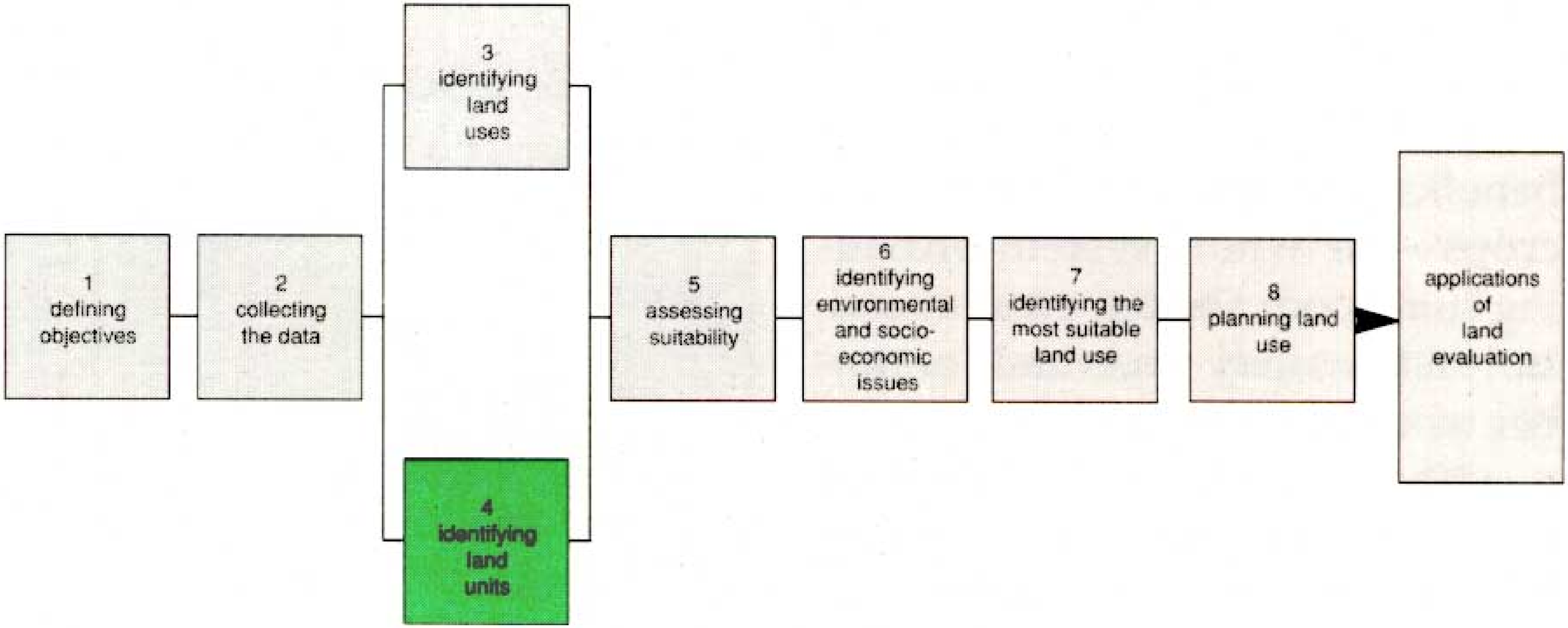

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