Lecture Notes: "Land Evaluation"

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Part 1: Basic concepts & procedures of land evaluation

Disclaimer: These notes were developed for the Cornell University course Soil, Crop & Atmospheric Sciences 494 'Special Topics in Soil, Crop & Atmospheric Sciences: Land evaluation, with emphasis on computer applications', Spring Semester 1994, and were subsequently expanded and formatted for publication. They are not to be considered as a definitive text on land evaluation.

Contents for Part 1: “Basic concepts & procedures of land evaluation”

This unit introduces land evaluation concepts and terminology, using the FAO "Framework for Land Evaluation" and subsequent guidelines as the reference system. In this unit we learn *what results* we want from a land evaluation and the *procedures* to follow, i.e., the *structure* of a land evaluation exercise. In later units we will study the analytical techniques necessary to actually carry out the land evaluation.

1. Outline of a land evaluation exercise

This lecture presents the overall structure of the evaluation exercise. Most of the steps will be explained in more detail in later lectures.

Before presenting the steps, we must define the *actors* in this drama.

1.1 Client, evaluator, experts, and stakeholders

These are the five types of 'actors' in the land evaluation process

(1) *Client*: A person or organization that requests the work and will act on the basis of its results. Also called the *user* of the land evaluation results.

(2) *Evaluator*: A person who carries out the land evaluation (this means you!). The evaluator must understand the concepts and methodology of and evaluation, and be able to use appropriate analytic techniques and computerized tools as necessary. The evaluator acts as the intermediary between the client and the experts. A land evaluator must have a good knowledge of natural resources and land uses, be able to think logically and systematically, be able to use computers with some facility, and, most of all, be able to communicate with clients, land-use experts, and land resource experts using *their* specialist language. Land evaluation is an integrative and iterative process, so the evaluator must have an open mind.

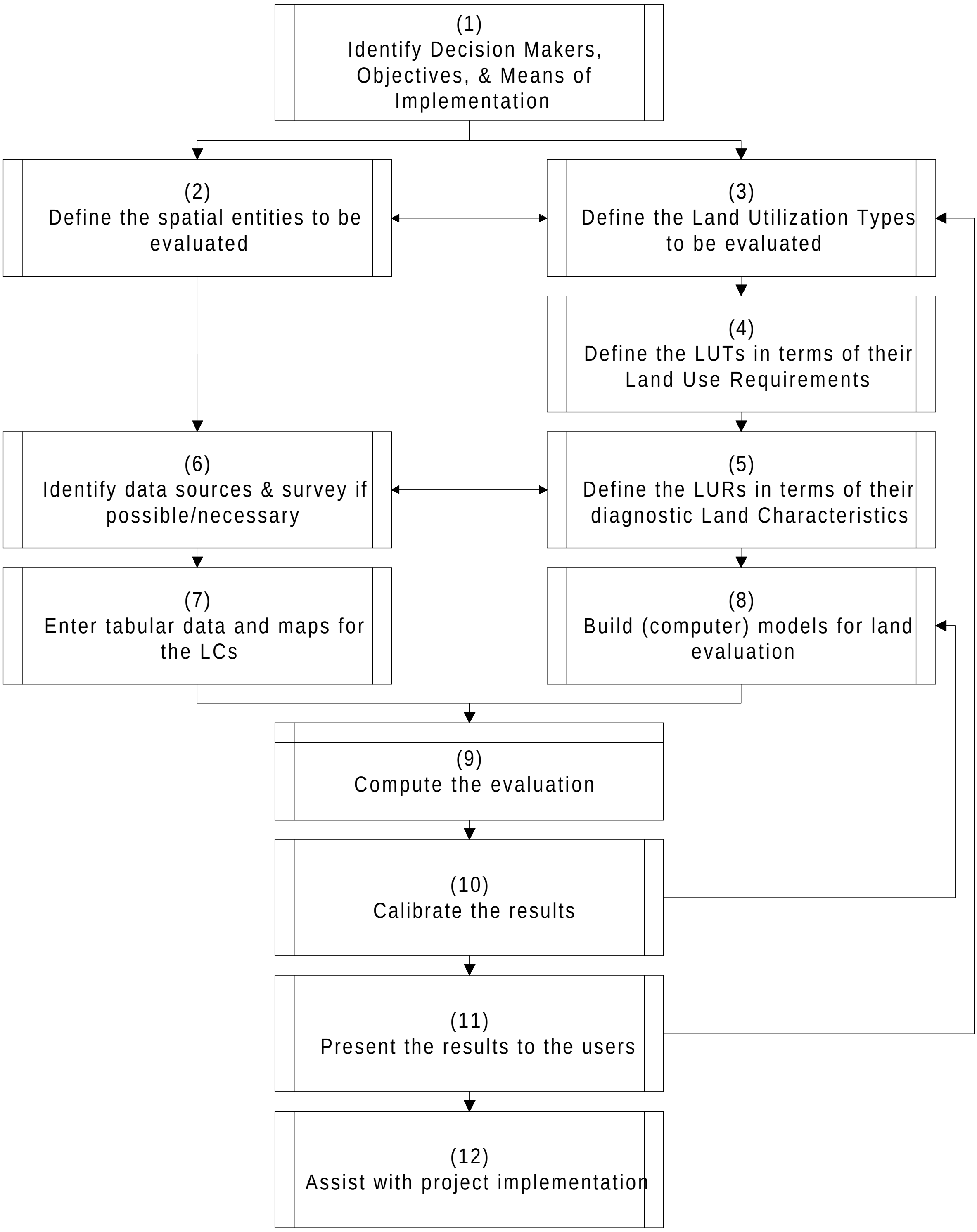
(3) *Land-use expert*: a person who has information about a land use or land quality, in relation to the land, for example, soil scientists, agronomists, economists, , rural agents and farmers with good powers of observation. The expert must be committed to undergoing a series of interviews by the land evaluator, and later reviewing the results of the preliminary evaluation. This is not a trivial time commitment. Land-use experts usually view their area of expertise in specialist terms, and must work with the land evaluator to express their knowledge within the land evaluation framework.

(4) *Land resource expert*: a person who has information on the land resource, for example, soil surveyors, climatologists, census takers, rural agents and farmers with good powers of observation. The expert must be prepared to explain their data to the informed outsider, in particular, its provenance, meaning, and reliability, and must be able to construct map units and data bases as required by the land evaluation computer system. The land resource expert must interpret the data as they collect it in the terms required by the land evaluator.

Farmers or other country people are a special category of experts: often intimately familiar with land use and land qualities in a restricted area, but usually with a poor understanding of the scientific (predictive) relations underlying the observed phenomena. Their observations can provide an excellent starting point for further investigation.

(5) *Stakeholders*: all parties who will be *affected* by the results of the planning decisions taken on the basis of the land evaluation. This is usually the whole rural population of the planning area, but may include workers in related industries such as transport or food processing.

1.2 The land evaluation process



A land evaluation exercise can be divided into twelve steps, as shown in the figure. These steps certainly can contain *feedback*, i.e., the results of a step may suggest modifications that should be made to previous steps. The most important feedbacks are shown in the figure, but there may be others. For example, it may become clear during the identification of data sources, that there is not enough data to evaluate a certain land use.

And of course once you've finished the whole process, it's time to start over, with all the experience you gained the first time, so there should be an arrow from the bottom to the top of the entire diagram.

We now discuss each step in the figure in some detail.

1.2.1 (1) Identify the decision makers, their objectives, and their means of implementation.

The key point is that land evaluation can not take place as an isolated activity. It *must* serve the needs of land use planning, in some sense. This implies that there is a recognized need to plan, and decision makers who are prepared to plan, so that the results of the land evaluation will be used by these decision makers to inform their plan. Therefore, the first step in the land evaluation exercise is to determine exactly *who* wants to plan, their *objectives*, and the scope of their decision-making *power* to implement a plan.

To carry out this step, the evaluator conducts a series of *interviews* with the decision makers and other affected parties, and reviews relevant documents, to answer the following questions:

<u>Decision makers</u>

Who are the actors in rural land use and what are their roles? The primary decision maker is often the party who commissioned the study, i.e., the client. In some cases, the study is commissioned by one party to benefit another (e.g. FAO to benefit a national planning board), in which case the latter is the decision maker.

<u>Objectives</u>

What problems do the decision makers want to solve? (1) *General* objectives, e.g., 'reduce rural poverty', 'promote sustainable land use', (2) *Specific* objectives, e.g., decide where to improve rural roads and locate rural assistance centers. These objectives determine the selection of land utilization types and evaluation units. Obviously, the more specific the objective, the easier it is to determine land utilization types to meet that objective.

<u>Resources, Methods of implementation and enforcement</u>

By what means can the decision makers affect the land use? What do they actually have the power to do, and what do they intend to do with the results of the study? Will they use directly prescriptive, indirectly prescriptive, or proscriptive methods (previous lecture)?

The point here is to avoid unrealistic (politically unfeasible) land utilization types. A good example is agrarian reform: does the client have sufficient resources to purchase large estates for distribution to landless farmers? Does the client have the political power to expropriate these estates? If there is no practical way to acquire the land, there is no point in including settled estates in the evaluation exercise (other than to show how much better off the landless farmers would be if there were a way to expropriate the estates).

<u>Other affected parties</u>

What other parties (not the decision makers) will be affected by the evaluation? How can they be included in the decision-making process? These are generally the *stakeholders* mentioned above as one of the types of actors in the process. Without their *active participation* in the formulation of objectives and implementation plans, it is unlikely that the results of the land evaluation will be useful.

It is generally impractical to include all stakeholders in the land evaluation and planning process; instead their *representatives* are included. This is much easier if there are existing organizations that well-represent the stakeholders, for example, peasant cooperatives, unions, and professional associations. Of course, if these are not democratic, there may be stakeholders not- or poorly-represented by their supposed 'leaders', in which case some method must be found for directly involving these stakeholders.

<u>Output of this phase</u>

A document detailing the above points. Please, to the point! Statements such as 'county X is by nature an agricultural and peasant nation' or 'the problems of rural poverty and land degradation are every day more acute' are not helpful unless they lead directly to a specific policy on the part of the decision maker. This document should be approved by all the stakeholders.

1.2.2 (2) Define the *spatial entitie*s to be evaluated (evaluation units)

... based on the planning needs of the decision makers (separate lecture). Includes *scale* of the final map(s) and *type* of map unit. May be influenced by data sources (below).

<u>Output of this phase</u>

The list of the evaluation units, how they were defined, the minimum decision area, the total project area, the map scale or resolution for evaluation results.

1.2.3 (3) Define the *Land Utilization Types* (LUT)

... to be evaluated, both *actual* and *potential.* (separate lecture). These are the land use options, and are specified in enough detail to support the later phases of the evaluation.

Output of this phase

> The list of the Land Utilization Types and their detailed description, probably according to a standardized form prepared by the evaluator.

1.2.4 (4) Define the LUTs in terms of their *Land Use Requirements* (LUR)

Define the LUT by a set of more-or-less independent *requirements*, which are the general conditions of the land necessary for successful use according to the system specified by the LUT.

This is the computable definition of the land use. The land use *experts* participate in this phase. (separate lecture)

Output of this phase

> For each Land Utilization Types, its list of Land Use Requirements, the number of severity levels of the corresponding Land Quality, and their effect on suitability, including decreased yields, increased costs, and physical limitations as applicable. The evaluator should fill in one worksheet for each LUT.

1.2.5 (5) Define the LURs in terms of their diagnostic *Land Characteristics* (LC)

Identify the measurable *diagnostic land characteristics* that will be used to determine to what degree the Land Use Requirements are satisfied.

The land resource and land-use experts participate in this phase. (separate lectures)

Output of this phase

> For each Land Use Requirement of each Land Utilization Types, a list of the Land Characteristics that will be used to evaluate it, and a general description of how the LCs will be combined.

1.2.6 (6) Identify data sources (& survey if possible/necessary)

... according to how the Land Use Requirements are to be evaluation (separate lectures). May influence choice of evaluation units (above).

Output of this phase

> A list of the data sources, along with the diagnostic LCs that will be supplied by each one.

1.2.7 (7) Enter tabular data and maps for the LCs

... into the computer, ready for the model. Ideally, the data would already be in digital form (true in the US for base maps, digital elevation models, many thematic maps such as soils, climate records) and a simple format conversion would be the most that would be required. In general, data validation, entry and transformation will be necessary.

<u>Output of this phase</u>

Computerized database and digital maps, possibly including remotely-sensed images.

1.2.8 (8) Build (computer) models for land evaluation

(all these in separate lectures)

1. Infer LQs from the diagnostic LCs.

2. Infer suitability for LUTs from the LQs.

3. Model the economics of the LUT.

4. Geographic analysis (part of 1, 2, or 3)

5. Optimization under constraints

<u>Output of this phase</u>

The computer model itself.

1.2.9 (9) Compute the evaluation

1. Apply the model to each LUT/evaluation unit combination.

2. Export results for optimization and/or geographic analysis

3. Perform the optimization and/or geographic analysis

In each step, estimate the uncertainty of the result.

<u>Output of this phase</u>

The results of the computation, in the form of tables and maps, preferably digital.

1.2.10 (10) Calibrate the results

Present the preliminary results to the *experts*, verify if possible with experience (for actual LUTs only). For potential LUTs, verify the *internal consistency* of the results, e.g., yields and predicted costs and returns should be reasonable and consistent. Adjust the model accordingly and recalculate.

Notice that we don't talk about *validation* of land evaluations, because that would imply that each land use would be tested on each land area for an extended time period! Obviously impossible, so we *calibrate* against expert judgment and related experience.

Output of this phase

Same as (9) and (10), but calibrated and extended to all LUT/land unit combinations.

1.2.11 (11) Present the results to the users

Without effective *dissemination* of the *results* of a land evaluation, it remains an academic exercise with no practical value nor effect on land use.

Outputs of this phase

1. The *report* and *accompanying maps* are the traditional products of a land evaluation exercise and are delivered to the client who commissioned the land evaluation. However, these are *static* and may be *misinterpreted*. So, …

   …the ideal situation is that the land *evaluator* keep a formal relation with the *client*, to (1) explain anything that is not clear, (2) make minor *adjustments* the evaluation during the implementation phase, (3) *extend* the evaluation based on the experiences gained during implementation. In other words, a *long-term* relation between evaluator and user would be profitable for both. At the very least, the evaluation project should include a *follow-up* stage.

2. The *automated system* itself, with the data and models constructed for the evaluation, can be delivered to the client. Most clients have sufficient computer resources to receive these, possibly without some of the more specialized peripherals (e.g., digitizers, plotters, high-resolution color displays) that might have been used by the evaluator. The client can receive instruction to be in condition to change parameters and re-run the model, and to produce *ad-hoc* reports (this depends on their level of sophistication).

3. *Technical workshops* can be presented to the client and other stakeholders, explaining in detail the procedures that were used in the evaluation. By making the decision-making process transparent, the client can gain public support for the plan's implementation.

4. *Executive workshops* can be presented to the decision makers and the interested but non-technical public, to provide an overview of the project and its results.

In all dissemination methods, the land evaluator must try to communicate the *reliability*, or conversely the *uncertainty*, of the results.

1.2.12 (12) Assist with project implementation

During the course of the exercise, the land evaluator should have become intimately acquainted with the project area and its problems. This practical experience should not be lost, so that the evaluator should have an advisory role in the implementation of the evaluation recommendations, perhaps by serving on the appropriate planning board as a technical advisor.

1.3 'Rapid prototyping' applied to land evaluation

In any engineering activity, it is unwise to invest too much in the early stages of the project, without being sure that the methods to be employed will work. One approach to this problem is called 'rapid prototyping', i.e., the idea is to produce a working prototype to illustrate the essential features of the proposed engineering solution as quickly as possible, so that the client can react to the ideas-made-visible in the prototype. This approach has been advocated especially in software engineering.

Applied to land evaluation, this implies that it is often more cost-effective to build *simplified* models incorporating the *most critical* factors for a selected *set* of the *most important* or *best understood* land uses, identify and enter data for a *set* of the *most important* or *most representative* evaluation units, and assure that this evaluation gives reasonable and useful results.

Then, the model can be made more *complex*, a wider set of land uses can be modeled, and data can be entered for all evaluation units. This will lead to a final evaluation. This iterative approach to land evaluation works best when the evaluator is accepted as a more-or-less permanent part of the planning team, not as a consultant hired to produce a single document.

2. Principles of the FAO Methodology for land evaluation

FAO = Food and Agriculture Organization of the United Nations

References: The original statement is in (Food and Agriculture Organization of the United Nations, 1976) but better references are the subsequent guidelines (Food and Agriculture Organization of the United Nations, 1983, 1984, 1985, 1991). Van Diepen (1991) provides a critical review (p. 153-172 and the conclusion).

2.1 Background

In the early 1970s, there was growing dissatisfaction with then-existing land classification systems insofar as their ability to support rational land-use planning, in three main respects:

(1) Existing land classification systems were mostly or completely based on physical factors and ignored socio-economic aspects of land use;

(2) They did not specify land uses in sufficient detail for realistic evaluation, i.e., a single classification was being applied to land uses with distinctly-different requirements;

(3) They were being uncritically applied outside of their area of calibration (not really a fault of the system, except insofar as, being ready-made and apparently 'scientific', they were easy to apply, without the obvious modifications for local conditions, by ill-informed or lazy land evaluators).

The main promoters of the development of the FAO system were European soil scientists working in development projects, especially Beek (1978), working in Brazil. Cornell University participated in the person of Prof. Gerald Olson[†], who spent a sabbatical at FAO in 1972.

The FAO's Land and Water Development division (AGL), in approximately 1973, sponsored working groups, leading to publication of the Framework in 1976 (Food and Agriculture Organization of the United Nations, 1976). Subsequently, the FAO organized workshops leading to publication of guidelines for land evaluation in:

- dryland agriculture (Food and Agriculture Organization of the United Nations, 1983);

- irrigated agriculture (Food and Agriculture Organization of the United Nations, 1985);

- forestry (Food and Agriculture Organization of the United Nations, 1984, Laban, 1981);

- extensive grazing (Food and Agriculture Organization of the United Nations, 1991); and

- steeplands (Siderius, 1986).

Presently the FAO Framework is used in FAO and UNDP projects, and by many national agencies, with modifications and simplifications made locally. It is practically unknown and non-influential in the USA, for a variety of reasons. Among the positive reasons are (1) the fact that domestic methods have worked well for their intended purposes and (2) modeling approaches are more popular and data for these are available. Among the negative reasons are (1) a 'not invented here' mentality and (2) the lack of international experience/orientation of soil surveyors.

The FAO Framework uses some new technical terms, and some redefinitions of common terms, that were agreed on after intense negotiations.

Judgment of van Diepen (1991) p. 196-197: at its conception, the FAO Framework represented the state of the art, borrowing the best from then-existing land classification methods; many weaknesses apparent on close examination and attempts to implement; "it is becoming outdated from an operational point of view, but with a function as background philosophy".

Judgment of Rossiter on van Diepen: the Framework is capable of modification and interpretation, the problems have been with unimaginative applications. The Framework can be extended with new analytical techniques.

2.2 Three levels of detail: Framework, Guidelines, Evaluations

The FAO method is not a ready-made, detailed land evaluation scheme. Instead, it is a flexible *framework* supplemented by *guidelines* to create specific *evaluations*.

1. *Framework*: how to carry out an evaluation exercise, including how to select land uses to evaluate and evaluation (map) units. This is contained in the Framework (Food and Agriculture Organization of the United Nations, 1976).

2. *Guidelines* (directives): what factors (land qualities) to consider when evaluating for certain general kinds of land uses (e.g. forestry), how to evaluate these qualities. These have been published as Guidelines (Food and Agriculture Organization of the United Nations, 1983, 1984, 1985, 1991, Siderius, 1986).

3. *Evaluations*: specific evaluation exercises. These are designed separately for each problem and area, by the local land evaluator. For example, the Papua New Guinea Land Evaluation System (Venema & Daink, 1992).

2.3 Basic principles of the FAO method

(van Diepen *et al.*, 1991) p. 153-154

These are mostly in reaction to earlier (pre-1973) methods.

1. Land suitability is assessed and classified with respect to *specified* kinds of uses (as opposed to a single scale of 'goodness' of land);

2. The suitability classes are defined by *economic* criteria (as opposed to purely physical criteria; in practice this has rarely been followed);

3. A *multidisciplinary* approach is required (in practice, not just soil surveyors);

4. Evaluations should take into account the physical, economic, social and political *context* of the area concerned (i.e., don't evaluate for impossible uses);

5. Suitability refers to land use on a *sustained* basis (i.e., can't deplete the resource base, in practice this is rarely achievable, and this principle is being weakened);

6. 'Evaluation' involves comparison of two or more *alternative* kinds of use; this seems redundant to point 1.

2.4 Key points

The following three key points distinguish the FAO Framework from previous land classification systems:

<u>Evaluate separately for each *specific* use, then compare</u>

There is not one scale of 'goodness' of land from 'excellent' to 'poor'; instead one must speak of *very suitable* through *unsuitable* land for a specific use.

'There are no bad land areas, only inappropriate land uses.' (Paraphrase: 'there are no difficult lands, only incompetent land users'.)

Many examples of perfectly suited land areas for one use which are extremely unsuited for another. E.g. intensive semi-mechanized irrigated rice vs. areas for urban expansion. Example of Caribbean pine nurseries in old Pleistocene terraces of the lower Orinoco (eastern Venezuela).

A broad definition of 'land'

(next lecture). Not just 'soil' or even 'physical resource base'.

A broad definition of 'land use'

The *Land Utilization Type* is a detailed description, at an appropriate level of detail, of the land use (later lecture). It includes all the characteristics of the *production system* and *social context* which influence suitability, including: (1) products (maybe the broad sense), (2) inputs (off- and on-farm), (3) production calendar, (4) markets and other external influences.

Land should be evaluated in both physical and economic terms

Ideally, both a *physical* and an *economic* land evaluation are undertaken.

A *physical* land evaluation is based only on physical factors that determine whether a LUT can be implemented on a land area, and the nature and severity of physical limitations or hazards.

An *economic* land evaluation is based on some economic measure of net benefits, should a given LUT be implemented on a given land area.

The physical evaluation reveals the nature of limitations and hazards, which is useful information to the land manager; however, the economic evaluation reveals the expected economic benefits, which in general drive the decision-making process, or at least are a *sina qua non* for successful land use.

2.5 Levels of suitability

Land Suitability may be defined as "the fitness of a given type of land for a specified kind of land use" (Food and Agriculture Organization of the United Nations, 1985).

Depending on the objectives of the evaluation, the suitability of an evaluation unit for a land use can be described in *four levels of detail*. See (EUROCONSULT, 1989) p. 140-142. From most general to most specific, these are:

(1) Suitability *orders*

All land is divided into two suitability orders, according to whether the land is suitable or not for a given LUT.

'S' = suitable, 'N' = not suitable, for the land use.

(2) Suitability *classes*

These are divisions of *suitability orders* that indicate the *degree* of suitability, not simply suitable vs. not suitable.

‘S1’ = suitable, ‘S2’ = moderately suitable, ‘S3’ = marginally suitable, ‘N1’ unsuitable for economic reasons but otherwise marginally suitable, ‘N2’ = unsuitable for physical reasons. The linguistic terms ‘moderately’ and ‘marginal’ are given specific meanings in the course of the evaluation.

N2 implies limitations that are not correctable at any cost within the context of the land utilization type.

In *physical* evaluations, S3 & N1 are combined into ‘S3/N1’ because the distinction between these is purely economic (cost/benefit of overcoming the limitation). The limits between S1 and S2, S2 and S3/N1 are arbitrary or based on single-factor yield reductions.

In *economic* evaluations, the limits between S1 and S2, S2 and S3, and S3 and N1 are made on the basis of predicted economic value (various measures, we will discuss these in detail).

> Note: the 4 (physical) or 5 (economic) class system is arbitrary, except the division of order ‘N’ into classes ‘N1’ (physically suitable but economically unsuitable) and ‘N2’ (physically unsuitable). The number of intermediate grades of ‘suitable’ could be reduced from three to two or expanded.

(3) Suitability *subclasses*

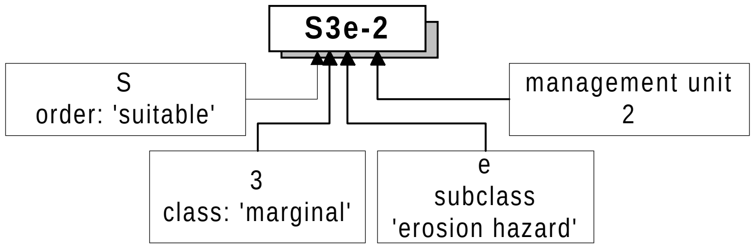
These are divisions of suitability classes which indicate not only the degree of suitability (as in the suitability *class*) but also the nature of the *limitations* that make the land less than completely suitable. (So, suitability class S1 has no subclasses.)

The subclass code consists of the suitability class code, augmented with a *suffix* which indicates the nature of the limitations. There is a suggested list of suffixes in some of the guidelines. E.g. ‘S3e’ : marginally suitable (‘S3’) because of erosion hazard (‘e’), ‘S3w’ : marginally suitable (‘S3’) because of wetness (‘w’).

(4) Suitability *units*

These are divisions of suitability subclasses, designated by numbers within subclasses, e.g. ‘S3e-3’, which are meant to be managed similarly. These have different *management requirements*, but the same *degree of limitation* and the same *general kind of limitation* (because they are divisions of subclasses). E.g. ‘moderate’ fertility limitations, but one management unit may require extra K and another extra P.

Summarizing, we can see the hierarchical nature of the suitability classification and the corresponding code:



<u>*Actual* vs. *potential* suitability</u>

Sometimes we want to indicate to the planner the suitability of the land area as it is now and/or under current assumptions (*actual* suitability) and as it would be were the land modified (*potential*), usually by a major land improvement or infrastructure development (drainage, irrigation, clearing, construction of access roads).

In this case, the suitability is given in two parts, separated by a slash, with the type of improvement implied or indicated. This can be at any level of detail. E.g., at the suitability subclass level: 'S3w/dS1' : currently marginally suitable because of wetness ('w'), but after drainage ('d') would be highly suitable.

3. What is the spatial entity being evaluated?

Before we can evaluate 'land', we must define what we mean by this term. Since land occurs over definite areas, we must decide what contiguous areas to evaluate: these are the *evaluation units*. Also before we can evaluate, we must decide on the appropriate *map scale* of the evaluation.

3.1 FAO definition of 'land'

A long but informative definition: *Land* is defined as 'an *area* of the earth's surface...

...the characteristics of which embrace all reasonably *stable*, or *predictably cyclic*, attributes of the biosphere vertically above and below this area...

...including those of the atmosphere, the soil and underlying geology, the hydrology, the plant and animal populations,...

... and the results of past and present *human activity*, to the extent that these attributes exert a significant influence on present and future uses of the land by humans.'

(Food and Agriculture Organization of the United Nations, 1985) p. 212.

Note that in this definition, 'land' is much more than 'soil', 'topography', 'climate', 'political division', etc. and in fact is an integrated geographic concept (both physical and human). It includes human occupation to the extent that this influences land use.

Gray area: does this definition of land include non-cyclic attributes that can be represented by *time series*, in particular, the (non-average) weather? In practice, yes.

This definition begs the question: What are the 'areas' of this definition? We now review six possible definitions: (1) map units of Natural Resource Inventories (NRI); (2) delineations of NRI; (3) management units; (4) economic units; (5) planning areas; and (6) grid cells.

3.2 Map units of Natural Resource Inventories (NRI)

When the evaluation starts with data from a *natural resources data base* (e.g., a soil survey or climate map), the map unit as shown on the resource map as a single *legend class*, or as derived from an intersection of several maps (e.g., soil type overlaid with climate type), is considered sufficiently *homogeneous* with respect to the land characteristics implied by the legend, and forms the unit of analysis. The *map unit* of the NRI is also called a *legend class* or category.

This has been the usual approach for physical land evaluations based on soil survey interpretations or agro-ecological zones. The simplest analysis considers all delineations of the map unit to be the same, no matter where located. This viewpoint is sufficient for evaluations of limitations to use that are based on *in-situ* natural resources (e.g., limitations to tillage or crop adaptation) and economic analyses that do not depend on geographical location but only on the *in-situ* characteristics of the map unit (e.g., soil fertility). Economic results are *normalized* to a per-hectare or other unit land area basis.

3.3 Delineations of NRI

It may be desirable to evaluate separately each *delineation* of the natural resource inventory map unit. These are *individual connected areas* of the NRI map unit, and are often relatively *small and compact*. In this type of evaluation, the analyst can consider the *geography* of the delineation, for example its location with respect to cultural features such as roads and cities, as well as its size and shape, to be land characteristics that can be used in the evaluation.

This kind of evaluation unit is appropriate when suitability depends on proximity (e.g., if transport costs are important), or if the spatial features of the delineation are important (e.g., a minimum size is necessary). In the economic evaluation, each delineation is analyzed separately. The results can be expressed on a per unit area (normalized) or a per-delineation basis.

The problem with evaluating all delineations separately is the number of delineations in a typical map (on the order of 1,000s to 10,000s), compared with the number of map units (on the order of 10s to 100s), and consequently the high data storage and processing costs. These are becoming ever less important with advances in technology.

3.4 Management units

A *management unit*, sometimes termed a *decision area*, is an area of land that the manager (farmer or planner) will treat or allocate differently. These may be quite large, e.g., in large-scale mechanized monocultures, or very small, e.g., in subsistence agriculture.

If the objective of the evaluation is to determine the land use options for *existing management units*, it makes sense to use these directly as the evaluation units. Each management unit is uniquely located, so geographic considerations can be included in the analysis.

> Note: If the units are taken from the current land-use pattern (e.g. fields or parcels), they are almost always less homogeneous with respect to natural resources than 'natural' map units, because the limits of natural resources rarely correspond exactly with the limits of management units. There are two ways to address this problem: (1) the dominant or most prevalent value of each land characteristic can be used as the representative value for the management unit, with a loss of precision in the analysis, or (2) the unit can be defined as compound, with two or more homogeneous constituents present in a defined proportion. In the latter case, data is entered for each constituent separately, each is evaluated separately for each proposed land use, and the results are combined in weighted linear proportion according to the defined proportions of the constituents, to arrive at the per-area result for the management unit as a whole. This procedure assumes that the land manager will implement or not the land utilization type on the entire management unit, no matter what the suitabilities of its homogeneous constituents. Whether this assumption is valid depends on the size of the management unit and the land use. For example, an improved pasture or forest plantation will usually be implemented over an entire parcel even if some areas within the parcel are limiting, whereas in mechanized cereal production, it is not feasible to plant in wet spots, which will be avoided during field operations.

The results of the economic evaluation are usually expressed on a per-management unit basis, i.e. the normalized or per-unit area result is multiplied by the area of the management unit to obtain a per-field result. These results can be aggregated to a per-farm basis.

3.5 Economic units

An *economic unit* is the collection of management units (see above) controlled by one land manager (direct prescriptive planning). Although decisions will be made separately for each management unit, the land manager (or zoning agency) may well require a *mix* of activities spread out over the entire economic unit or planning area, because the *overall benefit* of the economic unit is what is important to the manager, not the benefit from each management unit.

In addition, the economic unit usually has only one source of resources (machinery, labor, cash, capital) which is usually insufficient for some possible combinations of activities.

Therefore, the entire economic unit must be considered as a whole, to (1) ensure the correct mix of activities and (2) optimize the use of scarce resources.

Example: Dairy farms need a mix of grain, pasture, silage and hay in a fairly definite proportion.

Example: only family labor is available, this quantity is obviously limited.

The usual procedure is to evaluate each *management unit* separately (previous section), detailing their inputs and outputs, then use these results to *optimize* over the whole economic unit, now taking into account the constraints and goals.

3.6 Planning areas

A *planning area* is the collection of management units influenced by a planning agency (proscriptive or indirect prescriptive planning). Although decisions will be made separately for each management unit, the zoning agency usually has a *mix* of objectives that must be satisfied by the planning area, as well as *geographic constraints* on simultaneous land allocation.

Therefore, the entire planning area must be considered as a unit, in order to arrive at correct land allocation decisions.

Production constraint: minimum or maximum amount of land or product required. Example: at least 10 ha for developed campsites, at least 1 000 ha for conservation reserve.

Geographic constraints: (non-)adjacency, proximity. Example: can't have a developed campsite adjacent to a conservation reserve; or, campsites must be at least 50m from a designated wetland habitat.

The usual procedure is to evaluate each *management unit* separately, detailing their inputs and outputs, then use these results to allocate land iteratively, respecting the geographic constraints.

3.7 Grid cells

Grid cells are relatively small, regular, 'homogeneous' divisions of the land area, that between them cover the area to be evaluated. They correspond to the so-called 'pixels' of a remotely-sensed image. Essentially, they are tied to the technology of the grid-based Geographic Information System.

The evaluation is performed for each cell, and results are expressed per-cell. The results can be translated to a per-unit land area basis simply by dividing by the cell area. Results can be aggregated into any group of cells that can be delineated (e.g., management units), simply by summing over the group of cells.

3.8 Scale and precision

A crucial decision in the land evaluation exercise is the *map scale* of the evaluation results.

Even if the evaluation will not produce maps (not a good idea!) there remains the concept of *minimum decision area*, i.e., the size of the individual land areas for which decisions are to be made, and the *project extent*, i.e. the size of the total project area.

The basic relation between map scale and delineation size is (Forbes, Rossiter & Van Wambeke, 1982): the *minimum decision area* (MDA) corresponds to the *optimum legible delineation* (OLD) of a map, converted to ground scale. The OLD is conventionally taken to be 4 times the *minimum legible delineation* (MLD) of 0.4cm², i.e. 1.6cm² on the map.

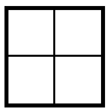


Figure: the small cells are 1 MLD (0.4 cm²), the group of 4 cells are 1 OLD (1.6 cm²).

> Note: Some authors such as Vink (1975) use 0.25cm² for the MLD and so 1cm² for the OLD, these seem quite small, although for the purposes of converting a paper or vector map to grid representation, using these smaller sizes will result in a more pleasing grid map. See the lectures on GIS.

Formula to determine the MDA in hectares (= 10.000 m²; 100 ha = 1 km²):

$$MDA\ ha = 1.6cm^2 \cdot 10^{-8}\ ha\,cm^{-2} \cdot (ScaleFactor\,mm^{-1})^2$$

For example, a map at 1:100.000 (scale factor 10^5) has a MDA of 1.6 x 10^2 ha (160 ha).

Here are some typical MDAs:

Map scale	MLD		OLD ≈ MDA	
1:5 000	0.1 ha	(1,000 m²)	0.4 ha	(4,000 m²)
1:10 000	0.4 ha	(4,000 m²	1.6 ha	
1:20 000	1.6 ha		6.4 ha	
1:25 000	2.5 ha		10 ha	
1:50 000	10 ha		40 ha	
1:100 000	40 ha		160 ha	(1.6 km²)
1:200 000	160 ha		640 ha	
1:250 000	250 ha	(2.5 km²)	1 000 ha	(10 km²)
1:500 000	1 000 ha	(10 km²)	4 000 ha	(40 km²)
1:1 000 000	4 000 ha	(40 km²)	16 000 ha	(160 km²)
1:2 000 000	16 000 ha	(160 km²)	64 000 ha	(640 km²)
1:5 000 000	100 000 ha	(1 000 km²)	400 000 ha	(4 000 km²)

We can reverse this relation to find the necessary scale for a given MDA:

$$ScaleFactor\ mm^{-1} = \sqrt{MDA\ \ ha \cdot 0.625 cm^{-2} \cdot 10^{8}\ cm^{2}\ ha^{-1}}$$

For example, to plan for a MDA of 100ha we need a map at a scale of 1:79.057 or larger. (Note that the *larger* the scale of a map, the *larger* a map sheet that is needed to show a given land area, so that a 'large-scale' map is capable of showing ground features with more precision. The scale is *larger* also in a mathematical sense, since as the scale factor decreases, the fraction itself becomes larger, i.e., further away from zero.)

4. Key Definitions of the FAO Framework

This lecture presents some key definitions of terms used by the FAO Framework. In later lectures we will see how to specify Land Utilization Types, how to select their Land Use Requirements, and how to select and use diagnostic Land Characteristics to evaluate the corresponding Land Qualities.

References: (Beek, 1978, Food and Agriculture Organization of the United Nations, 1983, 1984, 1985, 1991, Vink, 1975)

4.1 FAO definition of 'Major Kind of Land Use'

"A major subdivision of rural land use, such as rainfed agriculture, irrigated agriculture, grassland, forestry, recreation" (Food and Agriculture Organization of the United Nations, 1976)

The guidelines add 'annual crops, perennial crops, swamp rice cultivation, forest plantation, natural forests' which seems to be more specific. There was no attempt to create a hierarchical classification of land uses. The major kinds of land use each are covered, at least in theory, by their own Guidelines.

4.2 FAO definition of 'Land Utilization Type' (LUT)

"A kind of land use described or defined in a degree of detail greater than that of a major kind of land use (q.v.)" (Food and Agriculture Organization of the United Nations, 1976)

"In the context of *irrigated* agriculture, a land utilization type refers to a crop, crop combination or cropping system with specified irrigation and management methods in a defined technical and socio-economic setting." (Food and Agriculture Organization of the United Nations, 1985)

"In the context of *rainfed* agriculture, a land utilization type refers to a crop, crop combination or cropping system with a specified technical and socio-economic setting." (Food and Agriculture Organization of the United Nations, 1983)

"A land utilization type [in *forestry*] consists of a technical specifications in a given physical, economic and social setting" (Food and Agriculture Organization of the United Nations, 1984)

Key points: (1) the *context* must be explicit, both *socio-economic* and *technical*; (2): a *complete technical specification* is required: what crops, in what sequence, with what inputs, etc. Both of these are an important advance over previous land evaluation methods.

The next lecture explains in more detail how to define and specify a Land Utilization Type.

4.3 FAO definition of 'Land Use Requirements' (LUR)

A *Land Use Requirement* (LUR) is a condition of the land necessary for successful and sustained implementation of a specific Land Utilization Type. Each LUT is defined by a *set* of LURs. They are the 'demand' side of the land - land use equation: what the use requires of the land.

You can think of the LUT as 'requiring' certain general properties of land; these are the LURs. They are at the same level of generality as Land Qualities (below).

> For example, plants require water in order to grow, this might be called the 'moisture requirement'. The soil must be maintained without chemical degradation, this might be called the 'avoidance of salinization' requirement.

LURs can be assembled into understandable groups, e.g. 'crop requirements', 'management requirements', 'conservation/environmental requirements', as we will see in the worksheet in the next lecture.

4.4 FAO definition of 'Land Qualities' (LQ)

A *Land Quality* (LQ) is "[a] complex attribute of land which acts in a manner distinct from the actions of other land qualities in its influence on the suitability of land for a specified kind of use" (Food and Agriculture Organization of the United Nations, 1983)

"A *land quality* is the ability of the land to fulfill specific requirements" for the LUT (van Diepen *et al.*, 1991) p. 159, i.e., for each LUR there is a corresponding LQ.

Land qualities are the 'supply' side of the land - land use equation: what the land can offer to the use. In some sense, this is just a semantic difference, or a different point of view, from the Land Use Requirements.

> For example, the land can supply a certain amount of water to the crop, this might be called the 'moisture availability' Land Quality. On the other hand, the crop has a requirement for water; this 'moisture requirement' Land Use Requirement corresponds to the 'moisture availability' Land Quality.

Land Qualities are usually *complex* attributes of the land, i.e., they *can't be directly measured* or estimated in routine survey. This is as opposed to Land

Characteristics (see next §) which *are* directly measured or estimated. Therefore, LQs must be *inferred* from a set of *diagnostic* Land Characteristics (later lecture), with a variety of analytic methods.

Land Qualities act *more-or-less independently* to affect suitability. This is to avoid a proliferation of LQs in the evaluation. In practice, LQs may interact (e.g., moisture availability and soil fertility) but much of the complexity is avoided by abstracting from Land Characteristics to LQs.

<u>Severity levels</u>

In general, LQs are measured as *land quality classes*, also called (in ALES) *severity levels*, *single-factor ratings* or *degrees of limitation*. These are classifications of the LQ, indicating the degree of limitation or hazard associated with the LQ on a particular land area, from Level 1 = no limitation, upwards to some maximum. For each LQ, a linguistic scale is established, such as 'high', 'moderate', 'low', and 'very low' moisture availability, and procedures are developed for classifying each land area according to this scale.

> Note: There is a lot of argument about the term 'land quality', see (van Diepen *et al.*, 1991) p. 158-162, but the supply/demand view of qualities/requirements seems to me to be adequate and practical.

The next lecture discusses how Land Use Requirements are selected, and the corresponding Land Qualities evaluated.

4.5 FAO definition of 'Land Characteristics' (LC)

Land Characteristics (LC) are *simple* attributes of the land that can be directly *measured* or *estimated* in routine survey in any operational sense, including by remote sensing and census as well as by natural resource inventory. Examples: surface soil texture and organic matter, current land cover, distance to the nearest road.

In general, the effects of a LC on suitability are not direct, but through their effect on *land qualities* (see previous §). This is because a single LC may affect several qualities often in contradictory ways, e.g., sandy soils may have low fertility and water holding capacity, but may be easy to till and there are no problems with aeration of the roots. Here the soil texture is the LC, the others are LQ.

The FAO Framework does allow the use of LCs directly to assess suitability, but it is generally clearer to use LQ as an intermediate level of evaluation, both because the total complexity of the problem is broken down into more manageable units, and because LQs in themselves provide useful information to the land evaluator.

5. Defining a Land Utilization Type

Recall from the previous lecture that a Land Utilization Type (LUT) may be defined as "a kind of land use described or defined in a degree of detail greater than that of a major kind of land use" (Food and Agriculture Organization of the United Nations, 1976); the key points are that the socio-economic *context* in which the LUT is to be implemented, and the *technical* details of the land use system, must both be specified for the definition of the LUT to be complete.

5.1 What is included in the definition of a LUT?

The definition of a Land Utilization Type (LUT) is *not* a complete description of the farming or other land-use system, although if such a description exists, it can form the basis of a LUT definition. The LUT includes only those characteristics that (1) serve to *differentiate land areas* from the point of view of land evaluation, i.e., that can be expressed as Land Use Requirements with critical values in the study area, or (2) serve to *limit the land use options*.

In some contexts, it may not even be necessary to mention certain characteristics of the LUT, since they are uniform and universally understood in that context. E.g., the vast majority of agricultural production in the USA and W. Europe is for market (not self-sufficiency), it is a waste of paper to mention this.

5.2 Checklist for defining a LUT

The 'Agricultural Compendium' (EUROCONSULT, 1989) §2.10.8 (p. 161-2) distinguishes between *major* and *minor determinants* of LUTs.

Their *major* determinants:

1. Government
2. Location
3. Technology
4. Produce
5. Labor
6. Capital
7. Management
8. Socio-economic aspects of land

For each major determinant, they list several *minor* determinants, not all of which are applicable in every situation. For example, under major determinant 'Labor' they list:

“availability (total; per operational unit, e.g. family, state farm, cooperative); kind (male, female, child, part-time, full-time, on-farm, off-farm); limits to scale of operation due to labour availability and distribution; educational level; specialisation (e.g. experience with specific techniques or crops); labour density; trends; increase, outflow rate; seasonal distribution of available labour; season labour absorption; labour income; labour productivity per time unit effectively worked; labour productivity per hectare; labour productivity per capital unit invested; ...; preferences of labour for specific kinds of work (e.g., resistance to animal traction); labour organisations strength and behaviour; value of leisure as compared to labour; mobility of labour; availability of off-farm opportunities; percentage of income derived from off-farm activities (rural and non-rural); effective animal labour inputs per hectare and seasonal distribution; effective mechanical labour inputs per hectare and seasonal distribution.” (p. 162).

So, the minor determinants are *specific indicators* related to the major determinant. Obviously, only some of these will be applicable in a given situation. The aim is not to describe *per se* but (1) to identify land use requirements (see below) and (2) to set the economic context, in particular, the operational definition of economic suitability.

The various FAO guidelines give more detailed lists, e.g. (Food and Agriculture Organization of the United Nations, 1985) Table 10:

1. Cropping system
2. Markets
3. Water supply
4. Irrigation method
5. Capital intensity
6. Labor intensity
7. Technical skills and attitudes
8. Power source
9. Mechanization of farm operations
10. Size and shape of farms
11. Land tenure
12. Water rights
13. Infrastructure
14. Irrigation infrastructure
15. Material inputs
16. Cultivation practices
17. Livestock
18. Associated rainfed agriculture, forestry, or grazing
19. Yields and production
20. Environmental impact
21. Economic information

Similar lists can be devised for other major kinds of land uses. These could be grouped under the major determinants of the Agricultural Compendium, many under ‘Technology’.

The evaluator should create a *list* like this specifically designed for the set of Land Utilization Types to be considered in their evaluation exercise, with *choices* for each item, and then complete the list for each LUT. For example, under 'Livestock', the choices might be 'none', 'milk and meat for household use only', 'milk for market', and 'meat for market'. Notice that the choices depend entirely on the context of the land evaluation exercise.

5.3 Disaggregated or hierarchical definition of LUTs

Almost always we want to evaluate several similar LUTs. We can save work and bring out the relation between LUTs by organizing them in a convenient *hierarchy* or, more commonly, a *matrix* based on some *ad hoc* classification.

Example (adapted from (Food and Agriculture Organization of the United Nations, 1983)):

- Traditional smallholder cultivation at low input levels
  - with conservation measures
    - self-sufficiency crop mix
    - market-oriented crop mix
  - without conservation measures
    - self-sufficiency crop mix
    - market-oriented crop mix
- Semi-mechanized smallholder cultivation at moderate input levels
  - with conservation measures
    - export-oriented crop mix
    - local market-oriented crop mix
  - without conservation measures
    - export-oriented crop mix
    - local market-oriented crop mix

Another example from the same source: a multivariate (non-hierarchical) classification:

Main crop × General production system × cultivation factor × power source

E.g. 'maize, cooperatives, single-crop, oxen'

> Note: ALES allows the evaluator to *copy* a LUT definition, then modify it. So the evaluator can create a hierarchy of LUTs by creating the base type, then copying to the derived types at the next level in the hierarchy, modifying these, and so on.

6. Selecting Land Use Requirements

Of the many LURs that can be included in the definition of a LUT and hence in the evaluation, it is usually sufficient to select a small subset. More than 10 LQs are generally unworkable, and it usually is the case that the most important 5 LQs can be used to correctly classify almost all land.

See the worksheet 'Selection of Land Use Requirements' at the end of this lecture, which provides a checklist of LURs and allows the evaluator to judge their importance to the evaluation. Each of the Guidelines contains a list of possible LURs, e.g. the Rainfed Agriculture guidelines list 25. This is not an exhaustive list: new LURs can be added and listed ones can be split into more specific LURs, or several listed LURs can be combined, all according to the analysis.

6.1 Criteria for the selection of Land Use Requirements

There are *four* criteria by which we can select LURs: (1) *importance* for the use; (2) existence of *critical values* in the study zone; (3) *availability of data* with which to evaluate the corresponding LQ; and (4) *availability of knowledge* with which to evaluate the corresponding LQ. We now discuss each of these in detail.

(1) Importance for the use

The Requirement must be important for the use, or it is omitted from the analysis. Here is where a careful definition of the LUT will repay the effort.

Importance can be rated 'very important', 'important', or 'not important'.

> For example, harvest requirements are irrelevant to pasture lands, mechanization requirements are irrelevant to LUTs with only human or animal traction.

(2) Existence of critical values in the zone

There must be *differences* in the levels of the corresponding LQ in the zone, or the LUR becomes a *constant*, i.e., part of the context of the LUT, not a *variable*, i.e., a determinant of suitability.

Existence of critical values can be rated 'frequent', 'infrequent', or 'none'.

> For example, although mechanization requirements are important for mechanized agriculture, in a given zone there may be only level, easily-trafficable, medium-textured, stone-free soils, presenting no limitations to

mechanization. In this case, mechanization requirements would not be included in the evaluation.

Important note: if the geographic scope of the model is *increased*, the evaluator should go back through the checklist of LURs, to make sure that those LURs that are important but which don't have critical values in the *smaller* scope now don't have critical values in the *wider* scope. If they do, these LURs must be *added* to the evaluation.

(3) Availability of data with which to evaluate the corresponding LQ

Even an important LUR with differences in the corresponding LQ can not be included in the evaluation if there is not sufficient *land data* on the diagnostic LCs which would be used to evaluate the LQ.

Examples: The LQ 'moisture availability', in the absence of reliable long-term climate records and moisture release characteristics of representative soil profiles; the LQ 'erosion hazard' without measurements of rainfall intensity, without a slope map, or without information on topsoil particle size distribution and surface sealing characteristics.

Data availability can be rated 'available', 'not available but obtainable with survey', or 'not obtainable'. If 'obtainable with survey', an estimate of the cost/benefit of surveying must be included. New surveys may be impractical within the time or budget of the evaluation.

It may be possible to use a *surrogate* set of LCs, if the desired LC is not available. In the example above, perhaps natural vegetation type might indicate moisture availability. But at a certain point there is not enough precision, and the data availability is rated 'not obtainable'.

The final evaluation must include a *cautionary note* that an important factor was not considered, so that the results are provisional, and suggestions for how the necessary data might be collected.

Note that an analytical model can be built which requires unavailable data; the model is still valid but it won't be usable without further survey.

(4) Availability of knowledge with which to evaluate the corresponding LQ

A LUR can not be included if there is not sufficient *knowledge* on the relation of diagnostic LCs to the corresponding LQ. This motivates applied agricultural (etc.) research.

Knowledge availability can be rated 'available', 'not available but obtainable with research', or 'not obtainable'. If 'obtainable with research', an estimate of the cost/benefit of the applied research must be included. This is almost always impractical within the time or budget of the evaluation.

> For example, the LQ 'risk of compaction' (due to mechanization) is a very important LQ in the western plains of Venezuela; however there is no agreement on what measurable LCs can be used to predict this risk, so it has to be omitted from land evaluations.

The final evaluation must include a *cautionary note* that an important factor was not considered, so that the results are provisional, and suggestions for what research is needed.

6.2 Effects of land qualities

The effects of each Land Quality on the land use must be specified, or, looking at the 'demand' side of the equation, the reason each LUR is included in the evaluation must be specified. This information determines the *number of severity levels* (or, single-factor ratings) that are relevant for each LQ.

LQs can (1) affect physical suitability, (2) reduce yields, (3) increase costs, or any combination.

(1) LQs which affect physical suitability

This kind of LUR is typically a 'hazard', and influences the land use in a *negative* manner. Examples: erosion hazard, flood hazard, drought hazard. The idea here is that excessive severity levels of the corresponding land qualities makes the land *unfit* for the land use, and that increasing severity levels increase the management requirement, i.e., the lands must be more carefully managed. So, these LURs can be used to classify land into *management groups*.

(2) LQs which reduce yields

These LURs typically have to do with intrinsic factors of plant growth, such as water, light, temperature, and nutrients. Some limitations to culture can also be included here: e.g. planting conditions or harvesting conditions. The model builder must determine which land qualities can reduce yield, and how many yield levels can be distinguished.

(3) LQs which increase costs

Limitations can result in reduced yields; however, in the context of a land utilization type we may choose to *correct* or compensate for (completely or partially) a limitation by increasing inputs. If certain severity levels of a land quality increase costs, the model builder expresses this by listing the *additional inputs*, which can be either *annual* (recurring) or *one-time*, at one or more specific years within the plan. Each severity level may have a different amount of the input needed to correct the limitation.

> *Important note*: Although the application of an input to correct a limitation may be attractive to the extensionist, it may *not* be so to the land user, who

may prefer to accept a yield reduction, even if the extra input appears cost-effective in the economic analysis. This may be due to the opportunity cost for the same input (or the money needed to purchase it) in the land user's total system, or to the effective non-availability of the input (e.g. more family labor at labor-intensive seasons), or to the uncertainty of the input's effect in relation to the risk aversion of the farmer. The assumption that the extra input will be applied thus must be verified and *forms part of the LUT definition*, under the headings of 'level of inputs', 'access to working capital', and even 'social attitudes'.

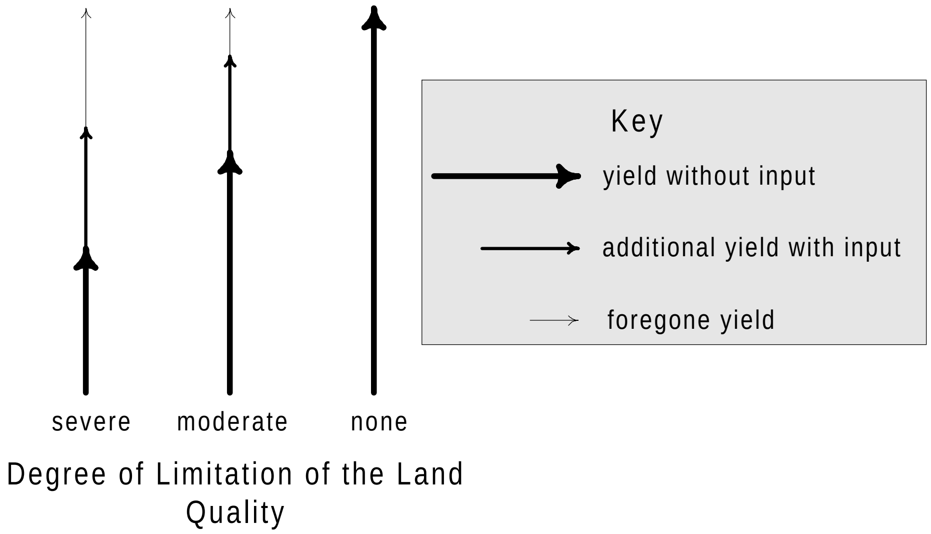
A related problem is that the land user must be made *aware* that a particular land unit requires the additional input. For example, if a land unit has low soil fertility which can be corrected by extra fertilizer, the soil test results must be made available (and possibly explained) to the user. Again, this assumption forms part of the LUT definition, under the heading of 'technical assistance' or 'social infrastructure'.

Given an *unlimited* amount of resources, any limitation could be overcome. This is fairly obvious for limitations of nutrients or water. Even limitations due to daylength could be corrected by putting supplemental lighting in the field! So, strictly speaking, there are no completely limiting land use requirements. In practical terms, however, there certainly are. The model builder determines the concept of impracticality in the context of the land utilization type.

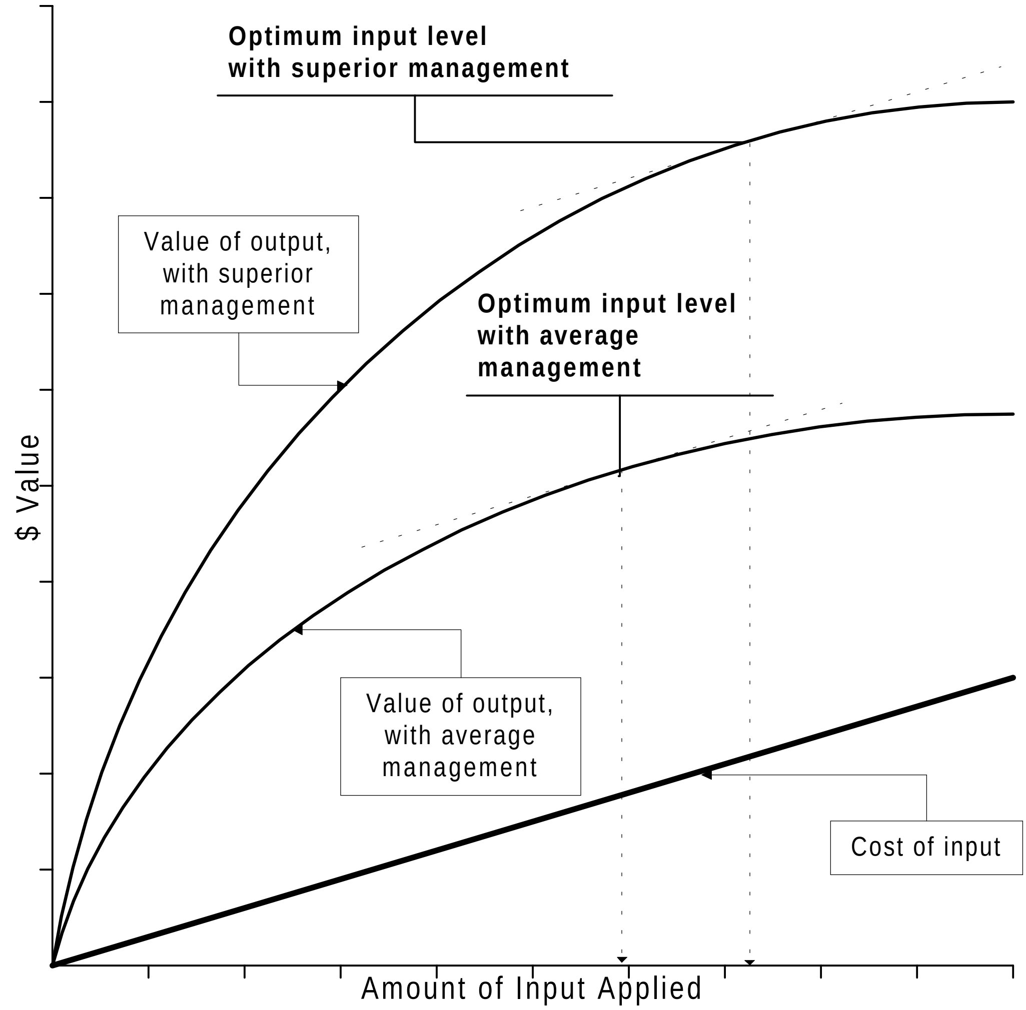
Combining 'decreases yield' and 'increases costs'

The land user may elect to only correct *some* of the limitation, for example, to apply a certain amount of fertilizer, but not enough to reach maximum attainable yield. This is usually an *economic* decision, and may also be based on risk aversion. An analysis of the production function and the relative costs of the input and the product(s) is necessary to determine the *optimum input level* for each severity level of the land quality. This analysis is prior to the actual land evaluation, and serves to define the LUT in terms of the land user's strategy in the face of each limitation level.

Combining 'increased inputs' with 'decreased yields'



See for example (Tisdale, Nelson & Beaton, 1985) Chapter 15 for a typical analysis of the economics of fertilizer use; a similar analysis can be made for any variable input. The ideal curve is as follows:



The **optimum input level** is the X-axis value of the point where the *slope of the response curve* is **equal to** the *slope of the cost-of-input curve*

6.3 Defining Severity Levels of Land Qualities

For each Land Use Requirement selected, the evaluator must decide how many *severity levels* (also called *single-factor ratings*, *degrees of limitation* or *land quality classes*) are to be distinguished for the corresponding Land Quality. The severity levels are the number of classes into which the LQ will be classified.

In the original FAO Framework there are four or five severity levels, corresponding directly to the physical suitability classes S1, S2, S3/N1 (these are separate for economic evaluation) and N2, possibly with some levels omitted because the LQ is never too limiting or because the LQ can't be determined with the precision implied by that number of severity levels.

> Note: ALES allows from 2 to 9 severity levels, with the correspondence with overall suitability being a later step in the evaluation, rather than necessarily being commensurate with the overall suitability classes. This allows greater flexibility and variable precision among the different LQs. However, the simplest way to use ALES is to divide each LQ into the *same* number of severity levels, and for this number to be the *same* as the number of physical suitability classes. This allows the use of the Maximum Limitation method of determining overall physical suitability.

There are three ways to determine how many severity levels to define, depending on the effects of the LQ (previous §). In addition, the number of severity levels should not exceed the required *precision* of the evaluation, which is determined by the objectives.

> For example, to identify promising areas for a new crop, we may only need to produce a preliminary suitability map 'promising', 'possible' and 'improbable', so that more than three levels of any of the LQs would be wasted effort.

(1) Defined by physical suitability (management differences or risks)

First, the proposed differences in physical suitability must be distinguishable in the field. Second, there must be enough data to differentiate them at this degree of resolution.

The number of severity levels may be obviously in *classes*, in which case the 'natural' number of classes should be evident. For example, the number of severity levels of an 'ease of mechanization' Land Quality (corresponding to a 'mechanization' Land Use Requirement) would correspond to the different management options. E.g., 'no limitation', 'must work on contour', 'must work on contour and apply a counterbalance to tractor', 'not feasible, tractor would roll over'.

In other cases, the LQ may be conceptually *continuous*, for example, erosion hazard: soil loss per year can vary from 0 T ha^{-1} upward. If we look at the *frequency distribution* of the area by the amount of soil loss (continuous density function or histogram), we might see one of the following cases:

In the first case there is no obvious break point between classes, whereas in the second we see bunched values leading to three classes and clear breaks near 4 and 7. If there are obvious breakpoints, it makes sense to use them. Otherwise, an arbitrary division must be used.

(2) Defined by decreasing yields

If the LQ affects yield, the number of severity levels should correspond to observable or predicted yield levels. Again, this depends on the quality of the data. In general FAO practice, the 'best' class corresponds to 80-100% of optimum yield, the 'moderate' class to 40-80%, and the 'marginal' to 20-40%.

(3) Defined by increasing costs

If limiting values of the LQ will be overcome by increasing inputs, the number of different levels of the input define the number of severity levels.

(4) Limited by the precision of the natural resources data

The number of severity levels of the LQ can not exceed the precision of the diagnostic LCs that will be used to evaluate it. For example, if slope is only measured in three classes in the natural resources inventory, and erosion hazard is determined by the single LC 'slope', it would be impossible to rate 'erosion hazard' in more than three classes.

6.4 Worksheet for selecting Land Use Requirements

Use of this worksheet:

Enter 1, 2 or 3 in each of the four columns under 'How significant?', according to the following key

For each LUR selected, enter the number of levels that can be distinguished for each of the three reasons under 'How many levels?'

Key

Importance

1	Large effect on the use
2	Affects the use
3	Little or no effect on the use

Existence of critical values

1	frequent (>5% of the area)
2	infrequent (<5% of the area)
3	rarely or never

Availability of data with which to evaluate the LQ

1	available
2	obtainable by survey
3	not available

Availability of knowledge with which to evaluate the LQ

1	available
2	obtainable by research
3	not available

For further information on the Land Qualities...

LQi	for *Irrigated* agriculture (Soils Bulletin 55)
LQr	for *Rainfed* agriculture (Soils Bulletin 52)
LQf	for *Forestry* (Forestry Paper 48)

Selection of Land Use Requirements						How significant?				How many levels?		
			Possible Requirements	suggested		Importance	Existence	Availability	Availability	Affecting		
FAO number				FAO code		for the	of critical	of	of	Physical	Lowering	Raising
LQi	LQr	LQf		i	r	use	values	data	knowledge	Suitability	yields	costs
Group A: Agro-ecological (growth requirements)						1/2/3	1/2/3	1/2/3	1/2/3	#.	#	#
1			growing period	b								
2	1	A1.1	radiation regime	j	u							
3	2	A1.2	temperature regime	c	c							
	9		air humidity for growth		h							
	8		establishment conditions		g							
4	7	A1.5	rooting conditions	r	r							
	10		maturity conditions		i							
5	4	A1.4	oxygen availability (drainage)	d	w							
	3	A1.3	moisture availability for growth		m							
6			water availability for irrigation	m								
8			water quality (short-term)	q								
	5		fertility: availability		n							
	6		fertility: leaching		n'							
7			macronutrients NPK	n								
11a			micronutrients	zc								
9		A1.6a	salinity	x								
10		A1.6b	sodicity	y								
11b	14	A1.7	toxicities, direct effects of pH	z'	x							
12	15	A1.11	diseases, pests, weeds	p	p							
13a	11	1.10.1	flood hazard	u	f							
		A1.10.2	physiographic hazards - landslide									
13b	12		climatic risks (general)	u'	c							
		A1.9.1	climatic hazards - fire									
		A1.9.2	climatic hazards - frosts									
		A1.9.3	climatic hazards - wind									
Group A2: Estimates of forest volume, growth and yield												
		A2.1	present forest stands									
		A2.2	estimated growth rates									
		A2.3	estimated survival rates									
		A2.4	estimated yield of non-timber products									

Selection of Land Use Requirements							How significant?				How many levels?		
				Possible Requirements	suggested		Importance	Existence	Availability	Availability	Affecting		
FAO number					FAO code		for the	of critical	of	of	Physical	Lowering	Raising
	LQi	LQr	LQf		i	r	use	values	data	knowledge	Suitability	yields	costs
Group B: Management							1/2/3	1/2/3	1/2/3	1/2/3	#.	#	#
	15			water management	w								
		16		tillage		k							
	16			pre-harvest management	v								
	17a		B2	harvest management	h								
	17b			post-harvest management	h'								
		19		storage and processing		j							
	18	17	B1	mechanization	k	q							
		20		seasonality (opportunity)		y							
Group C: Geography													
	14	23		location (transportation costs)	l								
				adjacency to other uses									
				distance from other uses									
			B8	accessibility									
			B5	proximity to nursery sites									
		21	B4	access within the production unit		a							
		22	B7	shape and size of the parcel		b							
Group D: Land improvement													
	19	18a		clearing	c'	v							
		18b		land shaping		v'							
	20			flood protection	f'								
	21			drainage	d'								
	22			levelling (topography)	t'								
	23	18c		physical, chemical & organic ammend	a'	v"							
	24			leaching	x'								
	25			recuperation period	r'								
	26			irrigation works (construction)	i'								
Group E: Conservation and environmental risks													
	27			prevention of salinity and sodicity	xy								
	28			long-term water quality and control	w								
	29	24	C1	erosion hazard	e	e							
		25		land degradation hazard		d							
			C2	streamflow response									
			C3	vegetation degradation hazard									
			C4	preservation of species (biodiversity)									
	30			environmental risks	v								
Group F: Sociological and political aspects													
				political entity									
				land tenure									
	31			farmer attitudes	f								

7. Evaluating Land Qualities from Diagnostic Land Characteristics

Since Land Qualities, by definition, can't be directly measured in routine survey, their severity levels or single-factor ratings for each evaluation unit must be *inferred* from one or more *diagnostic land characteristics*.

Diagnostic land characteristics are the LCs that will be used to evaluate the LQ. They must be *measurable* at the appropriate scale, and well-*related* to the land quality (which is why they are called 'diagnostic'). There may be a choice of LCs, in which case the simplest or cheapest to determine should be used.

For example, to evaluate the LQ 'erosion hazard', we may choose as diagnostic LCs 'slope', 'rainfall intensity', 'topsoil particle-size distribution', and 'topsoil mineralogy'.

There still remains the main question: How do we *infer* from the set of diagnostic LCs to the severity levels of the Land Quality? In other words, given data values for each diagnostic Land Characteristics, how do we assign an evaluation unit to its correct severity level of the LQ? This is the most difficult analytical problem in land evaluation, and requires great skill and judgment. We can distinguish five main methods: (1) matching tables; (2) decision trees or rules; (3) parametric indices; (4) empirical-statistical methods; (5) dynamic simulation. The first two methods work exclusively with *classified* (categorical) data, the last two with *continuous* data exclusively, and method (3) with either.

7.1 Matching tables

These are also called 'maximum limitation' tables. They are in the form of a matrix, with the *rows* being the different diagnostic LCs, the *columns* being the (classified) LQ ratings, and the *cells* being the value of the diagnostic LC (row) that must be met or exceeded in order for the LQ to be rated in the severity level indicated by the column. Thus, matching tables *limit* the land quality rating to the most *limiting* value of the set of diagnostic land characteristics.

Advantage: simplicity, easy-to-understand graphical presentation.

Disadvantage: can't account for interactions between diagnostic LCs (this is a serious disadvantage).

To use the table, start at the upper left and find the column corresponding to the LC value for the evaluation unit. The LQ rating is provisionally this column's heading. Now, move down one row and find the column corresponding to the LC value for the evaluation unit. If the column is the same as, or to the left of (less limiting than) the provisional rating, keep the same provisional rating. If the column is to the right, move to that column, which now becomes the provisional rating. Do the same for each row; at the end of the process, the provisional rating becomes the final rating, since all diagnostic factors have been included.

Another way to use the table is simply to find the column corresponding to the LC value for each row, and then use the right-most column as the final rating.

Matching tables evolved from similar tables used in USBR and USDA land classification systems. Their drawback is precisely that of the maximum limitation method: they do not take into account any *interactions* between diagnostic LCs. For example, evaluation unit A may have only one diagnostic LC rated ‘moderately limiting’, evaluation unit B may have all its diagnostic LCs with this rating, yet both units end up with the same LQ rating.

Here is an example of a matching table modified from (Sys, 1985):

	Severity Level of the Land Quality			
Land Characteristic	*S1*	*S2*	*S3/N1*	*N2*
texture/structure, class	C-60s, SiCS, Co, SiCL, CL, Si, Sil, SC,L, SCL, SL	C+60v , C+60s, C-60v, LfS, LS	Cm, SiCm, LcS, fS, S	cS
coarse fragments, volume %	<15	<35	<55	>55
soil depth, cm	>50	>20	>10	<10
$CaCO_3$, %	<25	<35	<50	>50
Ca_2SO_4, %	<6	<10	<20	>20

To use this table, a site must be characterized by values of the five land characteristics ‘texture / structure’, ‘coarse fragments’, etc. (Sys uses a distinctive texture / structure notation, e.g. ‘C+60v’ is very fine clay with vertisol structure.) Consider a hypothetical map unit with the following data:

texture/structure, class	LfS
coarse fragments, volume %	20
soil depth, cm	100
$CaCO_3$, %	45
Ca_2SO_4, %	5

This map unit is rated as follows. Data values are bold and the class is shaded in gray.

	Severity Level of the Land Quality			
Land Characteristic	*S1*	*S2*	*S3/N1*	*N2*
texture/structure, class	C-60s, SiCS, Co, SiCL, CL, Si, Sil, SC,L, SCL, SL	C+60v , C+60s, C-60v, LfS, LS	Cm, SiCm, LcS, fS, S	cS
coarse fragments, volume %	<15	20 <35	<55	>55
soil depth, cm	100 >50	>20	>10	<10
$CaCO_3$, %	<25	<35	45 <50	>50
Ca_2SO_4, %	5 <6	<10	<20	>20

The right-most shaded column is S3/N1, so the map unit is rated S3/N1, because of the $CaCO_3$ content.

7.2 Decision trees

These are hierarchical multi-way keys, in which values of the diagnostic LCs are the diagnostic criteria and the result is the severity level of the (classified) LQ to be evaluated.

Hierarchical: one decision may lead to others, until all factors are taken into account;

Multi-way: may have more than two choices for a decision;

Keys: answering the questions asked by the tree leads to a *decision*, in this case, a severity rating of a Land Quality.

Definitions

Nodes (also called branch points or decision points): the questions that must be answered as the tree is followed; in this case, these are the diagnostic LCs, and the question is, 'What is the data value of the LC?'

Leaves (also called decisions): the result of following the tree, the answer; in this case, these are the severity levels of the LQ.

Decision trees are more expressive than tables, i.e., any table can be transformed into a decision tree but not vice-versa. They allow complete control over interactions. ALES uses this as its primary method to evaluate Land Qualities.

Advantage: fully expressive, can explicitly rate any combination of LC values, i.e., any interaction between diagnostic LCs.; hierarchical structure is fairly easy to understand.

Disadvantage: An effective graphical presentation is difficult.

Example from the Papua New Guinea Land Evaluation System (Venema & Daink, 1992):

```
Land Utilization Type: rice upland-hi
Land Use Requirement: 't':* nutrient availability/retention capacity
Severity Level decision tree
 > ph (soil reaction  2/3(0-25 cm) + 1/3(25-100 cm))
   1 (weakly acid to neutral, pH 6-7) > cec (cation exch capacity (0-25 cm))
      3 (low) [0-10 me/100 g soil] > texture1 (topsoil texture (0-25 cm))
         1 (coarse)............. : *3
         2 (medium)............. : *2
         3 (fine but friable & blocky) : =2
         4 (very fine (massive)). : =2
         5 (peats).............. : =2
         6 (rock)............... : =1
      2 (moderate) [10-25 me/100 g soil] > anionfix (anion fixation)
         1 (no problem).......... : *1
         2 (moderate)........... : =1
         3 (high)............... : *2
      1 (high) [25-100 me/100  : =2
   2 (acid, pH 5-6)........      : =1
   3 (strongly acid, pH <5) > cec (cation exchange capacity (0-25 cm))
      3 (low) [0-10 me/100 g s : *3
      2 (moderate) [10-25 me/1 : *2
      1 (high) [25-100 me/100  : =2
   4 (alkaline, pH 7-8)....      : =3
   5 (strongly alkaline, pH > 8) : *3
```

This tree was implemented as part of an ALES model. We can see that LQ 'nutrient availability/retention capacity' is measured in three severity levels: 1 (high fertility), 2 (moderate fertility), and 3 (low fertility). The diagnostic LCs are 'pH' (5 classes), 'cec' (3 classes), topsoil texture (6 classes), and 'anionfix' (3 classes). Note that the tree is not balanced, i.e., some paths are longer than others. For example, in strongly alkaline soils, only one diagnostic LC was necessary, whereas in neutral, moderate CEC soils, three diagnostic LCs were necessary to arrive at a decision. Also, the LCs used at lower levels in the tree depend on the path to that point. For example, in low and high-CEC neutral soils, the texture is used as a secondary diagnostic LC, whereas in moderate CEC neutral soils, the anion-fixing properties of the soils are used as a secondary diagnostic LC.

7.3 Land indices from classified land characteristics

(Note: If a continuous index is desired, it should be based on empirical statistical relations as explained in the next §. The Land Index is included in these notes primarily for completeness, because the practicing evaluator will often encounter its use.)

Land indices (formerly and confusingly called *parametric* indices) are *point systems* with each diagnostic LC contributing points to an overall value, which then is classified into a severity level. It differs from empirical statistical methods (next §) in that classified LCs can be used, and that there is rarely an empirical statistical basis to the combination.

The indices may be *additive* (i.e., add up the individual point values) or *multiplicative* (i.e., multiply the individual point values, and then normalize) or a combination of arbitrary arithmetic operations, resulting in a 'continuous' value (which will in general be an integer only for additive indices), which is then *classified* into severity levels by arbitrary cut-off points. For example, on a scale of 0-100, 80-100 could be classified as 'slight limitation', 60-80 as 'moderate limitation', etc. Note that there is no objective basis for this classification nor for the original point system.

Land indices can in some degree compensate for problems with matching tables. Typically, the same table is used, but each row is assigned a point value, and each cell is worth a certain number of points. Each diagnostic LC is rated separately, and the points are added, multiplied, or combined according to some other rule. This allows the evaluator tremendous flexibility (and subjectivity). Interactions can still not be accounted for in a purely additive or multiplicative index, since each row is evaluated separately, but it is possible to use cross-products of point values for some LCs along with sums for others to get some approximation of interaction effects.

Land indices are not much used to estimate LQs, more to go directly from LCs to suitability as in earlier 'parametric' methods of land evaluation (see lecture in later section on pre-FAO land classification methods).

Advantage: Provides a more-or-less continuous scale of the Land Quality, allows a large number of LCs to participate in the rating, each more-or-less weighted according to its importance.

Disadvantage: Highly subjective, appears more precise to the casual observer than it is in fact.

Here is a *hypothetical* example of a table to compute an *additive* land index for a single LQ:

Physical soil characteristics for LUT 'millets, traditional management'
60 points maximum (total)
S1 : 51-60; S2: 31-50; S3: 11-30; N2: 0-10 total points

Texture/structure .... 20 points maximum
- C-60s, SiCS, Co, SiCL, CL, Si, Sil, SC,L, SCL, SL20 points
- C+60v , C+60s, C-60v, LfS, LS .... 15 points
- Cm, SiCm, LcS, fS, S .... 10 points
- cS .... 0 points

Coarse fragments, volume % 10 points maximum
- <15 .... 10 points
- 15-35 .... 6 points
- 35-55 .... 3 points
- >55 .... 0 points

Soil depth, cm .... 20 points maximum
- >100 .... 20 points
- 80-100 .... 18 points
- 60-80 .... 14 points
- 40-60 .... 8 points
- 20-40 .... 4 points
- <20 .... 0 points

$CaCO_3$, %............................. 10 points maximum
- 0-25 .... 10 points
- 25-35 .... 6 points
- 35-50 .... 4 points
- >50 .... 0 points

Notice that 'texture/structure' and 'soil depth' are twice as important as the other two land characteristics, also that each LC can have a different number of classes, and finally that the points do not have to be a linear function of class. The cut-off points for each severity level is arbitrary and at the discretion and experience of the evaluator.

The hypothetical map unit of the 'matching table' section (above) would be rated:

Land characteristic	Data value	Points
texture/structure, class	LfS	*15*
coarse fragments, volume %	20	*6*
soil depth, cm	100	*20*
$CaCO_3$, %	45	*4*
	total	*45*
	severity level	*S2*

7.4 Land indices from continuous-valued land characteristics

Another kind of land index (also formerly and confusingly called *parametric* indices) is a *point systems* with each diagnostic LC contributing points to an overall value, which then is classified into a severity level, with the difference that the LC is given points according to its value on a *continuous* scale, not according to its *class*. It differs from empirical statistical methods (next §) in that there is rarely an empirical statistical basis to the combination.

For example, each cm of soil depth up to 150cm can be assigned 0.2 points, so that soil depth gives 0 to 30 points towards the land index; each % coarse fragments can subtract 0.1 points from a maximum of 10 points, so that coarse fragment content gives 0 to 10 points towards the land index. As in the continuous case, land characteristics are weighted by assigning them different maximum points.

As explained in the previous §, if a continuous land index is desired, empirical statistical methods are should be used as explained in the next §.

7.5 Empirical-statistical methods

These are equations relating several diagnostic LCs to the value of the LQ. They are usually established by regression analysis (later section of the course). This method produces *continuous* ratings, i.e., an 'exact' value of the LQ, not a classified value; the result is typically *classified* into a severity level.

Example: 'Universal' Soil Loss Equation (USLE) for LQ 'erosion hazard': estimated from rainfall erosivity, soil erodability, slope degree and length, and land use: $A = R * K * L * S * C * P$, each of the factors is also estimated from primary LCs by a regression equation or table. E.g. $R = \alpha * a * b * c + \beta$, where a = average annual precipitation in cm, b = maximum day precipitation occurring once in 2 yr, in cm, c = maximum total precipitation of a one-year recurrence rain shower, in cm, α and β are parameters that must be estimated locally.

Problem: parameter estimation, regressions must be calibrated locally.

We will study statistical methods in detail in a later section of the course.

> In ALES, *formulas* can be used to relate a set of *continuous* diagnostic LCs to another *continuous* LC, which is then *classified* into a *discrete* LC, which is then used as diagnostic to a LQ, possibly in a 1-to-1 relation.

7.6 Dynamic simulation of land qualities

One way to determine the severity level of a Land Quality is to *simulate* it over *time*, using a *dynamic simulation model*. For example, we could estimate the land quality 'moisture availability' from time series of the diagnostic LCs such as rainfall and solar energy. This is especially appropriate if the *dynamic* or *time-dependent* nature of the LQ is important, for example, moisture stress at critical times. The results of the simulation are the behavior *over time* of the Land Quality. This must be *classified* to severity levels. For example, 'high moisture availability' could be defined as less than 10% frequency of three or more consecutive days with a moisture deficit in the growing season.

Advantages: (1) the model provides a more-or-less *mechanistic* view of the land quality, i.e., its causes as well as its severity level; (2) dynamic simulation provides a *time-series* of results.

Disadvantages in a land evaluation context: (1) high data requirements, (2) difficult calibration, and (3) the considerable expertise and judgment needed for their correct application.

We will study this in detail in a later section of the course.

8. Evaluating overall suitability from Land Qualities

In the previous lecture, we studied a variety of methods for determining severity levels or single-factor ratings for the various Land Qualities defined for a Land Utilization Type. Evaluation of individual land qualities is useful in itself, e.g., for identifying areas with special needs for soil conservation, or where foundations for buildings will need special treatment. However, in most land evaluation exercises, we also want a *single measure of suitability* of the land area for the land use. To do this, the single-factor ratings of the individual LQs must be *combined* in some way into an overall measure of suitability. The ways in which we can perform this combination is the topic of this lecture.

Definition of *(land) suitability*: "the fitness of a given type of land for a specified kind of land use" [Food and Agriculture Organization of the United Nations, 1985 #193]. Intuitively, the measure of suitability tells us how good the land is for the specific LUT being evaluated. This definition begs the question, what is 'fitness'? We have to give this an *operational* definition, i.e., something we can *compute*.

(1) An *economic* definition of suitability can be based on defined metrics of economic value, e.g., predicted gross margin, net present value, internal rate of return, benefit/cost ratio.

(2) A *physical* definition of suitability is more arbitrary, being based on a specified method for combining LQ ratings into an overall rating. The idea is to give the land user a feel for how limiting, or difficult to manage, the land is for the proposed Land Utilization Type, on an ordinal scale of 1 (no limitation) to some maximum.

8.1 The concept of suitability classes

The FAO concept of 'suitability classes' is appropriate if there is no *continuous* scale for the evaluation, or if we want to classify a continuous scale of suitability into a small set of classes, readily understandable by the client.

Recall from a previous lecture: the suitability *class* is the second level of detail in the hierarchy *order - class - subclass - unit.*

<u>Physical Suitability Classes</u>: S1, S2, S3/N1, N2: . Note that S3 and N1 can't be distinguished. N2 is defined as land that is completely unsuited to the use, i.e., the use would totally fail or cause irreparable environmental degradation. S2 and S3/N1 indicate land that is increasingly more difficult to manage or presents stronger limitations to production.

Economic Suitability Classes: S1, S2, S3, N1, N2: . Note that S3 and N1 are separated according to predicted economic value: S3 is economically viable and N1 is not. In any case N2 is physically unsuited, and is defined by the Physical Suitability classification. S2 and S3 are progressively less remunerative than S1.

There is no *a-priori* reason why the scale of suitability classes can't be finer or coarser than 4 or 5 (ALES allows this); but this division seems psychologically adequate for its purpose. Remember, if we have a predicted economic value on a continuous scale, the Economic Suitability Class is only a convenience to communicate the results in an easily-understood form.

There is an obvious confusion between physical and economic classes of the same name. Except for N2, they are not necessarily related. For example, there may be land with many physical limitations that place it in class S3/N1, but if the relation of prices of outputs to costs of inputs is favorable, it may be in economic class S1. Conversely, there may be land with no physical limitations to a use, but if the economic situation is not favorable, it may be in economic class N1.

8.2 Methods of evaluating overall physical suitability

(1) the Maximum Limitation method

The overall physical suitability of a land area for a LUT is taken from the *most limiting* land quality, i.e., the LQ whose rating is the worst. The LQs must be rated on a *commensurate* scale, e.g., '2' for LQ1 must in some sense be 'as bad as' '2' for LQ2.

Advantage: simplicity, 'law of the minimum'; if severity levels of LQs were defined according to a standard set of yield reductions, and if these yield factors do not interact, the suitability class obtained by this method will be correct. In general FAO practice, S1 corresponds to 80-100% of optimum yield, S2 to 40-80%, and the S3/N1 to 20-40%. But some physical factors do not affect yield, they just make management more difficult or exacting.

Disadvantage: does not differentiate between land areas with several limitations and those with only one, as long as the maximum limitation is the same.

ALES: Mark the LUR 'use in the maximum limitation method'.

(2) algebraic combinations of land quality ratings

The overall physical suitability of a land area for a LUT is computed according to a formula based on the individual factor ratings. For example, the average of the LQ levels, or a weighted average giving more weight to more severe limitations. Or, some rule like '3 moderate limitations are equivalent to 1 severe limitation'.

This is a more flexible version of the maximum limitation method. The individual LQ scales must again be commensurate.

(3) ad-hoc combination of land quality ratings

The overall physical suitability of a land area for a LUT is computed according to another decision rule.

Advantage: land qualities can be weighted, and they do not have to be on the same scale of 'goodness'.

Disadvantage: lots of work, subjective combinations

> ALES: Physical Suitability Subclass *decision trees* allow for any interactions or incommensurate meanings of LQ severity levels. The best approach in ALES is to use the maximum limitation method if possible, and put any interactions (special rules) in a decision tree, which takes precedence over the maximum limitation method.

8.3 Methods of evaluating overall economic suitability

This is more objective than physical suitability. Some economic *metric* (indicator) is chosen, and the value of each land area/land use combination is calculated, without reference to the LQ factor ratings *per se*, although the LQs affect yields (cash in) and costs (cash out).

The evaluator assigns the following values:

1. Lower limit of class S1 (= upper limit of class S2)
2. Lower limit of class S2 (= upper limit of class S3)
3. Lower limit of class S3 (= upper limit of class N1)

Then the value of the predicted metric is *classified* according to these class limits. For example, a predicted value less than the lower limit of class S3 places the evaluation unit in class N1.

In a later unit, we will study the various economic metrics and how they are calculated.

9. Glossary

Classified value: one measured on a discrete scale.

Client: A person or organization that requests the work and will act on the basis of its results. Also called the *user* of the land evaluation results.

Continuous value: one measured on a continuous scale, with arbitrary precision.

Decision tree: a hierarchical multi-way key, leading via a series of questions at the *nodes* of the tree to a *decision* at its leaves.

Delineation (on a map): the undivided portion of a map sheet inside a continuous boundary line, and outside any contained continuous boundary line, if any.

Economic land evaluation: an evaluation of suitability based on some economic measure of net benefits, should a given LUT be implemented on a given land area.

Evaluations: specific evaluation exercises.

Evaluator: A person who carries out the land evaluation.

Framework: how to carry out an evaluation exercise.

Guidelines (directives): what factors (land qualities) to consider when evaluating for certain general kinds of land uses, how to evaluate these qualities.

Land : an *area* of the earth's surface, the characteristics of which embrace all reasonably *stable*, or *predictably cyclic*, attributes of the biosphere vertically above and below this area, including those of the atmosphere, the soil and underlying geology, the hydrology, the plant and animal populations, and the results of past and present *human activity*, to the extent that these attributes exert a significant influence on present and future uses of the land by humans.

Land Characteristic (LC): a *simple* attribute of the land that can be directly *measured* or *estimated* in routine survey in any operational sense, including by remote sensing and census as well as by natural resource inventory. Cf. *land quality*.

Land Quality (LQ): a complex attribute of land which acts in a manner distinct from the actions of other land qualities in its influence on the suitability of land for a specified kind of use; the ability of the land to fulfill specific requirements for a LUT. Cf. *land characteristic*.

Land Quality class: see ‘severity level’.

Land resource expert: a person who has information on the land resource

Land Suitability: the fitness of a given type of land for a specified kind of land use.

Land-use expert: a person who has information about a land use or land quality, in relation to the land.

Land Use Requirement (LUR): a condition of the land necessary for successful and sustained implementation of a specific Land Utilization Type

Land Utilization Type (LUT): A kind of land use described or defined in a degree of detail greater than that of a major kind of land use.

In the context of *irrigated* agriculture, a land utilization type refers to a crop, crop combination or cropping system with specified irrigation and management methods in a defined technical and socio-economic setting.

In the context of *rainfed* agriculture, a land utilization type refers to a crop, crop combination or cropping system with a specified technical and socio-economic setting.

A land utilization type in *forestry* consists of a technical specifications in a given physical, economic and social setting

Major Kind of Land Use: A major subdivision of rural land use, such as rainfed agriculture, irrigated agriculture, grassland, forestry, recreation, annual crops, perennial crops, swamp rice cultivation, forest plantation, or natural forests.

Map unit: a set of map delineations designated by a single name, and representing a single legend category.

Minimum decision area: the size of the individual land areas for which decisions are to be made.

Minimum legible delineation (MLD) of a map: the minimum legible size of a polygon on a map at a given scale, conventionally taken to be $0.4cm^2$ on the map.

Nominal value: a *classified* value whose scale of measurement is not ordered (cf. *ordinal* value), i.e., the order of the classes is arbitrary and therefore not meaningful.

Optimum legible delineation (OLD) of a map: the minimum easily-legible size of a polygon on a map at a given scale, conventionally taken to be 4 times the *minimum legible delineation* (MLD) of $0.4cm^2$, i.e. $1.6cm^2$ on the map.

Ordinal value: a *classified* value whose scale of measurement is ordered (cf. *nominal* value), i.e., the order of the classes is meaningful.

Physical land evaluation: an evaluation based only on physical factors that determine whether a LUT can be implemented on a land area, and the nature and severity of physical limitations or hazards.

Scale factor of a map: ratio of distance on the *ground* to distance on the *map*. The *denominator* of the conventional representation of map scale.

Severity level of a Land Quality: a classification of the LQ, indicating the degree of limitation or hazard associated with the LQ on a particular land area, from Level 1 = no limitation, upwards to some maximum.

Stakeholders: all parties who will be *affected* by the results of the planning decisions taken on the basis of the land evaluation.

Suitability: see *land suitability*.

Suitability classes: Divisions of *suitability orders* that indicate the *degree* of suitability, not simply suitable vs. not suitable.

Suitability orders: Land is either *suitable* or *not suitable* for a LUT.

Suitability subclasses: Divisions of *suitability classes* which indicate not only the degree of suitability but also the nature of the *limitations* that make the land less than completely suitable.

Suitability units: Divisions of *suitability subclasses*, which have different *management requirements*.

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