Lecture Notes: “Land Evaluation”

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Introduction

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 "Introduction"

1. Introduction to the course

The problem: *Inappropriate land use*, which leads to inefficient exploitation of natural resources, destruction of the land resource, poverty and other social problems, and even to the destruction of civilization. The land is the ultimate source of wealth and the foundation on which civilization is constructed.

Part of the solution: *land evaluation* leading to *rational land use planning* and *appropriate* and *sustainable use of natural and human resources.*

So, this course presents the theory and practice of *land evaluation*, which may be defined as:

"the process of assessment of land performance when [the land is] used for specified purposes"

(Food and Agriculture Organization of the United Nations, 1985), or as:

"all methods to explain or predict the use potential of land"

(van Diepen *et al.*, 1991).

Key words of these definitions: method, process, assess, explain, predict, potential, opportunities, constraints, decision making.

Land evaluation can be a key tool for *land use planning*, either by individual land users (e.g., farmers), by groups of land users (e.g., cooperatives or villages), or by society as a whole (e.g., as represented by governments). This course introduces a diverse set of *analytical techniques* which may be used to *describe* land uses, to *predict* the response of land to these in both physical and economic terms, and to *optimize* land use in the face of multiple objectives and constraints.

1.1 The logical basis of land evaluation

Here is the basic logic that makes land evaluation possible and useful:

1. Land varies in its *physical* and *human*-geographic properties ('land is not created equal');

2. This variation affects land uses: for each use, there are areas more or less suited to it, in physical and/or economic terms;

3. The variation is at least in part systematic (with *definite* and *knowable* physical *causes*), so that...

4. The variation (physical, political, economic and social) can be mapped, i.e., the total area can be divided into regions with less variability than the entire area;

5 The behavior of the land when subjected to a given use can be predicted with some degree of certainty, depending on the *quality of data* on the land resource and the *depth of knowledge* of the relation of land to land use, therefore...

6. Land suitability for the various actual and proposed land uses can be systematically described and mapped, so that...

7. Decision makers such as land users, land use planners, and agricultural support services can use these predictions to guide their decisions.

1.2 Objectives of the course

1. Motivate the study of land evaluation, place it in the context of land use planning, natural resources systems analysis, and applied research;

2. Present a detailed framework or methodology for performing physical and economic land evaluations;

3. Present the theoretical basis and practical considerations underlying the application of the methodology;

4. Present diverse analytical approaches which can be used to carry out specific phases of the land evaluation procedure, including *expert judgment*, *statistical* methods, *dynamic simulation* of the soil-plant-atmosphere system, *spatial* analysis with geographic information systems, and *optimization* under constraints;

5. Survey other land classification methods that the student may encounter in the field;

6. Present computer programs that support the methodology.

Students who complete the course should be qualified to *manage and carry out land evaluation projects* in support of land use planning activities. They will be able to *explain the objectives and methods* of land evaluation to the consumers (planners) and to the land-use and land-data experts. They will be able to *use a set of computer programs*, and will be able to decide which are best for which purposes.

1.3 The lecture notes

These notes are both an *outline* of the lectures and a ready *reference* for when you are called on to carry out a land evaluation. The presentation is more detailed than is possible in the lectures, because of time constraints. An extensive *bibliography* for each section provides an entry into the specialized literature when the practitioner is faced with a specific problem.

The notes are organized into this introduction and seven sections:

	Introduction
1.	Basic concepts and procedures of land evaluation
2.	Geographical Information Systems
3.	Modeling
4.	Economic Land Evaluation
5.	Risk & Uncertainty
6.	Data Sources for Land Evaluation, including remote sensing
7.	Non-FAO Land Classification Methods

In the introduction (this section), we place land evaluation in the context of land-use planning. Also there is a brief introduction to computer technology for land evaluation.

The first section introduces land evaluation concepts and terminology, using the FAO "Framework for Land Evaluation" 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.

The second section presents Geographical Information Systems, an indispensable tool for map analysis and presentation for land evaluation. Two related topics presented in this unit are Digital Elevation Models and the Global Positioning System.

The third section presents some analytical techniques for quantified land evaluation, in particular, the two principal modeling approaches: *empirical* (or, *statistical*) and *dynamic simulation* modeling. The main use of modeling for land evaluation purposes is to predict yields. Another use of modeling is to predict individual land qualities.

The fourth section presents the micro-economic analysis necessary for land evaluation. Physical land evaluation provides no objective method to *compare* different land uses for a given land area, as there is *no inherent common scale of measure* between the land. The land user wants *maximum benefits* with *minimum effort,* subject to a set of *constraints*. In *market-oriented* societies that are largely organized by economic interactions, both benefits and costs can be expressed by *economic* measures. This section also discusses *risk analysis*, since land users are usually willing to trade some total income for more certain incomes.

No serious land evaluation should be without some *estimate of uncertainty* in its results. So, the fifth section discusses various aspects of uncertainty, including the concepts of data and rule uncertainty, spatial variability, and 'fuzzy' logic. The emphasis is on how to describe and evaluate uncertainty, and how to determine and express the uncertainty of our predictions in land evaluation.

Land evaluation is based on *land resources data*. The sixth section discusses various kinds of data (soils, climate, hydrology), how it is collected, especially by *remote sensing*, and how it is processed in the computer.

The seventh section presents various methods of land classification for specific purposes. These include the USDA Land Capability Classification, the USBR Land Suitability classification for irrigation, parametric indices of land quality, Agro-ecological Zones, the Fertility Capability Soil Classification System, and the LESA system. These classifications are not land evaluations properly speaking, but are closely related. In some situations, the land evaluator can use one of these systems in place of a complete FAO-style land evaluation.

2. Introduction to computers for land evaluation

This section presents an orientation to computers and programs for land evaluation.

The ‘personal’ or micro computer is revolutionizing the field of land evaluation, as well as every other field of applied science. The possibility especially exists for powerful analytical techniques to be brought to the project or local level. It is completely feasible to have a county-level land information system including remote sensing with a hardware and software investment of under $3,500 if expensive peripherals (digitizing tables, 9-track and cartridge tape, plotters, laser and color printers) are shared at a central site as necessary. (Of course, tariffs and import licenses of many less developed countries artificially raise this cost.)

At a more sophisticated level, but still within reach of national organizations and universities, is the ‘workstation’ or technical computer.

The trend is to ever-cheaper and more powerful hardware (machines), and ever more sophisticated software (programs). The problem becomes one of knowledge and imagination, not money.

2.1 General-purpose information systems

Although in this course we will study software specific for land evaluation, we should recognize that standard ‘productivity applications’ (i.e., the kind of programs that can be bought off the shelf and are used in offices of all kinds) can make a tremendous difference in the day-to-day tasks of project and manuscript preparation, project monitoring, data collection and verification etc. The well-equipped office will include the following applications (names of specific programs are given in parentheses for information and orientation, these are not endorsements and do not imply that these are the only or preferred programs for their purposes):

1. *Word processing* and *simple desktop publishing* (Microsoft Word, Ami Pro);

2. *Spreadsheet* for data storage, verification and reduction (Microsoft Excel, Borland Quattro Pro, Lotus 1-2-3);

3. *Presentation graphics* and *simple statistics*, often included in the spreadsheet, but there are also dedicated programs such as CorelDraw! and Microsoft PowerPoint for graphics.

4. *Database management* for mailing lists, bibliographies, collections, etc. (Paradox, Microsoft Access, FoxPro, dBase)

These are not new technologies, but for many less-developed countries they still are quite new, especially the more sophisticated applications of the packages that are already used. A 'computer culture' takes time to develop.

More sophisticated computer applications are also accessible to the microcomputer owner, for example:

1. *Statistical analysis*, including multivariate methods (MINITAB, SPSS, JMP, Systat, M-Stat)

2. *Relational database managers* (Paradox, Microsoft Access, FoxPro, dBase IV)

3. *Risk and uncertainty analysis* (@RISK)

4. *Computer-aided drafting and design* (AutoCAD)

5. *Mathematical modeling* (MathCAD, MATLAB)

6. *Dynamic simulation modeling* (Stella)

Almost all programs listed above are under $500 list price, many are available for under $200 street price. Import policies of many less-developed countries keep prices of legal copies artificially high.

2.2 Special-purpose programs for land evaluation

As in all areas of science and technology, computers are now indispensable for the practicing scientist or engineer. The following sorts of computer programs can be used to support of land evaluation:

1. *Expert system* and simple microeconomic analysis for physical and economic FAO-style land evaluation (ALES)

2. *Statistical models* for yield estimation and prediction of land qualities (MINITAB)

3. *Dynamic simulation models* for yield estimation and prediction of land qualities (GAPS, WOFOST, LEACHM, CERES, GRO, STOR, SUCROS)

4. *Geographical Information Systems* (IDRISI, ArcVIEW)

5. *Remote Sensing and image processing* (IDRISI)

6. *Spreadsheets* (Quattro Pro, Excel)

7. *Database managers* for natural resources databases (e.g., soils and climate) (Paradox, Microsoft Access, FoxPro, dBase)

8. *Optimization* under constraints (Quattro Pro, Excel, LINDO)

9. *Risk analysis* (@RISK)

10. Land classification (AEZ, CDA, LECS from the FAO)

Also, there are some programs designed to perform land evaluation in a specific area, e.g., MicroLEIS for Mediterranean climates.

2.3 Computer networks

By itself, the computer is a powerful tool, but when connected in a *network*, the computer becomes a medium of information exchange. There is a tremendous quantity of knowledge and data in the applied sciences related to land evaluation.

2.3.1 Local-area networks

Computers at a single location can be connected in a *local-area* network (LAN). This allows users to share scare resources such as printers and scanners, and to exchange files. Many programs are available in *network-aware* versions, that support multiple users working on the same files without undoing each other's work.

2.3.2 The Internet

Computers at different locations can be connected in a *wide-area* network (WAN). The outstanding example of this is the Internet. Its main uses in land evaluation are:

1. Electronic mail (e-mail): world-wide communication between collaborators.

2. Discussion lists: uses electronic mail to link people with similar interests. Example: soil erosion research, the IDRISI GIS, many other computer packages

3. News: there are specialized news groups on GIS, remote sensing, computer languages, software packages

4. File transfer sites (FTP): data and documentation. Very valuable are the Frequently-Asked Question (FAQ) files for newsgroups and discussion lists. Large datasets are available.

5. Mosaic/WorldWideWeb and Gopher: information structured with cross-references and hypertext links to make navigating the huge amount of information easier.

3. Land evaluation in the context of land use planning

Reference: (Food and Agriculture Organization of the United Nations, 1993) is a concise introduction to rural land-use planning, and places FAO-style land evaluation in this context.

Background reading: (Beatty, Petersen & Swindale, 1979), Chapter 3, (EUROCONSULT, 1989) §10.3

Land evaluation exists to provide answers to decision makers who in some sense *plan* the use of the land. This lecture presents an outline of rural land use planning to provide a context for the study of land evaluation. There is a lot more to say about land use planning!

Key point: in any kind of land use planning, the *decision maker* needs *reliable information* about the *characteristics* of different land areas and their *behavior* under land various uses; this is the function of land evaluation.

3.1 Planning

Planning is the process of allocating resources, including time, capital, and labor, in the face of limited resources, in the short, medium or long term, in order to produce maximum *benefits* to a defined group. Although individuals plan for the future, by 'planning' in the context of land evaluation we understand some form of collective activity, where the overall good of a group or society is considered.

Rural land use planning is the process of allocating uses to land areas, and resources to those uses.

3.2 Collective vs. individual rights

Planning becomes necessary as soon as organized society emerges and resources are not limitless. In some societies the planning process is simplified by having a single decision maker (autocrat) or a small group of decision makers (oligarchs), whereas in societies where individual rights are maintained there are a large number of decision makers who can influence a land use plan.

In societies where the rights of individuals are accepted, there is a natural tension between collective planning and the rights of the individual. An example is the "landowner's rights" movement in the USA, to oppose restrictions on land use. Another example is the long-running battle between collective and individual use of lands in the Adirondack Preserve of New York State. “Freedom” is relative and must be negotiated according to the rules of engagement of a society. The rights of individuals and society must be balanced. As far as is practical, decision making should remain with the individual, as long as society’s goals are met.

In some situations of collective resource use, the need for collective planning is self-evident, e.g., development and use of water resources. In others, there is little or no need for collective planning, e.g., the decision of which crops to grow can generally be left up to the individual farmer with the ‘invisible hand’ of the market providing signals to the farmer via the price mechanism. There are many intermediate cases, especially where markets are distorted or do not fully account for social values (e.g., environmental risks, inter-generational equity, non-renewable resources).

3.3 Planning vs. adaptation

In *static* or *slowly-changing* social, political, or physical settings, a series of slow, adaptive changes in land use are sufficient. This has been the case for much of human history, although there are many examples of complex societies even in prehistory that were forced to plan in order to survive.

However, in the face of rapid change in any of the settings, there is not enough time for trial-and-error and adaptive changes. Instead we must have *planned* change.

The biggest modern-day reasons for planning are the explosions of *population* and *wealth-expectation*.

3.4 Strategic vs. tactical planning

Strategic: medium to long term, involves an examination of goals, can consider fairly radical changes to current practice.

Tactical: short to medium term (usually less than a year), goals are already set, the aim is to maximize return in some sense within the context of the goals, can only consider fine-tuning current practice.

Land evaluation is fundamentally aimed at supporting *strategic* planning. Short-term or tactical plans (e.g., ‘When should I cut hay this year?’) can be assisted by *decision-support systems*.

3.5 Why plan rural land use?

3.5.1 On private land

√ To provide maximum *economic benefit* to the individual land owner or operator (e.g. farm planning)

√ To prevent or solve *conflicts* between individuals and other individuals or with the needs and values of society as a whole

It is not practical to allow landowners to do whatever they want with their land, for several reasons:

1. possible *direct* and *immediate* effects on *other* land owners or resource users; the classic example is diversion or discharge or waters into a stream that is then used by others

2. possible *indirect* and/or *delayed* effects on *other* land owners or resource users; a good example is aquifer depletion following excessive water use

3. possible *direct* and *immediate* effects on the *resource base*, e.g. water pollution

4. possible *indirect* and/or *delayed* effects on the *resource base*, e.g. climate change

5. Society may have a *collective interest* (valid or not) in discouraging certain land uses and promoting others. E.g., Japan's desire to be self-sufficient in rice and the US in sugar.

6. Different land uses have different *infrastructure requirements* (roads, schools) which the state may or may not be prepared to meet. E.g., an industrial park will certainly require that the state build new roads.

3.5.2 On state-owned land

In this case, the state must plan as would a landowner (e.g., 'management plan' for a national forest) but almost always in the face of multiple demands on the land and conflicting values.

In addition, the state is usually required by law or policy to take a long-term, at least partially non-market view of its land. This is because the state represents the interests of all of society.

Classic example: logging vs. wilderness in national forests; various sectors of society have different short- and long-term interests.

3.6 Proscriptive vs. prescriptive planning

Rural planning can be quite lax, generally orienting but not controlling (neoliberal) or quite strict (statist).

Planning activities are fundamentally of three kinds:

(1) *proscriptive*;

(2) *indirectly prescriptive*; and

(3) *directly prescriptive*.

In practice these may be combined, e.g. a government may create an agricultural district by zoning, favor it with tax incentives, and also build rural schools and community centers.

3.6.1 Proscriptive land use planning ('zoning')

The 'decision maker' has the power to prevent or regulate, but will not actually expend any energy or resources, other than that required by the police power.

General terms: *zoning*; 'passive' or 'normative' planning.

The state has police power over land use, backed up by the judiciary. In the final analysis, proscriptive planning depends on the police power of the state to prevent uses that are not in its interest, although without a *consensus* with the affected parties, and a judiciary system that is perceived as *independent* and *honest*, enforcement is problematic.

Examples: (1) wetland protection in the USA; (2) farmland preservation vs. development.

3.6.2 Indirectly prescriptive land use planning

The decision maker has power to perform indirect actions which cost it money and which affect the land use indirectly, by favoring certain kinds of uses. These are also called *incentives* to these land uses.

Example: preferential taxation for agricultural districts (reduced revenue).

Example: support prices for agricultural commodities (increased expenditure).

Example: tariff and non-tariff barriers to imports (e.g., US sugar quotas, EC tariff on Latin American bananas).

3.6.3 Directly prescriptive land use planning

The decision maker has the power to perform direct actions which affect the land use. These are of two types:

(1) Implement the land use

The land owner or operator has this power. The plans are of two basic types: a *management plan* and a *strategic plan*.

(2) Directly support the land use

... with actions that facilitate the use or remove a cost from the land users

Example: infrastructure improvement: roads, irrigation systems

3.7 Legal and institutional structure of land use planning

This varies greatly among countries or even provinces and states. Here we enter into the realm of political theory as well as sociology. The basic question is, What is the structure of political society, i.e., how are decisions made?, and How are rights to make decisions expressed in the law?

3.7.1 What is government?

One view: "We hold these truths to be self-evident, that all men are created equal, that they are endowed by their Creator with certain unalienable Rights, that among these are Life, Liberty and pursuit of Happiness. That to secure these rights, Governments are instituted among Men, deriving their just powers from the *consent of the governed*.". (Thomas Jefferson, 4 July 1776, Philadelphia PA).

In this view, the government and its laws codify the more-or-less common opinion of the people as to fair practice, arrived at after some process of consensus-building (various forms of 'democracy' within a defined structure for debate and decision-making). There are mechanisms by which all affected parties can make their opinions known (e.g., legislatures) and by which they can decide among competing claims according to the law (i.e., a judiciary system). The government exists to improve the welfare of the people and therefore is tolerated by them.

Another view: Government is the institution which holds at least some actual power over a territory and can convince, usually by the use or threat of force of arms, other political entities that it must be respected when dealing with that territory. This is the view of the United Nations. Democracy in any sense of the word is irrelevant unless it suits the needs of other powers (e.g. USA attitude towards Cuba/Castro vs. Chile/Pinochet).

In fact many *de jure* and *de facto* governments do not function with the 'consent' of large numbers of the governed, but instead represent certain classes, interests, ethnic groups, families, or even temporary assemblages of profiteers. The reactions of the unrepresented governed range from passive acceptance to open rebellion. In these hands the law becomes an instrument of oppression and control rather than expressing a consensus. The government exists to improve the welfare of the governing group and to suppress any opposition.

Many governments combine both types of behavior.

In a planning context, these differences have great practical implications. The more open and representative the government, the more participatory and transparent the planning process, the more likely is a successful long-term plan. Coercive governments with centralized decision making may be able to produce and carry out plans more rapidly, but in the long term they will be less successful (e.g., former Soviet Union).

3.7.2 Legal basis of zoning

Government gives permissions (implicit, from a zoning map, or explicit, by variances or permits); may be centralized or decentralized (local government).

Advantages of *centralization*: consistent standards, less chance of petty corruption

Advantages of *decentralization*: adaptable to local needs, less chance of large-scale corruption and influence-peddling.

The appropriate scale is where participatory decision making and accountability is greatest.

3.7.3 Legal basis of direct planning

By *individuals* or partnerships (e.g., farmers), from their rights of use over the land.

By collectives (e.g., irrigation districts), from their legal mandates as expressed in their articles of incorporation, supported by law or precedent.

By government agencies formed for the explicit purpose of *managing resources* (US Forest Service), or providing assistance to individual land owners (USDA Soil Conservation Service), by their legal mandate.

By governmental agencies that provide *infrastructure* (Departments of Transportation), again within their legal mandate.

In many developing countries, *social-welfare agencies* provide important rural infrastructure (Ministries of Education and Health): 'Integrated Rural Development'

3.8 A transparent and rational process is desirable

Almost always the various individuals and interest groups will be in conflict over any zoning plan, management plan, tariff policy, taxation plan, or infrastructure investment. Some parties (all?) will feel that the plan is against their interest.

In a *transparent* (or, *open*) process, the planner adjusts the plan according to the openly-expressed preferences and the relative political power of the various affected individuals and groups, so that the greatest number of parties be the most satisfied possible. Furthermore, all affected parties can see exactly how the plan was developed and how disputes were resolved. This has two great benefits: (1) the plan is likely to be better and 'fairer' at least in the aggregate, (2) all parties are more likely to support the final plan.

A *rational* process is reproducible by following a definite methodology. All the assumptions and any subjective judgments are clearly expressed and open to challenge. Even though preferences may not be 'rational' (in the sense of maximizing benefits) or even highly subjective, they must be quantified as far as possible.

In many countries there is a lack of transparency in many activities of the government, which brings with it a loss of confidence in government, political and social instability, and a loss of respect for and support of the management plan or other planning action. Of course, there is usually a reason for lack of transparency: the planner or decision maker has something to hide (hint: follow the $$).

The land evaluator can contribute greatly to making the planning process transparent and rational. The *rational* part comes from the use of sound analytical techniques (as taught in this course), and the *transparent* part comes from the presentation of all assumptions, data, and methods used in the analysis. For example, it is not acceptable to present a single 'final plan' without showing source documents, reporting on key assumptions, and explaining how the plan was derived.

4. Summary

The main conclusions of this course will be:

1. Have clear and realistic *objectives* in the land evaluation exercise. Develop these objectives in collaboration with the *clients* who will act on the results of the land evaluation. On the basis of these objectives, determine the land units to be evaluated and the map scale.

2. Think about land use in terms of Land Utilization Types, their Land Use Requirements, and the diagnostic Land Characteristics that will be used to evaluate the corresponding Land Qualities; i.e., think in terms of the FAO Framework.

3. Develop an *interdisciplinary* group of *experts* in two areas: (1) land resource inventory and (2) land use. In group (1) are soil surveyors, census takers etc.; they supply the data (land characteristics) and help you evaluate its reliability and depth. In group (2) are agronomists, soil physicists and chemists, agricultural engineers, economists, foresters etc.; they help you develop the diagnostic procedures. As the land evaluator, you interpret the specialized knowledge of the experts in land evaluation terms.

4. Select and apply the most appropriate *analytical methods* to evaluate land qualities and to combine these into overall physical and/or economic suitability. The methods we will study include: decision trees, matching tables, empirical (statistical) models, dynamic simulation models, geographic (spatial) models, and mathematical programming for optimization under constraints.

5. Select and apply the most appropriate *computerized tools* to support the analytical methods. In the practical exercises, we will experiment with the following programs, all of which operate under the MS-DOS or compatible operating system:

   (1) ALES V4.1: an *expert system* shell for economic and physical land evaluation, following the FAO Framework for Land Evaluation;

   (2) IDRISI V4.1: an easy-to-use grid-based *Geographical Information System* with strong image processing capabilities as well as uncertainty analysis;

   (3) MINITAB V8: an interactive *statistical analysis* program; we concentrated on descriptive statistics, exploratory data analysis, regression analysis, and multivariate methods including principal components;

   (4) GAPS V3: a *dynamic simulation model* of the soil-plant-atmosphere system with visualization;

(5) Quattro Pro V4 : an electronic *spreadsheet* for general data preparation and manipulation, with an *optimization* module; we concentrated on preparation and analysis of linear programs

There are similar programs on other operating systems, e.g. Microsoft Windows, the Macintosh OS, and Unix. To complete the toolkit you might want to use:

(6) A *relational database manager* (e.g., Paradox, FoxPro, dBase under the MS-DOS OS)

6. Be aware of, and try to express, the *uncertainty* in the evaluation results. Uncertainty comes in four flavors:

(1) *Data* uncertainty due to sampling and measurement at a *point*;

(2) *Data* uncertainty due to *spatial variability* in the evaluation unit;

(3) *Rule* uncertainty;

(4) *Risk* or probabilistic outcomes.

To express uncertainty, we will study the techniques of sensitivity analysis, Monte Carlo simulation, analytical error propagation, spatial statistics, and economic risk analysis.

7. Remember that your land evaluation has the potential to affect the lives of many people. Always maintain the highest standards of objectivity, honesty, and professionalism.

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