Land Evaluation for Sustainable Land Management

by

Klaas Jan Beek, Kees de Bie and Paul Driessen

Prof.Dr.Ir.K.J. Beek Professor in Land Evaluation
Ir.C.A. de Bie Tropical Agronomist; Agricultural, Conservation and Environment Division (ACE)
Prof.Dr.Ir.P.M. Driessen Visiting Professor; Agricultural, Conservation and Environment Division (ACE)

International Institute for Aerospace Survey and Earth Sciences (ITC)
P.O.Box 6, 7500 AA Enschede, The Netherlands

Summary

Land evaluation assesses the suitability of land for specified land uses. A distinction is made between qualitative evaluation, mainly based on expert judgment, and quantitative evaluation, based on process simulation models. Land evaluation and quantitative land use systems analysis support the planning of sustainable use of land. The FAO Framework for Land Evaluation (FAO 1976) provides guidance for land suitability assessment in developing countries where data scarcity often constrains modeling. Integration of bio-physical and socio-economic information and sustainable use of land resources are important principles. Several programming techniques are available to match the results of land evaluation with the available means of governments, land users and other stakeholders, to achieve optimal land use.

The contribution that information technology can make to land evaluation and sustainable land management is discussed. As yet, infrastructural obstacles hinder the effective use of information technology, but it is expected that digital land resource databases and networked information processing will free specialist time for data analysis and modeling leading to management and decision support systems for sustainable land management, based on spatial information of soils and other land attributes.

1. Introduction to land evaluation

Land evaluation assesses the suitability of land for specified land uses. The FAO (1995) defined **Land** as:

> A delineable area of the earth's terrestrial surface, encompassing all attributes of the biosphere immediately above or below this surface, including those of the near-surface climate, the soil and terrain forms, the surface hydrology (including shallow lakes, rivers, marshes, and swamps), near-surface sedimentary layers and associated groundwater reserve, the plant and animal populations, the human settlement pattern and physical results of past and present human activity (terracing, water storage or drainage structures, roads, buildings, etc.).

This definition encompasses at least eight functions of land that go beyond the production of food:

- It is the basis of a variety of life support systems, through the production of food, fodder, fibre, fuel, timber and other biotic materials for human use, either directly or through animal husbandry including aquaculture and inland and coastal fishery;
- Land is the basis of terrestrial bio-diversity by providing habitats and gene reserves for plants, animals and micro-organisms, above and below ground;
- Land acts as a source and sink of greenhouse gases and is a co-determinant of the global energy balance (reflection, absorption and transformation of radiative energy of the sun);
- Land regulates the storage and flow of surface- and groundwater resources, and influences their quality;
- Land is a storehouse of raw materials and minerals;
- Land retains, filters, buffers and transforms hazardous compounds;
- Land provides the space for human settlements, industrial plants and social activities such as sports and recreation, and connective space for transport of people, inputs and produce, and for the movement of plants and animals between natural ecosystems;
- Land stores and protects the evidence of the cultural history of mankind, and is a source of information on past climatic conditions and past land uses.

Early civilizations took account of environmental conditions in their choice of settlement and in the development of their cultures. Subsequent breakdown of these civilizations may often be traced back to their degradation of the land resource base.

It is this risk of land degradation that stands at the root of land evaluation. Soil survey and land capability assessment gained impetus in the USA in the nineteen thirties in response to severe soil erosion that threatened food production and the stability of society. Concerns about land degradation grew sharply, in part because of human and animal population explosions in the developing world. Increasing population pressure often causes over-exploitation of high potential land and/or misuse of marginal land. The rate of change of pressure on land in critical regions will increasingly violate the limits of the land's carrying capacity, even if available technological packages for managing the land resources have become better.
A score of land evaluation concepts and analytical procedures have been developed since the nineteen thirties. They can be grouped in two broad categories: qualitative evaluation procedures, based mainly on expert judgment; and quantitative evaluation methods, based on process-oriented simulation models.

2. Land evaluation for land use planning

Most land evaluation is qualitative and based on expert judgment. The experts are mostly soil surveyors and agronomists who interpret their field data to make them understandable to planners, engineers, extension officers and farmers. More recently, in-depth studies of specific soil-related constraints, in particular soil fertility, available water, available oxygen, soil workability and degradation hazards such as soil erosion and soil salinization have all facilitated quantitative simulation of specific land use processes and opened the way for yield prediction. The development of information technology during the last twenty years has enabled researchers to make rapid progress in the analysis of interactions between land resources and land use and in quantitative land evaluation based on quantitative modeling of land use systems.

However, placing land evaluation and land use systems analysis in the broader context of land use planning, revealed a potential gap between technology-oriented land resource specialists, concerned with the present and future performance of the land resources, and human-oriented (social) scientists, concerned with the land users and their well being. Later in this paper, we address the problems of inter-disciplinarity that dominate today's debate on the role and prospects of land use planning.

3. Land use planning and sustainable development

Land use planning is expected to make a major contribution to the realization of sustainable development. It can facilitate the allocation of land to the use(s) that provide the greatest sustainable benefits (Agenda 21, par.10.5). This demands that development remains within the carrying capacity of supporting ecosystems.

The United Nations Conference on Environment and Development (UNCED 1992) and the resulting Agenda 21 have bestowed worldwide political respectability on the concept of sustainable development. The continuing worldwide mismanagement of soils, inadequate land use policies and ineffective implementation of soil management and conservation programs, raises questions about how the communication of natural resources information to land use planners and decision makers can be improved and how this knowledge can be put to good use.

4. From qualitative to quantitative land evaluation

Land capability classification is a qualitative system that was developed by the US Department of Agriculture, in the nineteen thirties, as part of an erosion control program (Klingebiel and Montgomery 1961). Land capability refers to the potential of land to sustain a number of predefined land uses in a built-in descending sequence of desirability: arable crops, pasture, woodland, recreation/wildlife (Figure 1). If the capability of land decreases, the land becomes suited for fewer major land uses. Land capability is assessed by comparing the characteristics of a land mapping unit with critical limits set for each capability class. To obtain limits for the capability classes, expert knowledge was related to land characteristics. Sub-classes indicate kinds of limitation while capability units aggregate management recommendations according to technology and productivity levels of farming in the USA.

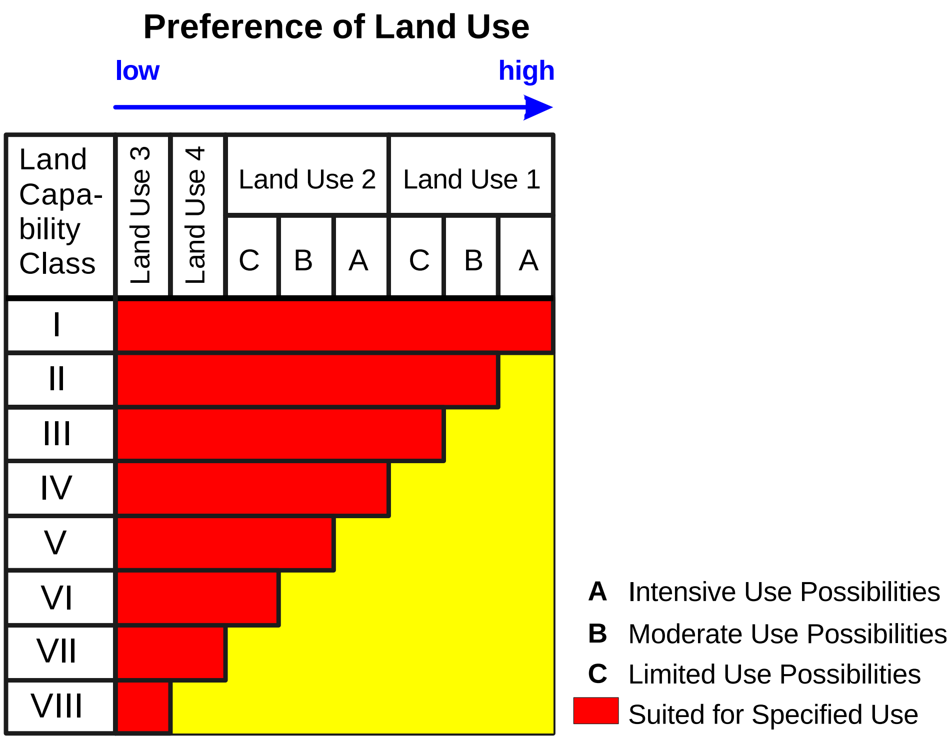

Figure 1. General outline of a land capability classification system (adapted from McRae and Burnham 1981).

Land capability classification is primarily supportive to the planning of large farms and it augments land use planning, e.g. balance the need for agricultural land against urban development or forest land against agriculture or pasture development. In doing this, the land capability classification has made an important contribution to the development of land use planning and management.

The Framework for Land Evaluation (FAO 1976) is meant particularly for use in areas with limited availability of basic data and can function at several levels of detail. The FAO Framework received conceptual inputs from the reconnaissance soil survey interpretation methods in Brazil (Bennema *et al*. 1964, Romalho *et al*. 1995). Most applications are qualitative, matching degrees of limitation or 'quality' of the land with the corresponding requirements of specific kinds of land use, and the overall suitability class is usually based on the most severe limitation of the land. However, the principles underlying the Framework are equally valid in quantified methods:

- Evaluation of land, not just soil;
- Prediction of response to future conditions must be facilitated;
- Land suitability must be for specific land uses;
- Evaluation should be in terms of benefits obtained in relation to inputs;
- Evaluation must be related to local physical and socio-economic circumstances;
- Land suitability is for use on a sustainable basis (without degradation of the land resources);
- All the relevant kinds of land use should be compared;
- A multi-disciplinary approach is needed.

The Framework assesses the suitability of land mapping units for specific land use types (LUTs). The procedure starts by identifying relevant LUTs. Definitions of LUTs include levels of know-how, available technology and available inputs and also the land tenure situation in as far as it indicates the degree to which the land user can manage or overcome constraining land qualities/limitations. Subsequently, the land use requirements (LRs) of present and probable LUTs are matched with the defined land conditions. The land conditions are described as dynamic regimes or 'land qualities' (LQs) that have a direct effect on the use. Examples of land qualities are the soil fertility level, water availability, oxygen availability, workability, resistance to erosion or salinization and these qualities may be described more clearly in terms of sufficiencies, e.g. sufficiency of nutrients, water etc. for the defined LUT (Melitz 1986).

The degree of quantification and detail of the description of land qualities over time, and the description of individual LUTs depend on the available data, which in turn depend on the scale of the analysis. Scale is an important factor when comparing the value of different land capability/evaluation systems.

At small scale, e.g. continental or country level (FAO 1981), the FAO has published semi-quantified methods, e.g. for assessing the population supporting capacity of land by agro-ecological zone. In this trade off between comprehensiveness and accuracy, potential constraint-free biomass production is determined on the basis of fourteen thermal regimes. The land is then sub-divided according to lengths of possible growing period (LGP), i.e. the period when moisture is sufficient for plant growth. Further reduction factors on yield are based on constraints caused by pests and diseases as common in each zone. This part of the evaluation is worked out for standard sets of basic data, and for eleven different crops. The soils are individually assessed on the basis of expert knowledge on the effect of soil conditions on the growth of each crop (at different input levels) in the various LGP-zones. This was done because soil data and the understanding of the effects of soil properties on crop yield are not fit to support quantified land evaluation on a country or continental scale. Applied at country level in Kenya (FAO/IIASA 1993), agro-ecological zoning resulted in a land productivity data set that was matched with the goals and objectives of government and local users. In this two-stage approach, subsequent socio-economic analysis estimated what land distribution would optimally approach the set goals. The analysis was based on linear and non-linear programming methods and employed multi-objective functions which, in principle, enable the interests of different stakeholders to be combined.

The FAO Framework for Land Evaluation combining computer technology and expert knowledge on specific soils and crops has been demonstrated by several authors (Wood and Dent 1983; Jones and Thomasson 1987; Hong Cheng 1989; Robert 1989 and others). However, transferability of the analyses is limited because the expert knowledge applies only to the conditions for which the systems have been developed and calibrated.

5. Interdisciplinary approach

The Framework employs the concept of relevant land use type and its associated crop and management requirements. These requirements include both the bio-physical requirements and socio-economic setting. A choice is offered between a two-stage land evaluation procedure where the bio-physical analysis is followed by a socio-economic analysis, which is preferred by most physical scientists, and a parallel procedure that attempts to integrate bio-physical and socio-economic analyses. The latter is favored by (social) scientists, especially at the farm level. An integrated sequence of land evaluation and farming systems analysis procedures, based on new tools such as relational databases, geographical information systems and modeling techniques, was proposed by Fresco *et al*. in 1992.

Physical, process-oriented land evaluation (Bouma *et al*. 1993), in alliance with crop growth theory (De Wit *et al*. 1978), yields quantitative assessments of inputs, outputs and the variable states of land qualities. Although such process-oriented modules support overall land suitability assessment, they are in the first place applied to produce quantitative expressions of land qualities for physical land evaluation, e.g. crop growth potential and water-limited bio-physical yield, the uptake of nutrients by crops, and erosion hazards / losses.

Coordination with social scientists and combining biophysical results with a socio-economic analysis needs to be structured. The FAO (1995) advocates decision-support systems, in which physical land evaluation and socio-economic evaluation run parallel for planning of sustainable use of land resources (see Figure 2).

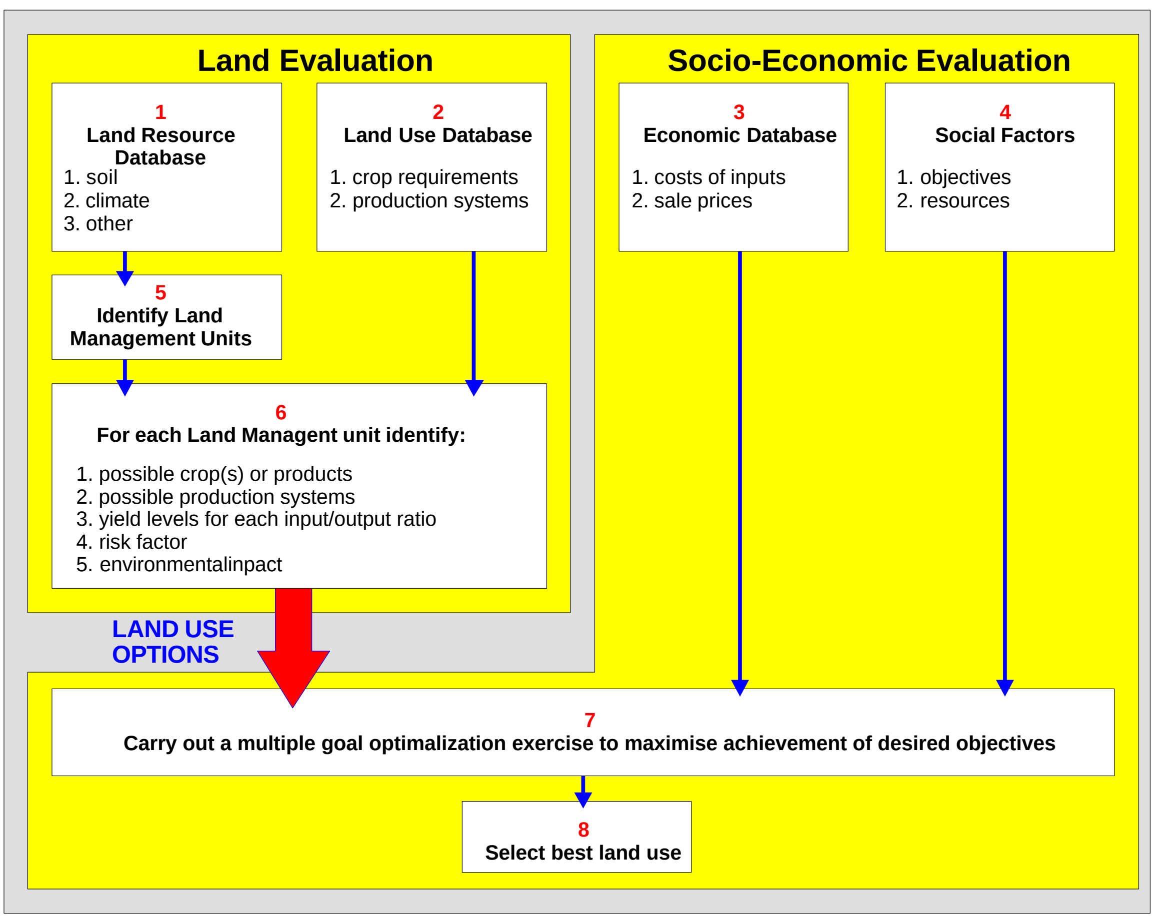

Figure 2. Decision Support System for Land Use Planning (FAO 1995).

Stoorvogel (1995), for purposes of land use planning in a Costa Rican rural settlement, linked external biophysical models with a Geographical Information System (GIS), applying linear programming for the analysis of alternative land use scenarios at farm and field levels. Six consecutive steps were identified:

- geometry operations of farms and soil types;
- attribute operations;
- data export from the GIS to the external model;
- model run;
- data import from the model into the GIS and,
- visualization or spatial analysis of the model results with the GIS, providing an indication of maximal net farm income, as well as a quantification of specific sustainability factors such as biocides.

Schipper *et al*. (1995) used in this study area the same land use planning methodology called USTED (Uso Sostenible de Tierras en el Desarrollo) to analyze the impact on sustainability of policy measures at changing socio-economic conditions such as a reduction in market price of a particular commodity grown in the area or of an important input like biocide and of quantitative restrictions on biocide use and soil nutrient losses.

Huizing and Bronsveld (1994) used GIS and bio-physical modeling to calculate the effect of crop diversification, changing from maize to tamarind on erosion losses and on income per village in an area of Thailand.

The above examples of bio-physical process models in combination with GIS and socio-economic analysis have been selected to demonstrate a certain change of paradigm through interdisciplinary land evaluation and land use planning from the traditional mono-disciplinary scientific study of soils, mostly of a descriptive nature (e.g. soil survey and classification) to an inter-disciplinary study of integral land-use systems, leading to quantified prescriptions for optimal utilization (Figure 3).

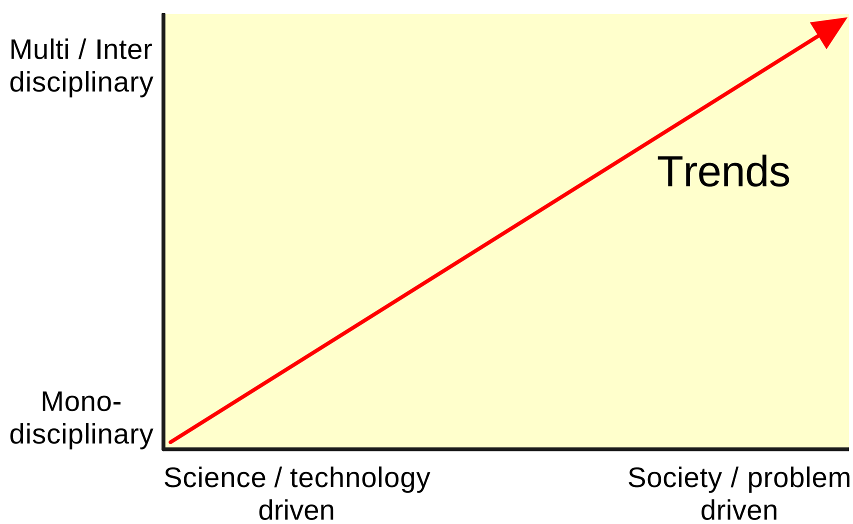

Figure 3. Trends in approach to problem solving.

Comparing the contents of the soil science conferences in Latin America, and in Brazil in particular near the 1960's, this change of paradigm is very remarkable. Most soil research in Brazil is nowadays dedicated to the dominant limiting factor: soil fertility, while in the 1960's, the soil surveyors played a dominant role to inventorize the spatial distribution of pre-dominant soil problems and possibilities. The challenge for the future lies in the integration of geographical information with all other scientific research results into practical management and decision support systems for the different levels of aggregation required for sustainable land management. Information technology and a systems approach will help to overcome the traditional communication problem between disciplines. It should be noted that integration of bio-physical disciplines may be difficult, integration with the socio-economic disciplines is even more difficult.

Factors, which complicate interdisciplinary communication include:

- the culture of individual disciplines;
- the kind of knowledge involved;
- the nature of development problems;
- the institutional setting;
- differences in perception of problems between the producers and the users of (geo-graphical) information.

Universities often emphasize mono-disciplinary study, and the prestige of scientists is more often derived from publications in a highly specialized scientific journal. Inter/multi-disciplinary research has at the moment a lower standing than mono-disciplinary research. This complicates the search for solutions to environmental problems and for sustainable development.

6. Sustainable land management: a land use system approach

The term sustainable development can be criticized for being open to a wide range of interpretations. According to Olembo (1994), the confusion arises because "sustainable development", "sustainable growth" and "sustainable use" have been applied interchangeably as if their meanings were the same. Sustainable growth is a contradiction in terms. Nothing physical can grow indefinitely. "Sustainable use" is applicable only to renewable resources: it means using them at rates within their capacities for renewal.

Dumanski's (1993) definition of Sustainable Land Management (SLM) is:

> Sustainable Land Management combines technologies, policies and activities aimed at integrating socio-economic principles with environmental concerns to simultaneously:
>
> - maintain or enhance production and services;
> - reduce the level of production risk;
> - protect the potential of natural resources and prevent degradation of soil and water quality;
> - be economically viable;
> - be socially acceptable.

National and local governments, interest groups, and specifically the land users themselves, should make efforts to meet these criteria. The objectives of many land users are to 'maximize production and/or net profit' and to 'reduce costs and labour'. Equally important to land users, planners and policy makers alike is the aim to 'conserve the environment'.

The Brazilian land evaluation method (Ramalho 1995) recognizes that different management levels due to societal differences have to be taken into account when evaluating the suitability of land. Different management levels may lead to different levels of sustainability. Winsemius (1995) uses the term "environmental hierarchy of needs", referring to the American psychologist Abraham Maslow (Figure 4). In this hierarchy a person can move only to the next level of sustainability after fulfilling his needs at a lower level. Thus, if within a society certain categories of land users are occupied fulfilling needs at a lower level (e.g. hunger is not satisfied; subsistence farming), then land use and degrees of sustainability are dominated by this unfulfilled need.

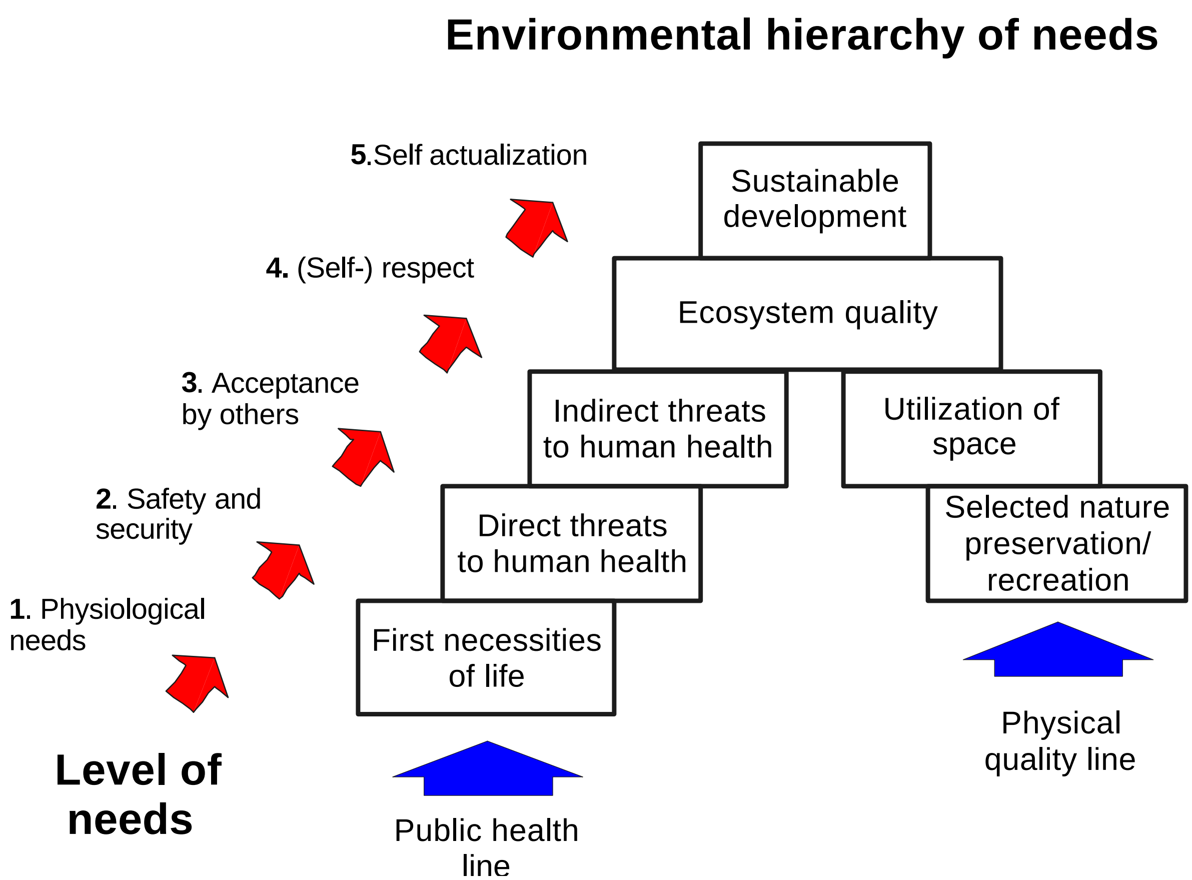

Figure 4. Environmental hierarchy of needs (Winsemius 1996).

The use of land resources takes place in the context of land use systems. Figure 5 shows the major features of a land use system. Sustainable land use systems can be evaluated at scales from farm plots to country and global scale. Ecological sustainability can only be adequately defined with reference to specific spatial and time scales. Processes external to the system may act at different time scales from the internal processes. Also, the acceptability of certain degrees of land degradation depends on the time and spatial scales concerned; for example deterioration of chemical soil fertility, soil pollution or soil erosion may be acceptable for particular local communities if this degradation occurs in small patches and at a slow pace, assuming that new technology or adapted management will eventually put the situation back under control.

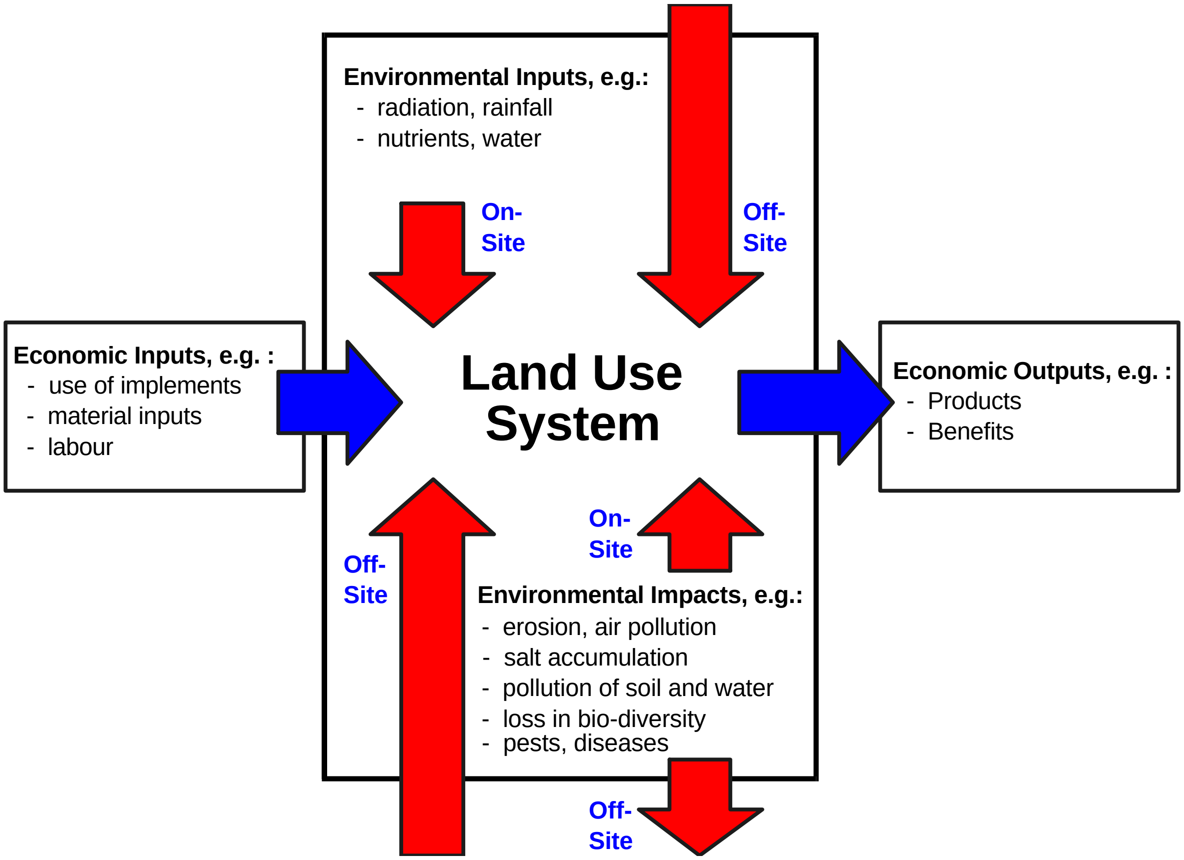

Figure 5. Major Features of a Land Use System.

Land suitability must therefore be expressed in terms of boundary conditions that define acceptable levels of loss of matter and energy from the land use system, as well as acceptable levels of input and of acceptable change in the status of the underlying land qualities. Land suitability based on the concept of sustainability nearly always limits production potentials, decisions on limiting the area of the land type taken into production and/or limits temporal rotations. This is true both for the evaluation of existing land use systems and for the design of new systems.

A relevant contribution towards better understanding the complexities of 'sustainability' is published by Kruseman *et al*. (1993). A set of operational definitions and a framework for analysis of sustainable land use at plot, farm and regional levels has been prepared, allowing for interactions between agro-ecological and socio-economic variables. Farm household models have been developed to make sustainability issues operational at a level where socio-economic disciplines meet with bio-physical disciplines. Quantitative models at this level calculate changes in land quality specifications due to both natural occurrences and human intervention.

Figure 6 presents the elements of a land use system and aspects influencing the holder’s decision-making. The goals of the land holder are specific for the holding and may be food production, including protection against risks, or income generation. Land use purposes are different from holder goals. A land use purpose is specific for a kind of land use and can include sustainability aspects. Land use purpose decisions depend on the holder's goals and on bio-physical and socio-economic possibilities and constraints.

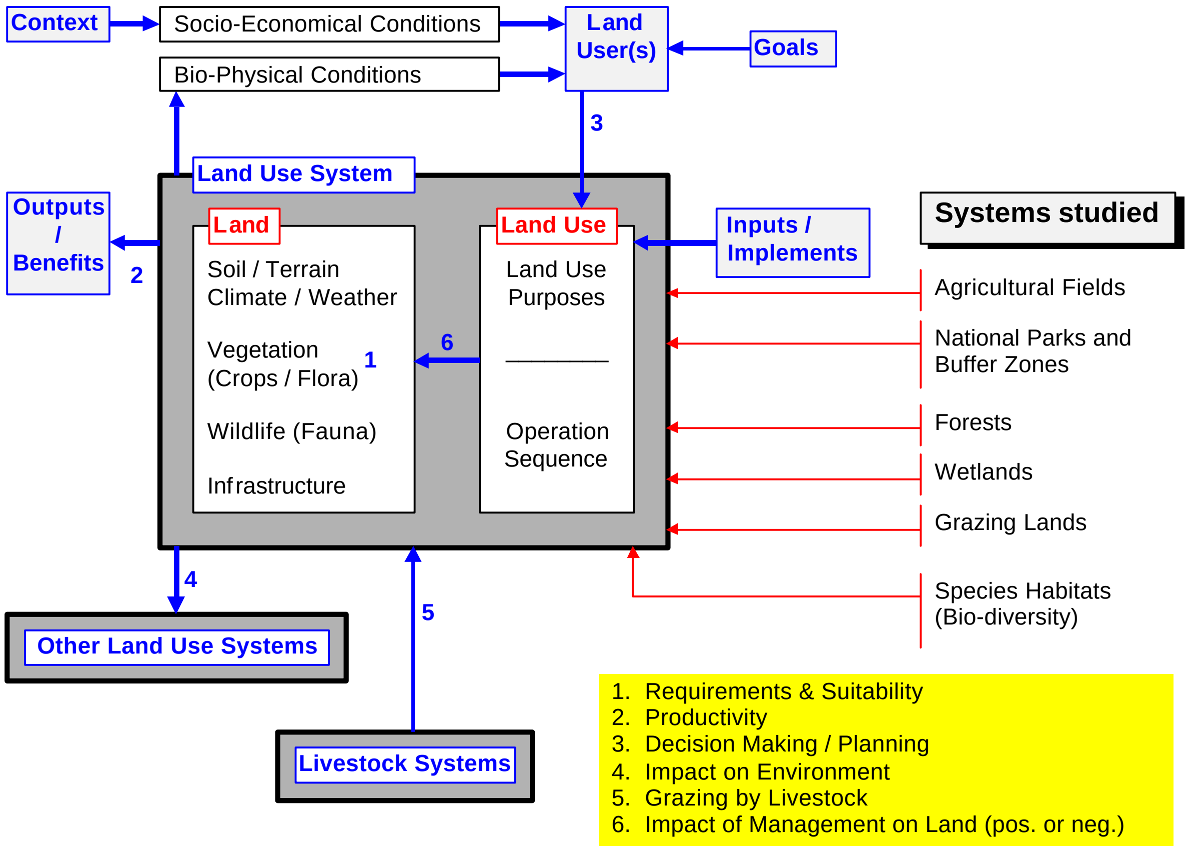

Figure 6. **Elements of a land use system with attributes that influence the holder's decisions. Flows of information and materials within the Land Use System are not shown** (adapted from: de Bie *et al*. 1996).

In a land use planning exercise it is important to distinguish between the stakeholder at the farm level, here called the holder, and other interested parties which can be individuals, communities or government entities that have a traditional, current, or future right to co-decide on the use of the land in a planning exercise (FAO 1995).

A land use systems approach reveals that decisions have:

- a **bio-physical component**, dealing with the bio-physical performance of specific land use systems (at various scales);
- a **socio-economic component**, the decision-making process itself.

Land users/holders are at the interface between the bio-physical and socio-economic components. The knowledge, flexibility and awareness of the holders are vital to sustainable land management. Local, regional, national and global governments and organizations, are responsible for:

- the socio-economic framework (including tenancy arrangements);
- the knowledge and awareness of the land users/holders (through extension services);
- the technology for sustainable land management (through research).

7. A sustainable land management model (SLM model)

The UNCED conference in 1992 and Agenda 21 identified the importance of widely accepted indicators by which to monitor the status of the environment. Recently the World Bank initiated the development of Land Quality Indicators (LQIs) to enable monitoring changes in land resources and the sustainability of managed eco-systems (Pieri *et al*. 1995). The LQI concepts are somewhat different from the land quality concept of the FAO Framework for Land Evaluation. Distinctions are made between:

- Pressure indicators - indicators of pressures exerted upon land resources by human activities;
- State indicators - indicators of the state of land resources and, specifically, of changes over time;
- Response indicators - indicators of the response by society to pressures and to changes of the state of land qualities.

State indicators are similar to the land qualities of the FAO Framework. However, the World Bank approaches them from a dynamic point of view, distinguishing between:

- Descriptive state indicators, which provide information in absolute terms, on land quality state or change of state;
- Performance indicators, which relate descriptive indicators to predetermined standards or target values (a kind of land suitability classes in terms of land evaluation).

Earlier, Dumanski (1993) set down generic indicators that could be developed as international standards for evaluation and monitoring of SLM:

- Crop Yield (trend and variability);
- Nutrient Balance;
- Maintenance of Soil Cover;
- Soil Quality/Quantity;
- Water Quality/Quantity;
- Net Farm Profitability;
- Use of Conservation Practices.

Such indicators may be used as objectives and parameters in the construction of an 'SLM Model' (de Bie *et al*. 1995; Table 1). Functions in the model relate SLM-objectives with SLM-parameters at three hierarchical levels. SLM-Objectives must be realized to achieve sustainable land management. SLM-Parameters are system attributes that have or may have an impact on the set objectives.

Table 1 does provide an overview of aspects of sustainable land management; it does not show temporal or scale aspects, on-site and off-site effects, or interactions between land use systems. The SLM model demonstrates that SLM objectives and SLM parameters are intricately intertwined. Any change, made at any point in the system, may have an effect on any other part of the system.

It is not always possible to realize all set SLM objectives. Trade-offs between objectives are inevitable, e.g. an increase in fertilizer use may enhance productivity and profitability but it can, simultaneously, create environmental problems.

Table 1. **Sustainable Land Management Model at three hierarchical levels**
(Beek, de Bie and Driessen, 1996)

SLM-Objectives		***SLM-Parameters***
1. Land use system (LUS) level: *(Land management takes place here; it is strictly bio-physical)*		
• Get target benefits • Achieve set yield targets • Avoid production variability and a negative production trend • Conserve the environment, i.e.: - soil quality/quantity - water quality/quantity - nutrient balances - others	**= f**	• Land conditions: - climate/weather - landform; soil - flora; fauna (incl. crops & livestock) - infrastructure • (→2) Management aspects as based on land use purposes, e.g.: - maintenance of soil cover - use of conservation practices
2. Holding level: *(The land user/holder acts here; relevant decisions on SLM are made)*		
• Decisions on (modified) land use purposes and management aspect: - to maximize the level of holding's profit/production - to reduce costs and the use of non-renewable inputs - to optimize available labour use - to conserve the environment	**= f**	• (→1) Condition of holdings fields • (→3) Socio-economic setting • (→3) Acquired SLM-knowledge • (→3) Tenancy arrangements by parcel • Indigenous LUS-knowledge • Flexibility, awareness, social acceptance • Household specifications • Off-farm economic activities
3. Local, regional, national, and global levels:		
• Create the required socio-economic framework, e.g.: - to maintain food security - to generate wealth/welfare - to preserve biological production potentials - to protect rural landscapes - to prevent excess production • Develop SLM technologies • Extension of SLM technologies • Improve tenancy arrangements land property rights	**= f**	• (→1) LUS aspects • (→2) Holding aspects • Rural infrastructure and facilities • Incentives; input/product prices • Legislation, e.g. on: - land conversion rates / urbanization of good lands / use of marginal lands - inputs, implements, land use operations • Long-term development policies, support, and investment programs • Agricultural support systems and institutional structures • Trading opportunities

8. Information technology (IT) and SLM

The Atlantic Institute which is a kind of Think Tank of a number of faculties from the NE USA and E. Canada and some European ones met in Vienna in 1994 and coming to the conclusion that:

- we are shifting towards a field that nowadays is often called *geomatics*, defined by this Atlantic Institute as the scientific “management of spatial information”. The boundaries between formerly separate disciplines become more and more fuzzy.
- We are moving from the period of innovation (1960-1980: technology driven, little data) through the period of integration (1975-2000 : building databases) to a period of proliferation (1990 -: systems integration, mass market, information marketplace customer driven).

Information technology (IT) is the combination of computers, electronic communication and process technology. Where IT is being introduced, in the financial service industry, in construction design, or other applications, a number of related generic characteristics emerge which are worthwhile mentioning. Recognizing them helps in understanding trends and identifying what changes in the collection, processing, and use of geographic information can be expected, but also in assessing the organizational, institutional and human resource effects. The characteristics are as follows:

- integrating, of both production processes and information
- decentralizing of production processes
- customizing of processes and information products

Simplistically speaking the integration of production processes occurs through the software in which technical, previously often specialized human activities are encoded. An example of this is desk top publishing, GIS, accounting and management information systems, Global Positioning Systems, Total Survey Station, Digital Photogrammetry and Digital Cartography. The issue here is that when previously is surveying and mapping specialized technical skills were required, and on which a lot of emphasis was given in education, we now find that non-technically specialized people can operate these systems and get out of them what they need.
When these integrated systems are combined with communication technology, opportunities arise for the decentralization of production processes as closely as possible to the user.
This puts into question the need for large production facilities which were centralized so that the specialized human skills could be coordinated into effective operations usually devoted to satisfying many different users with one standard product.

The integration of information is facilitated by the IT. Already this is clearly visible in the management decision support systems which grew out of the management information systems. It is also visible that the capacity to combine digital data sources is leading to many questions about the privacy of the individual and of corporations.
GIS is of course a direct result of this integrating characteristic. It is clear that GIS put capacities in the hands of the user community which are on the one hand unprecedented in their potential but on the other hand provides challenges to existing power centers.
The customization characteristic of IT relates to the capability to transform a data set at relatively low cost into new information products for specific users.

An important consequence of the customization and integration characteristics of IT is that a certain data set in combination with other data sets can deliver new information products with an added value compared to the individual data sets. This leads to the notion of information as a basic economic resource. Like a primary natural resource it can be refined and enriched to new products.

To give you an example of economic data use:

> The World Development Report 1994 of the World Bank, is this year concentrating on infrastructure: roads, energy, water supply, etc. The conclusion is, that developing countries can save up to 55 million dollars per year through a better management and maintenance of their physical infrastructure, this means 25% of the total annual investment in infrastructure.
> In Africa for instance timely investment of 12 million dollars in road maintenance during the past 10 years could have saved an actual cost of 45 million dollar in road repairs. One of

the reasons for their inefficiencies are monopolistic state companies. Decentralization lead to remarkable improvements of road quality and in the efficiency of water and energy supply, especially in combination with privatization and realistic pricing policies. Such processes of decentralization and privatization are best served by an adequate information infrastructure!.

Information technology has significance for interdisciplinary land use planning in facilitating:

- decentralization of Governance
- sustainable use of natural resources
- great progress in communication
- open international market for technology and knowledge.

At present, digital databases are being developed to create the information infrastructure required for sustainable land management at various scales. UN organizations supported by specialized institutes are in the process of establishing data standards and developing software for the collection and analysis of geo-referenced information on climate, soil and terrain conditions, water resources, land use, land cover and bio-diversity, social conditions, and economic conditions. All these must be based on up-to-date and accurate topographic databases and cadastral information. National programs are needed to unite such databases in a uniform geo-information infrastructure. The formalization of basic landscape-ecological units as the basis for land use planning should be encouraged.

A significant cost element in geo-information exploitation in the establishment and maintenance of the relevant standardized databases, their up-dating and interoperability. Groot (1993) developed a model (Figure 7) for a Geo-information Infrastructure (GIT) to achieve cost-effective data sharing from different sources, however, requiring policies and standards that provide the legislative, regulatory, financial operating environment of predictable integrity. Its creation demands negotiating agreements defining the institutional environment and arrangements between database producing and using information.

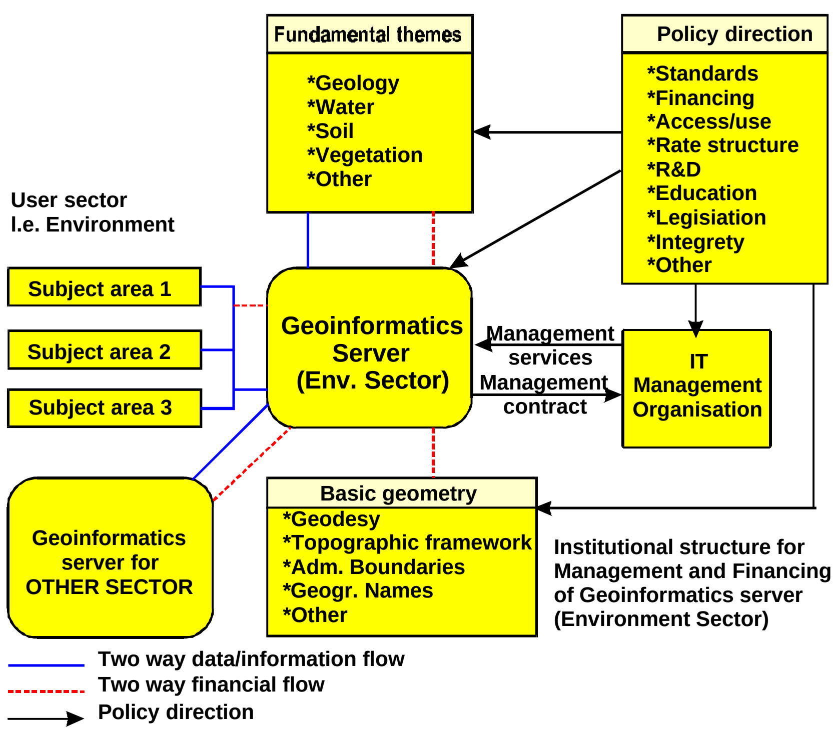

Figure 7. Geo-information Infrastructure (GIT) Model (Groot 1993).

To achieve this, the European Union sponsors the European Umbrella Organization for Geographical Information (EUROGI) to develop a Geo-information policy framework for Europe. Worldwide, the Open GIS Consortium is a similar initiative that started by US-based GI-industries. Expected is, that Internet will play an important role in the systems architecture.

Modern survey techniques, multl-scale/level approaches and for the maintenance of basic data sets the role of high-resolution remote sensing are major issues for the spatial referencing and data models. Sensitive issues are protection of intellectual property and copyright as well as the financing of GIT: government or privately finance and/or operated.

The development of geographical information systems has dramatically increased the demand for reliable geo-referenced data. GIS technology supports land use planning and management decisions at all levels of detail. However, it must be realized that detailed or even semi-detailed soil maps (on which farmers can identify their property) are still extremely scarce, with the notable exception of the USA which has nationwide soil survey coverage and a systematic data updating program at 1:25.000.

It seems unlikely, that all data, including soil data can be produced through convential mapping techniques of professional institutions. There should be more participation of the land users, making use of their indigenous knowledge. In many instances, ranging from the Maya culture in Yucathan to the Tonga culture in the Zambesi valley of Zimbabwe (Cecarelli 1997) have farmers developed their own soil classifications and interpretations.

Gonzalez (1994) found promising prospects for incorporating indigenous soil information in a GIS for land use planning in Costa Rica.

Mafalacusser (1995) compared land evaluation for specific crops (maize, cassava and groundnuts) as done by local farmers with the results of the FAO method, concluding that bringing together areas of knowledge and experience (scientific and indigenous) may provide a more complete and elaborated intervention, capable of improving sustainable agricultural production.

Sombroek and Antoine (1994) list four important technical and organizational constraints to the effective use of GIS technology, especially in smaller developing countries:

- The inadequate analysis of real-life problems as they occur at the household level and as they involve the integration of bio-physical, socio-economic and political considerations;
- The limitation in data availability and data quality at all scales, especially where they require substantial field-level survey;
- The lack of common data exchange formats and protocols;
- The inadequate communication means between computer systems, data suppliers and users, e.g. caused by poor local tele-communication networks.

Zinck (1994) summarized six weaknesses in today's soil studies in relation to their application in Geographical Information Systems:

- the way the information has been presented;
- the reliability of the maps;
- the cost of soil survey;
- the quantitative information needed for simulation models;
- the selection of adequate digital technologies;
- the user-orientations of the collected soil information.

Also the geo-referencing of collected soil data may not always be sufficient, requiring the revisiting of the locations and the assistance of global positioning systems (GPS).

Burrough (1993/1994) puts forward the following proposals for improving the understanding of soil variability and the provision of pertinent geo-information for land use planning:

- Record the **geographic location** of field observations (point-data) in the data-base. Global positioning systems will be of help for location definition;
- **Soil boundaries** need to be described in terms of the degree of change that occurs: sharp, gradual, fuzzy;
- **Digital elevation models** need to be included in the data-base to provide information about the landform related aspects of spatial variation of soil and climate;
- Ground-penetrating radar and other geophysical methods can contribute to sub-surface soil mapping in flat areas. (3-D modelling of sub-surface phenomena as applied in oil-exploration may often offer perspectives for continuous sub-surface soil modelling);
- **Geostatistics and other methods for interpolation**;
- When sufficient point data are available, statistical interpolation techniques of quantitative and qualitative data yield continuous maps as contour or grid cells.

Beek and Van Gils (1990/1992) described the prospects of remote sensing with continuous earth observation at different temporal and spatial resolutions for expanding the direct collection of dynamic land resource attributes from point data to area data.

Conceptual models are normally based on conventional measurements and address traditional problems, often at different spatial and temporal scales. The well-known rain gauge provides a good illustration. The common rain gauge taught us to think, and recently to model, in terms of millimetres of rain per point location. For many purposes, however, "mm of rain" describes a land attribute and not the land quality. The "operational variable" for crop growth is available soil moisture. Remote sensing can give us a better indication of land attributes (in this instance the satellite-measured vegetation index and correlated moisture availability). Moreover, remote sensing deals with areas rather than points. We often see attempts to transform remote sensing measurements (e.g., vegetation index or NDVI) and parameters (e.g., Leaf Area Index, LAI) into traditional parameters (e.g., mm of rain) that are then interpreted in terms of biophysical quantity (e.g., crop production). Instead, we should attempt to build vegetation index-driven models. Such models, fed by contemporary remote sensing technology, would make the use of isohyet maps (for example) redundant. Examples of other dynamic land attributes that can be mapped more directly (and by area!) using remote sensing technology include evapotranspiration (by the heat balance) and drought (by vegetation index anomalities).

Metternich (1996), using radar and multi-spectral image data accompanied by field-level surveys, was able to monitor the likelihood of changes in salinity-alkalinity of soils/areas and to predict salinity-alkalinity hazards in the Cochabamba area of Bolivia.

In qualitative land evaluations we have never hesitated to use the boundaries of natural vegetation types for correlation of soil/climate related land qualities such as available moisture and excess of water. Also present land use, often easier detectable than soils by remote sensing, reflects the boundaries of natural phenomena. In Brazil, the reconnaissance soil survey uses natural vegetation phases of the soil mapping units as an indication of water deficiencies.

9. Conclusions and Perspectives

Conclusions

1. Soil surveys should acknowledge the importance of soil / landscape / land cover interactions as well as land use processes to account for and monitor soil dynamics at different scales of time and space. Such information is essential for the data base in a national geo-information infrastructure.

2. Soil scientists and agronomists should seek the cooperation with socio-economic specialists, land-use planners and land users, in improving the existing land use systems at farm level in terms of a sustainable land management. Implementation of research requires the use of GIS and simulation modules for the development of decision support systems as needed to guide practical action. This may require some reconstruction of the professional models for practical purposes, simplification in relation to intended purpose ("what is the problem") and adaptation to the local means of communication (Cox 1996) and of indigenous knowledge.

Perspectives

1. Information Technology will increasingly facilitate the development of integrated, quantitative studies of land use systems based on the simulation of dynamic land-use interactive processes.

2. There is a strong tendency towards increased use of geo-informatics in the design of interdisciplinary geo-information systems and decision-support systems for realizing sustainable land management at different scales and for specific user groups (Chu Thai Hoanh 1996; Ceccarelli 1997). A digital geo-information infra-structure and policy framework is emerging for this purpose at global, regional, national and local levels. This will make a significant soil research output available that is now inaccessibly stored in archives and libraries.

References

BEEK,K.J. AND H.A.M.J. VAN GILS, 1990/1992, Global and environmental monitoring; the challenge to educators. *ISPRS Comm. VII Symposium*; Victoria (BC), Canada: 17-21. *Photogrammetry and Remote Sensing*, **47**, 51-58.

BEEK,K.J., C.A. DE BIE AND P.M. DRIESSEN, 1996, *Land evaluation (FAO method) for sustainable land use planning and management: Status and perspectives*. Presented at: Latin American Soil Science Congress, Aguas de Lindoia-SP., Brazil / ITC, Enschede, 24 pp.

BENNEMA,J. K.J.BEEK AND M.N.CAMARGO, 1964, *Un sistema de classificatçao de capacidade de uso da terre para levantamento de reconhecimento de solos*, Rio di Janeiro, Ministerio da Agricultura / FAO, Mimeografado.

BOUMA,J., M.C.S.WOPEREIS, W.J.H.M.WÖSTEN AND A.STEIN, 1993, Soil data for crop soil models, pp. 207-220. In: *Systems Approaches for Agricultural Development, Proceedings of an International Symposium*, Kluwer, Dordrecht.

BURROUGH,P.A., 1993/1994, The technologic paradox in soil survey: New methods and techniques of data capture and handling, pp 15-22. In: Zinck,J.A., 1994 (Ed.), *Soil Survey: Perspectives and Strategies for the 21st Century. An international workshop for heads of national soil survey organizations*; Nov.1992, ITC Publication 21, Enschede. / *ITC Journal* **1993,1**, 15-23, Enschede.

CECCARELLI,T., 1997, *Towards a planning support system for communal areas in the Zambezi valley, Zimbabwe*. ITC Publication, Enschede.

CHU THAI HOANH, 1996, *Development of a computerized aid to integrated land use planning (CAILUP) at regional level in irrigated areas*. ITC Publication, Enschede.

COX,P.G., 1996, Some issues in the design of agricultural decision support systems. *Agricultural Systems*, **51,3**.

DE BIE,C.A., K.J.BEEK, P.M.DRIESSEN AND J.A.ZINCK, 1995, *Towards operationalization of soil information for sustainable land management*. Position Paper, Brazil Soil Conference, July 1995. ITC, Enschede, 20 pp.

DE BIE,C.A., J.A.VAN LEEUWEN AND P.A.ZUIDEMA, 1996, *The land use database; A knowledge-based software program for structured storage and retrieval of user-defined land use data sets; User's reference manual (v1.04, DOS)*. ITC Enschede / FAO Rome / WAU Wageningen.

DE WIT,C.T. et.al., 1978, *Simulation of assimilation, respiration and transpiration of crops*. Simulation Monographs, Pudoc, Wageningen, 141 pp.

DUMANSKI,J., 1993, *Sustainable land management for the 21st century. Volume 1: Workshop Summary*. Compiled on behalf of the Organizing Committee. Proceedings of the International Workshop on Sustainable Land Management for the 21st Century. University of Lethbridge, Canada, June 20-26, 50 pp.

FAO, 1976, *A Framework for land evaluation*. Soils Bulletin 3. FAO, Rome. 72 pp.

FAO, 1981, *Report on the Agro-Ecological Zones project; Vol.3: Methodology and results for South and Central America*. World Soil Resources Report 48/3, Rome.

FAO, 1995, *Planning for sustainable use of land resources; Towards a new approach*. FAO Land and Water Bulletin 2. Rome, 60 pp.

FAO/IIASA, 1993, *Agro-ecological assessments for national planning: The example of Kenya*. Soils Bulletin 67, Rome. 154 pp.

FRESCO,L.O., H.G.J.HUIZING, H.VAN KEULEN, H.A.LUNING, AND R.A.SCHIPPER, 1992, *Land evaluation and farming systems analysis for land use planning (LEFSA)*. FAO Working Document. FAO, Rome / ITC, Enschede.

GONZALEZ R.M., 1994, *GIS incorporating indigenous knowledge: The care of local soil classification and utilization in Costa Rica*. MSc thesis, ITC, Enschede.

GROOT,R., 1993, Making information technology work. *ITC Journal* **1993,3**.

HONG CHENG, 1989, The soil resource evaluation system (SRES) in the Pearl River delta, pp. 265-268. In: J.Bouma and A.K.Brecht (Eds.), *Land Qualities in Space and Time*. Pudoc, Wageningen.

HUIZING,H.G.J. AND M.C.BRONSVELD, 1994, Interactive multiple-goal analysis for land use planning. *ITC Journal* **1994,4**, 366-373, Enschede.

JONES,R.J.A. AND A.J.THOMASSON, 1987, Land suitability classification for temperate crops, pp. 29-35. In: Beek, Burrough, and Mc.Cormack (Eds.), (1987). *Quantified Land Evaluation Procedures*. Proceedings of the Workshop on Quantified Land Evaluation Procedures, held in Washington DC, 27 April - 2 May 1986. ITC Publication 6, Enschede.

KLINGEBIEL,A.A. AND P.H.MONTGOMERY, 1961, *Land capability classification*. USDA Agricultural Handbook No.210, Washington DC.

KRUSEMAN,G., H.HENGSDIJK AND R.RUBEN, 1993, *Disentangling the concept of sustainability; conceptual definitions, analytical framework and operational techniques in sustainable land use*. DLV Report No.2. CABO-DLO. Wageningen, 60 pp.

MAFALACUSSER,J.M., 1995, *The use of indigenous knowledge for land use planning in a part of Xai-Xai district, Gaza province, Mozambique*. MSc thesis, ITC, Enschede, 165 pp.

MCRAE,S.G. AND C.P.BURNHAM, 1981, *Land evaluation*. Clarendon Press, Oxford, 239 pp.

MELITZ, P.J., 1986, The sufficiency concept in land evaluations, *Soil Survey and Land Evaluation* **6,1**, 9-19.

METTERNICH, 1996, *Detecting and monitoring land degradation features and processes in the Cochabamba valley, Bolivia - A synergistic approach*. ITC Publication, Enschede.

OLEMBO,R.J., 1994, Can land use planning contribute to sustainability? pp 369-376 In: Fresco,L.O., L.Stroosnijder, J.Bouma and H.van Keulen (Eds.). *The Future of the Land - Mobilizing and Integrating Knowledge for Land Use Options*. John Wily & Sons, Chichester.

PIERI C., J.DUMANSKI, A.HAMBLIN AND A.YOUNG, 1995, *Land quality indicators*. World Bank Discussion Papers no.315. The World Bank, Washington, D.C. / FAO, Rome / UNDP, New York / UNEP, Nairobi, 63 pp.

RAMALHO FILHO,A. AND K.J.BEEK, 1995, *Sistema de avaliaçâo da aptidâo das terras*. Rio di Janeiro, MAARA/EMBRAPA/CNPS 3ª revisâo.

ROBERT,P.C., 1989, Land evaluation at farm scale using soil survey information systems, pp. 299-311. In: J.Bouma and A.K.Brecht (Eds.), *Land Qualities in Space and Time*. Pudoc, Wageningen.

SCHIPPER, R.A., D.M. JANSEN AND J.J.STOORVOGEL, 1995, Sub-regional linear programming models in land use analysis: a case study of the Nehuev settlement, Costa Rica. *Netherlands Journal of Agricultural Science*, **43,1**, 83-109.

SOMBROEK, W.G. AND J.ANTOINE, 1994, The use of geographic information systems in land resource appraisal. *Outlook on Agriculture*, London.

STOORVOGEL,J.J., 1995, Linking GIS and models: structure and operationalization for a Costa Rican case study. *Netherlands Journal of Agricultural Science*, **43,1**, 19-29.

UNCED, 1992, *Agenda 21. 1. Adoption of agreements on environment and development. 1. means of implementation*. UNCED, Rio de Janeiro.

WINSEMIUS,P., 1995, *Sustainable development - sustaining the pace, sustaining the planet*. Presentation during the Clingendael series of The Netherlands-Canada / 1995 Distinguished Lectures, The Hague.

WOOD,S.R. AND F.J.DENT, 1983, *LECS: A land evaluation computer system. Manual 5: Methodology*. Ministry of Agriculture, Bogor, Indonesia.

ZINCK,J.A., 1992, (Ed.). *Soil survey: Perspectives and strategies for the 21st century*. An international workshop for heads of national soil survey organizations, Enschede. ITC Publication 21, 132 pp.