

**THE ANALYSIS OF LAND USE DETERMINANTS  
IN SUPPORT OF SUSTAINABLE DEVELOPMENT**

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May 1988  
CP-88-1

Present address: Environment Canada, Ottawa, Ontario K1A 0H3, Canada.

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## FOREWORD

One of the objectives of IIASA's Study *The Future Environments for Europe: Some Implications of Alternative Development Paths* is to characterize the broad-scale and long-term environmental transformations that could be associated with plausible scenarios of Europe's socio-economic development over the next century. Special attention is being given to a few low-probability, high-impact transformations. The future development of land use in Europe is one of the key issues.

The present Collaborative Paper contributes to the discussion of the major land use determinants that play a central role in sustainable development. The planning and management of land use change require knowledge both on the supply of land as well as on the demands to be placed on the land resource.

The author is from Environment Canada, and he prepared this paper as an input to IIASA's Workshop on *Land Use Changes in Europe: Processes of Change, Environmental Transformations and Future Patterns*, to be held in Warsaw, September 5-9, 1988.

R. E. Munn  
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# **THE ANALYSIS OF LAND USE DETERMINANTS IN SUPPORT OF SUSTAINABLE DEVELOPMENT**

by  
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## **1. Introduction**

The past decade has brought a growing understanding that the fate of the environmental resource base is critical to the future welfare of the inhabitants of the planet. There is mounting evidence that human activity is altering global climate; the continuing use of components of the environment is causing reductions in land capability and waste and other by-products of human actions are affecting the carrying capacity of other lands. The planning and management of land use change today for sustainable development tomorrow requires knowledge of two basics:

- ° the supply of land with different characteristics.
- ° the demands to be placed on the land resource.

Analysis of the current and future ability of the land base to serve the goals of society is dependent upon enhanced knowledge of the determinants of land use, particularly as these constitute opportunities and constraints to future land use options. This paper examines land supply and demand in terms of data requirements, useful analytical approaches, problem identification as well as solution development and implementation. These steps are central to the ability of planners to identify those factors (variables) most critical in the analysis of the ability of the land resource to serve the needs of society on a sustainable basis.

The World Commission on Environment and Development (Brundtland, 1985) has supported sustainable development as a central goal of international environmental and economic planning. This position has been echoed in the proceedings of the 1986 Ottawa Conference on Conservation and Development (Jacobs and Munro, 1987). With reference to land (here used

very broadly, reflecting the fact that land is a resource base and the location for most human activity), sustainable land use can be defined as the best possible long-term product of the interaction of supply (generally defined in biophysical terms) and demand (described in socio-economic terms). Given known biophysical resources, the objective is to take action in advance, ensuring that the land base will continue to serve the demands we will place on it, and maintaining sufficient margins of safety.

This paper begins by examining from a theoretical perspective how we need to analyze land if we are to plan to achieve sustainable development. It then proceeds to identify which are the key biophysical and socio-economic variables to support this approach. The considerations of spatial framework are then addressed and a supply/constraint modelling procedure is proposed. The paper ends with an examination of the use of such an approach to test different scenarios within a land supply/demand framework.

In general, the carrying capacity of the land base can be defined in terms of specific biophysical variables. These biophysical variables can be used within a supply/constraint modelling framework to analyze changes in the ability of the environment to support particular functions (provide goods and services). In addition to the biophysical variables which set limits to resource use options or define opportunities, there are many other social and economic variables, related both to past use patterns and to new needs and desires of users, which are important determinants of land-use patterns both current and future. The biophysical variables and the socio-economic factors link to provide opportunities or constraints affecting the need, or ability, to respond in the face of changing circumstances. From a practical perspective, we must identify which variables and which relationships will be most critical to the ability to mold land use to future foreseen needs. These factors must also be addressed as they apply to rational assessment of possible significant disruptions (e.g., climatic changes, energy supply alterations, geo-political changes) which might have major impacts on the supply of, or the demand for, environmental resources with particular characteristics.

Fundamental to the problem of achieving long-term sustainable use of environmental resources is the fact that many of the most important future influences may occur as surprise events (Holling, 1986). Even where broad trends can be anticipated, the precise magnitude and the differential impact on different parts of the world can seldom be accurately predicted (Clark and Munn, 1986; Munn, 1987). Yet a fundamental precept associated with sustainable development is that problems should be foreseen and that actions should be taken to minimize or avoid problems before they occur. Foresight, however, is clearly impossible for totally unexpected events. While it is impossible to anticipate all eventualities, actions can be taken to facilitate dealing with them when they occur or to eliminate, in advance, particular sensitivities of the system to a range of possible disruptions -- to keep options open. In particular, analytical systems and data sets can be developed which support preventive actions or quick responses. Such anticipatory systems require that the relationships (linkages) between known attributes of the land base (supply) and likely environmental, or ultimate human responses (demands) are clearly understood. In the case of land use, as will be addressed later, this may require a particular type of data and/or analytical procedure.

In response to a request from the International Institute for Applied Systems Analysis, this paper has been prepared as a contribution to the project to examine Future Environments of Europe: The Implications of Future Development Paths. It is intended to stimulate discussion of how to deal with future land-use patterns and problems at a continental scale. The paper is based on the work of Lands, Environment Canada and on work ongoing in Canadian, American and Australasian institutions. These observations are put forward in the hope that they may contribute to the development of a program in Europe ensuring that the land resource base is planned and managed in support of sustainable development.

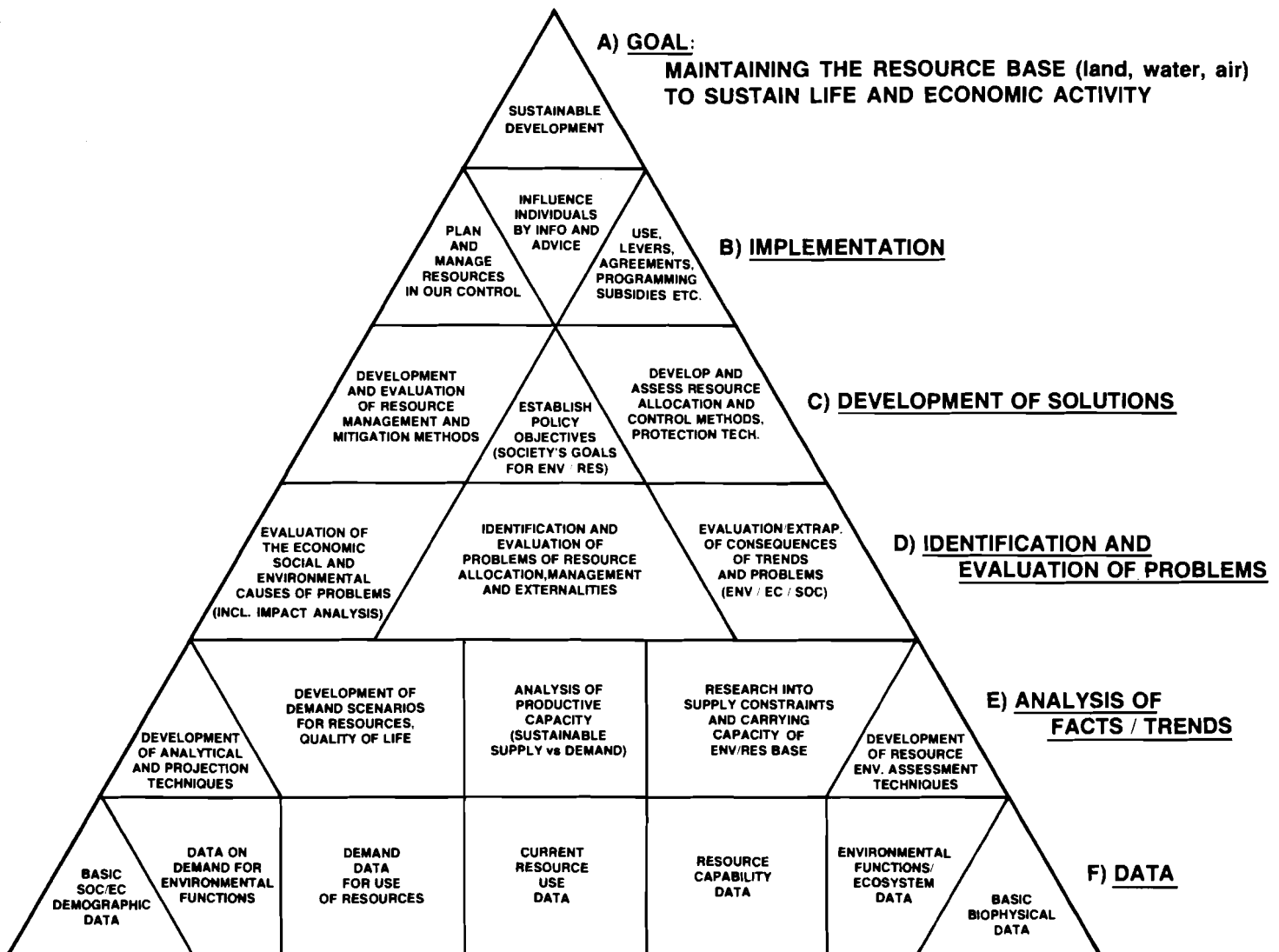
## 2. Analysis of Land in Support of Sustainable Development

The development of the ability to analyze land use must be seen within a far broader framework than just the collection and analysis of data. The identification of key determinants and the collection of supporting data are building blocks in a holistic approach to address the role of terrestrial resources in the achievement of the broad goal of sustainable development. In their 1984 paper, Manning and McCuaig proposed a pyramidal structure as a conceptual framework describing an ideal program to support "wise land use". Subsequent work by the same authors has further developed this framework into a strategy for research in support of the goal of sustainable development. The goal of "sustainable development" is very sweeping. Any more precise definition will depend greatly on Europeans and their governments as they set priorities in terms of lifestyle, economic development, etc. In fact, a whole range of demand modelling exercises could be undertaken wherein scenarios are developed and tested as alternative sustainable or non-sustainable futures.

In Figure 1, a pyramid is presented with the overall goal of "sustainable development"; this is defined as the maintenance of the environmental resource base to sustain those functions which maintain life and socio-economic activity. In terms of land, this objective could be defined as the maintenance of an adequate quantity of land with required qualities to support, indefinitely, the full range of societal demands which depend on the terrestrial resource base. These functions include not only the productive functions of the environment but also the support of special aesthetic values. The logic of the pyramid is that it is designed from the top down to support a particular societal goal -- in this case, sustainable development (level A). Each level of the pyramid is built upon lower ones to support the goal at the top. Level B of the pyramid, **implementation** involves those activities necessary to modify the use of the land resource base in order to achieve the goal. This involves such steps as

FIGURE 1

**SUSTAINABLE DEVELOPMENT:**  
**A STRATEGY**



the planning and management of resources within our direct control, the use of other government powers to mobilize economic instruments in moving towards sustainability, and the exercise of influence upon the actions of others. Implementation is built on the creation of practical **solutions** in the area of planning and management of resources (level C). Solutions are developed in response to **problems** which are known and/or foreseen (level D). Here, means to scan for sensitivity to unforeseen but important disruptions can also be addressed. The identification of specific current or foreseen problems relative to measures of sustainability will require the **analysis** of trends regarding land quality, land availability and land use (level E). This involves the development and application of particular analytical procedures. These analytical procedures, in turn have certain requirements for **data** (level F). Thus by following the logic downward from the specific goal, the nature of data and analysis required to support the objective becomes more readily definable.

While the pyramid is **defined from the top down**, it is in reality **built from the base up** -- commencing with data collection, then analyses, and so on. The raison d'être for the pyramid itself is the centre block -- the **existence of problems**. While we begin with awareness of problems (discontinuities) based on monitoring, scanning and analysis, the construction of this type of strategy involves focussed data collection and analysis which will address the specific problems identified or anticipated in achieving the overall goal of sustainability. To support the above strategy, much of the work would have to occur initially at the level of problem identification; this will imply the creation of scenarios, probable or possible, which may have significant impacts on either the resource supply or on demands to be made on it.

It should be noted that a wide range of procedures can be used to create future scenarios. These range from single or multi-sector extrapolations, and the modelling of changing relationships, to Delphi (consensus building) techniques. Because the range of possible future demands is so broad, it will be essential to build an evaluative capability which can accommodate a wide range of potential demands, and deal with alterations or disruptions to the land supply. The identification of problems (that is, unacceptable outcomes) will naturally depend on the ability of governments and society to clarify their own definitions of sustainability -- their own goals for production levels, lifestyle, population numbers, environmental quality, etc. The decision of what is desirable or acceptable must precede any definition of what is therefore unacceptable.

It is suggested that there are three distinct types of problems which can arise in the face of changes in the land base supply (quantity and quality) or in demands on that base. These are:

1. Problems of **allocation** of land between users and user sectors (e.g., agriculture or wetlands, urbanization of prime resource lands).
2. Problems of **management** of land once it has been allocated among sectors (e.g., agricultural land degradation, toxification, contamination).
3. Problems of **externalities** or intersectoral impact involving disruptions caused to one user by others (e.g., downwind or downstream pollution).

All three of these types of problems can be expressed in terms of a supply/demand equation for land. In the case of allocation problems, the type of information necessary for their analyses is generally quantitative -- referring to the amount of land with definable physical characteristics

in any particular location. With reference to management concerns, data requirements are more likely to focus on qualitative measures -- of the changes in those characteristics which can influence the productivity response for the functions for which the land is being managed. To deal with issues of conflict, both quantitative and qualitative data on the attributes of the physical base may be required as well as socio-economic information. The juxtaposition of conflicting activities can create problems which influence land capability for a range of uses.

The nature of information (level F of the pyramid) required to address all three of these general types of problems can be broadly defined to have the following characteristics:

1. Variables identifying the quantity of land of different types and different capabilities.
2. Variables identifying the quality of land with respect to certain biological and physical factors.
3. Variables identifying the location of the land.
4. Variables identifying the current pattern of use of the land.

It is suggested that a spatial framework would be the most useful format for holding land data. If the data are identified spatially, it is possible to estimate the supply of land with a defined set of capabilities in any location. Information on demands for land and for the products of the land can then be related to particular sites or particular data units. If the information can be analyzed spatially, the impact of any alterations in the attributes of the land base in any data unit can be performed. These can then be related to the provision of environmental functions within each data unit.



While the analysis of the biophysical resource base establishes, to a great extent, the long-term carrying capacity of the land base for different environmental functions, information on the use of the land resource is also pertinent. This "socio-economic" information can be used to qualify further the availability of land with different characteristics to satisfy requirements (particularly in the short and medium term). This information can also provide a baseline against which proposed alterations can be measured. While current land use patterns are a reflection of present and past demands for the products and services of the land, these patterns may relate little to future demands. Time series analysis can permit the extrapolation of trends indicating possible future scenarios but this is only one way of estimating future land use patterns. It may be more logical to treat the current biophysical and socio-economic determinants of land use as potential limiting or facilitating factors to the ability of the environmental resource to serve future demands (Manning, 1985, 1986b). If the information on land use determinants is handled in this fashion, and if data on the key determinants can be held in a spatially compatible form, it becomes possible to test future scenarios (however developed) for sustainability, relative to the characteristics of the land base in each data unit.

### 3. Key Biophysical Variables

If we accept a supply/demand framework within which to analyze European environmental futures, the selection of biophysical variables can be focussed on those which either (1) directly **affect the capability of the land base** to serve environmental functions valued by society, or (2) **serve as indicators** of this relationship. The work of deGroot (1986, 1987), Adamus and Stockwell (1983) and others has advanced the identification of the specific environmental functions served by the land base. Part of the problem is the selection from among these functions,

those which are most central to the objectives of society as they relate to sustainable use of land. In his 1986 paper, deGroot has identified a very wide range of regulatory, carrier, production and information functions of the natural environment. He has noted that the functions provided by the environmental base serve particular human values, for example, production of food, or of minerals, or provision of information or space, or buffering of toxics. Some of these environmental functions are very difficult to evaluate because the linkages between the provision of functions and the market place are very indirect or complex (e.g., aesthetics). In other cases, links such as those between some of the production functions and marketable commodities are very direct and make for easier measurement (e.g., forest products). The selection of which biophysical variables to use will therefore be dependent both on (1) the particular environmental functions which are critical to supporting production and environmental quality in Europe (and therefore based upon which functions are seen as most important by Europeans and their governments) and (2) data availability regarding the environment's capability to support these functions.

Ideally, comprehensive data sets covering all of the chemical, climatic and physical parameters which correlate well with productivity for each of the functions would be developed -- but these are impossibly complex and expensive. Therefore it may be wise to select a specific measurable variable which relates best to **productivity for key natural resource products** and others which relate to **key measures of environmental quality** affecting human health or overall usability of the environment.

Listed in Figure 2 are representative environmental variables which would prove useful in assessing both gradual changes in supply/demand relationships for the land resource and the evaluating impact of surprise disturbances. These variables have the following characteristics:

FIGURE 2

**REPRESENTATIVE VARIABLES FOR  
MEASUREMENT OF CHANGE  
IN LAND USE DETERMINANTS (Biophysical)**

| <b><u>ABILITY TO<br/>SUPPLY</u></b><br>(Environmental Functions) | <b><u>VARIABLE</u></b><br>(Measures of Productivity<br>Potential)  |
|--|--|
| PRODUCTION OF FOOD AND FIBRE                                     | <ul style="list-style-type: none"> <li>° Soil texture, susceptibility to erosion</li> <li>° Topsoil depth</li> <li>° Soil chemistry (e.g. pH, nitrogen)</li> <li>° Soil moisture</li> <li>° Growing season, length, degree days</li> <li>° Precipitation (in growing season)</li> <li>° Slope</li> </ul> |
| PRODUCTION OF WILDLIFE   | <ul style="list-style-type: none"> <li>° Vegetative cover</li> <li>° Wetland incidence, quality</li> <li>° Water table</li> </ul>  |
| HABITAT/OPEN SPACE<br>RECREATION                                 | <ul style="list-style-type: none"> <li>° Cover (measures of incidence, variety)</li> <li>° Current land use designation</li> <li>° Topography, shoreline quality</li> <li>° Wildlife incidence</li> </ul>  |
| REGULATION OF TOXICS<br>(Health, use ability)                    | <ul style="list-style-type: none"> <li>° Selected measurement of specific hazardous substances</li> </ul>  |
| MAINTENANCE OF GENETIC DIVERSITY                                 | <ul style="list-style-type: none"> <li>° Biota counts</li> <li>° Cover (incidence, percentage)</li> </ul>  |

NOTES

- <sup>1</sup> Demand scenarios are independently developed by a range of means including projection, other models, Delphi, policy goals, etc.
- <sup>2</sup> Selection of specific variables will depend on priorities established among valued environmental functions.

1. They have known relationships to productivity for key environmental products or functions (specific crop productivity responses, specific measures of forest productivity, or specific measures of the utility of the environment for key products or services valued by society).
2. They can be measured on a consistent basis both spatially and over time.
3. Scenarios can be established wherein these variables (either in quantity or quality) are altered by physical changes, by human activity or by surprise events.

#### **4. A Canadian Approach**

The Canadian experience in dealing with national-level data bases provides certain lessons regarding multi-sectoral data use at a continental scale. While baseline information for such factors as soil types (nomenclature classification), geological and topographic maps, and climatic information has been in existence for several decades, existing bases have proven very difficult to use within a framework assessing the ability of the resource base to serve changing demands. During the 1960s, efforts were spent to synthesize a great deal of existing biophysical information into spatial units that could be analyzed to help target economic development investments to areas where the return would likely be greatest. Therefore, climatic information (growing degree days, rainfall, frost free periods, snow cover) and physical data (such variables as slope, bedrock, soil type, or salinity) were integrated into a national land inventory (Canada Land Inventory) by sector of resource capability (Munn, 1986; Environment Canada, 1970, 1976). For each of the sectors of agriculture, forestry, recreation and wildlife, a seven-level classification was developed relative to generalized production capability. Thus Class 1 land had no limitations

for productivity for the particular sector, Class 4 had moderate limitations and Class 7 had no capability whatsoever. This was the first attempt to draw together a broad national data base to influence the planning process. Some 25 years later, unfortunately, certain attributes of that data base have made it inappropriate for the identification of changes in the physical land base (see Manning, 1986a). Because multivariate data were synthesized to produce planning-level information, disaggregation to permit measurement of change in any one of the variables which caused it to be classed high or low is very difficult. While certain relationships are known between productivity and land capability (e.g., rye grass production on Class 1 land has proven to be approximately double that of similarly managed rye grass on Class 4 land), more sophisticated analysis using these data has not been possible. While intersectoral trade-offs between land of high capability for one use versus another can be portrayed, the productivity implications of land allocation decisions are very hard to analyze using this type of ordinal data. Analysis of impacts of land degradation or climatic change fall outside the range of application of information held in aggregated classifications.

Because of problems in analytical application of current data, a new initiative was mounted in the late 1970s to develop ecologically-based spatial units where data would be held on key biophysical variables. Measures of soil chemistry, key climatic variables (such as length of growing season, precipitation, and degree days) and key physical parameters (such as depth to bedrock, soil texture, organic content, etc.) were collected for each unit. There have been certain problems in obtaining homogeneity within the units and in making certain that the manner of holding of variables optimizes their unity. Nevertheless, these "soil landscape units" provide a baseline for change measurement for individual biophysical variables (Coote and Shields, forthcoming). Because the regionalization has been done on a multivariate basis, other variables can, more or less, be held constant. Work is now under way to develop empirical data on productivity-response for important crops in response to changes in biophysical variables within each of the spatial units. One of the lessons of this exercise is that the variables which are most important may

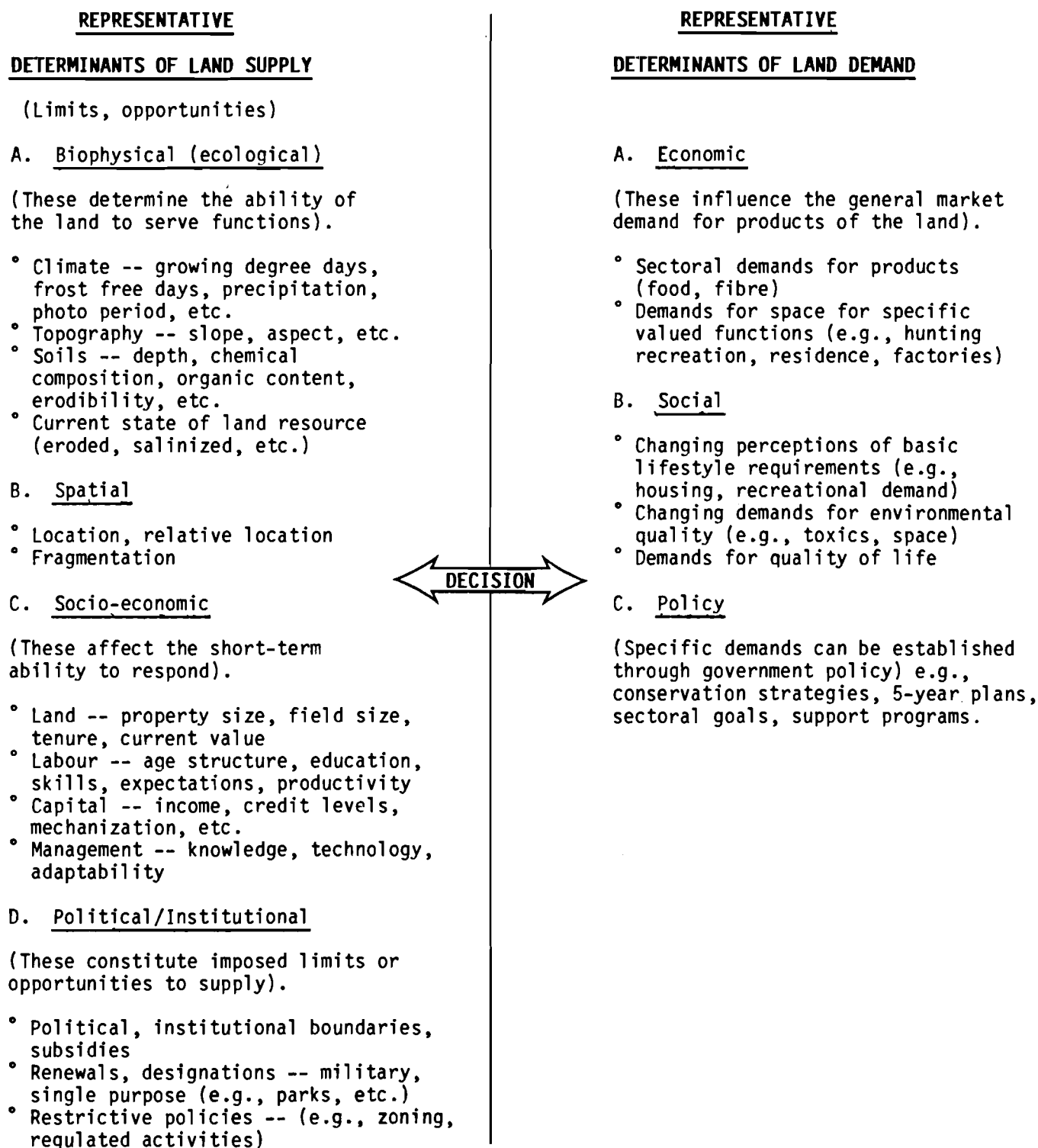
vary in importance from zone to zone or from crop to crop, but across most agricultural products (food crops, grains, fodder crops) the same variables are pertinent in determining productivity response. Because of the nature of the variables used (several climatic variables, soil depth, soil fertility, acidity, levels of salinization, measures of wetness), it seems reasonable that these same variables could be of considerable use in the modelling of forest crop productivity. Along with a very few other variables, the utility of the land resource for different types of wildlife production, certain recreational pursuits, and several other valued functions of the environment could be modelled. What would be required however, would be the empirical development of productivity-response relationships within each of the general biophysical zones for the most important functions (products). The addition of certain measures of toxicity or certain indicator chemicals at the same scale might also be of considerable assistance in projecting or predicting environmental suitability for other production or life-support functions. The further addition of land use information for the same spatial units would allow estimates of remaining reserve capability, identification of some barriers to change in use, and would allow minimum change responses to be estimated for the achievement of particular production goals.

I have indicated above, based on a Canadian experience, some of the key considerations in the choice of variables which are most important to the development of an operational means of understanding what happens to the ability of the environment to serve critical societal functions under changed circumstances. We can simulate or suggest certain changes in individual, biophysical variables based upon possible scenarios of future macro-level changes. It is possible to isolate the potential impact of a broad (for example, climatic) change down to the point where it can be shown to alter the attributes of particular sites or regions. Knowledge of the productivity response of key environmental functions to changes in such factors as length of growing season or precipitation therefore would

permit us to estimate likely alterations in the ability of each data unit to support a particular crop or function. While the choice of which biophysical variables are to be collected will be a result of which environmental functions are deemed to be most important, certain commonalities are clear. At a bare minimum, the base variables would have to include: amount of precipitation, some measures of growing season, and soil quality -- particularly quantitative variables such as depth of soil, pH, other chemical indicators, measures of physical capacity such as slope, wetness, drainage susceptibility to erosion, etc. If broader-derived indicators of capability for important functions such as crop productivity potential can also be obtained at an appropriate scale, these too would be of great utility, particularly if they have been derived from known relationships to these variables. The biophysical variables will assist in defining the opportunities and constraints of the environmental resource base at any point in time. Representative variables are portrayed in Figure 3. The more variables which are held, the greater versatility of the system to handle an unforeseen range of changes which may involve new substances or new phenomena. Set against this is the increased cost and complexity of analysis which additional variables necessarily create. Based upon the variables held in the system, and the known relationships between the range of environmental uses or functions and these variables, it becomes possible to adjust the estimates of carrying capacity of each part of the land resource base under any scenario involving changes in the biophysical base. The outline of an existing modelling procedure which could aid in achieving this objective is in part 8 of this paper.

FIGURE 3

THE DETERMINANTS OF LAND SUPPLY AND DEMAND





## **5. Key Socio-Economic Variables -- A Second Level of Opportunities and Constraints**

Were the land resource base a clean slate, the definition of carrying capacity in terms of biophysical variables would define the overall opportunities and constraints to change. Current and historic human occupancy, however, provide yet another layer of opportunities and constraints to land use. These socio-economic factors are important to society's or government's ability to adjust land allocation and management, given new goals or opportunities or a changed biophysical base. The situation with respect to the socio-economic variables which will influence societal response to future biophysical or political scenarios is at least as complex as the multitude of biophysical variables. It is useful to divide these socio-economic factors into two groups -- one pertaining to the land itself and another pertaining to current users and owners of the land. No matter what the institutional system, the ultimate delivery of human response to changing environmental, economic or social situations is through the individual, influenced to varying degrees by those institutions.

### **a) Current Land Use Patterns as Constraints and Opportunities**

The following discussion of the characteristics of present use and users which limit future capability is based primarily upon work from New Zealand (Manning, 1972) and North America (Beattie et al., 1981; McCuaig and Manning, 1982). This research indicates the range of variables with respect to individuals and property that are important in influencing individual abilities to respond to stimuli to alter land use. Work on European experience is also generally supportive of these factors (e.g., Franklin, 1969; Galeski and Wilkening, 1987).

As with the biophysical variables, it will be important to limit the selection of socio-economic factors contained in any monitoring program or modelling exercise. If we return to the concept of environmental functions, it becomes easier to see that some of the functions can be affected by changes in biophysical factors. But the reactions to them occur through individuals. Most food and fibre production functions occur only through specific actions by property owners or users. Realization of other functions (e.g., habitat maintenance or genetic diversity), is less directly constrained or directed by socio-economic factors. With respect to the land itself, several variables related to land holdings are important. The most obvious is that of property size which is a function of fragmentation and/or tenure. The specific variables discovered in Canadian and New Zealand studies to be important to the decision process in response to external environmental or economic stimuli were the following:

1. Property size.
2. Level of fragmentation of property holdings.
3. Shape of property.
4. Distance of property from home of owner/manager.
5. Tenure -- owned or leased, or other encumbrances.
6. Length of tenure (particularly with respect to leasehold or usufruct arrangements).
7. Present level of infrastructure.
8. Level of capitalization/debt.
9. Land value.

The first four are characteristics of the properties themselves. The latter are characteristics of the ownership arrangements. The variables relating to the size, shape or fragmentation of property relate very well to the ability of producers to adapt to changing economic or environmental situations. Larger property units are more versatile and open to fairly rapid change whereas more fragmented patterns can provide severe logistical problems. It is clear that in order to temper any biophysically-based

supply/demand modelling procedures, variables on the availability of land must also include size of property and fragmentation. Tenure is a further constraint or facilitating mechanism to action and data should probably also be held on this variable. For example, short-term leasing arrangements are not conducive to long-term investments in sustainable soil management or in products whose value will not be realized for decades. The nature of these property variables, however, is that they usually are not regionally homogeneous and decisions will have to be taken regarding the way in which the information is held. Mean size of property, for example, may be a very meaningful variable in regions where property sizes are relatively homogeneous. In areas of extreme variations it can be very misleading, particularly in terms of the ability of the land to adapt to changing economic or biophysical circumstances.

One significant socio-economic variable of considerable importance in short to medium-term response to the need to alter land use is that of dedicated land areas. Many governments have made major subtractions from the land base of their nations to serve specific functions such as security (military bases), public recreation (parks), water supply (reservoirs), flood protection (flood plans), or wildlife reserves. These areas are, for most purposes, no longer available to serve most other functions (habitat, buffering and wildlife production are notable exceptions) and should probably be considered outside the land base for most production-related scenarios. Even so, under major distortions, or extreme stress, these barriers to change can also disappear.

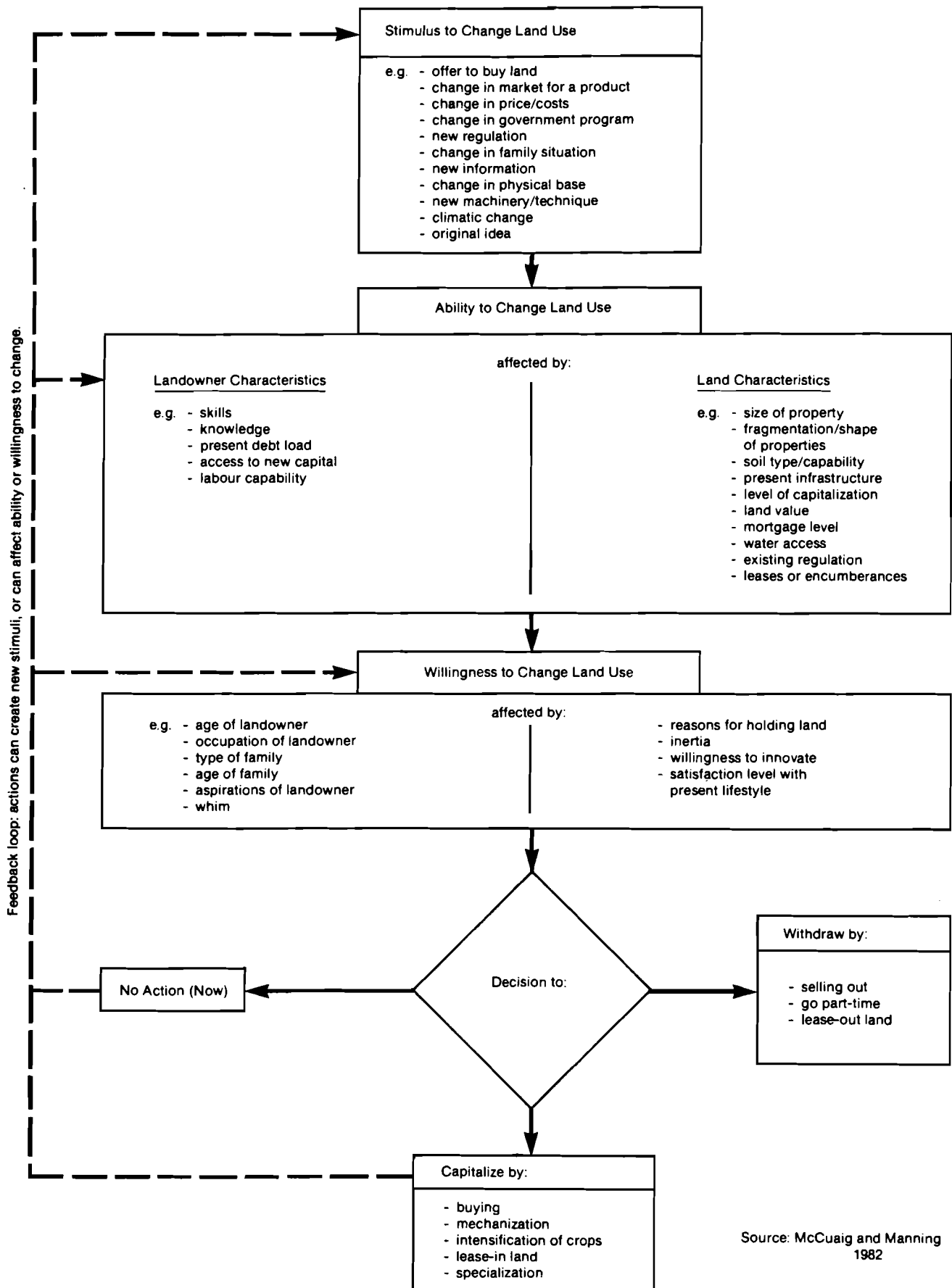
## **b) Characteristics of the Individual Owner or User**

Empirical research on the determinants of land use has identified the importance of landholder characteristics because they affect the ability of land-using systems to respond to needs to change (Manning, 1972; Mandale, 1984). What is becoming increasingly clear is that individual owners or managers of land resources vary greatly in their ability or willingness to undertake changes. Relative to continental-scale requirements to make fundamental changes to the way in which land is used, this factor may be very temporal. At least in the short and medium term, however, it is very important, because it influences the nature and pace of response. It is clear that many individual factors relating to the structure of ownership or management of the land resource and relating to the individual decision-maker are important. It is useful to characterize the factors into those influencing willingness to change and those influencing ability to accommodate the need for change.

In the North American situation (McCuaig and Manning, 1982), a model was put forward identifying several factors as critical to the willingness or ability of individuals to change land use or management, given the requirement to do so due to economic or policy stimuli. This model is shown as Figure 4. It is suggested that the same individual characteristics shown in this model will often be operative as filters to individual response to major biophysical changes, particularly those which occur over short periods. Specific factors found to be important include age, level of education, level of capitalization and aspirations of the landholder. While it would be very difficult to model this type of information at a continental scale, particularly as it is very individual, broad generalizations regarding the nature of the population in given areas could be of use as a filter in the assessment of scenarios developed through the more biophysically-based supply/demand modelling. This socio-economic filter would be applied to the supply/demand model as a further step in evaluating the practicality of policy responses.

# FIGURE 4

The Decision Process for Rural Land Use Change: A Simple Model



Source: McCuaig and Manning  
1982

Some specific areas where information would be of particular use in evaluating the practicality of specific policies in given situations are the following:

1. Levels of Education. It would be useful to establish baseline information regarding the general level of technical education of land managers/owners relative to crop production or other types of land management. More educated managers are more likely to be willing and able to adopt innovative technology or different crops/uses more quickly than those with less training in land management. Data on this would allow general evaluation or assessment of any result heavily dependent upon rapid alterations by individual property or users.
2. Age. In general, age structure or as an alternative, family structure of the landholders or users is pertinent in terms of the ability and willingness to respond to the need for changes. In general, the nature of response relates very well to the level of continuity of landholding or management of the individual or corporate collective unit. In the Canadian and Australasian context, empirical research has demonstrated a very clear relationship between the propensity to undertake investments which bring benefits in the longer term and the expectations of gain deriving from those benefits (Manning, 1972; McCuaig and Manning, 1981). In general, younger owners, corporations, and those with heirs who will continue to use the property were found to be most willing to make changes. With respect to the impact of personal factors on ability to respond, it is clear that broad scale anomalies or differences will act as filters to the overall response to the need for broad scale change in the use of the land. For example, in an area where virtually all of the rural population is aged and where there are very few younger individuals, one would expect less direct response than in areas where the population is younger or the land is held in corporate enterprises. At a continental scale, it may be difficult to generalize these variables, but major anomalies could be identified.

In Figure 4, other landholder factors important as influences on the willingness and ability of individuals to respond to the need to make land use changes are identified. Among those important at an individual or corporate scale were income levels, present debt load or access to capital, occupation of owner, and the aspirations or reasons for holding land. Whether any of these factors can be generalized to broad regional or continental scale differences pertinent to European futures would be worthy of further exploration.

In addition to the demographic and structural constraints which influence changes in land use, there are a number of other factors which are pertinent. If we are to view the process by which land use is changed from a holistic perspective, a number of other social, infrastructural and policy variables are important both in terms of their influence on the development of current patterns and their utility as vehicles for/or impediments to change. From one perspective, land use patterns can be seen as the product of the interplay of the biophysical variables and the whole of history. This brings us to the present where we are now looking for variables which may be manipulated either to reduce risk in the future or to assist in directing land use patterns to serve current and foreseen societal goals. Therefore, the overall social, political and infrastructural situation becomes very important. The analysis of determinants of land use change would be incomplete without identifying the key programs which both directly and indirectly influence decisions on land use. In the Canadian instance, these were categorized into 7 groups (Bond et al., 1982):

1. Ownership and management of land.
2. Construction activities.
3. Regulation.
4. Financial policies.
5. Sectoral support programs.
6. Regional development programs.
7. Research, information and planning.

A Canadian study (Bond et al., 1986) identified over 100 key federal government programs, comprising 25 percent of discretionary federal government expenditures, which significantly influence the use and management of the nation's land resources. These programs include both those which act as important influences on current land use practices and decisions as well as those which could in future be manipulated in order to achieve broader goals relative to the land resource base (e.g., Government of Canada and Government of the U.S.A., 1985). These federal programs were complemented by an even greater number of provincial and local policies and programs which had direct and indirect impact upon the use of land resources (Audet and LeHénaff, 1984; Ward, 1985).

In any given place, the interplay of these policies and programs would be quite different, sometimes reinforcing trends towards sustainable development, sometimes blocking them or working at cross purposes (Manning, 1986a; Munton, 1987). In each country or area there is a fundamental framework of public policies and programs which, at least in the short term, must be taken as "givens" within which changes will occur. A prime example is agricultural subsidization which has been a tenet of rural development for much of Western Europe and North America for many years. The complex and comprehensive system of support to all aspects of agriculture can be taken virtually as a given within which the decision process for land allocation and management has occurred. Any attempt to alter this system significantly will itself be disruptive because it will remove many of the assumptions on which past investments in land management have been made, both by individual landowners and by governments.



At a continental scale, if broad scale planning for sustainable development is to occur, it would be important to have information on the principal differences in policy from place to place. Most notable are those policies that are important in terms of infrastructure, direct and indirect price supports which protect particular lands for such functions as agricultural production, aggregate extraction or wetland habitat, or which favour particular sectors or regions. In any assessment of the impacts of change, these become important both in terms of influencing the changing demands on the resource base from one region to another and as levers by which land use change can be promoted or inhibited. Under most scenarios, many of these policy and program structures will have to be assumed to remain constant, with only incremental modifications at least in the short and medium term.

## **6. Demands for Land**

The determinants of demand for land are diverse, reflecting all of the different functions the land must serve (see Figure 3). The estimation of future requirements for land can be done in a variety of ways. Sectoral demand projections have commonly been used to establish trends, ranging from linear extrapolation of spatial trends through to more complex modelling of changing productivity. In the United States, work at Ft. Collins, Colorado has developed a linked set of sectoral models, beginning with forest sector demands, and carrying these through links to other sectors to examine sectoral impacts (Hoekstra and Joyce, 1988). Such approaches are workable in exposing implications of demand trends but suffer from the inherent problem of linked models -- output estimates from one step become input into the next, usually yielding very great (compounded) variability in the end product. Any predictive methodology is beset with uncertainty. Few multisectoral approaches improve at all on Delphi methods wherein consensus futures are estimated by appropriate experts. For this reason, this paper counsels an approach which does not depend on reliable prediction of future land demands.

This is even more essential given the concern for unpredictable surprise events. Instead it is suggested that one draw on existing goals, or develop scenarios which have some probability/possibility of occurrence. Work can occur to aid in deciding which of these scenarios are acceptable to people and their governments, and further effort will define the components of the chosen scenarios in terms relative to the demands they bring to bear on elements of the land resource. The literature on environmental functions, and work currently under way in North America on cumulative impact analysis (e.g., Peterson et al., 1987; Gosselink and Lee, 1987), give some indication as to how this can be accomplished. In research focussing on habitat preservation methodologies conducted under the North American Waterfowl Management Plan, specific links are being made to the various goals of society served by wetland habitat (Bardecki, Bond and Manning, 1988). This work shows the link between specific societal demands or goals and requirements for particular quantities of land with very specific characteristics. The key to analysis of future demands to be placed on the land will therefore be in establishing a range of scenarios, based upon explicit assumptions of lifestyle, levels of economic activity, population levels, etc. The development of conservation strategies, national plans, etc. is also a goal setting procedure which defines demand scenarios. Scenarios which have implications for land supply, leading to a reduced or enhanced resource base, can also be developed. Such scenarios can be based on ongoing predictive work, or on "worst case" probable outcomes.

## **7. Selecting A Spatial Framework**

Throughout this paper it has been suggested that a spatial perspective will be essential to permit productive analysis of the determinants of land use change. This implies a spatial framework for data collection and the use of a spatial framework for any subsequent modelling. A key problem is one of identifying a suitable spatial framework that will permit the integration of information from diverse sources so that trends and surprises can be evaluated against the opportunities and constraints afforded by the land resource base.

The selection of a spatial framework should be closely linked to the needs/requirements of the users. However it is also important to identify assumptions concerning resources, access to geographic information systems (GIS) technology, etc. The use of a powerful integration tool for discrete spatial data sets could reduce the importance of selection of a spatial frame (see for example Chorley, 1987). There are several schools of thought with respect to spatial frameworks. One favours the use of geometric grids where data are synthesized and reported by geometric units, thus giving something of an evenness which supports mathematical analysis. If a 10, 100, etc., sq. km grid is developed, all of the compromises in data are made at the stage of data input, where information obtained through various routes such as census, field trials, political or ecological units is abstracted to the nearest point on the grid through the use of a range of subjective or mathematical procedures. This has the advantages of being neat, and of not representing individual jurisdictions who may be sensitive to the portrayal of their data, particularly if they prove to be in the lowest cohort. Nevertheless, it has severe limitations, particularly for data which is not initially spatial (an attribute of socio-administrative/ecological units as well) where homogeneity must be assumed. This occurs simply because the point may not be representative of the whole and if larger grids are used, it may be quite unrepresentative of the locality. Thus spurious spatial correlations can appear to occur -- relationships that would drastically affect the testing of different scenarios that are dependent upon empirical relationships.

The use of political units (counties, districts, etc.) is another common way of data portrayal and integration. This is often easier to do than other means of portrayal simply because so much data tends to be collected on a jurisdictional basis. The key advantages of the use of political units, particularly fairly small ones in the 50-250 sq. km range,

lie in the fact that they are often relatively physically homogeneous at that scale and reflect the levels of authorities which may be suitable to deal with the planning of the use of land. Further, at a continental scale, smaller units may produce data sets so large as not to be easily analyzed. In Canada and the United States, county level data has frequently been used as a reasonable level to portray regional differentiation across these large nations. Typically, counties in Canada and the United States are in the 1000 to 10 000 sq. km range although there is some extreme variation. Variation in size is one of the drawbacks in the use of this type of spatial generalization although the superimposition of ecumene boundaries in the Canadian case has been of considerable aid in resolving this problem. A further problem with the standardization of political units is their failure to correspond to environmentally homogeneous units in many areas. Particularly in mountainous terrain or across natural boundaries this may be quite problematic. The principal advantage of the political units, particularly for output, is that the responsible authorities are clearly identifiable and when action needs to be taken the policy prescriptions can be phrased in terms that the current political structures find practical (see for example, Manning 1986a, 1987a; Chorley, 1987.)

A third type of unit is the ecological unit -- a unit based on biophysical characteristics. Ecological units have the great advantage of being expressions themselves of the biophysical characteristics of the land. Therefore, the data acquisition and analysis of the significant biophysical variables is often easier, and far fewer spatial compromises need to be made with respect to physical information. The integrated analysis of the variables influencing the quality of the resource base for certain uses is therefore facilitated. Unfortunately, it is very rare that socio-economic information is available on the same basis.

Further, if results are made available solely on the basis of biophysical units, experience has shown that political response may be less easy to obtain, as the units are unfamiliar and do not correspond to areas of jurisdiction (Manning, 1987b). It should be noted, however, that in some countries responsibility for conservation-related activity is sometimes based on biophysical regions (e.g., Conservation Authorities, River Basin Management Agencies). In these cases, this type of reporting unit would be ideal.

A compromise approach which appears valuable is the combining of well-established political units with ecological units to form standardized hybrid units designed to accommodate both socio-economic and environmental (biophysical) data. Preliminary work using data for the Canadian prairies has demonstrated the utility of these "environomic" units to integrate, analyze and display both types of data at a regional/continental scale (Gélinas, 1988). A similar basis was used for the definition of modelling units by the University of Guelph in the development of a supply/demand response model for the federal government and the province of Ontario (Land Evaluation Group, 1985; Land Evaluation Project, 1982). A multi-sectoral application (agriculture, forestry, other) in New Brunswick shows some promise as a means to deal with intersectoral competition for scarce resource lands under different scenarios of demand (Smit and Brklacich, 1985).

The advent and improvement of geographic information systems (GIS) has made the integration of data from different units far easier, although caveats still exist with respect to the way in which spatial data are handled and integrated. Nevertheless, GIS make it possible to operate a system of biophysical units and undertake integration of data from other spatial units permitting an output to be formatted on any geographical base or on hybrid units (Crain and MacDonald, 1984). The main concern is that

the data held in the systems must be truly spatial -- that this information must refer, to the greatest extent possible, to a homogeneous characteristic of all places within each spatial unit. Thus extreme care must be taken when dealing with non-spatial data, with the understanding that assumptions of averaging and homogeneity are inherent in any of the information used in spatial overlay. Nevertheless, the versatility of such systems can permit the generation of output on a wide range of spatial units -- biophysical units for analysis, political units for implementation. In the use of GIS, the compromises need not be made at the input stage -- data are held by the geographical units for which they were collected, therefore permitting the data to be used to their limits of validity relative to other spatial data in quite sophisticated analysis.

The selection of specific variables to be held will be difficult. It would be folly to amass huge banks of data in its rawest form, and would be a duplication of existing sectoral or national data banks. At the same time, aggregation of data into very general indicators or very large compromise units will not serve well. The solution may well be in using an intermediate level of spatial aggregation for data holding -- such as administrative units, drainage basins or sub-basins, or ecological units, while maintaining the base variables in quantitative format. Ideally, one would use well-established reporting units for which most of the required data are already available, and point data sources for other information such as extraction sites, soil quality monitoring points, etc. are obtainable. If GIS are used, then many means of integrating point data with spatial data are available.

## **8. Testing Scenarios Within A Spatial Supply/Demand Framework**

This paper has defined the types of information pertinent to the key variables determining land use which would contribute to a supply/demand modelling exercise for land. It is suggested that a supply/demand model would be the most useful framework within which to test changes either

in the quality and quantity of land supply or in the nature and quantity of demands to be placed on the resource base. In this section, a particular type of model is proposed based on a number of modelling exercises which have been developed as policy support instruments in Canada and other jurisdictions (e.g., Land Evaluation Group, 1983a; Heckland, 1984). The particular framework put forward is most directly derived from the modelling exercise for the governments of Ontario and New Brunswick, through the University of Guelph. This model is a supply/demand model for land with a spatial framework (Smit, 1981). When tested, scenarios result in an output which gives not only the total requirements from the land base but shows where these land-based requirements for products or services can be satisfied across a large number of spatial units. This approach therefore permits the testing of scenarios and the valuation of their implications for each spatial data unit. This type of procedure can be called supply/constraint modelling. The supply/constraint model is dependent on a knowledge, for each of the spatial data units, of approximately a dozen biophysical variables adequate to permit analysis of supply/response for the essential products or functions of concern. In the Ontario application of the model, the spatial data units selected were combinations of political units (counties and townships) approximating major biophysical zones within the province of Ontario. The selection of boundaries was done primarily through climatic data and broad physical differences. The units varied somewhat in size from one representing a single county with relatively unique biophysical features to another much larger zone representing several thousand sq. km of relatively flat, climatically favoured land. The information necessary for the analysis of major changes in the biophysical base or in other political or socio-economic constraints is related to the quantity of land with particular qualities to be found within each of the

data units (Land Evaluation Group, 1985). In the Ontario case, the environmental functions of concern were primarily those supporting production of agricultural products. Information was obtained from test sites within each of the data units showing supply/response for key agricultural crops to changes in precipitation, soil chemistry, etc. This initial step permitted modelling of a number of scenarios over these hybrid biophysical/political units. Some applications included:

**a) Satisfaction of Future Demands for Particular Products**

Several runs were done to evaluate different future demands for agricultural production to be placed on the resource base and of changes in the constraints (e.g., energy costs, climatic changes). For example, the model was run to test the impact of different urban expansion scenarios, each of which would subtract different quantities of land with known characteristics from each of the data units. The questions asked were:

1. Are the present production quantities for key products feasible under each of the urban expansion scenarios?
2. What are the major spatial shifts required in key products to satisfy these scenarios?
3. Are there any specific spatial units where the pressures will intensify to the point where the alterations are not practical?



## **b) The Impact of Policies on Resource Supply**

A second approach examined the impact of particular policies on land use options. For example, if it was decided to reduce the impact of farming practices on soil and water quality, a buffer strip along all water courses could be created (Land Evaluation Group, 1983b). What would be the impact of this on the satisfaction of a number of demands? Would it still be possible to achieve feed grain self-sufficiency without sacrificing other major products under this scenario? What would be the impact of continued erosion over 25 years?

## **c) The Impact of Climatic Change**

A third type of application of the model was the evaluation of the ability to meet production goals under different climate change scenarios. Each climatic scenario was run in terms of its projected impact on physical attributes of the land base. The changes in climate would therefore enhance or reduce productivity for particular crops on each type of soil within each unit. The questions focussed on the need to change location of crops and the impact on overall production. The model runs showed where production would be most important to the achievement of future scenarios. The model was also run to discover whether adjustments in location of production for eight crops could be done to maintain production or to optimize production of priority products. Typical "answers" included -- "no", only one of the two production goals could be satisfied under a particular scenario, or "yes", but only if over 80 percent of the land with particular biophysical characteristics in a particular data unit was put into one crop. No further work was done on implications for other sectors like forest products or habitat protection as essential productivity-response relationships were not available for these sectors.

While this type of modelling procedure has proven relatively effective for scenario testing for agriculture, it is clear that there are many more capabilities which could be exploited. For example, the addition of productivity-response information for tree crops, biomass production, waterfowl production, etc. would permit the extrapolation of these approaches across other sectors.

One element in the further development of this type of modelling that would enhance its utility for the assessment of environmental futures would be the development of an integrated biophysical baseline data on biophysically defined units. If biophysically homogeneous units at an appropriate scale were defined, then productivity response, in the face of alterations in key climatic or other physical variables, could be estimated for the most important environmental functions -- particularly those viewed as most strategic to the achievement of government strategies or defined goals (e.g., Conservation Strategies). That would entail the development of productivity-response models for the major food crops, for forest products and consumed wildlife as initial steps. In addition, the definition of relationships between the utility of particular parts of the environment to serve recreational functions, buffering, habitat or any other functions which are particularly sensitive to alterations in biophysical variables would be valuable. In some cases, the environmental functions such as many forms of built environment (environment as space) are remarkably insensitive to biophysical change, depending more upon attributes of site and relative location than physical attributes of the resource base. These kinds of functions can be factored into this type of model primarily as subtractions from the available environmental resource at the outset of each run or separately modelled in terms of demand functions and used to develop scenarios which are then tested through the primarily biophysical supply/constraint model. Some types of scenarios amenable to this type of approach and pertinent with reference to the attainment of the goal of sustainable development are highlighted in Figure 5.

FIGURE 5  
TYPICAL SCENARIOS TO BE MODELLED

1. Production Capability under Changed Land Supply
  - reduced land base due to urban growth
  - changed land capability due to climatic change
2. Impact of Land Use Practices
  - changed capability due to erosion, chemical use
  - changed productivity response due to new crops, practices
  - altered environmental quality due to use trends (toxification)
3. Changes in the Demand for the Land Base
  - need to achieve self-sufficiency on land base
  - need to consecrate land areas to habitat/recreation
  - major impact constraints for particular products
4. Social Impact
  - changed demand for natural areas, etc.
  - changes in social acceptance of particular land use practices
5. Policy Impact
  - changed regulations on fertilizer use, pesticides
  - changed policy re.: use regulations (agricultural land protection, buffer strips)
  - trade agreements, barriers
  - immigration/emigration scenarios
  - changes in capital depletion changes (re.: forest stumpage, mineral royalties)
6. Catastrophe
  - environmental change scenarios/sensitivities (e.g., climate change)
  - drought/flood scenarios (short term)
  - environmental disaster scenarios (X% of base sterilized by accident)
  - crop diverse scenarios (agriculture, forestry)
  - civil disruptions/economic surprises.

Specific demand scenarios can be tested against the ability of the land base (even if altered) to respond.

The objective of such model runs would be to answer the following genre of questions:

1. Can we maintain desired levels of supply of key functions given hypothesized disruptions or competing demands?
2. Do current trends in use or abuse of aspects of the land base threaten our future desired uses?
3. Do current (or proposed) policies create satisfactory outcomes?
4. Where are the pressure points? Are particular uses or levels of productivity critical, for particular areas in many scenarios?
5. Can we plan to reduce fragility of the system (sensitivity to surprises) or overdependence on specific parts of the resource?
6. Can all our goals be simultaneously satisfied by the resource base, or must we plan now to make adjustments/trade-offs between our goals?

If feasible scenarios from a land supply/constraint approach can be identified, the final step would be to evaluate these in terms of satisfaction of goals. In some cases (e.g., agricultural production), economic analyses of the results would be valuable because a significant subset of physically feasible scenarios are not economically viable. Other means of evaluation of political, social, etc. desirability could also be applied where appropriate. One way of viewing this entire approach is to see the supply/constraint modelling as one side of the overall strategy, and the scenario building or demand-evaluating side interfacing with it through the operator. The role of the operator, through as many iterations as is required, is to try to optimize both sides of the model. The objective of sustainable development is therefore to modify demand for, or manage supply of, environmental resources in an anticipatory fashion so that unacceptable outcomes are made less probable.

## **9. Conclusion**

The objective of the testing of scenarios is to identify those points of intervention where undesirable futures can be averted or at the very least the risk of unacceptable outcomes can be reduced. Such approaches can also identify those "hot spots" which are particularly fragile or sensitive under a range of demand scenarios. The conceptual approach and modelling procedure described in this paper have very significant information requirements. Like all models, the utility is related directly to the amount of work necessary to create it. One of the most serious problems will be the selection of appropriate scale. Clearly, the more detailed the output the more directly applicable to problem-solving at a regional scale. In contrast, the greater the detail required, the more expensive and complicated will be any modelling procedure.

The crux of the practical problem in defining an overall program to amass information and to integrate it in a way that permits the assessment of future land use options is the selection of an appropriate level of generalization. The ideal is impossibly complex and expensive. The practical is probably inappropriately general. Yet I would suggest that the overall problem of creating something usable and something which will in fact be able to identify sensitivities, points of intervention and the need for pre-planning lies in the selection of a small number of clearly definable biophysical variables and a limited number of socio-economic factors which modify supply. These must correlate well with the productivity response for the most important environmental functions. The next step is the selection of moderately-sized data units which are preferably biophysically based to permit better synthesis. I would further recommend the use of geographical information systems so that output can be obtained not only for biophysical units but also geo-political ones and the adoption of a supply/demand modelling framework which, while it would not address all environmental questions for Europe's future will permit the testing of many of the most probable scenarios in terms of potential land use impacts. The spatial perspective will permit not only the broader scale identification of supply/demand problems but also the regionalization of these to the point where specific interventions can be possible in order to reduce sensitivity or to avert probable/possible future difficulties.

This paper has been developed as a contribution to the definition of a program which will allow the examination of the determinants of land use for Europe in order that Europe's environmental future can be addressed. In a sense, it is an attempt to see the unseeable. Surprise events will continue to be just that -- surprises. By casting our net fairly broadly, and by understanding the response of those environmental functions upon which society is so dependent, we are at least better armed to deal with surprises in a quick-response fashion. We are also able to identify the weakest links in our system, and perhaps plan in advance to reduce situations of particular fragility or sensitivity, particularly those which threaten sustainability of the system. At the very least, these types of approaches help us understand, at a continental scale, what is occurring and what are some of its implications for the sustainable development of the land base.

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° The author would like to express his appreciation for the input, comments and critiques of the following individuals whose help was invaluable in the preparation of this paper: P.D. Bircham, W.K. Bond, H.C. Bruneau, R. Gélinas, C. Lisiecki, J.D. McCuaig, L.C. Munn, I. Reiss, W. Simpson-Lewis.

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