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Perspectives for Developing the Land Component of the Biosphere Program

Harnos, Z.

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PERSPECTIVES FOR DEVELOPING THE LAND COMPONENT OF THE BIOSPHERE PROGRAM

Zsolt Harnos

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INTERNATIONAL INSTITUTE FOR APPLIED SYSTEMS ANALYSIS
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Preface

One of the goals of IIASA's Biosphere Project is to develop strategic frameworks showing the net impact of human activities on properties of the environment that are relevant for sustainable human development. The first contribution to this goal was Paul Crutzen and Thomas Graedel's paper on "The role of atmospheric chemistry in environment - development interactions", published in W.C. Clark and R.E. Munn (eds.) 1986. *Sustainable Development of the Biosphere* (Cambridge: Cambridge University Press).

In this paper Zsolt Harnos begins the task of shaping a complementary framework for the land/soil system. The challenge is in many ways greater than that for the atmosphere, due to the extreme spatial heterogenity of soil systems. Dr. Harnos' paper is especially useful as an effort to bridge the gap that normally separates the microscale of studies of soil dynamics from the macroscale surveys of soil state and classification.

Acknowledgements

This paper reflects the efforts of many people. I am grateful to William C. Clark, leader of IIASA's Biosphere project, who provided a stimulating environment for my writing in the summer of 1985. I am indebted to Janos Hrabovsky, Kalman Rajkai, Ferenc Toth, and the participants in IIASA's 1985 Young Scientists' Summer Program for their comments and suggestions. Special thanks to John Ormiston for editing the paper.

About the Author

Dr. Zsolt Harnos is Deputy Director of Computer Center of the National Planning Office, Budapest, Hungary. He has been working on modeling of agricultural systems over ten years, and has several publications in this field. He was the leading modeler of two major studies on the future of the Hungarian agriculture organized by the Hungarian Academy of Sciences. He also contributed to the Food and Agriculture Program at IIASA.

His mailing address is:

Computer Center of the National Planning Office
Angol u. 27.
Budapest
H-1149 Hungary

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PERSPECTIVES FOR DEVELOPING THE LAND COMPONENT OF THE BIOSPHERE PROGRAM

Zsolt Harnos

Computer Center of the National Planning Office
Budapest, Hungary

1. Introduction

The basic goal of IIASA's Biosphere Program is to describe the long-term interactions of human activity and biosphere elements and to call attention to the damaging effects of those interactions and their probable consequences. Its aim is to describe such processes for large regions, by synthetizing the knowledge accumulated to date.

Describing probable future alternatives may result in changes in the attitudes of politicians and decision makers, and so bring attention to the need to consider economical-ecological aspects versus the short-term economic trends currently enforced in most cases. I am convinced that a change in attitude is an essential precondition for the sustainable utilization of resources.

The Biosphere Program deals with the problems of the biosphere in terms of four main components:

- atmosphere,
- land,
- water, and
- biota.

In the initial phases we handle the factors that affect the elements of the biosphere separately, but later in the synthesizing phase they will be combined and the processes will be analyzed in a complex, interrelated way, as shown in Figure 1.

The scenarios describe the possible "development paths" (e.g., population growth, energy policy, consumption, technical development, water use, etc.). The output of the system answers questions such as:

- How do the elements of the biosphere change due to the above development paths?
- How does the carrying capacity of the Earth and life conditions in general change?
- Which processes lead to harmful consequences in the different scenarios?

This list of possible questions is far from complete, but it is useful to provide an outline to better understand the concept.

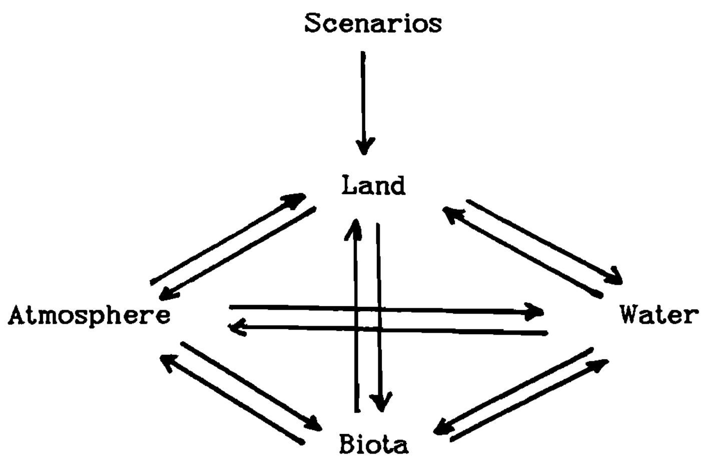


Figure 1.

In the rest of this paper only the land component of the biosphere is considered. We focus on the role of land with respect to human conditions, specifically in food production. In this context the following questions can be raised:

- What is the carrying capacity of the Earth ?
- What are the factors that change this carrying capacity ?
- How can we provide, in the long-term, an increase in the Earth's carrying capacity that parallels the population increase ?

In the above questions, by Earth we mean the land that is potentially arable. These questions are all concerned with carrying capacity, but there is no generally accepted definition of this. To bridge this problem, a consistent conceptual framework has to be established in accordance with the goals of the Biosphere Program. The conceptual framework describes the hierarchical, areal partitioning of land and, linked to this, the evaluation system (productivity) of the building elements of the area. The conceptual system, its elements and the relations of the elements are shown in Figure 2.

The details are explained later.

2. Definition and classification of land

With the aim of the Biosphere Program in mind, a practical definition of land is: "that terrestrial part of the Earth's surface on which a significant quantity of biomass is formed". This area can be broken down into three major groups:

- arable land	1.5×10^9 ha
- meadows and pastures	2.6×10^9 ha
- productive forest	4.1×10^9 ha.

The rest of the continents (some 6.2×10^9 ha) is unsuitable for plant production. With respect to the Earth's carrying capacity the most important factor is the area of arable land and its productivity. According to FAO estimates, potentially

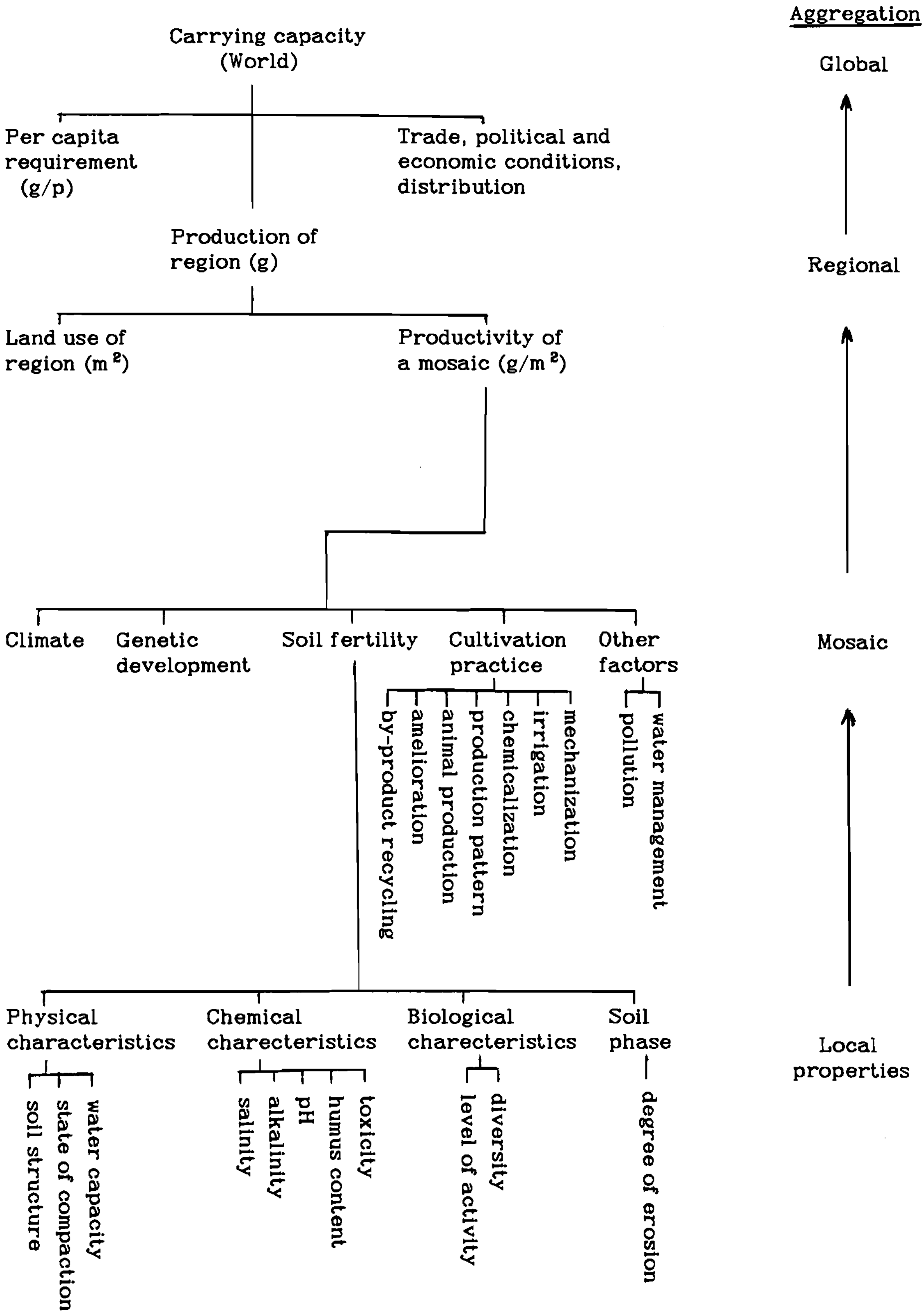

Aggregation
Global
Regional
Mosaic
Local properties
Carrying capacity (World)
Per capita requirement (g/p)
Trade, political and economic conditions, distribution
Production of region (g)
Land use of region (m²)
Productivity of a mosaic (g/m²)
Climate
Genetic development
Soil fertility
Cultivation practice
Other factors
mechanization
irrigation
chemicalization
production pattern
animal production
amelioration
by-product recycling
water management
pollution
Physical characteristics
Chemical charecteristics
Biological charecteristics
Soil phase
water capacity
state of compaction
soil structure
toxicity
humus content
pH
alkalinity
salinity
diversity
level of activity
degree of erosion

Figure 2.

arable land could be as high as 3.2×10^9 ha.

The distribution of arable and potentially arable lands is uneven among the continents. In Europe, 31% of the total area is under cultivation, while in Africa only 9% is. Thus, there is practically no reserve in Europe while there is much in Africa [5]. This definition and grouping provides a very rough categorization of land, since it combines nonhomogeneous regions. Land is nonhomogeneous in space and its productive features (chemical and physical properties of the soil, organic matter content, etc.) are highly dependent on other external conditions, such as hydrology, climate, etc.

Therefore, the description of global processes can only be built up gradually. That is:

- The Earth's surface has to be divided into ecologically homogeneous regions (mosaics).
- These mosaics must be classified into higher groups, eg. into regions, which can be continent-like.
- These regions can be combined to form the complete Earth's surface.

Each of these hierarchical levels is discussed further below.

(1) With respect to the global character of the Biosphere Program the mosaics would be homogeneous in the sense that they show a similar behavior with respect to the most important processes described in the Biosphere Program. Such ecologically homogeneous regions can be:

- potentially salt-affected regions,
- potentially acid soils,
- potentially erodable soils,
- potentially irrigable land, etc.

The processes that occur on these mosaics are relatively well known and "hypothetical models" can be constructed to describe the most important relationships. These models can be

- simple mathematical models, or
- input-output models that integrate expert judgements.

The input list related to land is included in the scenarios and in the actual characteristics of the other elements of the biosphere (atmosphere, water, and biota).

(2) Processes that occur in the regions can be described using a model system of mosaics, taking into consideration the exogenous variables of the system, such as population growth, urbanization, energy consumption, afforestation, climate, etc. The parameter list can be completed only after determining the main relations of the "biosphere system". The model system can be validated using the available data base over a certain time period.

(3) From regional models one can easily construct the so-called "world-model", which describes the Earth's carrying capacity. The study of carrying capacity is not an easy task either, because the distribution of products is not equal and thus a local surplus in one place is not available for those in other places who need them. To solve these problems requires the consideration of different social and economic processes.

3. Land evaluation

The regional aspect includes the following problems: How to characterize the separate parts and what kind of evaluation system to use for comparing them and describing any changes? A possible solution could be the evaluation system described hereafter, which is related to the hierarchical modeling of the land as well.

A given piece of land, a so-called mosaic, can be characterized by its ***productivity***, which in terms of land use, is determined by four group of factors:

- genetic development,
- climate change,
- change in soil fertility,
- cultivation practice,
- other factors.

External effects can also be considered, such as pollution (eg. acid rain) and water management, by which we mean water use that directly affects productivity: for example, building artificial lakes and water basins, which can raise the groundwater table and cause salinization. We do not deal with these here.

As was mentioned earlier, the Earth's surface is represented as regions, regions built of ecologically homogeneous mosaics. Mosaics are unambiguously determined by their defining environmental parameters, such as geographical location, relief, soil type, climate, etc. Thereby, mosaics are located geographically and are considered to be homogeneous

- in productivity,
- in their reaction to external effects that influence their soil and ecological properties (salinization, erosion, etc.).

Productivity needs to be defined for these homogeneous mosaics. There is no known, exact causal relationship between the productivity of a piece of land and its determining environmental parameters. Let us sidestep the problem and define productivity as a dynamic process and assume its general development.

Furthermore, assume that the environmental conditions (climate, soil fertility) are stable during the study period. So the gradual increase in productivity is solely due to biological (genetical) improvement and improvement in cultivation practices.

The ***base productivity*** of forests is determined by the continuous exploitation of "wood yield". The base productivity is ultimately stable for natural forests, while for plantation forestry it is assumed to be a monotonously increasing function of time. The actual nature of the function will be determined by other assumptions; it is too soon to consider them here.

In the case of meadow-pastures the base productivity can be expressed practically in terms of hay yield or grazing capacity. The definitions cannot substitute for each other, but, depending on the land considered, it will be practical to use sometimes one, sometimes the other. Increases in the productivity of meadow-pastures come from genetic and agrotechnological development, while in livestock carrying capacity improvements in fodder utilization are important.

When characterizing arable lands problems occur because of changing land use and the constraints due to specific conditions required for crop production. To substitute "production" by "carrying capacity" seems to eliminate this problem. With time, in every larger region a particular structure of consumption has been formed according to the local environmental conditions. This structure is mainly the result of plant-growing possibilities in a given region. This consumer structure can be used as a reference point, in which case productivity means the number of people that can be supplied by a given structure. In this case, changes in consumer behavior may cause problems.

Productivity can also be characterized by the average yield of a certain reference crop. In this case, it is practical to choose the most important crop of the region (wheat, corn, rice, barley, etc.) as a reference crop and to deduce from its changes the carrying capacity of the land. It is necessary to emphasize that the productivity function is not only determined by the mosaic but also by the time period considered, during which increases occur due to agrotechnics, genetics, etc. The slope of the productivity function can be determined by a time-series analysis. The derived productivity function curve may be modified by changes in the state variables of the land and by applied agrotechnics, so the actual productivity remains within a certain range around the determined productivity function (see Figure 3).

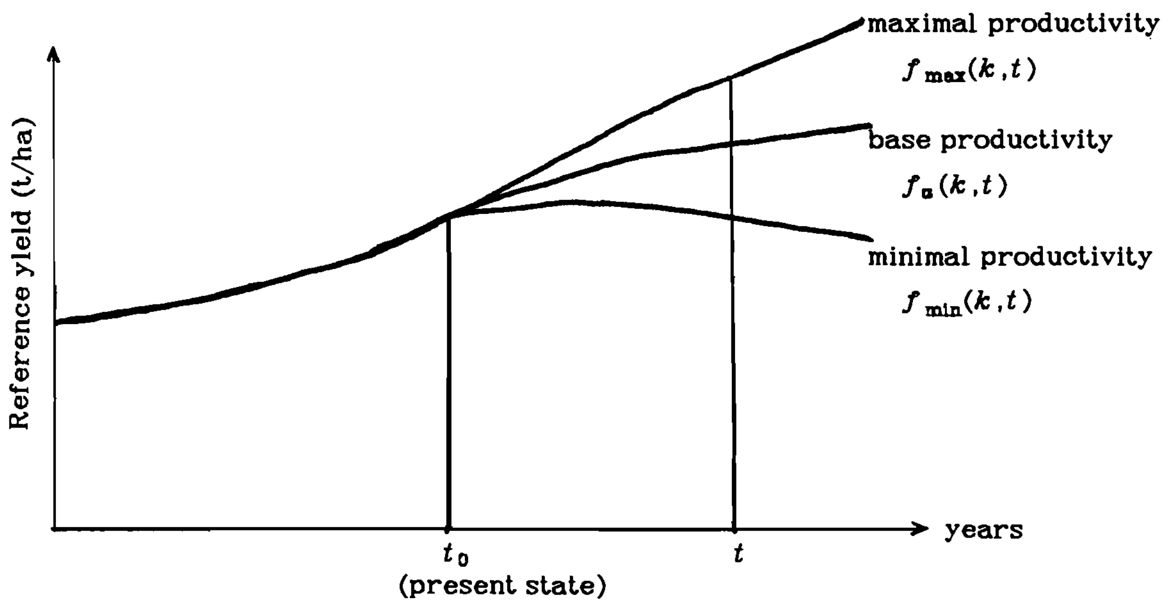


Figure 3.

We assume that the environmental factors (soil fertility and climate) are constant in the study period for the function that describes the base productivity. The upward shape of the function is caused by general genetic development and improving cultivation practices. Maximum productivity can be reached by maximum utilization of the land, by application of the best available cultivation practices, and, if necessary, by amelioration or restoration. Minimum productivity is determined by low level cultivation practices and land degradation.

In a given period, the potential productivity is expressed by the interval:

$$[f_{min}(k,t), f_{max}(k,t)] .$$

Thus, the actual productivity falls somewhere within the interval. In the base scenario, the actual productivity of the mosaic is determined by soil fertility (*sf*) and cultivation practice (*cp*), formulated as:

$$f_{act}(k,t) = f\,[sf_k(t), cp\,(t)]$$

and

$$sf_k(t) = g\,[sf_k(t_0), cp\,(t_0), \cdots, cp\,(t-1), cp\,(t)]\,.$$

It is necessary to emphasize that this productivity is valid if changes do not occur in the climate and in the expected genetic development. If changes are assumed in these, the curves should be modified according to the new hypothesis.

The *production of regions* can be constructed from land use and the productivity of mosaics. The definition is given as follows:

Let us suppose that a given region is built up from $\{X_k\}_{k=1}^{K}$ pieces of mosaics, where X_k expresses the area of the k th mosaic. Each mosaic has a specific productivity function, as described above, which are the implicit functions of cultivation practice. With respect to land use, each mosaic is divided into four categories — arable land, meadow-pasture, forest, unused area.

$$X_k = X_{k,1} + X_{k,2} + X_{k,3} + X_{k,4}\,.$$

These categories change in time, thus $X_{k,n} = X_{k,n}(t)$, and the actual distribution is given in the scenarios. The actual production of the region in time t is

$$f_{n,r,act}(t) = \sum_{k=1}^{K} f_{n,act}(k,t) X_{k,n}(t) \qquad n = 1,2,3\,,$$

where the index n means the cultivation type (arable, forest, etc.). The production capacity (i.e., maximum production) of the region is given by solving the following extreme problem:

$$P_{\max}\left\{f_{r,pot}(t)\right\}\,,$$

assuming that

$$f_{r,pot}(t) = \left[f_{1,r,pot}(t), f_{2,r,pot}(t), f_{3,r,pot}(t)\right]^{*}$$

$$f_{n,r,pot}(t) = \sum_{k=1}^{K} f_{n,max}(k,t) X_{k,n}(t)$$

$$\sum_{n=1}^{3} X_{k,n}(t) = X_k - X_{k,4}(t)$$

$$X_{k,n}(t) = X_{k,n}^{0}(t)\,.$$

The last assumption expresses restrictions in land use and P-max is the Pareto optimality.

However, one can produce a meaningless land-use structure in this way, so to describe land use using scenarios seems practical. Then, production capacity is defined as:

$$f_{n,r,pot}(t) = \sum_{k=1}^{K} f_{n,max}(k,t) X_{k,n}(t)\,.$$

Here $X_{k,n}(t)$ is determined by the actual scenario.

For the Earth in total, production can be substituted by the carrying capacity. The *Earth's carrying capacity* is determined by population requirements and by total production of the regions. If the regions are considered as closed systems, the carrying capacity can be defined for them similarly, which would regulate the population of the given region, as has happened historically in subsistence societies. However, the general development of society has eliminated the enclosure of the system such that, because of the development of the division of labor, trade, etc., the carrying capacity of a region is difficult to determine.

So we will use carrying capacity at the global scale only. Carrying capacity also changes over time, just as the above-mentioned production and productivity. In spite of this, its introduction suits the goal of the Biosphere Program, since the program is concerned with global questions, such as, e.g., the carrying capacity of the Earth. This problem cannot be solved exactly, but it is quite practical to analyze whether the processes affect it positively or negatively. Such processes are, e.g., land area reduction, changes in land productivity, improvement in nutrient supply, etc. Depending on these trends one can postulate the future food production capacity of the Earth or, indirectly, the carrying capacity.

Of course, the effective carrying capacity is not only determined by the total food quantity produced, but is also influenced by distributional relationsships, which are affected by different political, social, and economic considerations. But we do not consider these issues herein.

From the above arguments one can see that the analysis of carrying capacity develops from problems related directly to land use. We feel that the Biosphere Program should analyze the processes occuring in the regions, so we summarize the related problems below.

4. What determines the production of regions?

The production of a region in a given time, with significant simplification, is determined by the following factors:

(1) The area of the region and its division into cultivation types (land use)

(2) The division of the region according to productivity

4.1. Area and land use

The area of the region is constant, but its division changes over time. Through history the extent of arable land has changed significantly. According to FAO estimates, soil loss may have affected a greater area than is presently cultivated and, currently, because of soil degradation the cultivated area is decreasing by 5–7 x 10^6 hectars per year. According to forecasts the degree of soil decrease will increase until the turn of the twentieth century and will reach 10 x 10^6 ha/year. [4] Besides soil degradation, another significant cause of land loss is urbanization and industrialization.

The increase in land area occupied by settlements and their infrastructure is a consequence of the natural development process. The fast increase in nonproductive area is caused by human intervention that neglects ecological conditions.

Table 1: Distribution of land in Europe

	Area 10^3 ha			
	1974-76	1978	1980	1982
Arable land	127506	127263	126575	126412
Permanent pastures	87602	86727	86349	85881
Forest	152536	154630	155106	155276
Other land	89510	89608	90458	91072

Table 2: Arable hectares per capita

	1951-55	1961-65	1971-75	Alternative	
				1985	2000
Industrialized countries	0.61	0.56	0.55	0.50	0.46
United States	1.17	0.95	0.95	0.86	0.84
Other major exporters	1.72	1.66	1.58	1.29	0.94
Western Europe	0.33	0.30	0.26	0.24	0.22
Japan	0.06	0.06	0.05	0.05	0.04
Centrally planned countries	0.45	0.39	0.35	0.30	0.26
Eastern Europe	0.50	0.47	0.43	0.39	0.36
USSR	1.16	1.02	0.93	0.83	0.73
People's Rep. of China	0.19	0.18	0.16	0.13	0.11
Less developed countries	0.45	0.40	0.35	0.27	0.19
Latin America	0.56	0.51	0.47	0.38	0.28
North Africa/Middle East	0.68	0.58	0.47	0.33	0.22
Other African LDCs	0.72	0.73	0.62	0.49	0.32
South Asia	0.38	0.32	0.26	0.19	0.13
Southeast Asia	0.38	0.41	0.35	0.28	0.20
East Asia	0.15	0.15	0.13	0.11	0.08
World	0.48	0.44	0.39	0.32	0.25

Note: Arable area includes land under temporary crops (double-cropped areas are counted only once), temporary meadows for mowing or pasture, land under market and kitchen gardens (including cultivation under glass), and land temporarily fallow or lying

Source: [2]

In principle, it is possible to recultivate nonproductive areas, for example, by the watering of deserted areas, but these days this occurs only to a small degree and yet requires significant investments.

In Europe, the decrease of arable land has been caused mainly by urbanization and industrialization. In Table 1 we illustrate these processes in Europe.

The data show that over 8 years arable land has decreased by roughly 1% and permanent pastures by 2%, and forest has increased by 2%. In Hungary, the ploughland has decreased by roughly 14% over 40 years. In Europe there are no "reserves" from which this loss can be replaced.

The relative decrease of arable land can be better shown with respect to the population, as in Table 2.

The data show that the world average has decreased by 50%, thus, assuming the same consumption, the yields should be twice as much as before. This increase can be achieved by high level agricultural technology (in the developed countries per capita production was doubled over an even shorter time). A shift in the type of land use or in the increase of nonproductive areas not only has a direct effect on food production, but also on the climate, hydrological conditions, and biochemical cycles, all of which have unpredictable consequences.

One third of the Earth's territory is covered by forests. Out of the 4.5×10^9 ha forest area, 2.7×10^9 ha are "closed forest", where at least 20% of the area is covered by canopy. This distribution is the result of a long development process. In the dynamic process of land utilization today, industrialized societies try to maintain and increase forests, while in many developing countries the forest acreage is decreasing. In Europe, however, a 8 to 9% growth in forest area is planned. The main problem is that in the poorer, developing countries the harvest is greater than the annual growth. In Europe, the USSR, and the US, the annual harvest is less than the growth. [2]

The composition of agricultural land with respect to the quality has also changed unfavorably. In most cases, urbanization and industrialization occupy fertile territories (riverside, plain areas), but there are no exact data on this.

4.2. Productivity of a region

According to the definitions introduced above, the productivity of a mosaic is determined by several factors, which, with some simplification, can be grouped as:

- genetic development,
- climate change,
- change in soil fertility,
- cultivation practice,
- other factors.

In all five cases the change that occurs is emphasized, since in the definition of productivity genetic development, climate, and soil fertility are included.

GENETIC DEVELOPMENT

To describe genetic development one can consider several scenarios instead of one. It is assumed that crop varieties of significantly higher productivity can be produced by biotechnological methods, which would cause a significant increase in productivity, but it could also be diminished.

CLIMATE CHANGE

In the long-term it is quite practical to consider climatic change. Climatic changes can be caused by, among other things, the unbalanced ecology of large areas. Without drawing any final conclusions, the annual average precipitation values for Hungary were calculated regarding the last 100 years (see Figure 4). Data show a significant decline in the average values.

Changes in ten-year precipitation averages
(1871-1980)

Figure 4.

SOIL FERTILITY

The definition of productivity is related to land mosaics, and it is practical to make two assumptions:

(1) Their productivity is similar with respect to land use.

(2) They react similarly to endogenous and exogenous actions.

The second assumption means that mosaics react identically to erosion, salinization, acidification, etc. Beside these constant characteristics of land, productivity is affected by the physical, chemical, and biological conditions of the soil, which change with time and have different impacts which modify productivity.

The term "soil fertility" is used to characterize land. Any change in soil fertility modifies the function that describes the productivity of the land (mosaic) (Figure 3). We assume in terms of the base productivity that soil fertility is constant. However, in the long-term, this assumption is not valid. Considerable land area is exposed to erosion, salinization, etc., which affect its productivity. Soil fertility is the measure that indicates these changes, more exactly the changes in productivity under the present conditions compared to the previous ones.

Soil fertility can be increased by applying amelioration. In spite of the fact that there is no known exact relationship between soil fertility and crop yield we should, somehow, handle this relationship because only through this can we show the consequences of nonsustainable management practices. The parameters that determine soil fertility can be divided into four groups:

- physical characteristics,
- chemical characteristics,
- biological characteristics, organic matter content,
- degree of erosion.

Physical characteristics include soil structure, water capacity, and compaction. Among the causes of soil structure deterioration (compaction) are the intensive use of heavy machines, the decline in organic matter content of the soil, and irrigation. Soil compaction directly affects water capacity of the soil and via this the nutrient supply of plants. According to an estimate made by Hungarian experts, soil compaction results in a yield loss of roughly 10% [8]. Compaction can be eliminated by amelioration (deep-loosening, etc.).

Chemical characteristics include soil pH, salinization, and alkalinization, of which acidification has a significant effect on soil fertility. The sensitivity of plants to soil acidity is different and species dependent, but the deterministic relationship between pH and fertility is still not known. According to experience the relationship between soil pH and relative fertility for wheat and alfalfa is as shown in Figure 5. [8]

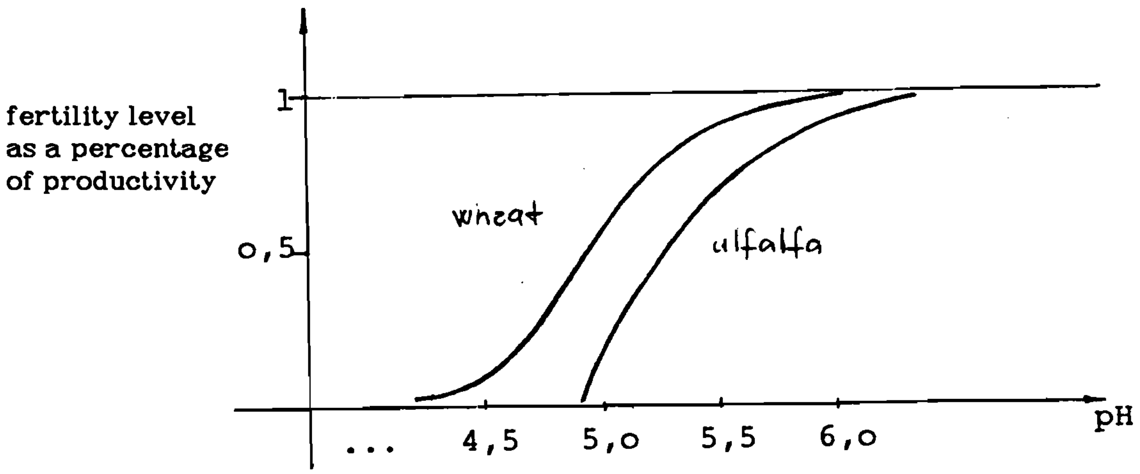


Figure 5.

Observations show that below a certain level of pH value fertility drops sharply [8].

Factors that cause acidification are:

- acidic N fertilizers,
- acid rain.

No analytical function is known that describes the relationships between causal factors and soil pH. It is recorded and predictable that soil acidification has increased due to acid rainfall from heavily industrialized regions. International concern has initiated actions to stop this unfavorable process; thus, for example, some developed countries have undertaken to reduce their SO_x emissions by 30%. The acidification of agricultural lands can be stopped and even the pH level increased by e.g., ameliorative lime application.

With the expansion of irrigation the proportion of lands under water has increased. According to estimates, roughly 125 000 ha of productive land is lost annually through waterlogging, salinization, and alkalinization. This is only 0.06% of the total irrigated area, but since irrigation is applied almost solely on the most productive lands, this phenomenon is not negligible [2].

Biological characteristics and organic matter content together characterize the humus content of soil, its biota, and, in a broader sense, the flora and fauna of the given region. The organic matter content of soil varies from zero to a few per cent. This is significant with respect to biomass production because it improves the water management and nutrient supply of the soil. According to estimates, in Europe the humus content of soil that has been under cultivation for a long time has decreased by 25 to 50% with respect to the original state [5]. This is partly due to the use of heavy machines and partly to soil loss, but the degradation of soil structure also contributes to erosion. The decrease in organic matter content is influenced by other factors:

- The effective use of modern agricultural technology is restrained by plant residues returned to the soil, therefore, the by-products, stalk- and root-residues are removed from the biological cycle (they are usually burnt).
- The fast decay of stalk- and root-residues can be promoted by N-fertilizer; this increases the direct costs of nutrient supply.
- The use of chemical fertilizers is significantly cheaper than the use of organic fertilizers or composts, besides which large scale methods for chemical fertilizers are better developed.

The decrease in soil organic matter results in the decrease of microelements, which adversely affects plant growth.

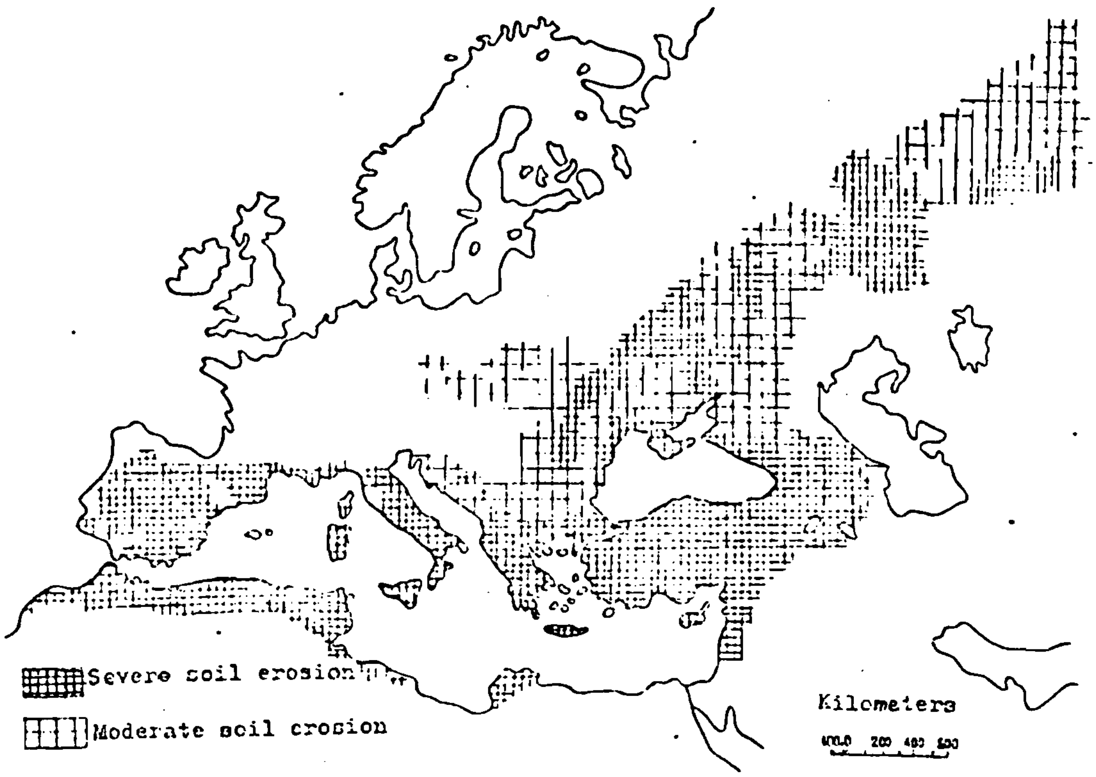
In many countries, the possibility of multipurpose utilization of the biomass has recently been considered seriously and the general remark is that a greater share of the biomass should be returned to the soil. In Hungary, the dry matter content of the plant produced in plant production was 48×10^6 tons in 1980, more than 50% of which can be considered as by-products and wastes. According to experts, more than 60% of this should be used in the organic matter supply [3].

The decrease in soil organic matter content is not only due to agricultural technology, but also to overgrazing and burning of savannas and prairies. The degree of these and their direct effects cannot be measured.

Erosion takes two main forms, wind and water. Soil loss due to erosion leads to a decrease in soil productivity. The measure of productivity loss after erosion can also be estimated but there is no accepted, verified relationship between the two. The man-caused factors responsible for water erosion are:

- mode of soil cultivation,
- coverage of soil,
- organic matter content of soil.

The most serious loss caused by erosion occurs after deforestation in tropical regions, but there are also some significant soil losses in North America and Europe. The lands endangered by erosion in Europe are shown in Figure 6. (see: [5]).



Soil Erosion in Europe

Figure 6.

Erosion affects water management (significant surface runoff), plant nutrition, and soil organic matter content, besides the reduction of the depth of the soil profile. Wind erosion mainly affects low-lying sand areas and occurs because of poor vegetation coverage of the soil, due to inappropriate agrotechnics or overgrazing. An illustrative example of this is the Sahel region, where the carrying capacity of the area is less than the needs of the human and animal population is. The result is desertification, which positively feeds back into the climate through decreasing precipitation, and thus desertification becomes more intensive. The prediction is that the by 2000 desert areas will be three times that at the end of the 1970s [5].

To raise the productivity of deserts is only possible through irrigation. To protect the lands against wind erosion it is necessary to keep the soil covered and to build up wind shelters (e.g., tree rows, etc.).

The characteristics of soil fertility brought about by the deterioration processes develop slowly, so their manifestation in productivity is delayed. This generality is not valid in the case of amelioration, when improvement is immediate.

CULTIVATION PRACTICE

Cultivation practice (input) determines the actual productivity at a particular soil fertility level, but it also influences the soil fertility itself, though this effect is detectable only later.

Input groups are as follows:

- mechanization,
- irrigation,
- chemicalization,
- production pattern,
- amelioration,
- by-product recycling,
- animal production.

Mechanization through technological level term expresses how it is used. From this last aspect finer categorization might have, eg.:

- the quite generally used non-sustainable type which is followed by a decline in soil fertility,
- sustainable type, which prevents soil degradation.

Irrigation level speaks for itself.

Chemicalization includes both plant nutrition and plant protection. We emphasize here that in chemicalization what is important is not only the nutritional aspect, but also the application method, since many disadvantages of the practice are due to this.

Production pattern deals with crop rotation, vegetation cover of slopes, etc.

Amelioration covers those actions that improve soil fertility, but is not the same as the so-called general agrotechnics. Occasionally, ameliration requires a significant degree of investment. Hydro-regulation, chemical amelioration of soils, reclamation of salt-affected soils, etc., belong to this category.

The effect of *animal production* is changing. Extensive (grazing) animal husbandry significantly affects lands that are sensitive to desertification (overgrazing), while intensive animal husbandry affects the crop production structure and contributes to the nutrient supply of crop production, but because of the concentrated manure production it can be a source of environmental pollution (nitrification of groundwaters, eutrophication).

By-product recycling affects the organic matter content of soils. Utilization of by-products as fodder or energy carryer increases land productivity.

OTHER FACTORS

Among other factors I consider those that affect significantly the soil fertility, the productivity of regions through soil properties, and the type of land use.

Now we consider two illustrative examples:

- water management,
- pollution.

Irrigation and hydroregulation can significantly affect crop production either directly or indirectly. Building a water reservoir, for example, may directly improve the conditions of irrigation, but at the same time it can raise the groundwater table in the neighborhood, thus increasing the danger of secondary salinization or wetland formation. Also, the expansion of industrial water consumption lessens the amount of water used for agriculture. Industrial pollution can affect surface waters to such a degree that rivers become unsuitable for irrigation.

Pollution is a very broad category. Toxic elements can reach cultivated lands by

- acid rain,
- plant protection,

- exhaust gas of cars,
- atmosphere
- communal and industrial waste waters, sludges, and other wastes.

A recent major environmental problem is that caused by acid rain in highly industrialized regions. The deterioration is significant in forests and it can be assumed that, after a while, acid rain will also cause a significant loss in crop production.

The mechanism of toxicity has not yet been discovered, but it is known that toxicity prevents biomass formation and, after entering the food chain through plants, it is inherently dangerous to human beings.

A summary of the factors that influence production and fertility is given in Table 3. The "+" sign indicates a strong effect on soil fertility, or in a broader sense, on production. The effect can be either positive or negative. The "-" sign indicates no significant effect. The last column of Table 3. shows the environmental impacts other than soil fertility, e.g., nitrification of groundwaters and eutrophication of fresh waters.

These problems are important with respect to the Biosphere Program, since they are related to future perspectives of "life quality".

5. Functioning of the land-use model of the Biosphere Program

The introduced definitions and relationships have sense only if they can be organized into one, functioning system, an example of which we give below.

The Biosphere model is directed by scenarios designed by scientific experts, decision makers, etc. These scenarios describe the main socio-economic processes and resource utilization policies, e.g., population changes by regions, energy consumption, product distribution, technical development, water consumption, etc. Besides these general areas, the scenarios determine activities that directly regulate the different components of the biosphere, which in the case of land are:

- land utilization,
- genetic development,
- climate change,
- cultivation practice, and
- other effects (water management, pollution).

Based on the above, the system functions as is shown in Figure 7.

The land model is a simulation model. In the first run it calculates the actual production of mosaics by using actual inputs and soil fertility values; additionally, it determines the changes in soil fertility and environmental impacts by regions. The change in soil fertility is reflected in the modification of the curve shown earlier in Figure 3.

Environmental impacts include the impacts of other actions on the elements of the biosphere, but these are not formulated yet. After these modifications, the simulation proceeds to the next, $(t+1)$th, time period description.

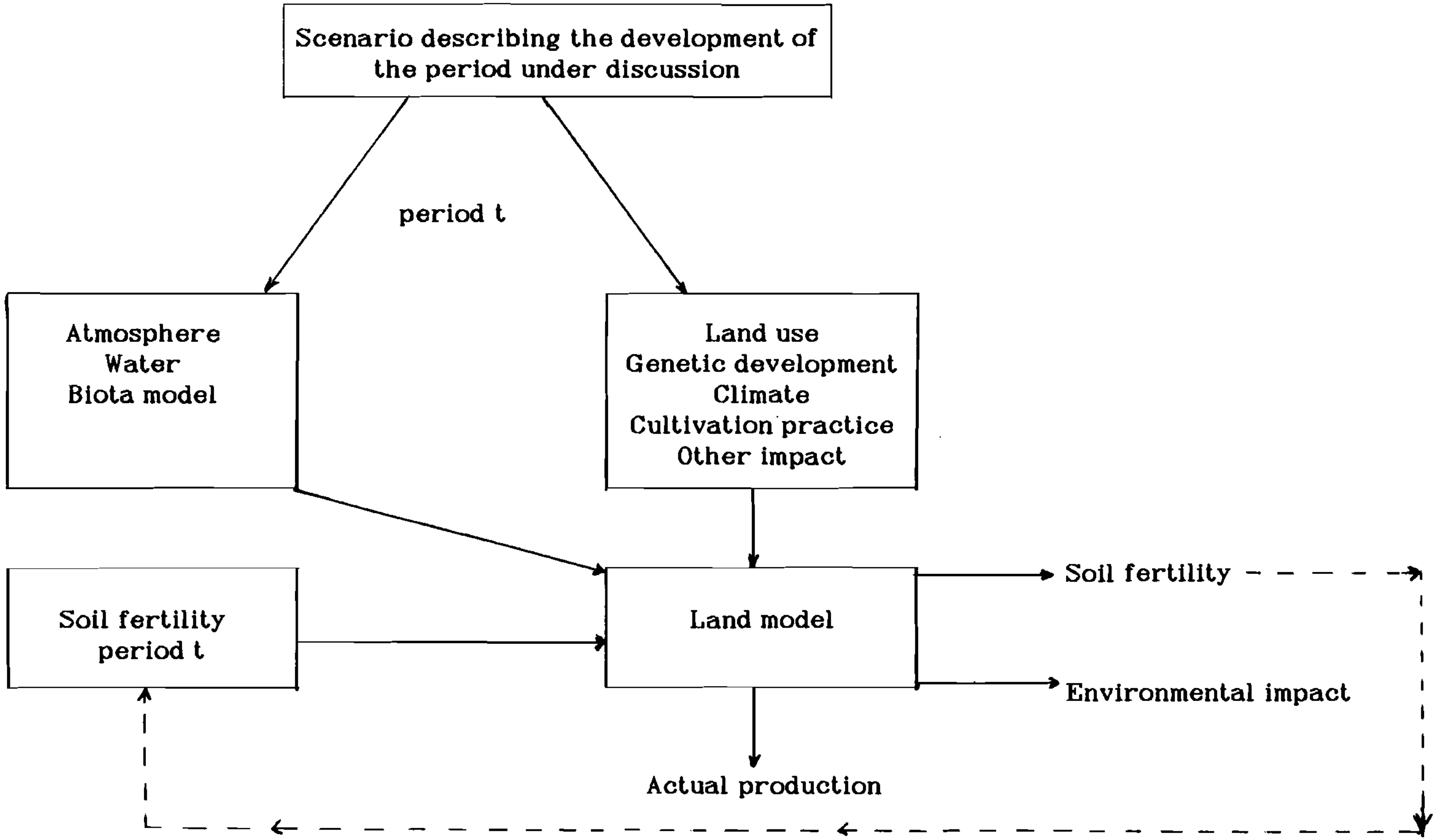
The results of the scenario analyzed are given in terms of three parameters:

- change in production,
- change in fertility,
- environmental impacts.

Table 3

Activity		Production of region				Soil fertility				
		Crop	Wood	Meadow pasture	Unused	Physical	Biological	Chemical	Soil depth	Environ-mental impact
Land use area		+	+	+	+	-	-	-	-	+
Mechanization		+	+	+	-	+	+	-	+	-
Irrigation		+	-	+	-	+	+	+	-	+
Chemicali-zation	Fertilizer	+	-	+	-	-	+	+	-	+
	Biocide	+	+	+	-	-	+	+	-	+
Production pattern		-	-	-	-	?	+	?	+	+
Amelioration		+	-	+	-	+	+	+	+	+
Animal husbandry		+	-	+	-	+	+	+	-	+
By-product recycling		-	-	-	-	+	+	+	-	+
Climate		+	+	+	-	-	-	-	-	-
Breeding		+	+	+	-	-	-	-	-	-
Pollution		-	-	-	-	-	+	+	-	+
Water management		-	-	-	-	+	-	+	-	+

Figure 7: Functioning of the system



Of primary importance is production, because decision makers can be directly influenced by it. A change in production can only be interpreted by the analysis of soil fertility, from which one can establish the effect that caused an unfavorable change and find out how the scenario should be modified to eliminate that. When building the system an interactive form would be practical so that the parameters of scenarios could be changed.

By tracing environmental impacts we can make direct conclusions as to changing of life conditions, which can have a feedback on resource management. For example, the nitrification of ground water may reach a level such that no drinking water is available from natural sources, in which case the purification of water would require enormous efforts and resources.

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