Working Paper

METHODS FOR ANALYZING MULTIFACETED PROBLEMS APPLIED TO FOREST DIE-OFF

Wolf-Dieter Grossmann

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International Institute for Applied Systems Analysis
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PREFACE

This paper is concerned with the ecosystems inhabited by humans (living systems) which exhibit complexities of all sort at all possible spatial and temporal scales. The long-term unpredictability is an inherent property of such systems. What are the causes of this unpredictability? One is certainly the stochastic nature of these systems; as the Author says they exhibit at least partial indeterminism. But there are two other important properties of the living systems which make prediction of their future behavior difficult. First one of them is viability, defined by the Author as a "capability of long-term existence of a reasonable degree of life." The second one is resilience – the ability of a living systems to persist after severe shocks or during periods of stress because of their capacity to accommodate variability in individual system elements. The mutual relationships among unpredictability, indeterminism, viability, and resilience of the living systems are explored in this paper, with an objective of formulating analytical approach which taking into account the above mentioned system properties is still capable of yielding some prediction and other useful insight about future system states and its behavior.

The system is viewed here to consist of two parts: the process and the 3-level hierarchical control structure. Each level of this hierarchy corresponds to the different scale of a system being analyzed. Uncertainties in system structure and available data, as well as system nonlinearities, usually increase from the lowest (operational or local scale) to the highest (strategic or global scale) levels of the hierarchy. The analytical approach developed by the Author distinguishes several methods which may be used at each particular level of the enquiry. Many failures in analysis of complex living systems are caused by application of methods which are not compatible with the hierarchical level and the scale of the problem being analyzed.

But what to do in case of the multi-layer as the Author says "multifaceted," problems? An answer to this question is presented in form of an illustrative analysis of the pollution problem, in particular pollution impacts on forest resources (perhaps misleadingly known as "acid rain.").

The approach formulated in this paper provides an interesting and innovative framework to deal with the analysis of complex living systems. It certainly is a valuable contribution featuring a good deal of attractive ideas however, the brevity of the paper causes that sometimes it is difficult to follow operational details of the approach proposed. But additional papers will certainly follow, and hopefully they will give more explicit consideration to socio-cultural factors both as potential constraints on change and as determinants as to the direction of change. Incorporation of these factors in the analyses of complex living systems poses several conceptual difficulties, but to ignore their existence usually results in a failure to appreciate the social objectives and aspirations of the society thus leading to the scenarios theoretically possible in physical terms but socially unacceptable and institutionally unimplementable.

Janusz Kindler

ABSTRACT

Systems methods, applied inappropriately, have resulted in frequent failures. Moreover, complexity, variety, and widespread partial indeterminism of ecosystems and systems inhabited by humans, need to be addressed with tools that can achieve both a holistic and at the same time detailed and intelligible — that is parsimonious — treatment and that can combine a systematic approach with the necessity to allow for erratic behavior.

A method of scale for overview and a hierarchical approach are used to achieve the above stated objectives. A very effective new method is reported, where a dynamic model is used to generate time series of maps on pollution and forest damage.

Keywords: Appropriate methods, combination of systems methods, hierarchical systems, problems of scale, multifaceted problems, resilience, viability.

CONTENTS

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1. DEVELOPMENT IN SYSTEMS APPROACHES

Somewhat jokingly it is sometimes stated that a system is more than the sum of its parts. Available methods have usually been developed to deal with just parts (or "disciplines"). It was a hard lesson to learn that systems science has to be more than the sum of the individual sciences each dealing with parts.

The first large-scale interdisciplinary projects on urban, regional, and environmental problems were finished in the mid-1960s, and it seems that most of them failed (whereas most large-scale classical operations research applications were successful). As a consequence, similar projects were carried through much more carefully and with multiplied efforts. Reports on failures of this "second generation" of projects date back to the early 1970s. Lee's 1973 "Requiem for Large-Scale Models" was perhaps the first, Holcomb (1976) gave a very cautious summarizing report, Jeffers (1976, 1979, 1981) shared with Holling (1978) a few years history of new approaches which were "parsimonious" instead of large-scale and were fairly successful.

At the same time, reports became ever more frequent covering ever more phenomena about strange characteristics and strange behavior of complex systems in general and of ecosystems and systems inhabited by humans in particular ("human systems," "human ecosystems," socio-economic-ecological systems). These strange phenomena cannot be addressed with the old tools.

One strange characteristic is the partial indeterminism in such systems. Unpredictability in the long-term is an inherent property even of the much simpler physical systems. For example, Lorenz (1963) formulated a system of differential equations describing the turbulence, which implies an exponential growth of errors or other deviations until the growth rate ultimately slackens leading to a prediction not better than a randomly picked reasonable atmospheric state. With global circulation models, a surprisingly short doubling time of errors of about 2.5 days was found (Lorenz 1975). Partial indeterminism of turbulence causes a partial indeterminism of the weather and of systems influenced by the weather (e.g., forests, agriculture). The same system of equations describes lasers, where chaotic behavior could be verified with experiments (Haken 1978). Also the system of differential equations, describing the movement of the planets, allows for erratic developments (Thom 1975, Arnold and Avez 1968 and essentially already Poincaré 1899).

Open systems usually exhibit partial indeterminism, if they can be described by differential equations, and almost all complex systems are open systems and many of their aspects allow for description by differential equations.

But an even stronger reason became known why attempts seem doomed to make complex systems fairly predictable. Two of the most important characteristics of living systems are viability (the capability of long-term existence of a reasonable degree of life) and resilience (the capability of an ecosystem to "bounce back" after a disturbance and to maintain this capability). Viability and resilience both depend on variability, variety, and the occurrence of erratic events and other forms of irregular and unexpected behavior — either from within the system or from the system's environments. Some of the reasons are

(i) only variety can destroy variety (Ashby — only variety of the system can overcome the variety of the system's environment)

(ii) a system can only maintain a vigorous fitness to bounce back, if this fitness is needed, that is, if the system is kept in a steady training by erratic events (Holling 1978). If these events were not really erratic but predictable, the biosystems would most probably have learned to anticipate these events and therefore would have diffused the necessity for their vigorous fitness. It is the partial indeterminism in many systems that allows for really erratic events.

If erratic events and variabilities are eliminated to make a system more manageable, the system will in the long run lose its resilience and viability and will become prone to breakdowns, that is, it will become partially unpredictable. This will be elaborated in Section 2.

As a summary, there is a basic contradiction between viability — one of the most essential long-term properties of a system — and predictability — at present a basic requirement for management and also usually required in research. Given this situation, systems approaches have to be developed which can use both predictability as far as it is existent and the strange additional ingredients of viability, e.g., variability, variety, and partial unpredictability.

2. COMPLEX SYSTEMS — AN OVERVIEW

Two different approaches will be used to get an overview over systems and relationships between them, firstly aspects of scale and secondly hierarchy-based descriptions.

2.1 Aspects of Scale

Human ecosystems consist of two main parts — the biosystems and the proper human system. The smallest example is a farmer with his fields or forests or agroforestry unit, the largest is humanity and biosphere. Examples on intermediate scales are a village with its fields, aquatic parts and forests, or a nation with its agricultural, silvicultural, natural, and aquatic subsystems. For a description of the intricacies of this relationship, see Messerli and Messerli 1978. The character of relationships changes with scale. Moreover, the biosystems of the farmer may have manifold connections to the inhabitants of cities. Two different "ekistic logarithmic scales" of Doxiadis (1977) will now be combined to give a frame for considerations on relationships between biosystems of different scales and human systems of different scales.

The ekistic population scale starts with unit 1, the individual person. The next unit is two individuals (for human relationships arising from social, psychological, and sexual reasons). The third unit is the single family (estimated at five members). After the family, the scale proceeds with each unit seven times larger than that unit preceding it. (Extracted from Doxiadis, op.cit., xxii and 56. Doxiadis also gives reasons why to adopt this factor of seven). In a similar pattern, biosystems of different sizes are being classified, beginning with 10^{-2} km^2 for the individual farmer, $2 \cdot 10^{-2}$ km^2 for the group of two individuals, $5 \cdot 10^{-2}$ km^2 for the family and afterwards also proceeding with a factor of seven. Figure 1 is the matrix resulting from the combination of both scales, which supports study of the relationships between human groups and biosystems in their dependence on scale. In dealing with one particular ecosystem, e.g., a UNESCO biosphere reservat, the fields of this matrix can now be filled: what is an individual's attitude towards this ecosystem. How does this attitude change for the group of two, the family, the (neighboring) villages, etc., ending with humanity. (In the case of a biosphere reservate, there is even

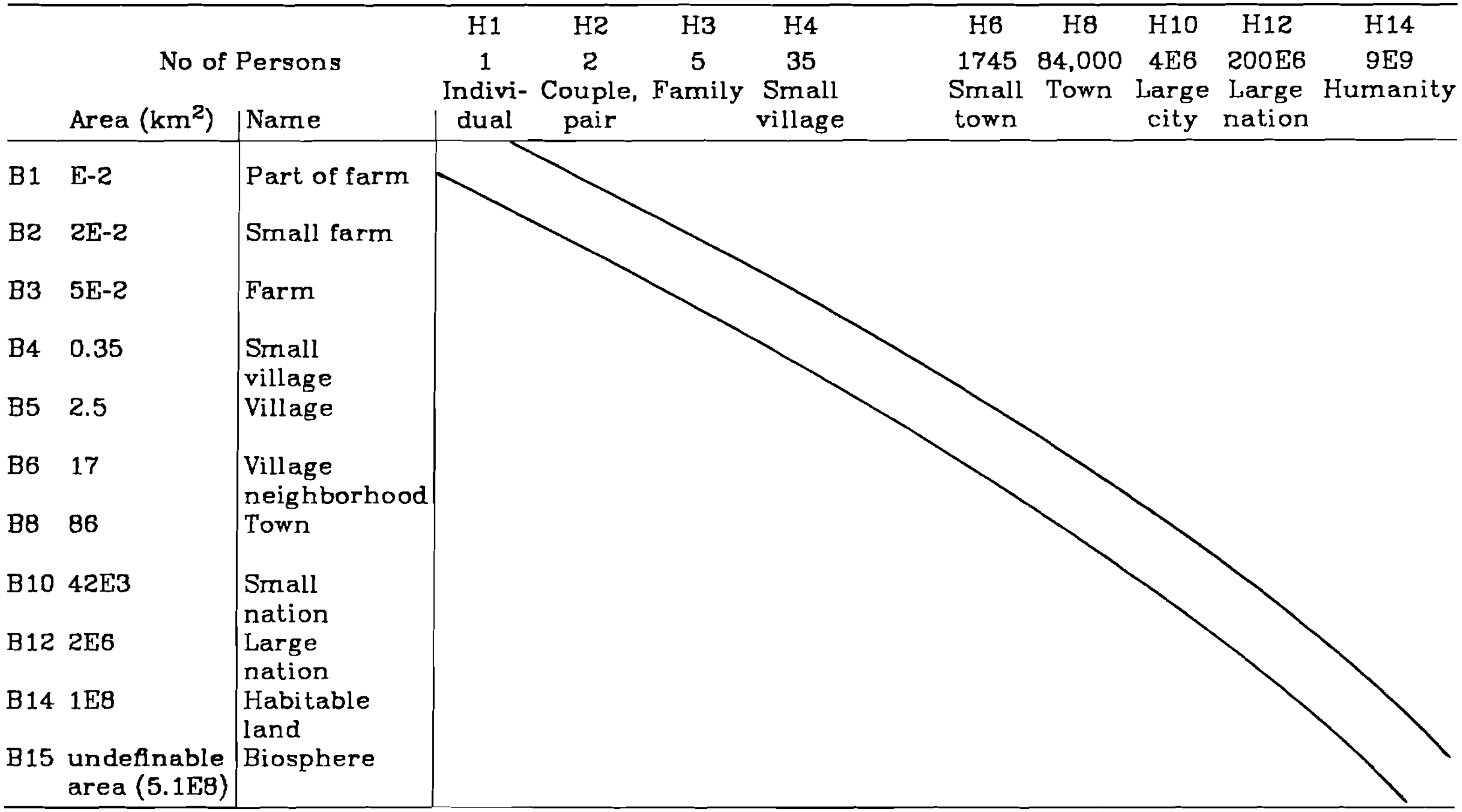


Figure 1. The ekistic Matrix S(B,H) to study relationships between the human subsystems (H) and the biosubsystems (B) depending on scale. The most direct connectivity exists within the bend diagonal; the bend is due to infrastructure becoming necessary and due to natural not inhabited areas such as lakes, swamps, deserts, reserves, oceans. In this scheme, different problems can be analyzed, for example attitude towards the biosphere by H1 the individual, H2 the couple, H8 the town (sewage, pollution), H14 humanity, or importance of an element B_i, say B_{15} the biosphere for H1, H2, etc. ($4E6 = 4 \cdot 10^6$)

a connection to humanity.) The advantage of this ekistic matrix is that it gives a complete typology of the relationships between human systems and biosystems with respect to scale, which is still manageable.

Now another scheme will be used to elaborate necessary features of systems approaches in dealing with complex systems, based on the characteristics of information processing.

2.2 Characteristics of Control

In the theory of hierarchical multilevel systems (e.g., Mesarovic et al. 1971) a system is viewed to consist of two main parts, the process — where processing of material and energy is done such as metabolism or industrial production processes — and the control structure — where the information processing for the control of the "process" is done. The control structure can be subdivided into layers, if viewed according to some characteristics of the control processes. These layers can be ordered hierarchically according to e.g., the "priority of action" — which control unit is superior to which other(s) (or according to "time horizon", or aggregation of variables, etc.). This ordering is a scheme depending on perception, which is not necessarily the "actual" structure of the studied system. ("Actual" can only be defined arbitrarily. In the case of corporations, often the established organizational schemes are mistaken as the actual structure.) See Figures 2 and 3 for a possible difference between both, as well as for the following.

On the lowest layer of the control hierarchy, all subprocesses (or subunits) of the process are controlled. Typical methods are real time process control or automatic control in industrial processes or control of metabolism or regeneration in ecosystems.

On intermediate layers, objectives are derived from more aggregated variables of the system. Examples are: preserving of liquidity in a corporation, or

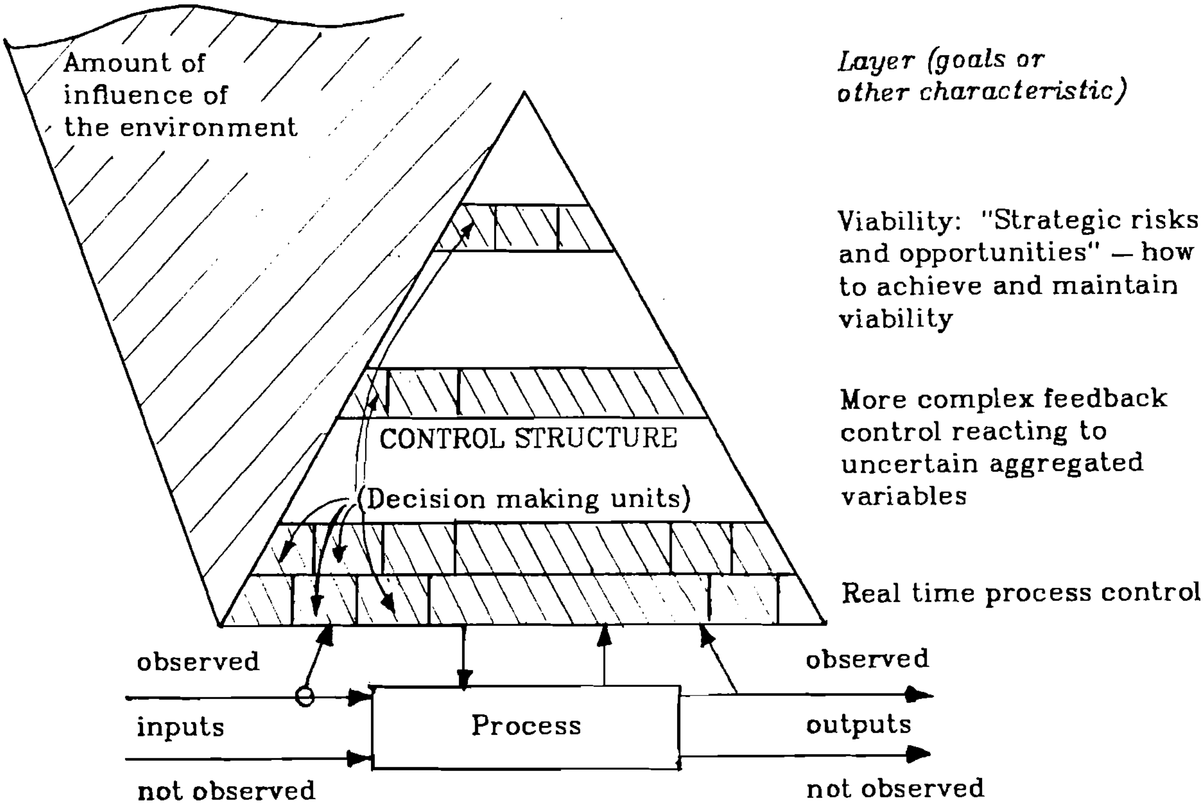


Figure 2. A possible hierarchical description of the control structure of a complex system such as an ecosystem, or human system. Here the vocabulary describes a company, organized according to some characteristics of goals or objectives and their respective priority of action.

the adaptation of an ecosystem to the overall supply with water and sun in one specific year. Both of these objectives are dynamic, as liquidity and climate may fluctuate considerably.

On the highest layer, typical objectives deal with the viability and resilience of the whole system. In strategic management these issues are named "strategic risks and opportunities." In ecosystems there are manifold behaviors which seem to aim at a long-term existence of life (viability) by allowing for temporary replacement of the present systems by totally different ones, for example, in a succession. (A typical successions: beech forest of about 200 years of age eventually breaks down, is replaced by small pioneer plants, which in turn are pushed aside by brushes, which in turn are suppressed by (fast

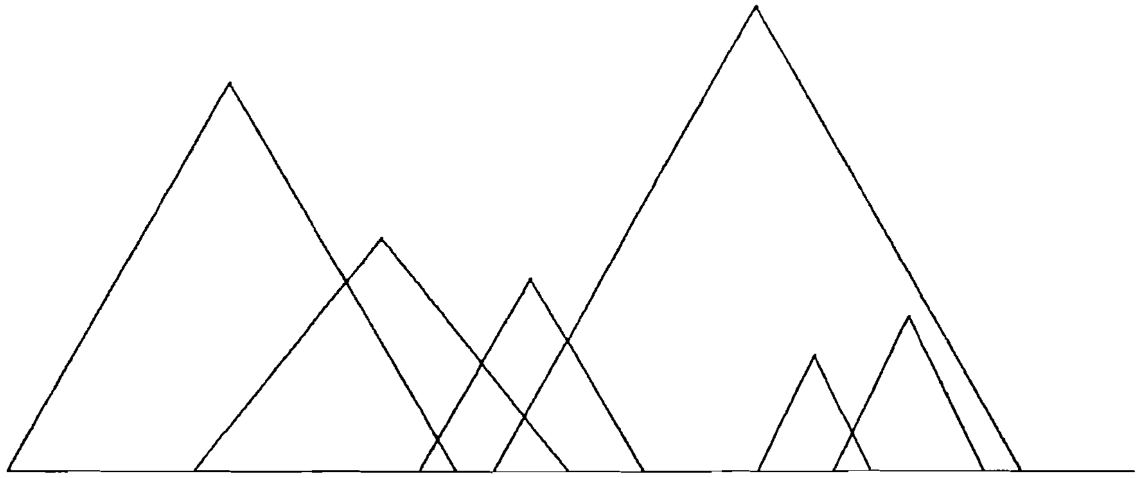


Figure 3. A possible "actual" organization of a system, which is viewed as a single hierarchy in Figure 2. Each triangle corresponds to an administrative hierarchy. This whole can be a diversified corporation, or a region comprising several cities and villages. Control may overlap, if the same entity in the "process" (see Figure 2) is controlled by two administrative units. An example of overlap may be the control of a forest which is used for firewood production by a village, for timber production by a corporation, and for groundwater preservation by a city.

growing) pioneer trees. Wherever a pioneer tree dies (they usually live only a few decades), a beech tree fills the gap in the canopy. After 200 more years, the cycle starts again).

2.3 Uncertainties

The characteristics of uncertainties correspond to the hierarchy of control of Figure 2. On the lowest layer many and precise data are readily available and have to be evaluated rapidly for real time process control (be it in industry or in metabolism). Uncertainties are kept low with schemes such as preventive maintenance or redundance or simple feedback mechanisms. For example, electrical bulbs have a known average life expectance. They are preventively replaced by new ones after, say, two thirds of this time. Also, there may be redundant bulbs. On intermediate layers, uncertainties can no longer be controlled so easily, because the influence of the (outside) environment is considerably higher: Customers can go bankrupt, orders can be withdrawn, climate may (temporarily) change erratically, or a storm or fire may destroy the fodder of some species.

Additional uncertainties arise from within the system. In an economy, some corporations can suddenly grow beyond all expectations. Also, some animal species show drastic fluctuations in population numbers. May (1974, 1981) discussed these in terms of "chaotic behavior." Systems being capable of chaotic behavior (defined as a seemingly random behavior produced by clearly defined structures, Haken 1978), and/or only partially determined behaviors are slowly being recognized as being the rule rather than the exception. Deker and Thomas ask (1983:73): "How important are chaotic systems? Are they perhaps only examples out of the collection of curiosities in physics? The answer is a surprise, to be mild: Chaos is the rule." This widerspread capability of chaotic behavior is correct for both "real" and mathematical systems. It is found that those mathematical systems which are capable of chaotic behavior are often more appropriate to describe "real" systems than mathematical systems, which are not capable of chaotic behavior. But in all these systems, chaotic behavior is the exception rather than the rule.

Erratic behavior by the environment forces a system to maintain a vigorous fitness to fight back such behavior or to bounce back after a (partial) destruction. Erratic behavior generated within a part of the system also has the effect of forcing the system to maintain a vigorous fitness against the unanticipatory. In the last years reports have become very frequent on how those biosystems, which regenerate only through fires, slowly develop into a state where fires can easily occur, (and it is nearly impossible to prevent them) and there are also reports about the equivalent development into a permanent "pre-outbreak state" for biosystems regenerated by pests, etc. (and it is nearly impossible to prevent the outbreak of the pest) (e.g., Walter 1970, Peterman 1978, Holling 1978). In such systems, it is at times absolutely certain that a serious change of the present state of the system is inherent, but it is uncertain when this will happen. This is a mildly erratic behavior. Verhaegen and Deneubourg from Prigogine's group summarize another consequence of erratic ("a-rational") behavior: A-rationality of insect populations opens new dimensions of behavior for these insects. As a summary: Only erratic behavior (by a system) can overcome erratic behavior (of its environment).

On the highest level, developments of the outside environment have a direct unmitigated impact upon the system and the system has only limited possibilities to control developments of its environment. Therefore, uncertainties are high, in particular, as many developments in the system's environment may be unpredictable. Additional uncertainties arise out of some behavior of the subsystems of the system. Examples are, in addition to those mentioned before: exchange rates are being changed (and nearly no corporation can directly influence that), attitudes of people fluctuate or change totally. For example, in Germany, at about 1800, the century-long tradition of deforestation was very suddenly replaced by a new tradition of continued afforestation, which now already lasts for about 200 years.

As a summary, usually uncertainties increase from the lowest to the highest layers due to both: increasing outside influence and increasingly more subsystems participating in the layer's behavior, which at times behave unpredictable. This, although quite common, is not a general law, as there exist both real and mathematical systems, which are large and fairly predictable, e.g., deep-sea ecosystems (Holling 1978) as there exist at least mathematical systems, which are small, closed, and essentially unpredictable (e.g., May's (1974) chaotic system).

2.4 Characteristics of Data and Structure

The hierarchy outlined so far also provides an appropriate frame for the description of data and structure. Data on the lowest layer are abundant, precise and of simple nature and can be measured immediately and perhaps hundreds of times per second, e.g., actual temperature, actual position and speed of a prey, or rotary velocity of a machine. Data on intermediate layers are far less precise, far less readily available and of a far more complex structure. Here, very aggregated data are the rule, e.g., medium temperature or the extreme values of climate of the last ten (or hundred) years, or balances of money, energy, material, etc. By definition, it often takes years to "measure" such data. The structure of subsystems is very obvious and simple on the lowest layer, and no longer so simple, but still observable on the intermediate layers. ("Structure" is defined by the connections between elements of a system and the characteristics of these connections.)

Moreover, the structure is often linear on the lowest level, which is the simplest and most appropriate structure to deal quickly with masses of data. The structure is of multiple interconnected feedback type on intermediate layers and feedback is often very appropriate where uncertainties enter, if the structure of the interactions is still known. Therefore, this layer is characterized by uncertainties in the data but not in the structure. On the lowest layer far more subsystems (or units) exist but these are usually fairly independent from each other, whereas the number of subsystems is far lower on intermediate layers but the connectivity is higher. More specific, usually only very few links exist between the different units for process control. The different subsystems in an ecosystem are fairly decoupled. Liquidity, on intermediate layers, or the energy use in a biosystem, are aggregates out of data and behavior from many units on lower layers.

On the highest layer, data are few, very aggregated and very imprecise. This impreciseness corresponds to these data's very nature; it is usually not just a shortcoming, which could be eliminated to a considerable degree by use of more precise methods for measurement and evaluation. In fact, highly aggregated data can only be made more precise, if the preciseness of all of their more important components is being improved and if the uncertainty and variability of these components is also decreased. In other words, preciseness of aggregated data is a phantom. (A moving average is, by definition, almost always not the presently correct value). It seems, however, that some scientists have drawn the conclusion, any effort to improve such data is a waste of time and money. But wrong data (the likely outcome, if no effort is made to have correct data) are very certainly detrimental for decision making. On the other hand, a presentation and use of a highly aggregated data as if they were very precise, is also misleading and detrimental. Impreciseness and uncertainty have to be expressed by the representation of these data to make them most useful. (For instance, it is a dishonest practice to present such data with several decimals.) Very summarizing visualizations can be a very appropriate presentation of highly aggregated data.

As was stated before, the structures are usually still very well-known on intermediate layers, whereas the data are not that well-known. On the highest layers, even the structures are usually not well-known. This is a situation of uncertainty in both data and structure. Therefore, feedback approaches are no longer very appropriate on the highest layer, as feedback approaches are based on structures. Structures may only slowly become known or — at least — slowly be guessed (e.g., which structural relationships exist between the characteristics of the atmosphere and the average temperature if CO_2 level and air pollution increase? Another example: does succession really exist, or is it pure imagination?) The situation in the perception of the "true" structure is often similar to the "true" value of a moving average: due to variability the present structure may be very different from the perceived structure.

As the structure is not well-known, it is explored for example by probes or tests, e.g., by tests of the market, or the trial and error behavior of evolution. On this layers, impreciseness, fuzziness, and subjectivity are prevalent. For example, the two notions just used: "market" and "evolution" name very complex phenomena, which are themselves not very well understood. It is evident that the "true" structure is not well known in any of these cases. Walters and Holling (1983) suggest a "Brainstorm, Probe and Monitor" approach. Moreover, due to complexity of the "reality" (whatever that is), the perception is primitive compared to reality.

3. APPROPRIATE SYSTEM APPROACHES

It has now been elaborated how problems differ with the scale (see 2.1) and how they differ according to the layer in the hierarchy where they originate (see also Chapter 2). Systems approaches have to be chosen so that they match the characteristics of the problem. Usually some approaches are more appropriate to deal with a given problem than are most others. Automatic control, applied to strategic management, would fail, as would portfolio analysis (Markowitz 1959) applied to process control. We say, a method is appropriate for a given problem, if the characteristics of the method fit those of the layer, where this problem originates. This is depicted in Figure 4. For problems with characteristics of many layers, see 3.2. A second, different definition of appropriateness may be helpful for the highest layers in the hierarchy. The very peculiar characteristics of methods of the highest layers can be described with the statement that "these methods should mirror the atmosphere of the problems, data and structures on these layers." Gigon (1981) explains, why subjectivity correctly enters on these layers. Overextension of any method, that is application to layers where it is inappropriate, is a common cause for failures of methods. In Figure 4, the characteristics of data, structure, problems and methods are summarized in the hierarchical scheme of Figure 2.

3.1 History of Successes and Failures

Systems models failed due to many reasons. Comprehensive models failed due to characteristics of the "reality" such as variability, impreciseness, and overwhelming number of data (and overwhelming number of missing and incorrect data); feedback models often were not accepted by decisionmakers due to their inherent and often advantageous high aggregation (Forrester's Urban Dynamics, see Forrester 1969, and Lee's (1973) evaluation who is a planner and devotes a special very acid, chapter to "Urban Dynamics" and see also the defendence of Urban Dynamics in Mass (1974) and Schroeder III et al. (1975)), or they failed due to sheer complexity combined with poor documentation which makes models unacceptable for decision makers or other scientists. Moreover, many models will fail, if they disregard the relationship between viability and predictability. For reports on failures see Lee (1973), HOLCOMB (1976), Jeffers (1976, 1979, 1981), Holling (1978), TIME (1981).

Many systems approaches, however, have been successful. Portfolio analysis (Markovitz 1959, Waterman et al. 1980) works well in strategic management, automatic control works well in process control. Both methods are appropriate for their respective problems. The methods mentioned in Figure 4 are appropriate for the layer, where they are listed, insofar as their characteristics correspond to the characteristics of problems, structure and data on the respective layer. Successes in system approaches are more likely, if methods are chosen, which are appropriate for the given problem in this meaning of appropriateness.

Problems	The Hierarchy	Characteristics	Methods
Preserve viability. To do so: decide structure of all lower levels subject to general principles. Decrease risks. Explore, recognize and exploit opportunities. Prepare system so that it can better cope with "whatever may happen" (Strategic risks)	Highest layers	Uncertainties in structure and data. High influence of the outside environment.	Strategic management. R&D. Evolution, succession. Bio-cybernetic approach (Vester 1976, 1981). Principle of viability and resilience. Importance of subjectivity and experience. Scenarios.
Within the defined structure: Preserve the structure, keep the system going. Problem solving such that interdependencies and feedback reactions are taken into account.	Intermediate layers	Uncertainty in data and to a lesser degree in structure. Considerable influence of the outside environment. Many interdependencies and competition as well as cooperation.	Holistic approaches Considerations must include (feedback) reactions. Aggregated dynamic models. Preserving of balance (e.g., liquidity)
Solve the many routine jobs quickly and precisely	Lowest layers	Preciseness in data and structure. Many usually not interacting decision systems. Low influence of the outside environment. Nearly no uncertainty in data or structure.	Optimization both heuristic and exact. Automatic control. Real time process control.

Figure 4. Characteristics of data, structure, problems and methods in the hierarchy described in the text. This figure is an elaboration of Figure 2.

3.2 Synthesis

There are problems with characteristics of many layers ("multifaceted problems"). Due to such problems, synthesis of approaches are necessary. Two types of synthesis will be outlined: one of methodology for multifaceted problems, and one between the approaches based on scale and those based on appropriateness.

3.2.1 Synthesis in Multifaceted Problems

One multifaceted problem is the impact of "acid rain" on forests and other biosystems. "Acid rain" is a term used to "explain" widespread damage of forests due to — most probably — air and soil pollution. About a dozen hypotheses are discussed in the literature (SO_2, SO_4^{--}, NO_y, Photo-oxidants, Fluorids, combined impact of SO_4^{--}, and NO_y and many other synergisms). In the "Plan for the Preservation of the Cleanliness of the Air—Rheinschiene South" (Luftreinhalteplan Rheinschiene Süd) one thousand air pollutants are listed (Michelsen et al. 1981:35). On the lowest layer in the hierarchy of Figure 4 there is the immense problem of the effects of the different pollutants on different tree species growing on different soils in different geographical and climatical zones. Ample, comparatively precise knowledge is available. Still, the complexity of the whole problem area is so beyond all comprehension that some scientists guess, the cause of the wide collapse of forests may never become known, a "factor x" is made responsible (e.g., Schütt 1982:126, Salzwedel et al. 1983).

On the intermediate layers, the most important interdependencies and non-linearities with their feedback reactions and delays must be depicted in a holistic way, e.g., the interdependencies between levels of air pollution, soil pollution, deposition, decomposition of pollutants, forest area, other areas, density of the forests, patterns of investments in agriculture, forestry and the economy, etc. It may seem strange that holistic models should be possible without knowledge of the details. But this is often the case.

Aggregated knowledge often is available where the details are missing. For example, forests cause about three times as much deposition as agricultural plantation or buildings. (See Salzwedel et al. 1983:59-61: Their factor is 4.7 for German forests, the factor of 3 is for Swedish forests, which are less dense (Acidification Today 1982)). The reasons for the higher deposition effect are manifold, e.g., greater height above ground, greater surface due to leaves, greater geometrical roughness causing more turbulence and filtering the air, higher biological activity for example in absorbing of nitrogen components, which account for roughly one third of the pollution. The factor of three is sufficiently correct for the average of all depositions of smoke, fog, dust, gaseous substances, and rain.

Damage of the forests decreases this deposition factor. A removal of the forests would reduce this deposition factor from three to one, identical with that of other types of surface coverage. This factor of three is due to general physical and other principles and is therefore even applicable for most of the unknown air pollutants, most probably also for the "factor x." One feedback model is based on such information regarding the relationships between air pollution, deposition, soil pollution and the damage of forests. It depicts the following sequence of events: slight damage of forests due to pollution in 1978, therefore decrease of deposition and consequently increase of air pollution even if emissions are kept constant. The higher air pollution causes an increasing damage of forests further increasing air pollution with an accelerating collapse of forests, see Figure 5. (For the years 1978 – 1983, this model is correct. For a more holistic model which is more aggregated with respect to forests and pollutants but shows the same behavior see, Grossmann's (1981) description of a "Framework" model which links many areas and provides linkage points for higher and lower layer approaches). This example shows how a feedback model is based on the aggregated knowledge typical for the intermediate layers.

The overall issues (some with structural uncertainty), to be addressed at the highest layers, are e.g., (1) attitude of populations, economy, politicians: will they change their attitude from disbelief to counteractions and how fast — can the change be fast enough. (2) How "viable" is the problem, or, with a term more adequate here: How persistent is the problem. This persistence depends on general structural characteristics, which are evaluated with typical high layer approaches. Some examples of general structural characteristics are:

- number and distribution of sources of pollutants
- number (diversity) of pollutants
- number and diversity of affected systems
- connectivity of the pollutants and of the affected systems (the higher the connectivity, the more synergisms are possible, such as e.g., in the biological concentration of DDT).

The principles outlined so far are applied in the Man and Biosphere Project 6 in Berchtesgaden (On Interactions between Human Ecosystems and High Mountainous Ecosystems):

(i) The two dynamic models, which were just mentioned, depict the development 1978-2003 on a year by year basis for air pollution, soil pollution, deposition, damage of forests, etc. These two models belong to an intermediate layer in the hierarchy.

(ii) A Geographical Information System is used on the lowest layer (Landscape Ecology 1981). This Geographical Information System keeps very detailed data on soil types, vegetation types, geographical height, exposedness, roads, amount of car traffic, amount of felling, etc.

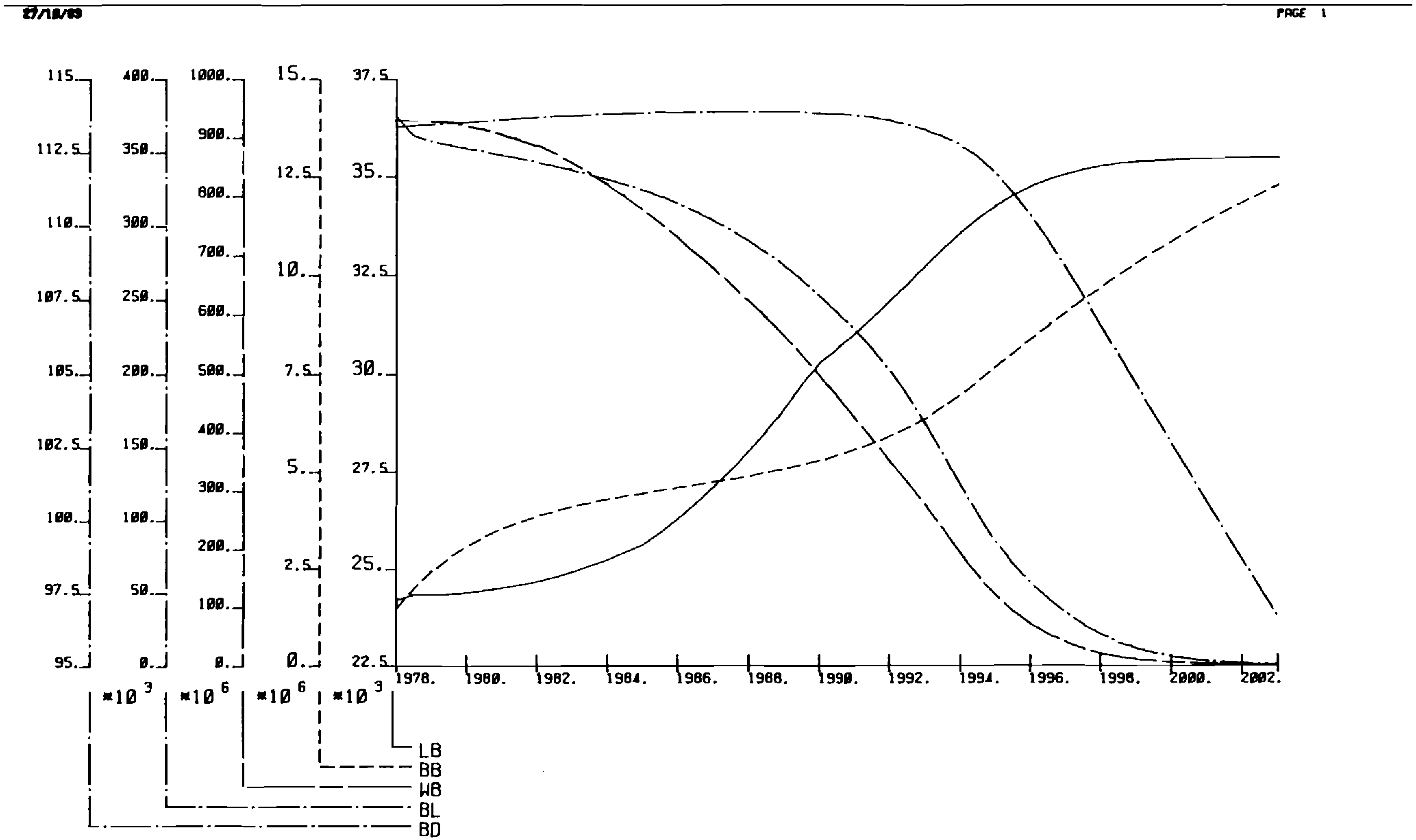


Figure 5. Development of some crucial variables in the problem of collapse of forests and pollution (LB: air pollution, BB: soil pollution, WB: forest biomass, BL: soil life in forests, PK: buffering capacity of the soil).

- If the hypothesis is: "The damage of forests as depicted by the dynamic models is mainly due to SO_2," then the geographical information system is used to produce geographic maps (e.g., scale 1:25000) of those areas, which fulfill simultaneously all of the following requirements: They are inaccessible to long-range transport of pollutants (blocked by mountains), but are accessible to deposition from the nearby CSSR (mainly SO_2), have a "critical" height of about 800m above sea level (high deposition of SO_2), little car traffic (no local emission of NO_y), low buffering capacity of the soil and susceptible species (abies and picea). One such map is generated for each of the seven years 1978 to 1984 and the sum of the damage depicted in these maps should proceed in agreement with the aggregated development depicted by the dynamic model.

If the damage increases, ever less susceptible areas are affected. But the susceptability of each area, each species and each soil type is known, so that an ordering of forest areas according to decreasing susceptability is possible. Based on this ordering, the maps can now depict in fine details how the damage proceeded in time and will proceed, if the overall development of air pollution, soil pollution, and forest damage is provided by the aggregated model. The first reports on comparison of maps and the mapped forests state a striking agreement between predictions and reality (Schaller 1983: personal communication, observations done by D'Oleire). See the maps 1.1 and 1.2 on the susceptibility of the soil and the forests, and the maps 1.3 to 1.5, which are a translation of the development according to Figure 5. Figure 6 indicates how the precise information available in the geographical data bank was added to the information from Figure 5 and translated into these maps.

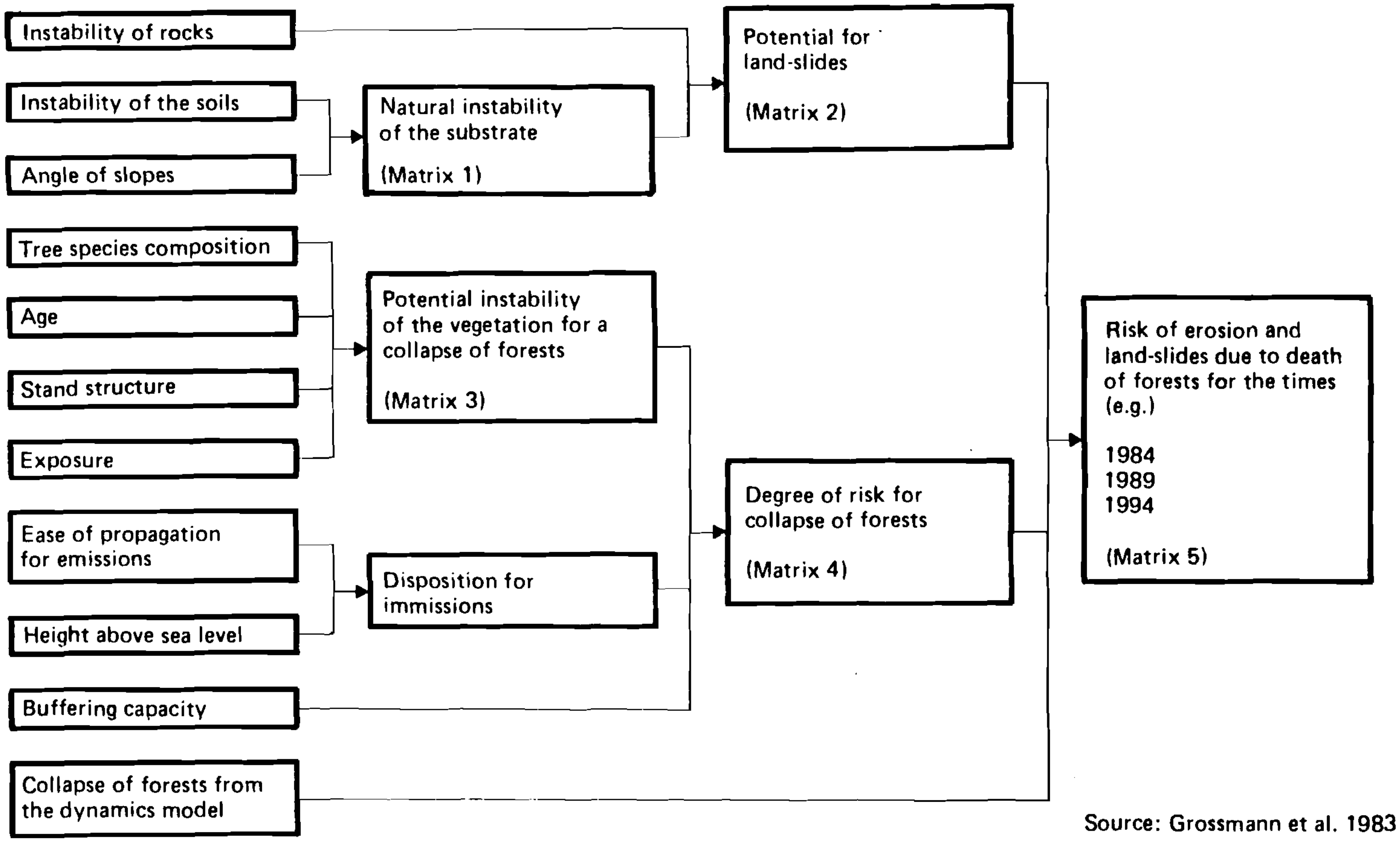
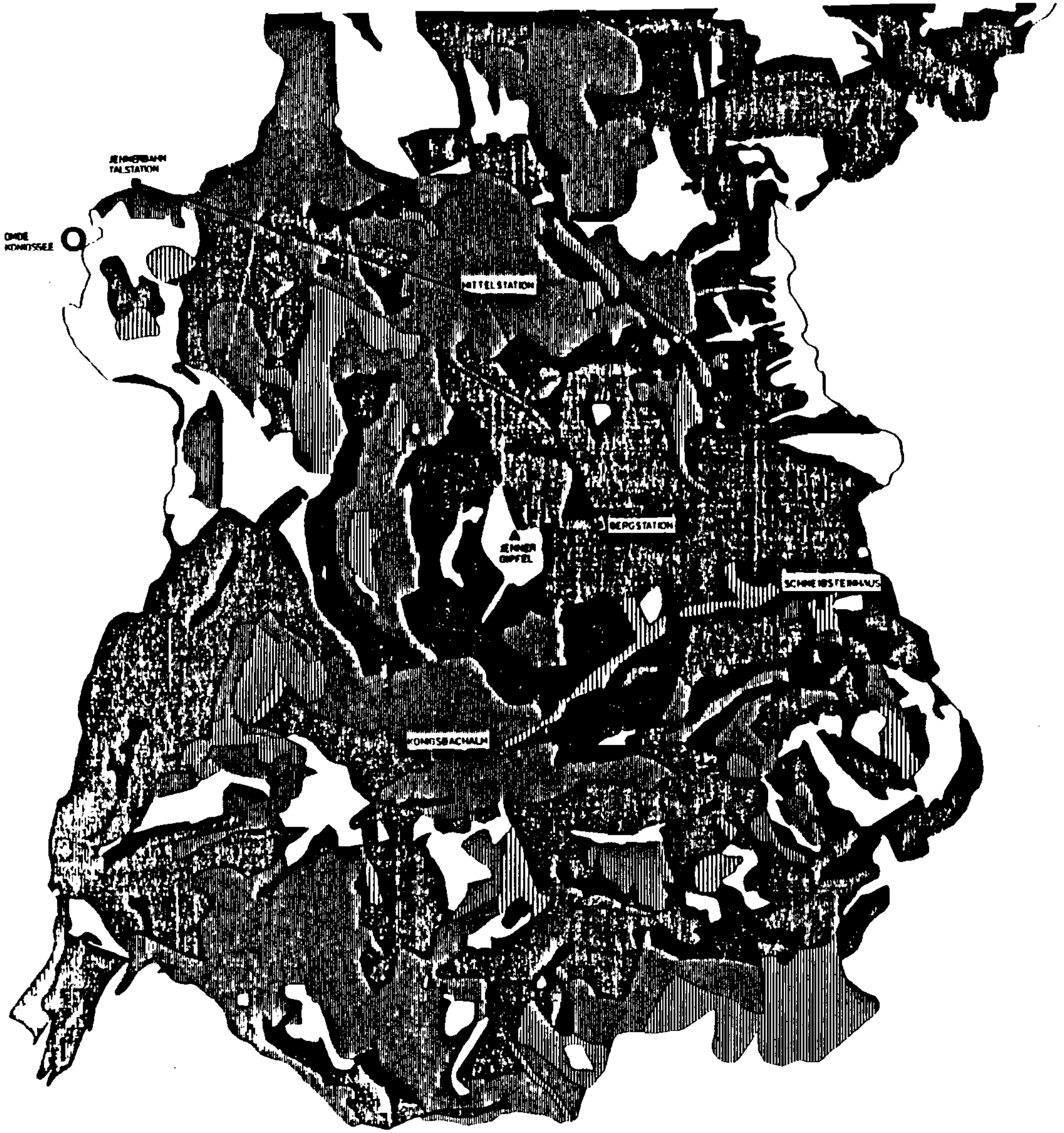


Figure 6. Computation of the aggregated variables within the area-model on the risk regarding erosion and land-slides due to collapse of forests.



Map 1.1

MAB PROJEKT 6
ECOSYSTEMS RESEARCH
BERCHTESGADEN

Area for Test: Jenner

Scenario Collapse of Forests

Potential for Erosion

Explanation of Symbols:

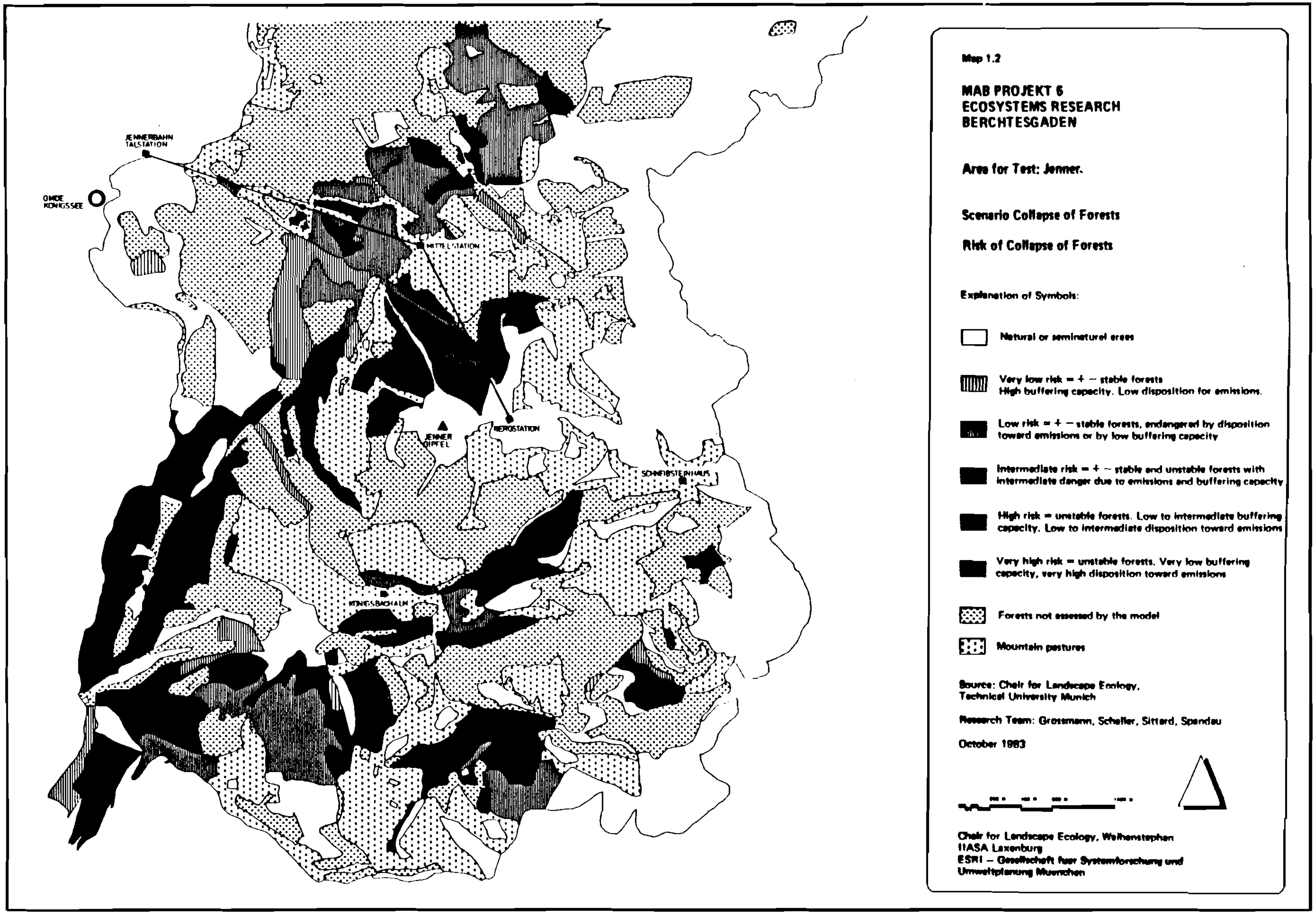
- No information / Evaluation not possible
- Stable
- Low instability = Low instability of substrate / High instability of rocks
- Unstable = High instability of rocks / Intermediate instability of substrate
- Unstable = High instability of substrate / Low instability of rocks
- Very unstable = Very high instability of substrate / Low instability of rocks
- Highly unstable = Very high instability of substrate and rocks

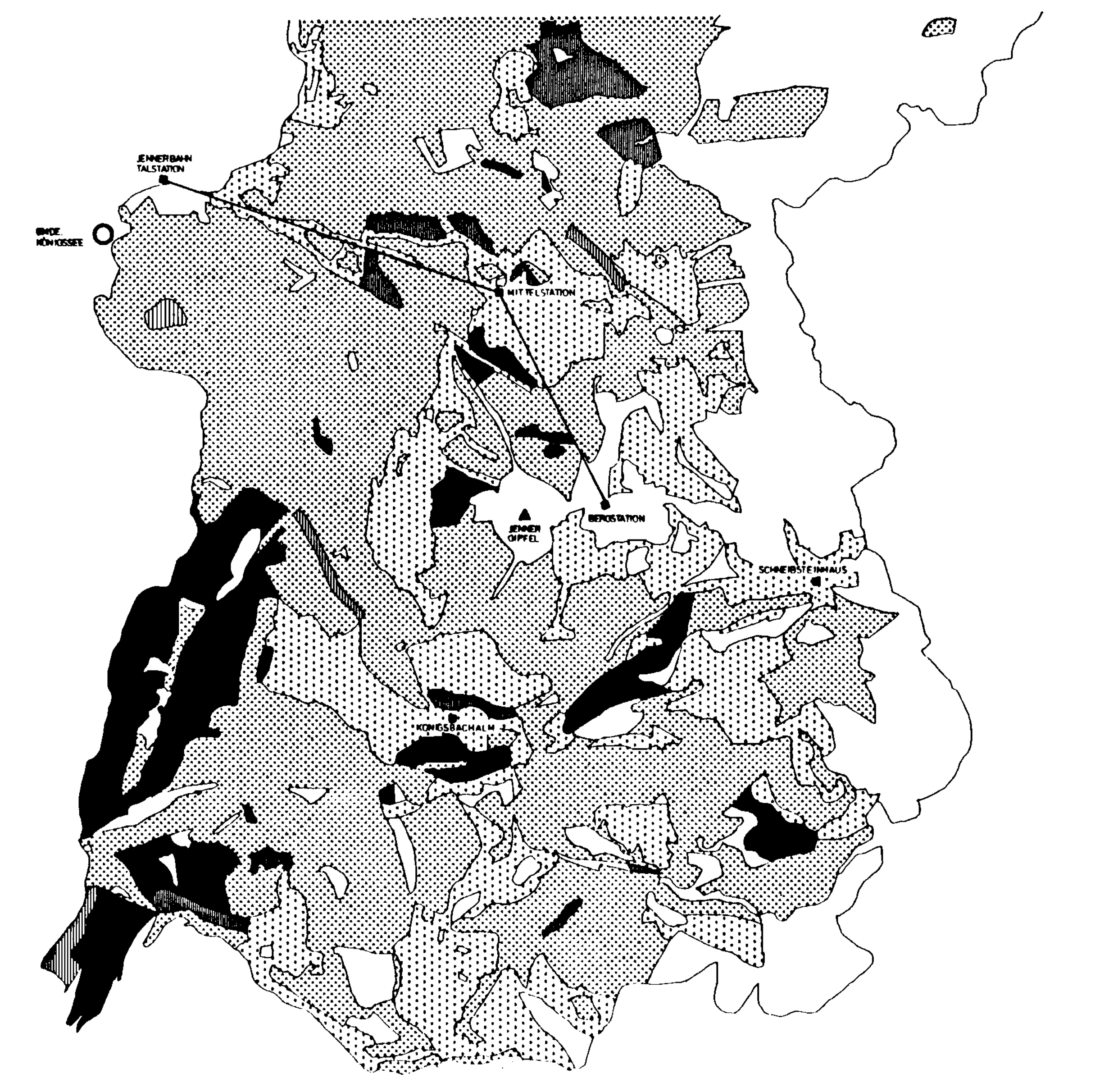
Source: Chair for Landscape Ecology,
Technical University Munich

Research Team: Grossmann, Schaller, Sittard, Spandau

October 1983

Chair for Landscape Ecology, Weihenstephan
IIASA Laxenburg
ESRI – Gesellschaft fuer Systemforschung und
Umweltplanung Muenchen


Map 1.2
MAB PROJEKT 6
ECOSYSTEMS RESEARCH
BERCHTESGADEN
Area for Test: Jenner.
Scenario Collapse of Forests
Risk of Collapse of Forests
Explanation of Symbols:
Natural or seminatural areas
Very low risk = + – stable forests
High buffering capacity. Low disposition for emissions.
Low risk = + – stable forests, endangered by disposition toward emissions or by low buffering capacity
Intermediate risk = + – stable and unstable forests with intermediate danger due to emissions and buffering capacity
High risk = unstable forests. Low to intermediate buffering capacity. Low to intermediate disposition toward emissions
Very high risk = unstable forests. Very low buffering capacity, very high disposition toward emissions
Forests not assessed by the model
Mountain pastures
Source: Chair for Landscape Ecology, Technical University Munich
Research Team: Grossmann, Schaller, Sittard, Spandau
October 1983
Chair for Landscape Ecology, Weihenstephan
IIASA Laxenburg
ESRI – Gesellschaft fuer Systemforschung und Umweltplanung Muenchen
JENNERBAHN TALSTATION
MITTELSTATION
BERGSTATION
JENNER GIPFEL
SCHNEIBSTEINHAUS
KÖNIGSBACHALM



Map 1.3

MAB PROJEKT 6
ECOSYSTEMS RESEARCH
BERCHTESGADEN

Area for Test: Jenner

Scenario Collapse of Forests

Risk of Erosion and Land-slides due to Collapse of Forests

Prognosis for 1984 (Area model)

Explanation of Symbols:

- Natural or seminatural areas
- No or only little risk = stable conditions on the site
- Little risk = intermediate instability of the site, low to intermediate risk of collapse of forests
- Intermediate risk = comparatively stable forests on very unstable sites
- High risk = unstable forests on + − unstable sites
- Very high risk = highly unstable forests on + − unstable sites
- Extremely high risk = extremely unstable forests on extremely unstable sites
- Forests not yet affected by pollution
- Mountain pastures

Source: Chair for Landscape Ecology, Technical University Munich

Research Team: Grossmann, Schaller, Sittard, Spandau

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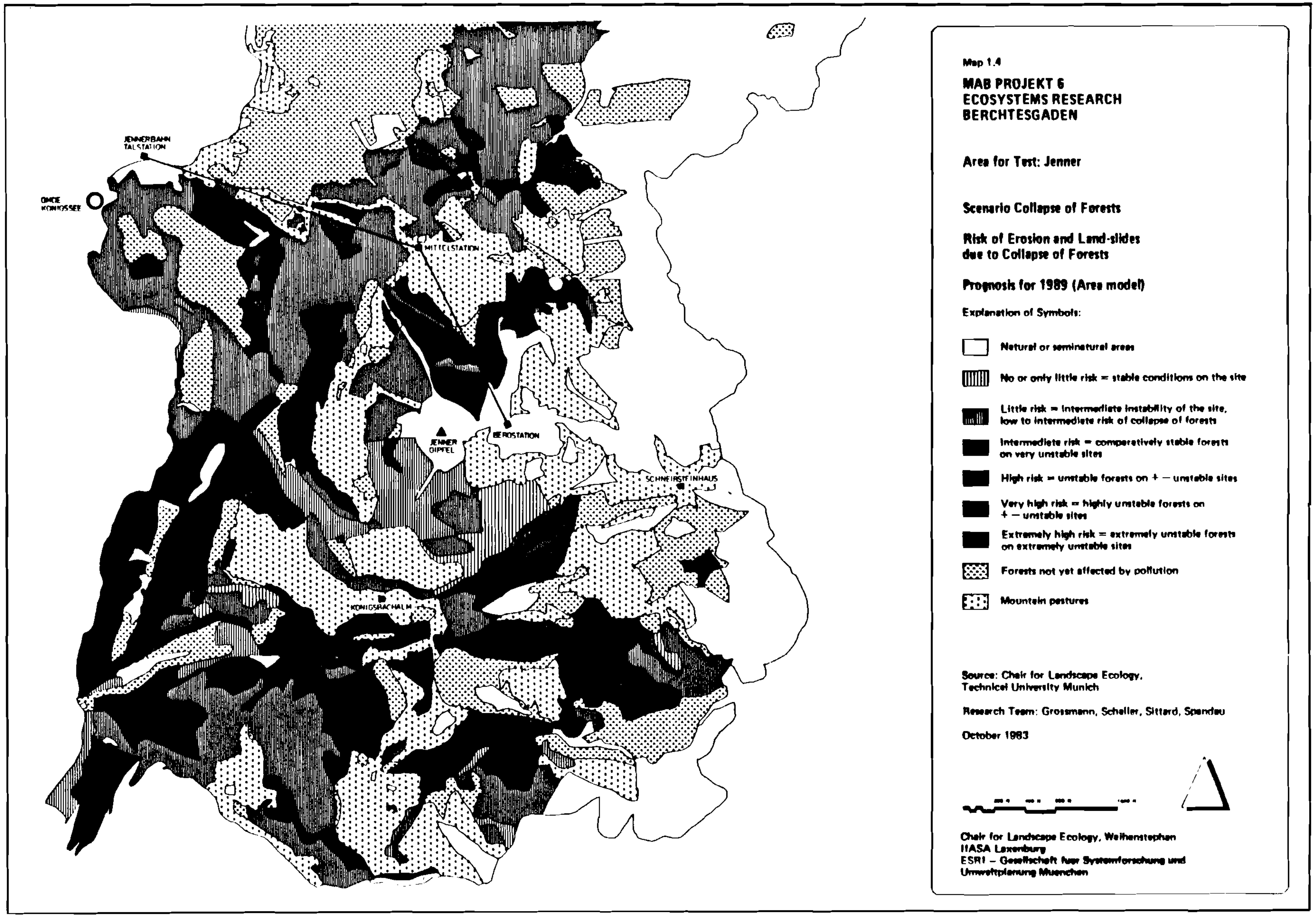
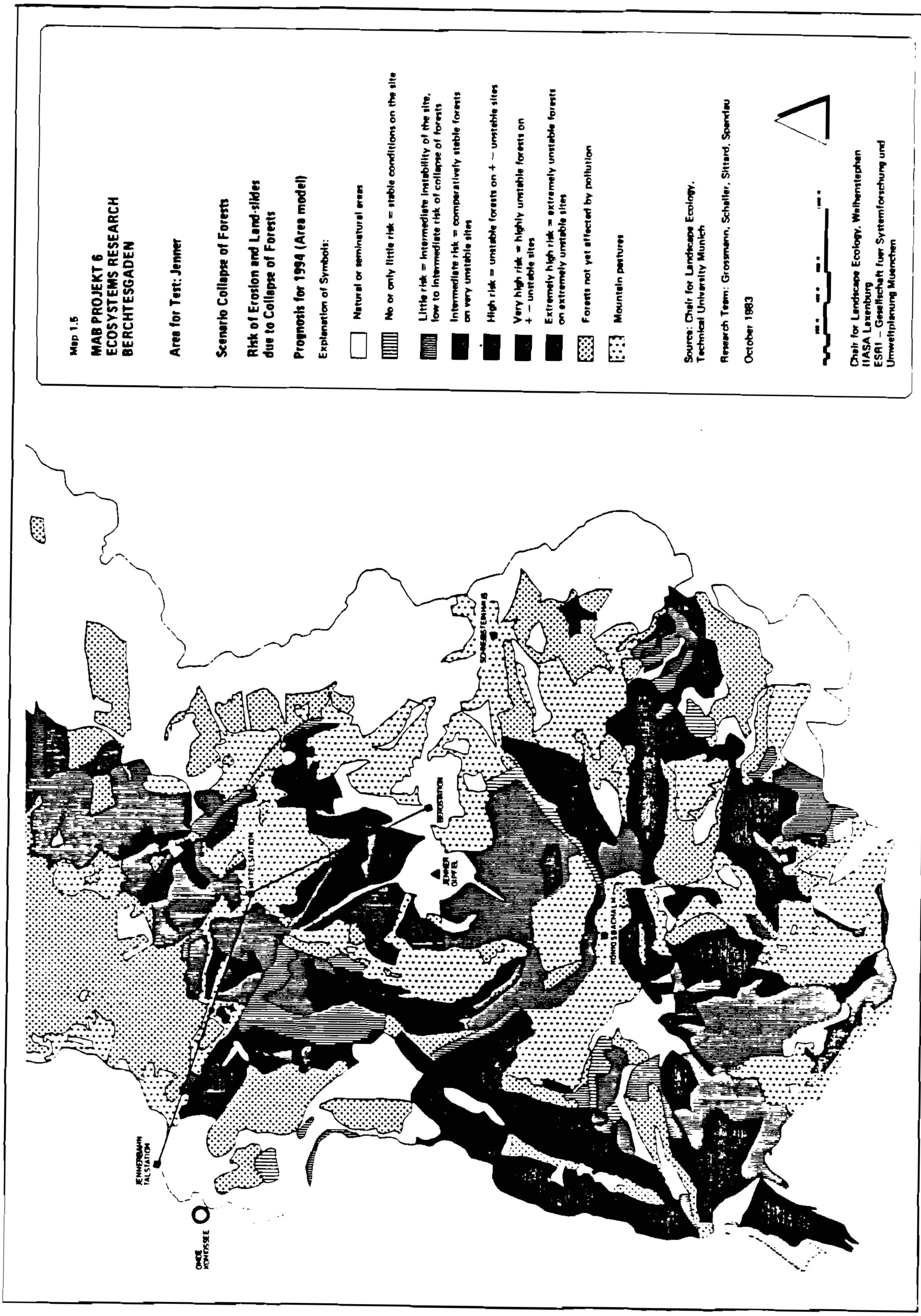

Map 1.4
MAB PROJEKT 6
ECOSYSTEMS RESEARCH
BERCHTESGADEN
Area for Test: Jenner
Scenario Collapse of Forests
Risk of Erosion and Land-slides
due to Collapse of Forests
Prognosis for 1989 (Area model)
Explanation of Symbols:
Natural or seminatural areas
No or only little risk = stable conditions on the site
Little risk = intermediate instability of the site, low to intermediate risk of collapse of forests
Intermediate risk = comparatively stable forests on very unstable sites
High risk = unstable forests on + — unstable sites
Very high risk = highly unstable forests on + — unstable sites
Extremely high risk = extremely unstable forests on extremely unstable sites
Forests not yet affected by pollution
Mountain pastures
Source: Chair for Landscape Ecology, Technical University Munich
Research Team: Grossmann, Schaller, Sittard, Spandau
October 1983
Chair for Landscape Ecology, Weihenstephan
IIASA Laxenburg
ESRI – Gesellschaft fuer Systemforschung und Umweltplanung Muenchen
JENNERBAHN TALSTATION
MITTELSTATION
BERGSTATION
JENNER GIPFEL
SCHNEIBSTEINHAUS
KÖNIGSBACHALM


Map 1.5
MAB PROJEKT 6
ECOSYSTEMS RESEARCH
BERCHTESGADEN
Area for Test: Jenner
Scenario Collapse of Forests
Risk of Erosion and Land-slides due to Collapse of Forests
Prognosis for 1994 (Area model)
Explanation of Symbols:
Natural or seminatural areas
No or only little risk = stable conditions on the site
Little risk = intermediate instability of the site, low to intermediate risk of collapse of forests
Intermediate risk = comparatively stable forests on very unstable sites
High risk = unstable forests on + – unstable sites
Very high risk = highly unstable forests on + – unstable sites
Extremely high risk = extremely unstable forests on extremely unstable sites
Forests not yet affected by pollution
Mountain pastures
Source: Chair for Landscape Ecology, Technical University Munich
Research Team: Grossmann, Schaller, Sittard, Spandau
October 1983
Chair for Landscape Ecology, Weihenstephan
IIASA Laxenburg
ESRI – Gesellschaft fuer Systemforschung und Umweltplanung Muenchen
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MITTELSTATION
BERGSTATION
JENNER GIPFEL
KÖNIGSBACHALM

The Geographical Information System or other low-layer approaches, however, cannot themselves generate the development of the crucial variables depicted in Figure 5 because too many areas are interacting and only very general information is available. For example, the levels of SO_2 and of all other pollutants can certainly not be measured throughout time in all relevant parts of the geographic area, which will be mapped. In particular, the "factor x" cannot be measured, as it is not known. But most probable, also "factor x" satisfies the general principles of deposition, etc., as expressed e.g., in the deposition factors. Therefore, dynamic hypotheses on the development of these levels must be generated on a more aggregated more holistic layer to bridge this gap in knowledge and to provide general indications, what levels of pollutants influenced the system at different times.

— Generate an equivalent set of maps for the hypothesis that photo-oxidants are responsible: To make this hypothesis testable, those areas are depicted, which are blocked to all long-range transport by mountains, but are high above sea level so that the more intense UV radiation from the sun leads to a locally higher ozone level and where car traffic is heavy, so that NO_y concentrations are high.

The foresters can take say twelve such sets of maps for twelve different hypotheses and can directly compare these maps with the actual developments in the forest, the actual state of the forests, and also compare with the observations from the last six years. It is known where the first damages occurred and how they proceeded. In this way, both become testable: the aggregated dynamic model and the different hypotheses. If no reasonable fit is observed, either all hypotheses are irrelevant for this particular situation, or the aggregated model has provided a wrong overall picture.

Still, it would be unreasonable to say if there is a good fit between one hypothesis and the actual development, that this was a validation for the hypothesis and the aggregated model. But such a fit is a good indication that this hypothesis should be further pursued. See the following paragraph on monitoring of control policies. This combination of an overall dynamic scene provided by aggregated feedback models, with maps detailed in space, species and other criteria, is a considerable improvement to what could be done without this combination:

- aggregated models on their own are often not applicable, because details, crucial for planning, are not available
- detailed evaluations on their own often cannot handle the overall scene, so that sometimes the most important developments are neglected because they happen outside of the necessarily very narrow scope of the detailed considerations. Also, a policy, after implementation, usually has many other effects than just the intended. Only, necessarily aggregated, feedback models can trace and anticipate at least some of these feedback effects.
- And this tracing of the feedback effects is the next possibility of the combined approach: Monitoring of the success of pollution abatement is greatly facilitated. Very specific advice can be given to explore the situation, e.g., recommendations can be made, where first to install scrubbers in power plants to produce the most easily testable consequences, or which roads should be blocked for car traffic to find new clues in the evaluation of the photo-oxidants hypothesis.

In particular, the recommendations should aim to reduce those emissions, for which a good fit between the hypothesis and the actual development was found with the aforementioned set of maps. Because immediate actions are necessary and the uncertainty is so high, the pollution control actions must be staged as a large-scale test. The monitoring and evaluation of these policies is first done with the aggregated models mentioned before (but changed to accommodate for these policies), and the disaggregation into local details is done with the Geographical Information System just in the way as described before. The maps are produced say one or for every three or six months to support monitoring. Also, it is acceptable and reasonable that the pollution control policies are implemented in such a way as to provide additional tests on the complex of pollution because not all intended pollution control can be done simultaneously.

(iii) The use of the highest layer approaches has led to the insight that the problem of pollution and forest damage will be very persistent, but these approaches also help to find out where connections can be cut most effectively to decrease synergisms, both known as well as unknown and possibly dangerous. (High smoke-stakes, for example, have brought about many synergisms.)

This application in the MAB6 Berchtesgaden Project is done in close collaboration with the group for landscape ecology (Schaller, Haber, TU Weihenstephan, Munchen), and ESRI (Environmental System Research Institute, Sittard, Munchen). They have developed the geographical data bank. The basic ideas for the synthesis first came up in a regional planning project (Vester 1979, Grossmann 1979, Vester and von Hesler 1980) the feedback models were developed by the author, the details of the coupling were developed with the Munchen groups. The idea to proceed with control policies in such a way as to support monitoring and learning, was brought up by Walters (1982). Now maps exist for half a dozen hypotheses; the first maps based on hypotheses were produced for the SO_2 hypothesis. With a synergestic hypothesis, depicting impact on forests by photo-oxidants, other air pollution and soil pollution, a better than 95% fit to reality was achieved for 95 forests around the small industrial town of Pfaffenhofen/Ilm in Bavaria.

Multifaceted problems are quite common in complex systems. Therefore the hierarchical synthesis has a wide applicability.

In addition to the synthesis in approaches usually also a synthesis of issues is necessary on the intermediate layer. In the complex of "acid rain," for example, the following areas are interacting:

- population (use of cars, generation of pollutants, attitudes opposed to or in favor of pollution control policies)
- the field of knowledge (with respect to technologies, efficiency in use of resources, knowledge on pollutants and synergisms)
- ecology (resistance of the forests, management of biosystems, sustainability, fluctuations, diseases and pests, etc.)
- economy (generation of pollution, adopting or rejecting pollution abatement policies, introducing new technologies, spreading to new geographic areas and slowly abandoning older areas)
- resources (land, land-use, characteristics of energy resources (low or high sulphur content, etc.), substitutes for forest resources)

Synthesis of issues can be done most effectively by integrating feedback models on intermediate layers. E.g., most of these areas and some of their more important interactions are depicted in the Framework model.

The synthesis between issues and methods outlined so far is summarized in Figure 7.

3.2.2 Scale and the Hierarchical Approach

The ekistic matrix of biosystems and human systems (Figure 1) gives an overview over systems according to scale. In the main diagonal the most important combinations of biosystems and human systems are listed. Multifaceted problems as summarized in Figure 7 can be found in each of the sys-

Methods/ characteristics	Issues/Areas Knowledge - know-how - technology - experience	Population - human ecology - attitudes - skills	Economy - cycles - innovations - capital	Ecology - forests - agriculture - pollution - sustainability	Resources - land - minerals - energy
Uncertainty - structural - in data	Viability/resilience approaches H. Odums (1977, 1983) "embodied energy"				
Wide inter-dependencies Feedback loops Delays Uncertainty in data Knowledge of structure	Holistic aggregated feedback models Balances in materials, energy, liquidity, etc. Layer of synthesis in issues				
Coping with vast amounts of details - precisely - quickly	Statistical evaluations Data banks and other information systems Large scale LP, DLP Heuristic optimization Automatic control Multistate (transition) analysis				

Figure 7. Summary of the synthesis between issues and methods, which is often necessary in problems in human ecosystem. This is a synthesis for multifaceted and holistic problems.

tems in the main diagonal:

There are first facets stemming from areas and issues because each of the areas of Figure 7 is a part of all these systems. This is even true for the smallest systems in the main diagonal, the farm, or the agroforestry or silvicultural unit. It is also true for almost all global problems (e.g., climate).

Second, there are facets stemming from characteristics of the problems, because structural uncertainty is widespread (e.g., in climate) (to be treated on the highest layers), as there are uncertainties in the reaction of the outside (to be treated on intermediate layers), as there are facets characterized by vast amounts of details (to be treated on the lowest layers).

Therefore, the same hierarchical synthesis (the same tool) can be used for many problems in each of the systems in the main diagonal (and for systems in the first column and in the first row of the matrix) in spite of their differences in scale. However, depending on scale, the same piece of information can have quite different meanings. Routine decisions, made on an intermediate layer of a large system (corporation, city, federal state), can pose strategic risks or opportunities for a smaller system. That is, the same issue may affect different layers of different systems, in particular, if they are different in size. Also, the same event may be answered by routine reactions by a large system, but by strategic decisions by a small system (e.g., the reaction of two corporations of different size to compete for an order).

Figure 8 summarizes this sometimes relativistic character of information (see also the work by Jumarie, i.e., Jumarie 1979).

3.2.3 Synthesis of Approaches in Scale with Hierarchic Approaches

The relativistic character of information is the basis for a synthesis of approaches in scale with hierarchic approaches.

Although the same hierarchic approach outlined so far may be appropriate for all systems $S_{k,k}$ in the main diagonal of Figure 1, the characteristics of relationships between systems in this matrix may change with scale.

The strategic (highest layers) issues of smaller systems $S_{k,k}$ are often (partially) originating from systems $S_{p,q}$ with $p,q \geq k$ and not $p=q=k$. If a problem refers to a system A, which within the ekistic matrix S belongs into th field $S_{p,q}$, then the intermediate layer problems of A partially originate from systems located in fields $S_{p',q'}$ with either p' or q' a little bit greater than p or q, respectively, say,, $p+1 \leq p'$, $q+1 \leq q'$. And the strategic issues of A partially orignate from systems located in fields $S_{p'',q''}$ with either p'' or q'' markedly greater than p or q, respectively, say $p+2 \leq p''$, $q+2 \leq q''$. Therefore, many of the issues of A can conveniently be discussed with right and lower fields of the the ekistic matrix S because S provides a comprehensive frame for analysis of issues depending on scale.

Zeigler (1979) gives a theoretical treatise of multifaceted problems, and Elzas and Zeigler (1983) deal theoretically with "adequate" modeling of systems.

3.2.3 Synthesis by Scenarios

Feedback models are tested and evaluated with methods such as "extreme parameter" test, policy tests, reference mode tests, etc. (About 30 methods are described in Forrester 1973, Forrester and Senge 1978, and Holling 1978 — Holling speaks about "invalidation"). But where do the extreme values, the policies and the reference modes do come from? How can they be made consistent? Scenarios provide a frame for evaluations of feedback models. But how to generate scenarios and make them consistent?

According to the principle of "priority of action," (high layer) considerations on viability/resilience and the right and lower fields of S should be

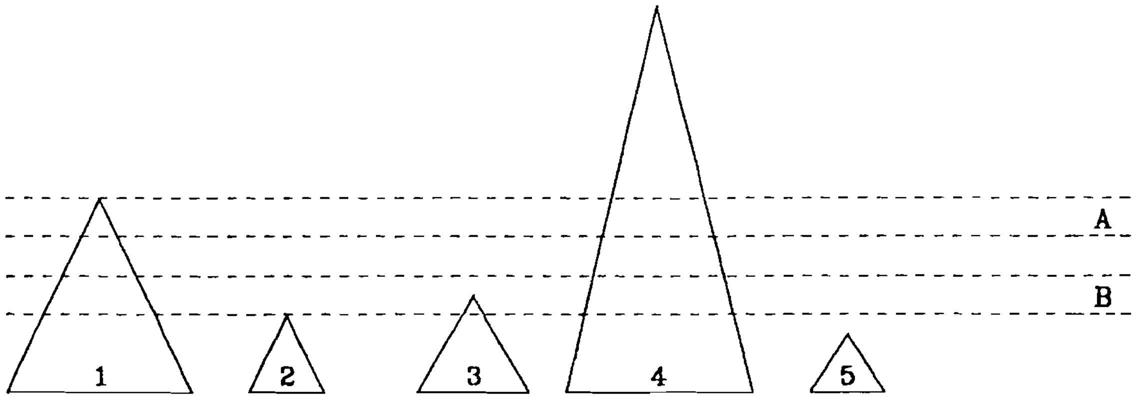

Figure 8. Relativistic character of information, certainty and uncertainty.
Here a strategic issue of system 1 (the layer marked A) is an only intermediate layer issue of system 4; and an intermediate layer issue of system 1 (marked with B) is a strategic issue of systems 2, 3 and an operational layer issue of system 4. System 5 rests in a niche.

exploited to derive scenarios to drive intermediate layer feedback models. Viability is achieved with a "reasonable" diversification (e.g., by portfolio analysis), more general with a "reasonable" variety and with a "reasonable" dependence of the system on its outside environment, and with about four other strategies including the use of (subsystems with) erratic behavior to keep the system vigorous and adaptable. Each scenario may affect a feedback system simultaneously at several or even many points. Affected are parameters of the model, or (nonlinear) functional relationships, or branching points in behavior. Also, exchanges of variables or subsystems of the model may be necessary. Some examples of the scenario generation by the viability concept are reported in Grossmann (1983). Theoretical concepts applicable here are the "second order cybernetics" or "cybernetics of cybernetics" (von Foerster 1975, Dobuzinski 1980), Vester's "sensitivity analysis" and "biocybernetic rules" (Vester and von Hesler 1980, Vester 1976, 1980), or Prigogine's (1972, 1976) concepts, Bossel's (1977) survivability and Holling's (1978) resilience (whereas usual cybernetics refer to the intermediate layers).

Scenarios help to test feedback models. But how can the scenarios themselves be tested? The viability and the ekistic approach can be used to generate scenarios and to make them more consistent. However, scenarios cannot be validated as the structural uncertainty is an inherent feature of the highest layer, and there are good reasons to assume that this feature is even necessary for viability. Therefore usually several different scenarios are used.

3.3 Applications

The ideas developed here came out of the necessities of applications, and they are now applied in several projects. The forest damage aspect of the MAB6 Berchtesgaden project was outlined in 3.2.1. Within this project, there will be applications of a model on forest, population, and environment ("framework model") and of the Geographical Information Systems to quite different areas, for example, problems in tourism.

Scientists from the "Bureau for Systems Analysis" (Budapest, I. Lang, H. Zsolt, I. Valyi, F. Todt, T. Asboth and many more) developed a large scale dynamic LP model on the possibilities of increasing scale and the intensity of use of biological renewable resources (Lang and Harnos 1982). They also implemented the Framework model for Hungary (mainly I. Valyi and F. Todt). Now a synthesis will be started.

At IIASA, B. Clemens (1983) evaluated detailed data on Austrian women with the multistate analysis with respect to transitions such as from married to divorced or widowed state, or changes in the number of children. Multistate analysis is a typical lower layer method, which in Clemens' work was linked with a long-term dynamic feedback model on secular trends with respect to liberation of women, etc.

With planners in Munchen a project is underway to develop new combined agricultural-silvicultural approaches to yield higher quality products, supported by the hierarchical synthesis, based on the Geographical Information System and made available to the local managers with "Teletext" (a simple type of telecommunication).

SUMMARY

In problems in human ecosystems, approaches can be based on scale, issues and methods. Considerations on scale are facilitated with an ekistic matrix. Methodologies for multifaceted problems are integrated with a hierarchical scheme. Interdependencies between elements (from different areas) are depicted in aggregated feedback models, this simultaneously is an integration of areas.

The synthesis between approaches based on scale and the hierarchical approach helps to evaluate the outside environment of a system. Synthesis of approaches provides very powerful new tools, which lead, for example, to new possibilities in the problem area of pollution and collapse of forests. At present, other applications are being pursued.

In particular, in the synthesis approaches aiming at viability can be combined with approaches aiming at holistic representations and with approaches aiming at precise detailed representations.

This synthesis can remove many of the weaknesses of the individual approaches and therefore turned out to be highly applicable and effective.

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