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MACROLEVEL ECOSYSTEM MODELS IN RELATION TO MAN: A PRELIMINARY ANALYSIS OF CONCEPTS AND APPROACHES

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for

Macromodelling Task Force[1/]

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1/ The 15 members of this group are identified in Appendix I on page 42-45. Financial support for their participation was provided by the biome studies of the U.S. International Biological Program and by separate support from the National Science Foundation.

SUMMARY

Man now accepts that he is both part of, and a manipulator of, ecosystems and that such systems are the basic units in renewable resource management. Ecosystems, however, can be considered simple subsystems of biomes. Biomes, in turn, can be combined into regional systems and regional systems into national systems. Through these increasing spatial scales one enters different components into the macrosystem--abiotic, biotic, economic, sociologic, and politic. Understanding the structure, function, and stability of ecosystems is important in affecting and varying the determinants of quality of human life. Quality of human life is reciprocally related to changing human attitudes towards uses of the resources of the biosphere. Man finds increasing need to be able to predict the ways his manipulations will affect the behavior of these complex biotic-economic-sociologic systems. His predictions must be by means other than simple contemplation, discussion, argument, or guesswork because these procedures, which may be adequate for simple systems, are inadequate for complex systems. Recent advances in mathematical modelling and computer technology, because they are more complete than is intuition alone, can provide outputs useful to the decision-making process.

Several needs and types of large-scale or macromodels are recognized. Output from solutions of these models can enable scientists, managers, and decision makers to examine the future consequences of systems manipulations and potential policy alternatives. We have identified 8 major types of uses of such macromodels and 13 major user groups. Categories of uses include scientific, resource management, and human resource. Categories of user groups relate to the time at which the models may be utilizable, i.e., short-range, medium-range, and long-range. User groups include scientists involved in integrated ecological research programs, program planning office personnel, natural resource management agencies, international planning agency programs, educational institutions, international investment and advisory groups, and other groups including legislators and the general public.

Eight major problems related to prospective advances in ecological and systems science, resource management systems, and human resource systems are identified: (*i*) techniques for modelling the interactions between biomes and the linkages between ecosystems and social systems are barely available; (*ii*) a macrolevel synthesis of biome or microsystem models has yet to be attempted; (*iii*) the macrosystem models useful for the assessment of environmental impact and the evaluation of environmental impact statements are not available; (*iv*) the dialog which must precede the establishment of data banks and models in the socioecological area has not yet begun in earnest; (*v*) macromodels that effectively address practical management problems in the natural resource area are not widely available; (*vi*) advances in scientific and management processes are inadequate without edification of resource managers, and inadequate training represents a significant impediment; (*vii*) macrolevel models will not achieve their ultimate potential of improving man's existence unless the present gap in providing the public and its various constituents information from the models can be overcome; (*viii*) the implications of a national population growth strategy, land use policy, new town program, or other such programs are unknown.

Six broad recommendations regarding macromodelling are identified: (*i*) the holistic, macromodelling approach toward the solution to environmental problems should be accepted in principle; (*ii*) an interdisciplinary task force should be mobilized to review, critically abstract, index into a functional framework, and document existing macroscale models; (*iii*) a national macroscale model should be developed using inputs from the U.S. IBP programs with the objective of advancing our understanding of macromodelling techniques; (*iv*) projects should be undertaken to demonstrate the potential of using ecosystem models to aid in evaluation of environmental impact statements and management manipulations of natural resources; (*v*) efforts should be initiated to examine alternative ways to bridge the gap from basic ecological research outputs up to regional and national political systems and to include societal feedbacks; and (*vi*) structure of, and output from, macroecosystem models should be explained to various educational and public groups from which feedback should be elicited.

This report, developed in a workshop format by a 15-man task force, also provides minimal time and cost estimates and procedural suggestions for accomplishing some of the tasks outlined. Specific attention is given to clarifying concepts of hierarchies of models and to providing a skeleton outline for a national modelling effort, based on biome and non-biome efforts both, to investigate the impact of abiotic factors, population growth and shifts, and land use policies on the production of food and fiber in the United States.

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I. INTRODUCTION

The stresses and strains that our society imposes on the environment and our biological support systems are all too obvious. The daily press details the lashes and backlashes struck and delivered by "environmentalists, corporations, labor, and government." The best of these thrusts and parries are, nonetheless, motivated by similar aspirations to better mankind's lot on earth, *to increase his measure of well-being*, his quality of life.

As we continue to increase our use of both renewable and nonrenewable resources and attempt to better our lot, we are faced with many problems. Society finds that in many instances the impact of our technological manipulation of the environment is not predicted correctly. Man often finds that "quality of human life" may not increase, but instead decreases in many instances. Debate then shifts to today's and tomorrow's determinants of well-being and quality of life. We ask whether to sustain physical growth at the possible risk of severe costs in environmental quality in the future or to begin limiting the accumulation of material goods now at the expense of shifting aspirations for a better tomorrow.

Determinants of human well-being include physical resources (such as nonrenewable minerals), and energy, and the interpersonal and cultural resources of society (ranging from the family structure to the nation-state structure, from love and friendship to art and religion). Many of the *determinants of man's well-being are related back to renewable natural resource* systems. Increasingly we recognize that the basic unit of management of natural resource is the ecosystem, or more specifically, man-occupied complexes thereof. We accept now that man is both a part of, and a manipulator of, ecosystems.

In order to manipulate systems for man's purposes without significant long-term deterioration, man must consider himself as part of the system, and he must integrate information from many disciplines. Such complex systems contain many components--*abiotic* (meteorological, edaphic, ...), *biotic* (plants, animals, ...), and *cultural* (economic, sociologic, political, ...). We also need to consider changing societal attitudes towards man's role in manipulating the environment.

Man has found that used alone the usual intuitive decision-making practices may be inadequate for developing long-term strategies, or specific tactics for maintaining complex physical-biotic-cultural systems in perpetuity. These inadequacies stem in large measure from the *presence of complex system feedback processes*, i.e., the causal paths by which the various system components interact. Feedbacks within models provide the linkage between man's value system, resource managers, and the long-range stability of renewable resource systems. Almost by definition, intuitive planning has a short look-ahead time horizon. But in dealing with complex systems a long time look-ahead may be required to isolate the cause of a problem and to obtain solutions.

Until recently there has been no way to predict the behavior of complex systems except by contemplation, discussion, argument, or guesswork. Although these approaches are often effective and may be adequate for simple systems, they are inadequate to explore the myriad of potential responses to intuitively useful manipulations of our resource support system, including man. Utilizing a number of recent advances in mathematical modelling, it is now possible to develop macromodels of complex systems. Through the use of computer simulation we can now solve these models and study the apparent response patterns to a variety of stresses to, or manipulations of, the system.

Macromodels developed and used in the above way would serve at least two important purposes:

i. They are themselves expressions of the relationships between biotic and abiotic components of ecological systems and so comprise theories of system structure appropriate to understanding the man-resource relationship.

ii. They are also useful tools for the analysis of management decisions.

The output from various solutions of the models, under different degrees of human intervention, can aid scientists in formulating and understanding ecological theory. Such models also enable the manager or decision maker to examine the future consequences of his potential policy alternatives. The output from the models is particularly useful as input into the decision-making process because it is *more complete than intuition* alone.

Macromodels of the form contemplated in this report will have to be developed from many individual submodels, and the submodels in turn will have to be interlinked. The submodels should be based on and tested against good data. Although voluminous data are available on many of the processes and variables needed in the various submodels, the data may not be of direct or immediate utility to the development or testing of macromodels. Specialists from many fields will be needed to find, screen, and refine the data to build and validate some new submodels as well as to construct the macromodels.

Many large-scale integrated research programs are in progress which include multidisciplinary teams cooperating in data collection, analysis, and modelling phases--all providing results eventually leading toward policy suggestions. Several projects of the U.S. International Biological Program (IBP) include study of the physical and biological components of ecological systems and the impact of man on them, e.g., the "biome" studies. Several other major projects, supported by various foundations, are concerned with economic, social, and political systems--including the System Dynamics group at Massachusetts Institute of Technology, the Resource Science Center at the University of British Columbia, and numerous others.

On the basis of the above rationale this report attempts to *provide a framework for, and recommendations toward, developing macromodels* combining the skills and outputs of the integrated systems modelling efforts already underway in numerous disciplines. We found it useful to examine first the classes of uses and users of model output. Then we specifically address concepts and problems in three general areas--scientific, resource management, and human resource uses. These analyses lead to several recommendations, including specific research that should be undertaken immediately and in the longer term. These recommendations are addressed to all individuals concerned with research and management policies stemming from the current advances in systems science as it applies to man, his natural resources, and the man-resource relationship.

II. MACROMODELS OF ECOSYSTEMS: USERS AND USES

A. A Table of Resource Goals and Users

In proposing an activity which looks toward the future, one should examine the goals of that activity in relationship to its anticipated users. In proposing modelling, one must examine the uses to which the models may be put. Furthermore, it is useful to indicate the minimum time within which a user can make a major use of a model.

The task group has identified *13 major categories of users* of models, which are listed and described briefly in Fig. 1, and these are grouped into short-term, medium-term, and long-term. The several uses of the proposed models are given as the *8 columns of uses*--grouped as "scientific uses," "resource management uses," and "human resource uses." The asterisks throughout the table indicate those areas where the match of user to use is greatest. The table entries are not meant to be exhaustive. The rationale of preparing such a table of anticipated users and uses of innovations in macromodelling is threefold:

i. It serves as a means of considering systematically the entire range of user groups and agencies that will have a need for the output of models contemplated in this report.

ii. It provides a means of examining the applications each user will make of modelling in the near future, over the medium time range, and into the distant future.

iii. It provides a means of aggregating from the several categories of users and uses three broad user-use categories which are examined in the remainder of this report.

The recommendations for research in section VI are those most likely to generate the progression of modelling applications represented in Fig. 1.

Scientific users and uses. Ecological and systems scientists can develop a better theory of ecological systems from a modelling effort. A model actually is a way of organizing information about and interrelationships within an ecosystem and *a model is itself an expression of ecological theory.* Systems scientists can also develop the techniques of modelling linkages between special microsystem models by moving towards a macrosystem modelling effort. These uses will be important at once to programs and agencies 1 to 5 in Fig. 1 and should impact on educational institutions within the next decade.

PROCESSES

Group	Process	1	2	3	4	5	6	7	8	9	10	11	12	13
GROUP III HUMAN RESOURCE USES	8. To explore alternative and emerging societal attitudes, particularly those concerned with man's relation to the biosphere.								*	*		*		*
	7. To provide support in programs most directly concerned with human well-being.								*	*			*	
	6. To assist in preparation of population and settlement policy and evaluation of changing land use patterns.					*			*	*		*		
GROUP II RESOURCE MANAGEMENT USES	5. To guide decisions concerning land uses and other resources.	*	*		*	*	*							
	4. To prepare guidelines for resource management.				*				*		*			
	3. To prepare assessments of unplanned and inadvertent environmental impacts.				*	*		*	*					
GROUP I SCIENTIFIC USES	2. To establish a theoretical basis for Ecosystem Analysis.	*	*	*			*							
	1. To investigate linkages among specialized and hierarchical models.	*	*				*							

SHORT-RANGE USERS (1 year ± 6 months)

1. INTEGRATED ECOLOGICAL RESEARCH PROGRAMS, including modelling efforts both in and outside IBP (e.g., AOE Studies, Hubbard-Brook).
2. PROGRAM PLANNING OFFICES located in federal, state, or private foundation agencies (e.g., OST, NSF, Ford Foundation, etc.).
3. ADMINISTRATIVE OFFICES OF NATURAL RESOURCE MANAGEMENT AGENCIES concerned with advance program or budget plan (e.g., Dept. of Agriculture, Dept. of Interior).
4. INTERNATIONAL PLANNING AGENCY PROGRAMS, including intergovernmental and nongovernmental organizations (e.g., MAP, SCOPE, The Conservation Foundation).
5. PLANNING SYSTEMS--STUDIES Personnel involved with the analysis, synthesis, and demonstration of alternative land allocation policies (e.g., Wisconsin Task Force on State Land Use Planning, New England Regional Commission).

MEDIUM-RANGE USERS (2-10 years)

6. EDUCATIONAL INSTITUTIONS both formal and informal, specializing in modelling and ecosystem science (e.g., high schools, universities).
7. FEDERAL AND STATE OPERATING AGENCIES required to prepare environmental impact statements (e.g., AEC, Corps of Engineers, Federal Power Commission).
8. PLANNING SYSTEMS--REGIONAL Personnel involved with operational aspects of decision making on land allocation problems--state or interstate (e.g., TVA, New York Port Authority, Delaware Valley Regional Planning Commission, New York State Urban Development Corporation.)
9. PLANNING SYSTEMS--NATIONAL Personnel involved with operational aspects of decision making on land allocation problems--National Land Use Policy (e.g., FAA in airport location, DOT in highway location, Legislative Reference Service).

LONG-RANGE USERS (10 years +)

10. NATURAL RESOURCE MANAGEMENT AGENCIES OR FIRMS Operational offices making day-to-day decisions (e.g., Forest Service, Bureau of Sport Fisheries and Wildlife, American Petroleum Institute).
11. INTERNATIONAL RESOURCE MANAGEMENT AGENCIES OR FIRMS dealing as an international body to manage a resource (e.g., Tuna Commission, International Potash Association).
12. INTERNATIONAL INVESTMENT AND ADVISORY GROUPS (e.g., World Bank, AID, FAO).
13. OTHER USERS, including special interest groups, legislators, and the general public.

MINIMUM TIME WITHIN WHICH MAJOR USE CAN BE MADE.

Fig. 1. User/utilization analysis of macromodelling effort (* indicates a match between uses and users addressed in this document).

Natural resource management users and uses. Macrosystem modelling will benefit medium-range planning agencies by:

i. allowing the assessment of environmental impact and the evaluation of environmental impact statements,

ii. guiding natural resource management, and

iii. guiding land use.

The ability to assess and evaluate environmental impact should be an immediate result of modelling endeavors, whereas an improved ability to manage renewable and nonrenewable resources by the use of macroecosystem models should be available within the next decade. Scientific consideration of land use policies will require the integration of socioeconomic models with ecological models and will become available somewhat later.

Human resource users and uses. As the time horizon or geographical scale of models expands, their ability to encompass the social behavior as well as ecosystem function increases. This increased projective capacity of broad-range models will also demand new insights into the explanatory role of system structure. Among the medium-range and long-range goals of these models are:

i. population distribution and settlement policies,

ii. enhancement of the determinants of human well-being, and

iii. exploration of alternative societal values and attitudes, especially the values and attitudes concerned with the relation of man and the biosphere.

B. An Integrated View

The proposed programs will generate a *hierarchy of ecosystem models* (see Appendix II for a discussion of the utility of a hierarchy of models in the context of the modelling objectives), possibly coupled with hierarchical models of the economic, sociologic, political, and natural resource systems and having a highly developed "zoom capacity." By zoom capacity we refer to the ability of the final models to focus on relatively small portions of the system with quite high resolution as well as to consider the overall system. This activity is identified as *Task 1* (Fig. 2). Outputs of this hierarchy of models can be in either of two categories:

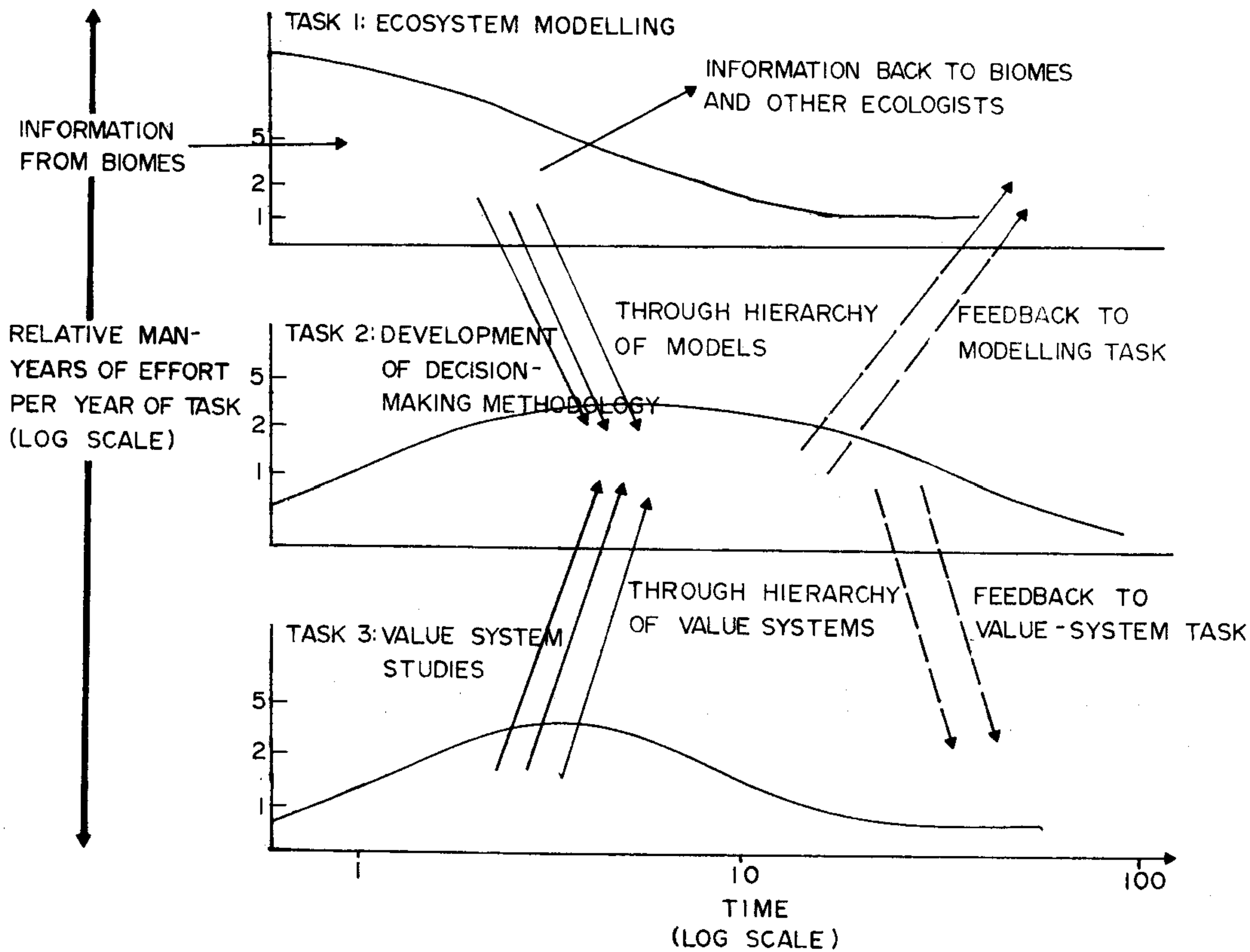


Fig. 2. Relationships among tasks related to macroscale modelling. Vertical scales indicate relative man-years of effort per annum on each task by the heights of the figures; the horizontal scale indicates the time required for completion of the tasks.

i. information for the use and decision-making processes or

ii. advancement in the state of knowledge.

The above discussion, particularly the material in Fig. 1, relates to eight uses of an effort not yet thoroughly described. In effect, then, these types of uses (scientific, resource management, and human resources) are broad objectives of the programs which are being considered. These programs relate to "macrolevel" ecosystem models, with man both a manipulator of factors in the model and a component of the models. Most of the activities of the proposed programs will influence the two above categories of output, either directly or indirectly. For example, information needs exist at many levels of organization. This requires that model outputs be provided at many levels of organization. The development of models, variable in scope and organization levels (zoom), is needed to further the understanding of ecosystems so that the development of model structures to this end will serve both objectives. The fact that model structures constitute theory about ecosystems means, in a sense, these objectives are inseparable.

An aspect of the modelling program that deserves particular attention is the conceptualization of external variables at the various levels. The so-called *emergent properties* of systems also are of considerable importance in this synthesis approach. These are properties of the systems which are not apparent from consideration of the components of the system. An example of an emergent property might be the stability of an ecosystem. This stability may not be characteristic of the components of the system, and stability analysis cannot be carried out by examining only individual components. One of the present difficulties in preparing statements of ecological consequences is the absence of clearly defined and understood terms for describing immediate and higher levels of organization and wider scope. Development of such terminology is a high priority item.

Ecological information used in decision-making processes is sometimes descriptive, but for predictions model building is needed. This *predictive requirement dictates a quantitative data base* which often necessitates the establishment of scales for variables normally not quantified. If we restrict ourselves to ecological models, most of this information can be put into the framework of prediction of the ecological consequences of man's activities.

The following case examples are identified, but are not intended to be mutually exclusive or exhaustive:

i. consequences of pollution (effluents, etc.),

ii. consequences of changes in land use (agricultural to urban, etc.),

iii. consequences of public works (dams, highways, etc.),

iv. consequences of technological practices (agricultural, chemical, etc.),

v. consequences of public policy and regulation (fishing regulations, etc.), and

vi. consequences of behavioral changes (Zero Population Growth, etc.).

Task 2 (Fig. 2) is identified as the development of the methodology and strategy of making environmental decisions. This involves specification of the predictions to be made to evaluate a particular activity and the evaluation of these predictions in terms of the value system (*Task 3*, Fig. 2). This also involves a strategy for identification of ways in which a plan might be modified leading to or from new predictions and evaluations (Fig. 3).

Task 3 is the analysis and use of a value system so that it is possible to generate an objective function for each possible hierarchical form of the predictive model (*Task 1*). This leads effectively to a hierarchy of value systems (objective functions). These in turn provide inputs to the decision-making process (*Task 2*, Fig. 2). Note *values are essentially policy parameters or assumptions* in the models. But explicit provision must be made for their inclusion in many models. The relative units given to different values will vary widely with different users.

Because of the important interlinkages between the several tasks of Fig. 2, it is important that they be initiated and conducted simultaneously. Yet, it must also be recognized not only in planning but also in the organization of the effort that progress in a given task may have to await developments in one of the other tasks.

C. Time Merging of Utilization of Output

As one proceeds from the short-term to the long-term of Fig. 1, the *columns within blocks will merge together* or become less distinct. This is

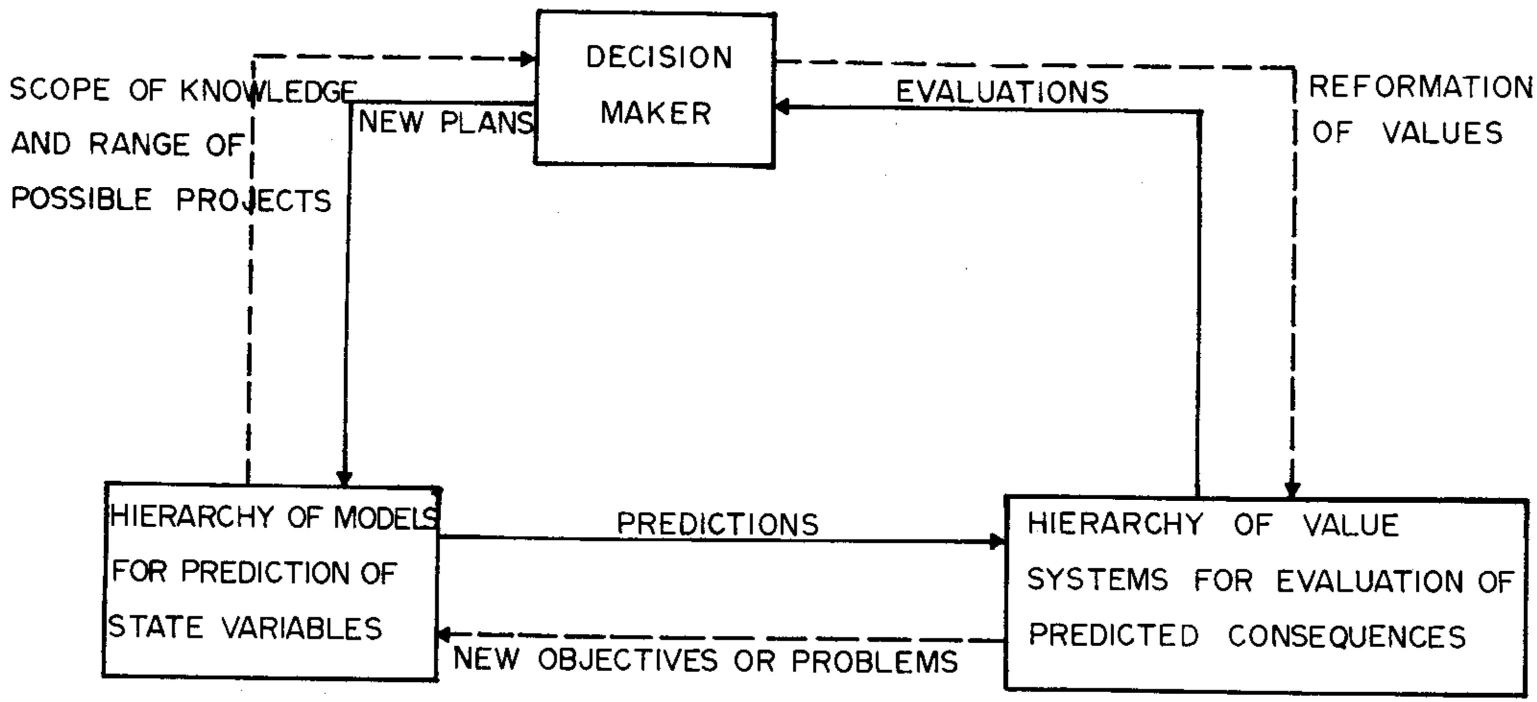


Fig. 3. The roles of a hierarchy of models and a hierarchy of value systems in the planning loop. Solid lines indicate the usual flow of information; dashed lines indicate how some elements of the system may modify the entire system. Information flows in both directions about this loop. Particular people may also assume more than one role in the loop.

most evident for the resource management set of uses (columns 3, 4, and 5). Another feature of Fig. 1 is that if there is a component of the short-range impact, it generally will carry into the medium- and longer-range user groups also.

Furthermore, in the long run we expect there will be a *gradual merging of the three groups of uses* that are identified as blocks in Fig. 1. This will perhaps come about through a merging of scientific uses with resource management uses, and finally these uses will become important in terms of the human resource component. We feel that *futuristic resource management will require models based on ecological subsystems* and will include provision for testing impacts of alternative value systems.

III. PROSPECTIVE ADVANCES IN ECOLOGICAL AND SYSTEMS SCIENCE

A successful macrosystem modelling effort will provide information and concepts that are not now being provided by current ecological research on microsystems (e.g., as within particular biome programs) by *integrating the principles developed at the microsystem level.* This integration will make explicit the feedback and interaction between these small systems and expand the time horizon and geographical range of the resulting models to accomodate man's impact on the macrosystem. These new concepts are expected to provide a revised prospective through which ecological research and scientific applications can be made more efficient.

PROBLEM: *Techniques for modelling the interactions between biomes and the linkages between ecosystems and social systems are barely available.*

See section VI, p. 33 and 34 for recommendations.

As an example, consider the possibility of bringing together the data on biological productivity available from within the separate biome studies into a national model of food and fiber productivity. Such a model, driven by population growth and climate and with a 2- to 3-decade time horizon could be used to explore the effects on biological productivity of climate modification, population growth, and population density.

The approach to such a model would begin by exploring the assumptions that *ecosystem processes everywhere exhibit a general and underlying similarity*, modulated by the physical environment and evolutionary history of the system. By integrating the principles developed at the microsystem level into a macrosystem model this assumption can be tested, and discrepancies in ecosystem behavior can be developed.

We shall call those models which are equally facile in dealing with macro- and microsystem structure and function "*macro-micro syntheses*"; these models represent a major advance in ecological and system science to be achieved through an interbiome modelling effort. Appendix II develops the concepts of hierarchical models in further detail, and Appendix III examines some elements of a national bioproductivity model.

PROBLEM: *A macrolevel synthesis of biome or microsystem models has yet to be attempted.*

See section VI, p. 33, 34, and 35 for recommendations.

On a still broader context, however, a national bioproductivity model could be expanded to include the population and other socioeconomic elements as endogenous variables. A full national model, merging ecological and economic concepts, could explore the effect of bioproductivity on gross population, as well as its distribution, and could examine the costs of food production and transportation in a dynamic, interactive framework or the competition between the population and food-fiber production for land. Fig. 4 illustrates the form such a macro-micro synthesis might take. The coupling between the ecologic and cultural sectors, as well as the degree of aggregation within each sector, is explicit. The *integration of ecologic with socioeconomic models will represent a major advance in general systems science.*

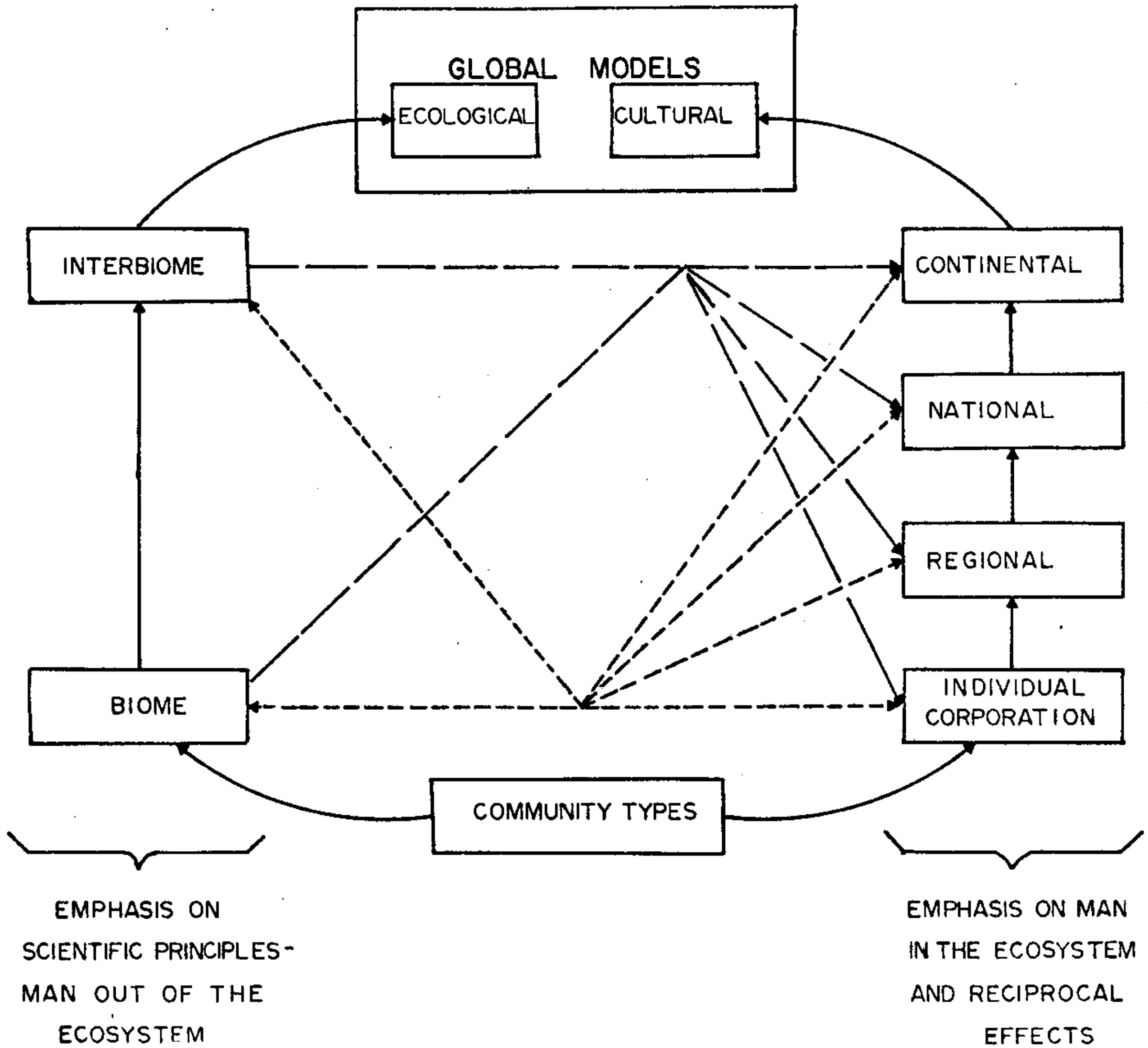


Fig. 4. Parallel hierarchies of ecosystem models. One path emphasizes the biological processes occurring in ecosystems. The other emphasizes more strongly the reciprocal relationships of man and ecosystems. Long dashed lines indicate how knowledge of biological processes can guide management; short dashed lines indicate how man's activities may perturb ecosystems.

IV. PROSPECTIVE ADVANCES IN RESOURCE MANAGEMENT SYSTEMS

A. Introduction

The National Environmental Policy Act of 1969 (NEPA) spells out broad goals and specific multidisciplinary procedures of large-scale developmental projects and other aspects of government policy. Environmental impact statements are expected to help responsible agencies *minimize those adverse impacts* and to *improve previous methods* of evaluating tangible and intangible costs as well as benefits. In other words, we seek the following:

Goal	*Objective Functions*	*Constraints*
Minimize	Environmental deterioration	Human needs
Minimize	Cost	Minimum deterioration

These brief notations summarize incompletely a complex series of evaluations which customarily use mathematical methods in economics and engineering, but which are just beginning to be applied to models of ecosystems. The increased scale of effort is emphasized by the *rising curve of the number of impact statements* indexed by the U.S. Government (Table 1).

PROBLEM: *Macrosystem models useful for the assessment of environmental impact and the evaluation of environmental impact statements are not available.*

See section VI, p. 36 for recommendation.

The models to which we address ourselves here include those developed to provide answers concerning:

i. *guides for improving normal management of resources*,

ii. *evaluation of environmental impacts* incidental to man's development activities, or

iii. *prediction of consequences of changes in policy of land use* and other resources.

Table 1. Summary of 102 statements filed with the CEQ through 11/30/71.

	Draft 102's for Actions on Which No Final 102's Have Yet Been Received	Final 102's on Legislation and Actions	Total Actions on Which Final or Draft 102 Statements for Federal Actions Have Been Received
		By Agency	
Agriculture, Department of	45	90	135
Appalachian Regional Commission	1	0	1
Atomic Energy Commission	27	24	51
Commerce, Department of	1	7	8
Defense, Department of	3	2	5
Air Force	1	3	4
Army	6	5	11
Army Corps of Engineers	149	265	414
Navy	6	4	10
Delaware River Basin Commission	3	0	3
Environmental Protection Agency	3	9	12
Federal Power Commission	14	5	19
General Services Administration	16	19	35
HEW, Department of	0	1	1
HUD, Department of	10	10	20
Interior, Department of	47	35	82
International Boundary and Water Commission--U.S. and Mexico	1	4	5
National Aeronautics and Space Admin.	16	6	22
National Science Foundation	2	0	2
Office of Science and Technology	0	1	1
Tennessee Valley Authority	11	2	13
Transportation, Department of	868	416	1284
Treasury, Department of	1	3	4
U.S. Water Resources Council	4	0	4
	1235	911	2146
		By Project Type	
AEC nuclear development	8	7	15
Aircraft, ships and vehicles	0	5	5
Airports	26	116	142
Buildings	0	5	5
Bridge permits	14	4	18
Defense systems	2	2	4
Forestry	2	4	6
Housing, urban problems, new communities	8	6	14
International boundary	4	2	6
Land acquisition, disposal	12	24	36
Mass transit	3	1	4
Mining	5	1	6
Military installations	11	3	14
Natural gas and oil			
Drilling and exploration	3	5	8
Transportation, pipeline	3	3	6
Parks, wildlife refuges, recreation facilities	9	14	23
Pesticides, herbicides	7	10	17
Power			
Hydroelectric	18	4	22
Nuclear	24	16	40
Other	15	1	16
Transmission	6	6	12
Railroads	0	1	1
Roads	702	273	975
Plus roads through parks	119	20	139
Space programs	6	2	8
Waste disposal			
Detoxification of toxic substances	4	1	5
Munition disposal	2	3	5
Radioactive waste disposal	1	1	2
Sewage facilities	2	5	7
Solid wastes	1	0	1
Water			
Beach erosion, hurricane protection	2	20	22
Irrigation	16	9	25
Navigation	39	94	133
Municipal and industrial supply	4	1	5
Permit (Refuse Act, dredge and fill)	7	0	7
Watershed protection and flood control	115	221	336
Weather modification	8	3	11
Research and development	13	6	19
Miscellaneous	14	12	26
	1235	911	2146

Data source: data from CEQ publication "102 Monitor," December 3, 1971.

These categories show increasing levels of manipulation, control, or influence by man of natural resource systems.

B. Adapting Models to Evaluation of Environmental Impacts

A gradual buildup in modelling methods has been in progress over several decades in many specialties concerned with managing environmental resources. Earliest models naturally focused on target populations rather than whole ecosystems. Essentially all agencies now realize the desirability of recognizing indirect influences as a result of man's activities on the populations or resources of their special concern. Simultaneously, they must foresee changes in other parts or values of the system which might be affected inadvertently by management decisions as well as by circumstances outside the manager's control. Some of these *decisions can be aided by methods of operations research* which involve mathematically expressing the objective functions of importance for man and the constraints which are imposed by man, by nature, or by both.

Traditionally, the manager's objective is to *maximize* some yield as well as to *minimize* damage:

Goal	*Objective Functions*	*Constraints*
Maximize	Products	Other uses
Maximize	Multiple uses	Natural and human limitations

Both expressions summarize an objective function conventionally measured in market values, but now often involving *both monetary (physical) and intangible values*--as in the case of environmental impact evaluation.

Resource management for many kinds of products may be involved in concerns of the type summarized in columns 4 and 5 of Fig. 1. Except for recognizing and then resolving the possible conflicts implicit in multiple use, the manager's decisions may continue along similar lines for a number of years. However, there may be trends as well as fluctuations over a several-year period. New needs arise, or minor objectives may rise in importance. *Changes in resource policy are then called for* as distinct from minor variations in management under a continuing policy.

This kind of change in policy is especially timely regarding changing land uses. Many natural resources depend closely on landscapes and water bodies which flow from the lands. The idea of policy change as well as the special complex of problems related to land are, therefore, given separate attention in column 6, Fig. 1.

C. Sequential Approach to Resource System Analysis

We do not mean to imply that the above objective functions can result in the immediate mathematical implementation of suitable management models. We recognize that some time must be allowed for orderly development of modelling before specific questions in the area of resource management can be answered. Thus, the objective functions identified above should be viewed in a time frame to allow consideration of the diverse inputs that are needed and the types of output which might be supplied in response to needs of specific users.

Within the short-range time span (Fig. 1), there are far more inputs needed than can reasonably be expected from existing models. *Cautious use* of some existing models can be made for selected environmental inputs, such as has been done in adapting a forest carbon cycle model to predict the persistence of DDT (O'Neill and Burke 1971). However, as defined in this report, most of the envisioned *ecosystem-level models are only beginning to be conceptualized*, much less implemented in a form suitable for resource management systems. The short-range needs must, therefore, concentrate on inputs that would allow progression toward implementation of hierarchical models. The applied science phase of the Lake Wingra project in Madison, Wisconsin, provides an example of early application of a drainage basin systems model to assessment of lake management strategies. Although still in the proposal stage, this work contemplates the comparison of controls for nutrients in storm waters from the city, using computer simulation to assess their effectiveness for alleviating lake nuisances and for making specific recommendations for management action by the city of Madison.

The stages or steps in management modelling include:

i. conceptualization of models which can directly answer questions about isolated responses to particular environmental impact;

ii. the establishment of appropriate feedback mechanisms to allow for continuous reassessment and revision to make the models responsive and realistic;

iii. preparation of both the data base and nested models in a holistic approach;

iv. direct inclusion of policy implementation and evaluation in modelling effort; and

v. education of potential model users to emphasize the limitations and dangers of misapplying a model, and to avoid these dangers, model users should be involved in the model-building process.

This is needed to allow for flexibility in both the general treatment on a broad scale and for finely resolved questions on the local basis. A zoom capability will be required for several of the outputs.

Over a slightly longer time frame many developing models will have *major application in environmental impact evaluations*, e.g., the first of the three resource system application types (see Fig. 1). Predictions from models during development can serve a variety of practical purposes, while the models evolve further to link the submodels that hitherto focused on separate systems. Resource management will continue to need and use its special purpose models, but applications derived from whole-system approaches will help reveal where there are cases involving unintended side effects of normal management policy. Experience to date suggests that *management games can be very instructive in helping clarify the variables and conflicts* inherent in a problem and for establishing decisiom-making processes. These sorts of results, if explored more fully, may be helpful long before the model or the data are complete enough to inspire deliberate large-scale changes in policy based on modelling results.

The long-range period represents user groups which in the short and intermediate ranges have begun the development of models and input systems for the purpose of answering questions about environmental impact, resource management, and land change use. As such, this is the time period of goal achievement. Conceivably by this time, such sophistication and implementation of general hierarchical systems of models will have been achieved to simultaneously answer questions posed by many pertinent objective functions relative to each scale of spatial resolution required by the user. It is not expected, however, that any current degree of sophistication will have satisfied each new requirement.

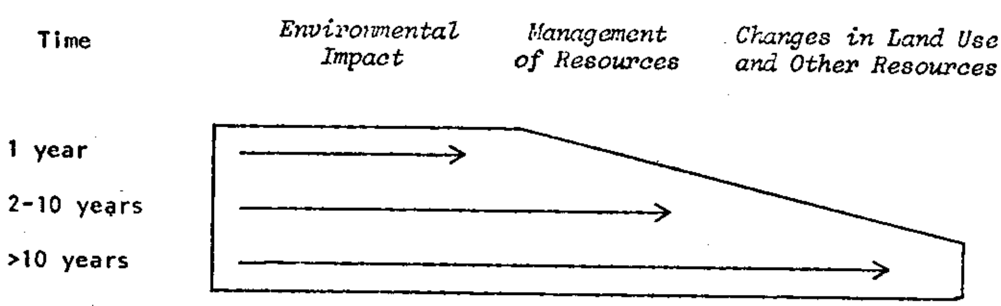
On the other hand, policy changes are continuously being made which are based on incomplete information. The structured data base being organized for mathematical modelling will almost certainly prove useful before the models have been tested thoroughly. Even the model tests are likely to provoke more thoughtful discussions about policy change. Feedback from such real life decisions ought to be coupled with the latest model development. Institutional or agency cooperation for establishing this has been started on a moderate scale in some of the IBP programs. Such cooperation should be expanded throughout medium-range periods.

Continued reassessment and feedback to the models and modelling specialists will be necessary. The *potential users of models should be involved* in their development. In addition, linkage of various national data banks to each other and to interested user groups will provide tests of whether the resolution is appropriate for their needs. With a continually evolving system of models, options of higher resolutions will be needed at times. Details that were left out in earlier years (due to limitations of insight, computer speed, or memory capacity) would be added as policy questions of long-range, large-scale importance justify the cost.

PROBLEM: *The dialog which must precede the establishment of data banks and models in the socioecological area has not begun in earnest.*

See section VI, p. 34 for recommendation.

The movement toward *holism in modelling* at the ecosystem level offers significant opportunities at each time period to affect policy changes. Studies on ecosystem functioning under stress can be judged and reassessed on their ability to identify the consequences of these environmental policies. In turn, knowledge gained about ecological processes in models affects policy and management and thus further suggests the convergence:



Early models may have many benefits which will only be realized later through their contributions to understanding in other areas. Modelling studies can help crystalize this convergence by making common features explicit. The outputs from the models continually provide input for a reassessment for the decision-making process, and new experience with decision making will provide a continual input for the development of more realistic and useful models.

The use of modelling efforts and a spatially relatable data base in decision making and education within the scientific community is illustrated in Fig. 5. Several programs concerning natural resources, such as IBP, can offer structures to model the relationships within an ecosystem, and monitoring stations can provide the data base for parameterizing such models. In each information flow in Fig. 5, the arrowhead represents a particular format for the output of information, *which is probably different for each information transfer*. Thus, while monitoring stations and mathematical modellers use a particularly machine-readable format for their information, decision makers require a graphic and dynamic output format for the same information. In particular, an *interactive output format* for examination of the consequences of alternative policies would be a very useful tool for decision makers, while film and printed graphs might be more useful for the classroom or textbook. Of course, at each stage of information flow and use, the information user may change the processes by which information is handled, as indicated by dashed lines on the figure.

The focus of the above efforts would be the *spatially relatable data base*. The type of base and linkages to output formats is determined by the uses. This requires a stored data base with visual presentation of alternative options, including potentially the following procedures:

i. models that illustrate the consequences of decisions,

ii. spatial resolution of the magnitude of decisions on an explicit boundary data base, and

iii. visual statement of understood principles (movies, sequential aerial photos, etc.).

Eventually, although costly, the decision makers of an organization can be presented with options at terminals or "awareness centers" for examining alternative policies, scales, or degrees of resource system alteration.

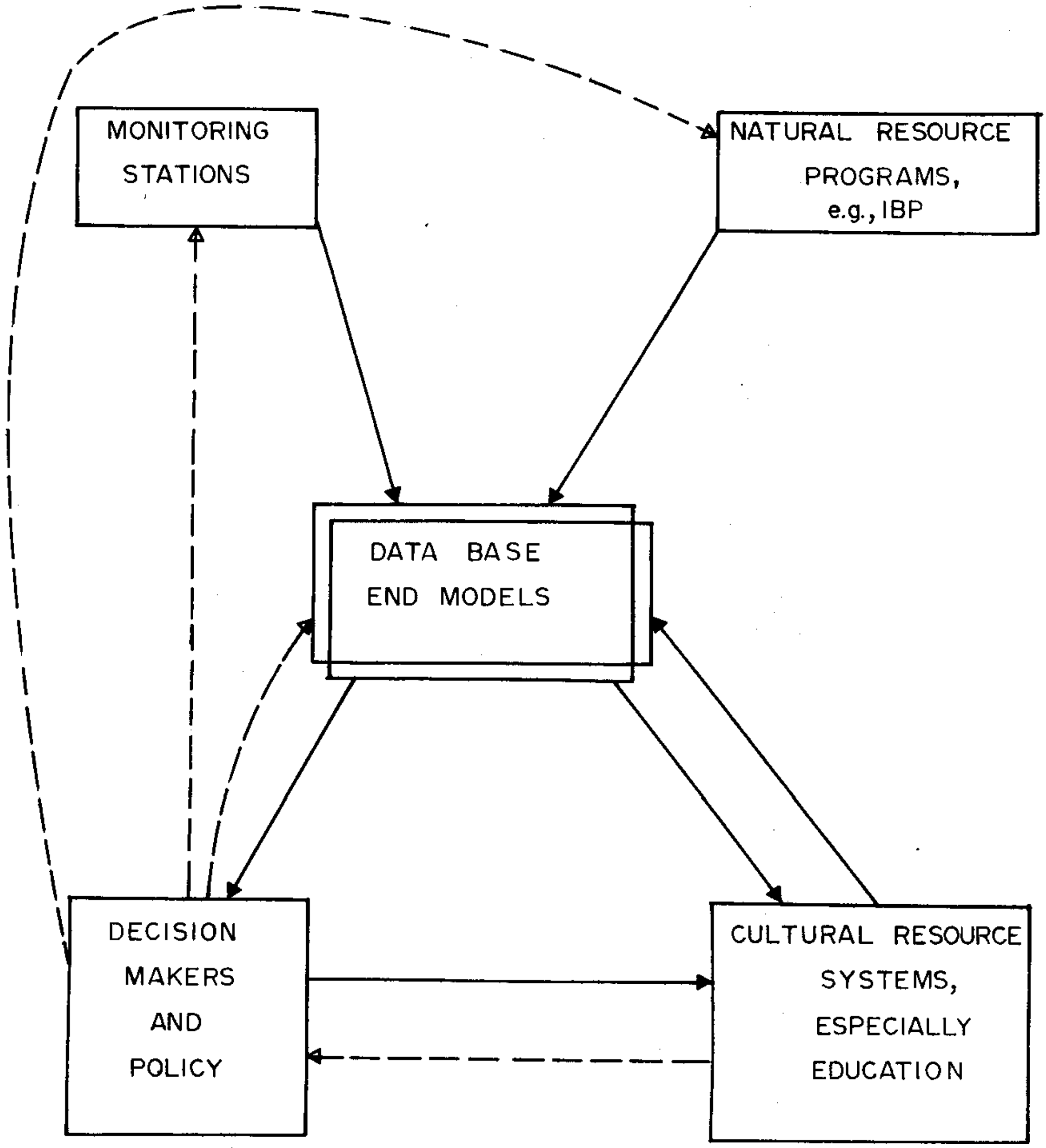


Fig. 5. The use of modelling efforts and a spatially relatable data base in decision making. ⟶ indicates the flow of information; each arrowhead indicates a format for that information which is best suited to the particular user. - - → indicates effects which information users can have on the information-handling system.

PROBLEM: *Macromodels that effectively address practical management problems in the natural resource area are not available.*

See section VI, p. 38 for recommendation.

V. PROSPECTIVE ADVANCES IN HUMAN RESOURCE SYSTEMS

A. Introduction

Many new and major national programs which interrelate the well-being (social and physical) of man have been initiated on a pilot scale at both the state and national levels during the past several years. These have included the model cities program, rural resettlement, and the legislation establishing air and water quality standards. Equally far-reaching legislation is being considered now in the form of bills to establish a program of new towns intended to settle 5,000,000 people outside the large metropolitan areas, recommendations such as Senate Bills 632 and 992 to establish a national land use policy, and the Public Land Law Review Commission.

PROBLEM: *Current and prospective advances in both scientific and management processes alone are inadequate without edification of present and future managers. Inadequate training, therefore, represents significant impediment to successful application of these advances.*

See section VI, p. 38 and 38 for recommendations.

These activities imply a degree of large-scale (spatial) governmental management for the well-being of the population in the affected areas and in the entire country and globe to a lesser degree. To implement and obtain widespread support for any of these programs, four types of activities are implied:

i. *actions* as contemplated in specific legislation, some of which are already underway;

ii. *organizations* or institutional arrangements to implement these actions;

iii. *criteria*, based on a holistic view of resource systems, for evaluating and recommending actions and institutional responses implied by *i* and *ii*; and

iv. *research* on the man-environment systems to provide the level of understanding needed for *i*, *ii*, and *iii*.

B. Methodologies Available

There is a parallelism between ecological and economic systems, and biome and man-dominated system models are potentially relatable (Fig. 6). There are

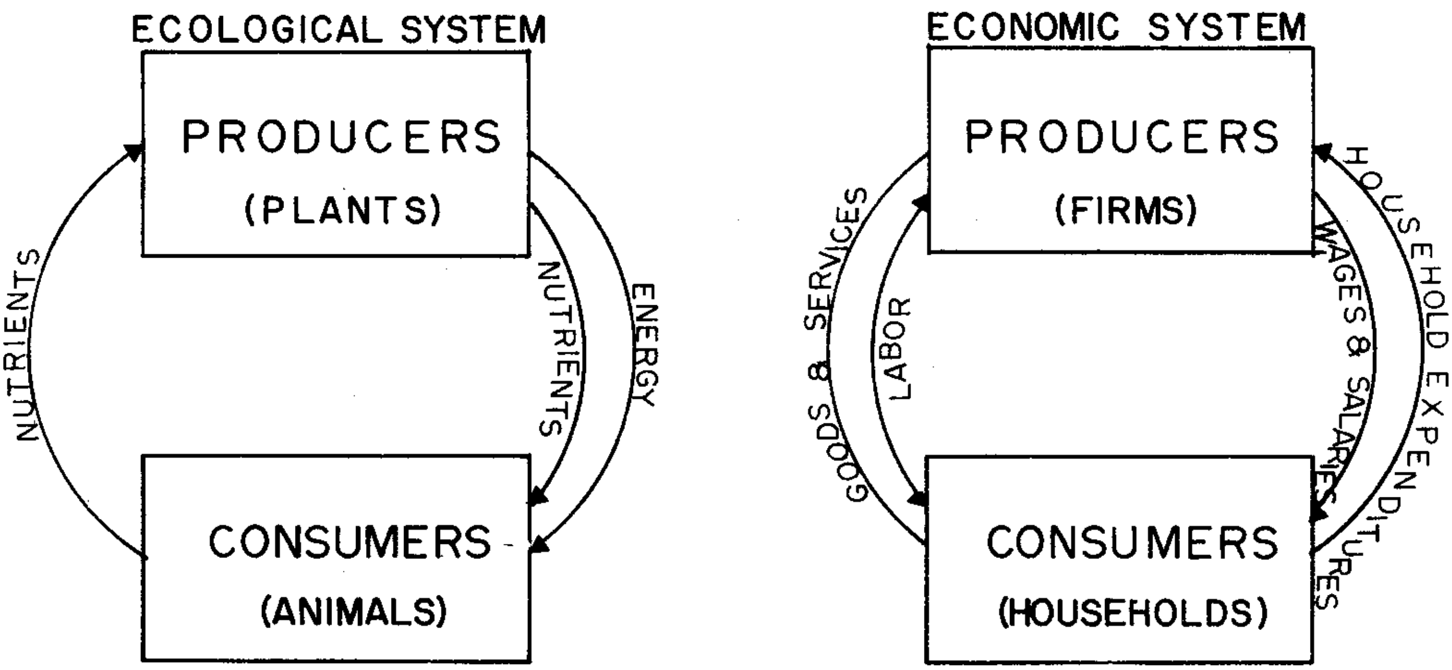


Fig. 6. Parallelism between ecological and economic systems. Both ecological and economic systems contain producers and consumers. Both are typified by flows of energy and money, of materials and nutrients, and of goods and services. The parallelism follows from the counter-flows of energy and money and of nutrients and goods and services in each. The parallelism is not exact, however, as these flows are reversed in coupled ecological and economic systems.

many outputs from models of ecological, economic, and coupled ecological-economic systems. The outputs range from documents and maps to movies based on pattern print-outs. Most of these are *condensations of voluminous records into graphic configurations* that can be readily understood. Such information is of interest to various decision makers and can greatly influence policy affecting the future uses of land and other resources. To be really effective model output information must be *up-to-date*, *easily understood*, *flexible*, *available*, and its *weaknesses understood*. Some output formats allow the observers to interact with the data file.

PROBLEM: *The new knowledge and alternatives which scientific research makes available to man is the purview of the public. The public through its value systems decides which alternatives will be selected. The present gap in providing the public and its various constituents with the new alternatives made available through research is a critical one. Bridging this gap is the most significant problem we see preventing macrolevel models from achieving their ultimate potential of improving man's existence.*

See section VI, p. 38 for recommendation.

Fig. 7 illustrates the general relationship between macrosystem models of the type currently being studied in the IBP Analysis of Ecosystems Program biome studies and environmental quality for general human well-being. A goal of the interbiome modelling work, as it relates to human well-being, should be to examine the positive and negative feedbacks between natural and the man-dominated systems and to provide information or alternatives for optimizing the objective function of human well-being.

Our assumption is that for such an effort *one of the major tools will be the now developing biome models*. The outputs from the biome models which interface with the man-dominated systems can provide the ecological input data which relate to various aspects of the social systems. These inputs would include levels of energy, water, minerals, building materials, and food from the natural to the man-dominated system and can perhaps be simulated by modest adaptations of the biome models.

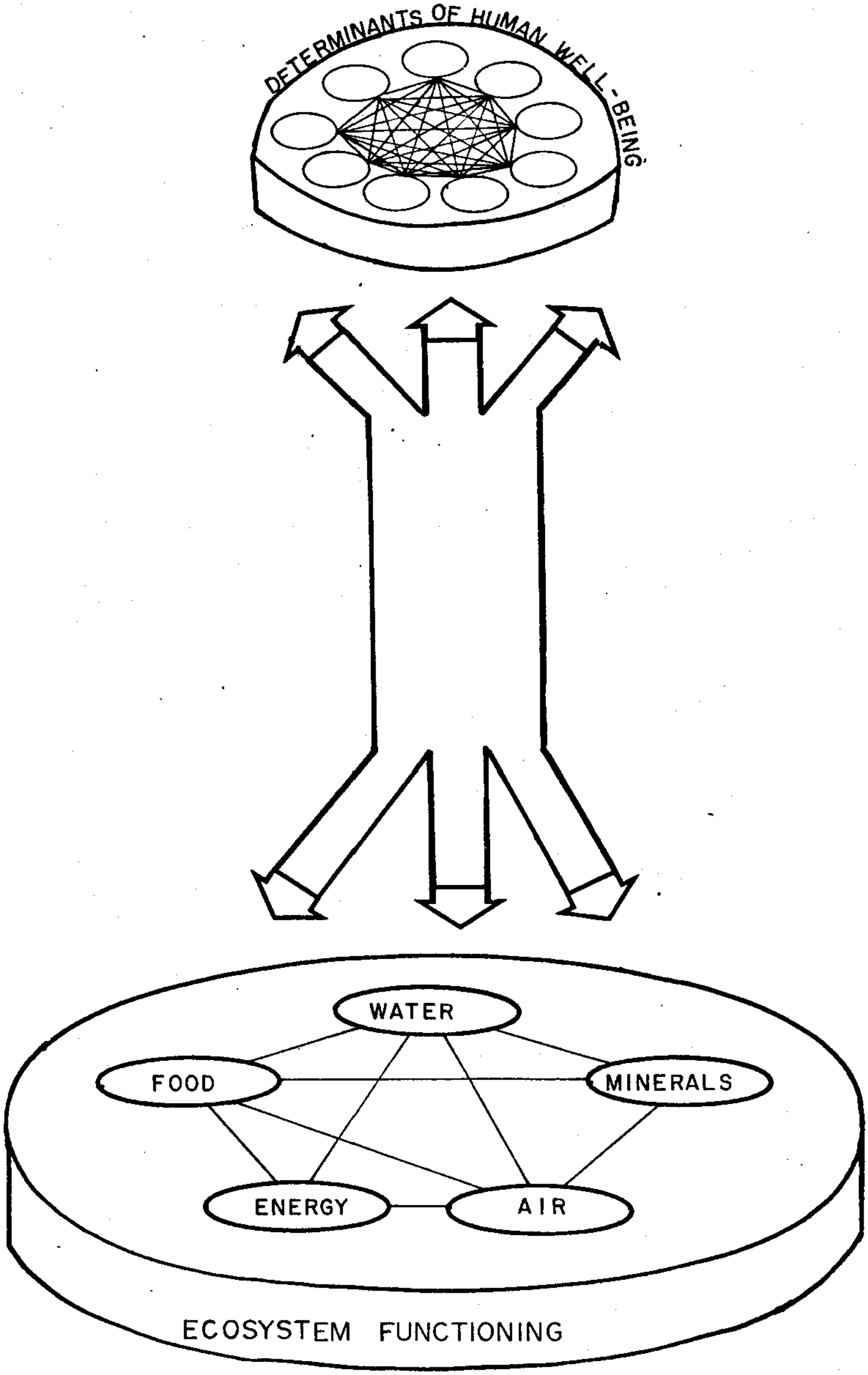


Fig. 7. Interrelationships of ecosystem functioning components and human well-being. Each element of ecosystem functioning components may affect one or more elements of human well-being. The determinants of human well-being are discussed later in the text and in Fig. 8.

C. Implementing Models of Human Resource Systems

Although the existing biome models provide an indication of the system principles that underlie the present man-dominated ecosystems of the U.S., many of the quantitative models for treating specific relationships will be found in recent advances in social and economic modelling. The general relationships between these subsystems are illustrated in Fig. 8. The biome models are shown as "biota," i.e., the biological production subsystem, together with its linkages to the abiotic systems of air, water, minerals, and the social and cultural systems.

The other subsystems in Fig. 8 have been quantified to varying degrees at different institutions in the U.S. (Abt Associates 1965). In general, the tools appear to be available for examining the couplings between the various subsystems as they affect the quality of man's environment, particularly the long-range stability of the system as a whole. Several of these questions have been summarized by Deevey (1971).

PROBLEM: *The implications of a national population growth strategy, land use policy, new town program, or other such programs are unknown.*
See section VI, p. 38 for recommendation.

Existing models of human systems components will provide important, new inputs to the existing biome models. Land use simulation models, air quality models, and others in Fig. 8 are all part of the macrosystem modification that takes place in a man-dominated system. In effect, these *subsystems operate as feedbacks upon one another*. In addition, the air quality models, water quality and quantity models, urban health models, and econometric models will all be influenced by inputs from the existing biome models. Perhaps the most difficult, yet most significant, aspects of the man-dominated ecosystem pictured in Fig. 8 are the *time dependencies* (the stability characteristics of the system) and certain *aesthetic value systems or attitudes* that man develops. The time dependent implications of the interrelationships between subsystems of the man-dominated system are illustrated in the lower third of Fig. 9. The four lower left materials of Fig. 8 are important to the man-dominated ecosystem. Energy, water, air, food, health, and dollar values can be studied for the interrelationships within the system and for their *response properties over*

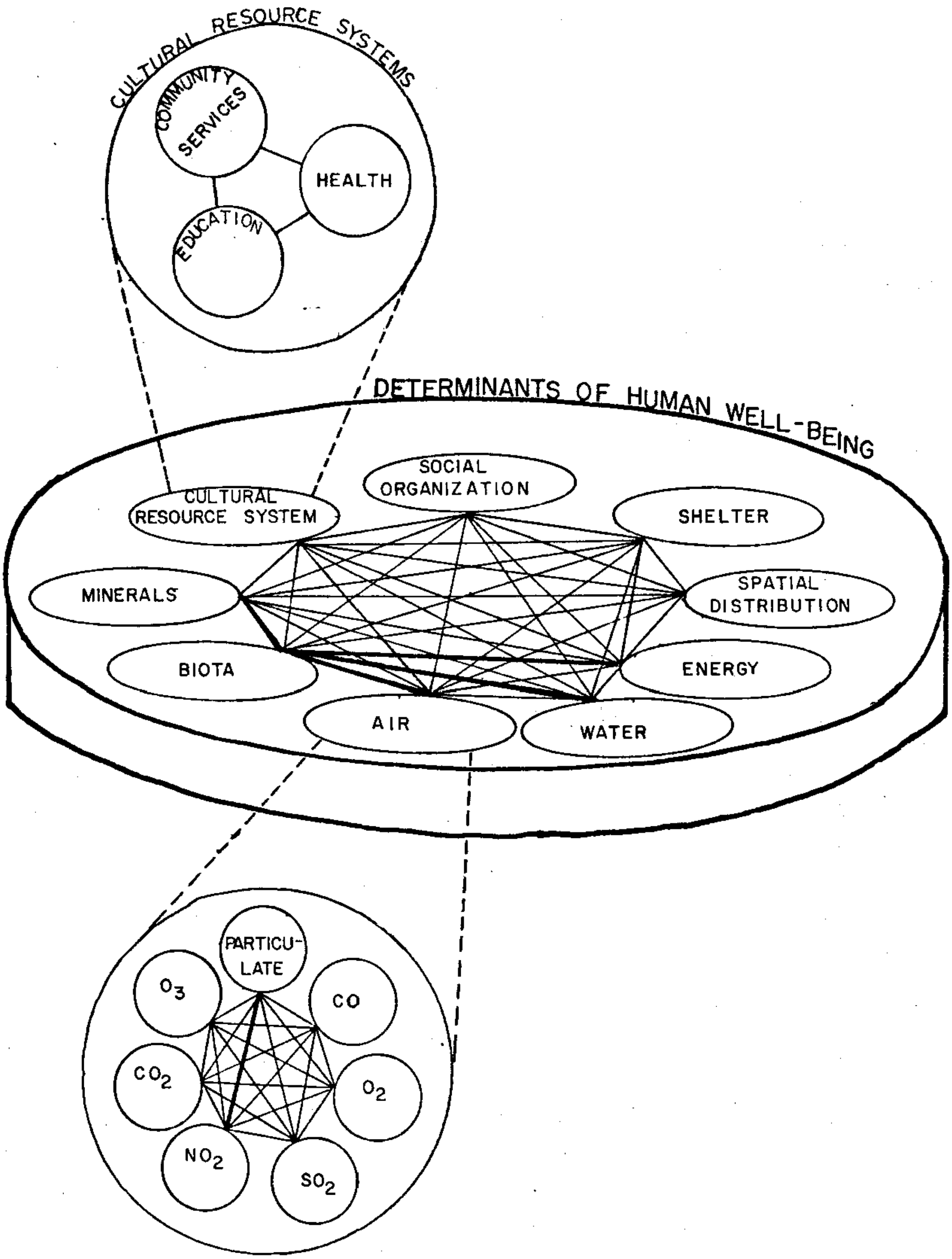


Fig. 8. An example of structure and interrelationship of some of the prime determinants of human well-being. Each major determinant also has its own complex substructure.

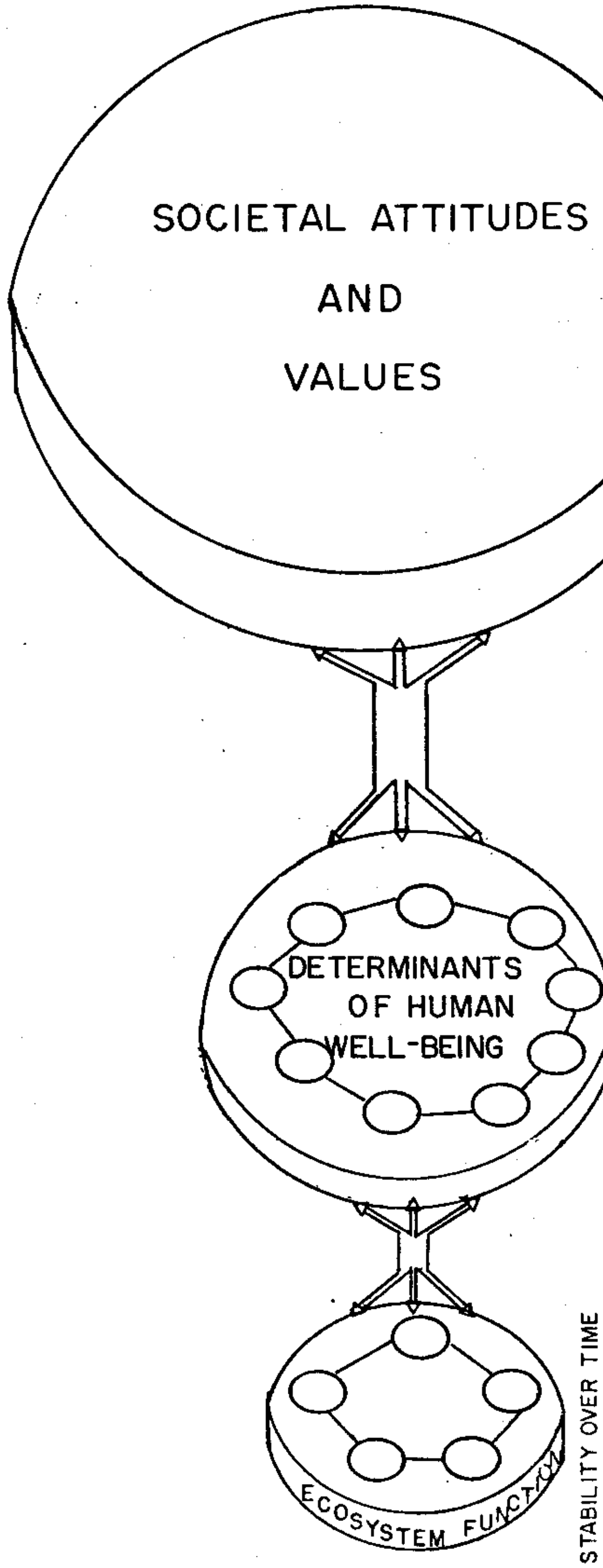


Fig. 9. Societal attitudes and values modify and are modified by the determinants of human well-being which in turn rest on ecosystem stability.

extended periods of time. Stability characteristics of the system under various strategies of legislation and regional action are probably the most important output to be expected.

At the same time the more sophisticated understanding of the man-dominated system can be expected to have a considerable effect on societal attitudes and value systems as suggested schematically in the upper third of Fig. 9. For example, considerable evidence of change in societal attitudes toward phosphorus and detergents is already apparent. There is a degree of responsiveness in social attitudes, therefore, that might be expected to operate without the strong measures for change that some have suggested. Good experimental simulations, using appropriate media including films, educational TV, and lectures with interactive terminals and graphic output, should all be viewed as media available for such a dialog. Less obvious, but of equal significance at the macrolevel modelling scale, is the feedback from the model to its environment and from the environment to the model. Thus, at the macrolevel *the model and its environment of policy makers, politicians, and public interact* in an analogous manner to the producers and consumers in an ecosystem. If the model is useful, it undoubtedly will modify the decision-making process and ultimately the system which the model represents. This will necessitate changes in the model to reflect the modified real world system. This feedback process is the model-building process, and like the world which is being modelled it is in a continual state of evolution. At any one point in time, the model (a species) is a product of that process. However, over time the model is just a force in the evolution of the modelling process.

Even before an actual model is built the initial stages of the process have merit in their own right by *forcing participants to broaden their perspective* to a system level with greater spatial and temporal horizons. This has certainly been the experience, for example, of many of the regional and civic servants in the Vancouver Regional Simulation Study.

The area of policy is central to many of the larger feedbacks from macro-modelling to its broader socioecological environment. Policy is a complex subsystem of our society. Policy makers run along a continuum from the narrowly technical bureaucrat to the broadly political elected representative of the public. Each of these policy makers is involved in the four stages of policy making: *formulations*, *selection*, *implementation*, and finally, *evaluation*. These stages also interact to form yet another feedback situation.

VI. RECOMMENDATIONS

A. General Approach

The previous discussions of hierarchical systems of models, of linkages between man inside vs. man outside the system, of the perspectives in human resource development, and of development of our natural resources, all support the development of modelling efforts. The matrix of users and uses identifies broad problems for which several types of models would be beneficial. The following sections contain several specific recommendations. The first specific model is an immediate *demonstration model* using biome material and current knowledge relative to other aspects of the system being modelled. The other recommendations relate to the *development of the background material* necessary in order to produce models which can have an impact on the management decisions relative to both our natural resources and our human resources.

RECOMMENDATION: *The holistic, macromodelling approach toward the solution to environmental problems should be accepted in principle.*

See problems, section III, p. 12 and 13.

At present, *largely intuitive approaches have shown themselves to be inadequate* and inherently unresponsive to rapidly changing needs to developing management programs for the solution of environmental problems, ranging from pollution through urban design to resource utilization. This is because the intuitive approach cannot cope with the *complexity* of the problems, has a *limited time horizon*, is *not holistic*, and *lacks provision for feedback* loops, especially within the framework of policy and program development. The macromodelling approach, now apparent in the large-integrated modelling programs, shows promise of overcoming all of these inadequacies of being able to accomodate much greater complexities.

Complex subsystem models have been developed successfully in a number of discipline areas--in the study of ecosystems and biomes and in a wide variety of social and economic phenomena. The *expertise and background now exist* to integrate these models and to increase the scale that they encompass to larger geographic areas and a wider range of social interactions. This will be profitable and useful both within disciplines and in the multidisciplinary context.

Three specific action recommendations are made with the view of taking several logical steps towards a longer-range and larger-scale program. Two of these relate to *educational functions* and are designed to present material to the public so as to achieve a greater appreciation of ecosystem science. The third is designed to *start the groundwork for integrating present biome and man-dominated ecosystem modelling.*

B. Documentation of Existing Macromodels

RECOMMENDATION: *An interdisciplinary task force should be mobilized to review, critically abstract, index into a functional framework, and document existing macroscale models or major segments thereof.*

See problems, section III, p. 13, section IV, p. 20.

A large number of specialized and large-scale modelling projects have been undertaken that overlap traditional disciplinary lines. In addition, operating models within disciplines (economics, regional planning, political science, sociology, transportation) frequently specify exogenous inputs or state variables which are in fact the output of models in other fields of inquiry. Example, but incomplete, reviews have been published on ecological models (Analysis of Ecosystems 1971) and on regional models (Meyers 1971). The purpose of this short-term project is to *expand the documentation* of these models at the interbiome level and to *examine the cross-disciplinary linkages* within an overall framework, such as is shown in Fig. 8. This activity would achieve at least the following purposes:

i. increased awareness of modellers and researchers of the vast array of existing large-scale models that bear directly on the work in progress in many fields,

ii. identification of missing links, real or potential, which could increase the usefulness of our operating models by providing inputs or outputs to models that deal with related subjects, and

iii. provision of greater perspective on the diversity of approaches and their strengths and weaknesses.

A literature search would be supplemented by interviews with representative model builders and model users in a wide variety of organizations and disciplines. A mail survey could supplement these two research procedures. The task of building and refining an agreeable overall conceptual framework would use the inputs of model users and model builders encountered in the interview schedule. The minimum time requirement would be for two researchers to undertake the data-gathering activity and documentation within 12 months.

C. A Pilot National/Macroscale Model Development

The following *simplified example* is designed to illustrate the approach that could be used in developing a national model to meet the kind of the objectives stated in the earlier sections. The limited objective for this initial model would be to demonstrate the effects of population and weather on production and land use criteria. The utility of the model can be demonstrated by asking questions of it, e.g.:

i. using net population and weather as driving variables, illustrate the change in food and fiber production over the nation,

ii. illustrate the effects of large-scale weather modification on production and therefore on the economy, and

iii. illustrate transportation bottlenecks which would appear as population areas force production to be even more distant from consumption.

Further specifications and needs for this type of model are provided in Appendix III.

RECOMMENDATION: *A program should be initiated to develop a national macroscale model utilizing as a basis the large ecosystem models stemming from the U.S. IBP biome programs with the objective of advancing our understanding of large-scale system processes and macromodelling techniques.*

See problem, section III, p. 13.

One of the early goals of the biome programs was the comparison of systems characteristics from region to region and the *development of means for aggregating* over large areas. This work has not yet been undertaken by any existing integrated research program, and it is essential before many of the important applications of systems modelling in man-environment problems can be resolved. The components for this project are substantially available. The directors of the major integrated research programs might take some of the preliminary steps toward initiating a national macromodelling project on an interbiome basis, but for significant advances toward this goal a major program with new funding will be required. The project should have a high degree of coordination with the leadership of the existing integrated programs.

D. Environmental Impacts and Resource Management

RECOMMENDATION: *A number of moderate-scale research projects should be undertaken to explore and demonstrate the potential of using ecosystem models to aid in evaluation of environmental impact statements and/or management manipulations of natural resources.*

See problem, section IV, p. 15.

Many of the proposals for developing reservoirs, transportation corridors, pipelines, new aircraft systems, or alternatives to phosphate in detergents involve the analysis of potential environmental impact by whatever tools are available. Most such developments involve evaluating long-range effects on complex systems with poorly understood feedback mechanisms. The use of appropriately modified ecosystem models is essential if we are to have both a better understanding of the system being modified and a better basis for the prediction of impact. A small number of such applications of current modelling capability have been identified, but many more should be supported, and over a period of time these should include uses of large-scale macromodels.

The procedures for implementating this recommendation rest with the following:

i. The directors of the large integrated research programs should see that local initiatives for the use of ecosystem models in import analysis or resource management are followed up.

ii. Federal or state agencies and foundations should be responsive to applied science initiatives in this area.

iii. Individuals within the scientific community should encourage the formation of teams capable of using the models now under development for the purposes described here.

Existing models generated by biomes and other non-IBP programs can and should be applied or adapted to questions posed by environmental impact statements *as an experiment*. It is recognized that at present most of these models are not sophisticated to the point that their output can be relied upon except for "order of magnitude" differences or direction of response. However, this *application will result in a more rapid development* through the feedback obtained with continuous revision and a closer tie to real life problems. At the same time a service will be performed.

It is expected that reasonably useful models, particularly those related to nutrient cycling, water transport, and biomass turnover, can function as a means to provide insight into chemical pollution problems at the present time. The further development and refinement of these models to the point of general usefulness within the next 5 years will require some means of getting interested people together.

The *development of a holistic data base* for environmental impact, resource management, and changes in land use is necessary before generalized models can be implemented. Substantial ecological data exist in each of the biomes. An effort must be made to make this data available on a rapid retrieval basis. Other data sources include agency data bank and data in the literature and other ongoing research projects. The production of a minimal scheme (that is, flexible conventions plus standards for coupling with ongoing efforts) for the storage and retrieval of this data can be implemented now at an incremental cost of about $20,000 and 1 year. Development of a nationwide data bank would involve a much larger investment of the order of $10,000,000 and 5 years.

The development of an interactive output model is a much needed device for several reasons. Such models provide an *excellent tool to conceptualize complex dynamic data output* for both research and teaching. Such models provide a means for better public understanding of ecosystem science. The intervention of decision makers in models (by model games or real life decisions) has an additional role in clarifying what is used or still required in different kinds of decisions. Costs of producing dynamic output varies greatly in the form used. The technology for producing this type of interactive output is well developed and readily available, but the simultaneous and cooperative interfacing with people possessed of different prospectives poses subtle questions of human relations.

E. Explicit Incorporation of Man into Macromodels

RECOMMENDATION: *Long-term research efforts should be initiated to examine alternative ways to bridge the gap in macromodels from basic ecological research outputs up to regional and national political systems and to include societal feedbacks.*

See problem, section IV, p. 23 and 28.

To use the model segments now available from the physical, biological, and social sciences for large-scale macromodelling, several innovations will be needed. As noted earlier (section B) a new approach and conceptual outline needs to be developed in which we can embed information on model segments in various fields. Special linkages and improvisions are needed to relate to proposed and ongoing new efforts relative to such problems as *the implications of a national growth strategy, land use policy, new town program, or other legislation proposed to improve the general well-being of man.* A part of this study, the potential responsiveness of society to develop and accept an alternative attitude towards resources, wastes, recycling, and the stability of the ecosystems, should be examined.

Although several recent large-scale efforts are underway in this area of work, the *participants are separated by geography and specialty.* Perhaps an early step would be to bring these groups into contact in a workshop to develop bibliographies of their work for exchange and to initiate and update a directory of such efforts and outputs. Some major tasks of the proposed workshop would be to have the participants develop a first-hand acquaintance with each other, to develop an outline or diagrammatic concept of their potential relationships, and to examine research structural alternatives (with analysis of costs and efficiencies) for conducting such work.

F. Types and Roles of Model Output

RECOMMENDATIONS: *The general structure of and output from man-ecosystem macromodels should be explained to high school, college, and university students and to the general public, from which feedback should be elicited.*

See problem, section V, p. 26.

Graphic computer output as an educational tool. The purpose of this project would be to make available to high school and college students film for on-line outputs of the ecosystem models or submodels in order to promote their application of ecosystem interrelationships. The method would be to provide suitable *films of graphic terminal output* or computer programs in addition to explanatory material (for use by teachers and students) based upon extant ecosystem models from some of the biomes.

The appropriate working party could be the interbiome modelling specialist committee of the U.S. IBP which is already considering the publication of an education-oriented collection of extant models. Probably less than 1.5 man-years of collaborative effort would be required to identify, simplify, and make operational the selected very simple models. Phototype preparation for replication of films, program decks, and other aspects of the task would be the major cost.

Model output as an attitude modifying tool. For the reasons outlined in the previous section, the results of ecosystem science must be applied more directly toward improving human well-being. This may cause some modification of social attitudes of both individuals and groups within our society. Man as an individual and as a member of societal groups can learn to view his role and the consequences of his actions in context to their effects on the ecosystem of which he is a part. General public awareness of the existence of an environmental crisis has recently developed. People now see many of the symptoms of ecosystem mismanagement, but they are aware neither of the causes nor of the courses of action necessary to correct the mismanagement. This has resulted in *extensive treatment of symptoms*, but very *little correction of the causes* of these threats to the environment. Before effective programs for management of ecosystems to optimize human well-being can be implemented, education at all levels of society will be necessary. For example, see Gillette's (1972) review of public presentation of concepts in a world dynamics model. The individual, as well as decision-making groups, must learn to view human activity in terms of its effects, both short- and long-range, on the systems which support mankind. If a model of the type described above could be developed which would predict the outcomes of alternative actions and illustrate the interrelationships within the ecosystems, it would be useful as a teaching or attitude-influencing tool. It can help individuals or groups obtain a proper perspective of the consequences of particular societal actions as they relate to the environment. Such a model might be particularly useful in making people *think about the long-range as well as the short-range consequences* of specific activities. The usefulness of a national model in modifying social attitudes will depend on how well the prediction of the model can be presented in a graphic and easily understood form. The objective, at first, would be to urge the individuals in groups to ask "*What would be the consequeneces of a particular action on the total system?*" If this objective is accomplished, later more specific outputs of the model can be used to examine traditional attitudes and conventional wisdom to see where this has been superseded by knowledge.

The predictions made regarding any particular course of action by simulation models could be summarized and prepared for presentation to groups at all levels of technical competence. A detailed and technically precise presentation might be given to specific users of the results (planners, managers, etc.). A more popular presentation of the predictions could be prepared specifically for the layman who is interested in the consequences of a particular course of action. An intermediate version might be used for presentation to other groups (undergraduate classes, etc.). This early work might also be undertaken for the biomes by the interbiome modelling specialist committee with other appropriate disciplines brought in for competence in the social sciences and applied arts. However, a special working group can also be convened if this seems more appropriate. Costs of this effort would be at least 1 man-year collaborative effort.

A major task of research in this area will be to *explore the attitude-changing power of interactive models*. Different types of models, methods and intensities of interaction, and user groups should be compared. Such study should provide new results on the learning and attitude-changing process.

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APPENDIX I

ORIGIN AND DEVELOPMENT OF THE REPORT

A. Background from the U.S. IBP

The Analysis of Ecosystems Program (AOE) developed early as a series of highly integrated studies on natural systems and comprised a major part of the United States' contribution to the International Biological Program. The central objective of the IBP is "*to examine the biological basis of productivity in human welfare*." The AOE was designed to produce basic ecological knowledge of a scale and kind capable of leading to solutions of the problems of human welfare. The highly integrated interdisciplinary studies of the AOE were organized into the "biome" programs. Five of the original six that were planned are now in operation: coniferous forest, deciduous forest, desert, grassland, and tundra.

In each of these biome programs scientists are attempting to understand how ecological systems operate with respect to both short-term and long-term processes. Both natural systems and systems disturbed or manipulated in varying degrees by man are included in the studies. One of the major contributions to the worldwide goals of the IBP will be in providing the information and predictive models tested against real life to estimate existing and potential plant and animal production in the major climatic regions of this country. This information will add to the scientific basis of resource management so that utilization for human welfare can be improved. These goals and the information derived will be consistent also with establishing a scientific base for programs to maintain or improve environmental quality.

One of the major purposes of defining the original six biomes and their programs was to *provide the information from which ecological theory can be developed and against which it can be tested.* The original approach was to derive broad principles of ecosystem structure and function through an integration of the results of the biome studies and to show how this information relates to the utilization of these biomes by man. *Initial activities focused largely on developing intrabiome* operational groups, procedures, and treatments. During autumn 1971, however, the biome directors met and discussed ways they could more closely integrate the individual biome activities. They recommended that a task force be formed to explore the conceptual and general operational framework for large-scale systems studies which utilized innovations of the various biome programs to solve problems of large geographic areas. This report represents the product of that task force and addresses the usefulness, feasibility, and possible approaches to such an effort.

B. Approach to Developing This Document

George M. Van Dyne of Colorado State University, Grassland Biome Director, was asked by the other biome directors to draw together a group to discuss concepts and possibilities for some major macromodelling studies. The approach to developing this report was to collect a group of scientists with both biome and non-biome interests. Each biome director suggested the names of one or two scientists from their program whom they felt might contribute. Suggestions were also solicited for names of scientists outside the biome programs and particularly those representing other disciplinary backgrounds to provide a balance within the group. The initial meeting was held 24-26 January 1972 at Colorado State University. The participants at that meeting, their area of expertise, and their current address were:

A. Ben Clymer	Consulting Analytical Engineer	2145 Tremont Road Columbus, Ohio 43221
Charles F. Cooper	Watershed Science, Resource Biology	Center for Regional Environmental Studies San Diego State College San Diego, California 92115 (*Tundra Biome*)
Gary L. Cunningham	Plant Physiology and Ecology	Biology Department New Mexico State University University Park, New Mexico 88070 (*Desert Biome*)
George S. Innis	Mathematics, Systems Analysis, Computer Science	Natural Resource Ecology Laboratory Colorado State University Fort Collins, Colorado 80521 (*Grassland Biome*)
John Kennedy	Meteorology	National Center for Atmospheric Research Boulder, Colorado 80302
Orie L. Loucks	Plant Ecology	Department of Botany University of Wisconsin Madison, Wisconsin 53706 (*Deciduous Forest Biome*)
Michael M. McCarthy	Regional Planning	Department of Landscape Architecture University of Wisconsin Madison, Wisconsin 53706
John M. Neuhold	Aquatic Biology, Research Administration	Ecology and Systematic Biology Section National Science Foundation Washington, D. C. 20550
Jerry S. Olson	Geobotany, Systems Ecology	Ecological Sciences Division Oak Ridge National Laboratory Oak Ridge, Tennessee 37830 (*Deciduous Forest Biome*)
W. Scott Overton	Biometrics and Population Dynamics	Statistics Department Oregon State University Corvallis, Oregon 97331 (*Coniferous Forest Biome*)
Felix Rimberg	Regional Planning and Analysis	Peat, Marwick, Mitchell, & Co. 1025 Connecticut Avenue, N. W. Washington, D. C. 20036
George M. Van Dyne	Resource Biology, Systems Analysis	Natural Resource Ecology Laboratory Colorado State University Fort Collins, Colorado 80521 (*Grassland Biome*)

In mid-December participants were contacted and sent information relative to the workshop. An agenda was developed for this 2-day workshop to discuss and evaluate the problems posed by the biome directors. The objective of the workshop was to develop a draft reviewing macromodelling with the following potential characteristics or output:

i. total U.S. coverage,

ii. computer generated graphic film output,

iii. intra- and interseasonal dynamics of biomasses as a function of climate and other factors,

iv. coupling between biome areas where appropriate,

v. incorporating possible economic and communication components of U.S. and other couplings between regions,

vi. demonstrate the potential for, and need of, an intensive interbiome effort that would result in outlining broad-term goals and identifying operational procedures to reach such goals, and

vii. demonstrate the way in which a preliminary modelling effort might be done, what it might cost, and what some of the many benefits would be.

Additional questions were distributed to the anticipated participants, and their written answers were distributed at the meeting. The many ideas and viewpoints discussed during the 24-26 January meeting were the basis of a "Draft 0," compiled by Van Dyne and Innis, distributed in middle February to the participants along with notes taken during the workshop. Draft 0 was reviewed by the participants, and their written and telephoned comments were used by Innis and Van Dyne in the preparation of a "Draft 1." This draft was distributed to participants in middle March. A small group met in Chicago during the interval of 22-25 March to review Draft 1 and outline a "Draft 2." This group included: Innis, Loucks, and Van Dyne from the original task force and the following scientists:

Jay M. Anderson	Chemistry, Ecology, Systems Dynamics	Systems Dynamics Group Massachusetts Institute of Technology Cambridge, Massachusetts 02139
Donald A. Chant	Zoology, Biological Control	Zoology Department University of Toronto Toronto, Ontario, Canada
Michael A. Goldberg	Economics, Regional Planning and Analysis	Resource Science Centre University of British Columbia Vancouver 8, Canada

The output of the late March meeting was used by Van Dyne and Innis in preparing the present draft.

C. Acknowledgements

The Ecosystems Analysis program of the Division of Biology and Medicine of the National Science Foundation provided funds for supporting travel and living costs of non-biome participants. The individual biome programs provided financial support for their participants. The Grassland Biome hosted the first working meeting and provided secretarial and clerical support for developing and distributing the drafts of the report and related questionnaires, memos, etc. We are *especially indebted to Beverly Metzler* for her able assistance in contacting participants, arranging meetings, taking notes during intense discussion sessions, and supervising and participating in the typing of memos, notes, and reports.

APPENDIX II

HIERARCHIES OF MODELS

A "hierarchy of models" is a set of models which are not coupled together but which *relate to one another in accordance with the relationship of inclusion.* A hierarchical model is a single model whose parts are hiarchical in their convectivity. See Clymer (1969*a*,*b*) and Clymer and Bledsoe (1970).

A. Hierarchies of Ecosystem Models

The biome programs of the Analysis of Ecosystems study under the U.S. IBP are developing a variety of mathematical models of ecological systems and their components. These include the models of individual physical and physiological processes, models of complete trophic levels, and models of total ecosystems at different scales (Hammond 1972). The "*community type model*" *perhaps is a common denominator* among the different biomes. Such a model includes producer, consumer, decomposer, and abiotic components. It is a model to simulate the components of the system, generally intra-seasonally and in many instances also interseasonally. Examples would be models of a shortgrass prairie, a creosote bush desert type, tulip poplar dominated deciduous forests, etc. At this level of abstraction, generally man is "outside the system" and acting as a forcing function or driving variable rather than being an integral component of the system.

Parallel hierarchies of ecologic and economic models have been shown in Fig. 4 (on p. 14), with both hierarchies starting from the community type as a basic building block. In one instance the emphasis is on the development of scientific principles:

i. Many community types may be combined into a "biome model."

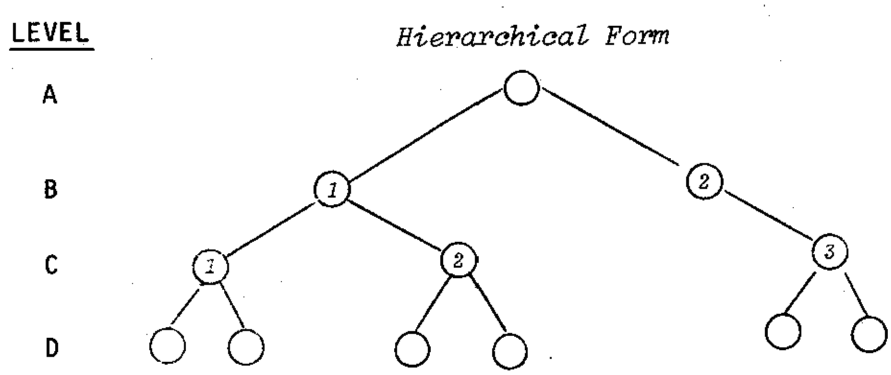
ii. Biomes may be combined into an interbiome model.

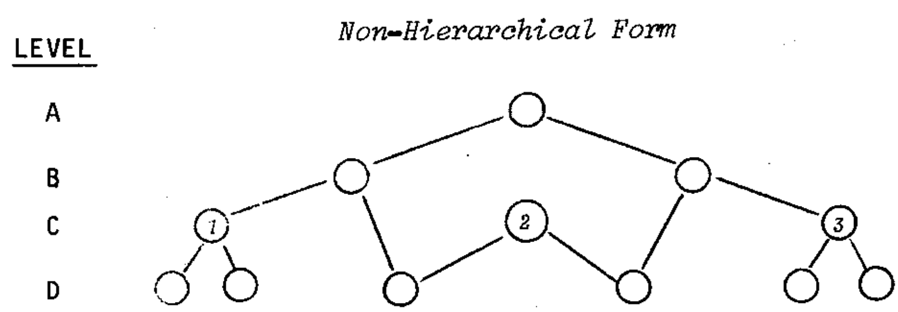
iii. Interbiome models may be combined into global models.

There are many other modelling steps or segments that could be inserted between these types. It is also true that the process of combining different models into a model at a different level is often a non-trivial task.

In another approach the emphasis is placed on *man "inside the ecosystem"* and his effects on it. Here man is a part of the system being modelled rather than an extrinsic factor. Thus, progressively one could deal with an individual corporation or other social unit as the community type. Similarly, going up through this hierarchy one could develop regional models which would have combinations of economic firms as well as other inputs from the regional level. National, continental, and finally global models could be constructed. It is important to note in Fig. 4 that different *global models* would be developed through emphasis on man outside the ecosystem vs. those global models reached through emphasis on man in the ecosystem. The dashed (long and short) lines in the center of Fig. 4 denote that the building of biome and interbiome models based on ecological principles has direct feedback to the construction of models with emphasis on man and that the building of economic models has a direct feed-back to the environment in which biomes function. The primary difference is that models with the emphasis on ecological principles would be designed to search for underlying principles related to the structure and function of ecological systems of larger and larger scales.

To clarify the concept of hierarchical modelling systems, consider the two structures below.





In the first of these each entry on each level (say level A) has a predecessor at the next higher level in the form. This is the requirement of a hierarchical form. In the non-hierarchical form the element labelled "2" at level C does not have a predecessor in that form. Therefore, it is termed non-hierarchical. It is not necessary for a model represented at several levels of organization to be hierarchical in form, but there are often advantages to the hierarchical form.

It is desirable to consider two forms of models (Appendix Fig. 1):

i. those in which the ecological system is explicitly modelled in the other systems (that is, economic, political, etc.) and is represented by driving variables to the ecological model and

ii. those in which all of the systems are modelled and the models are coupled in an appropriate manner.

A feature of the two forms is that the *driving variables* of each of the subsystems developed at the several levels become *coupling variables* when the subsystems are linked to form the final model. In the non-hierarchical form, however, the driving variables for the element labelled "2" in level C remain driving variables even after the models have been linked together. The great advantage of the hierarchical form is apparent when the several subsystems are linked together. The coupling between the subsystems takes the output from one subsystem and uses it as input to another subsystem. One often finds that important outputs from a given system would not have been identified from consideration of that subsystem alone. It is only in the context of a needed input to another subsystem that these important outputs are identified.

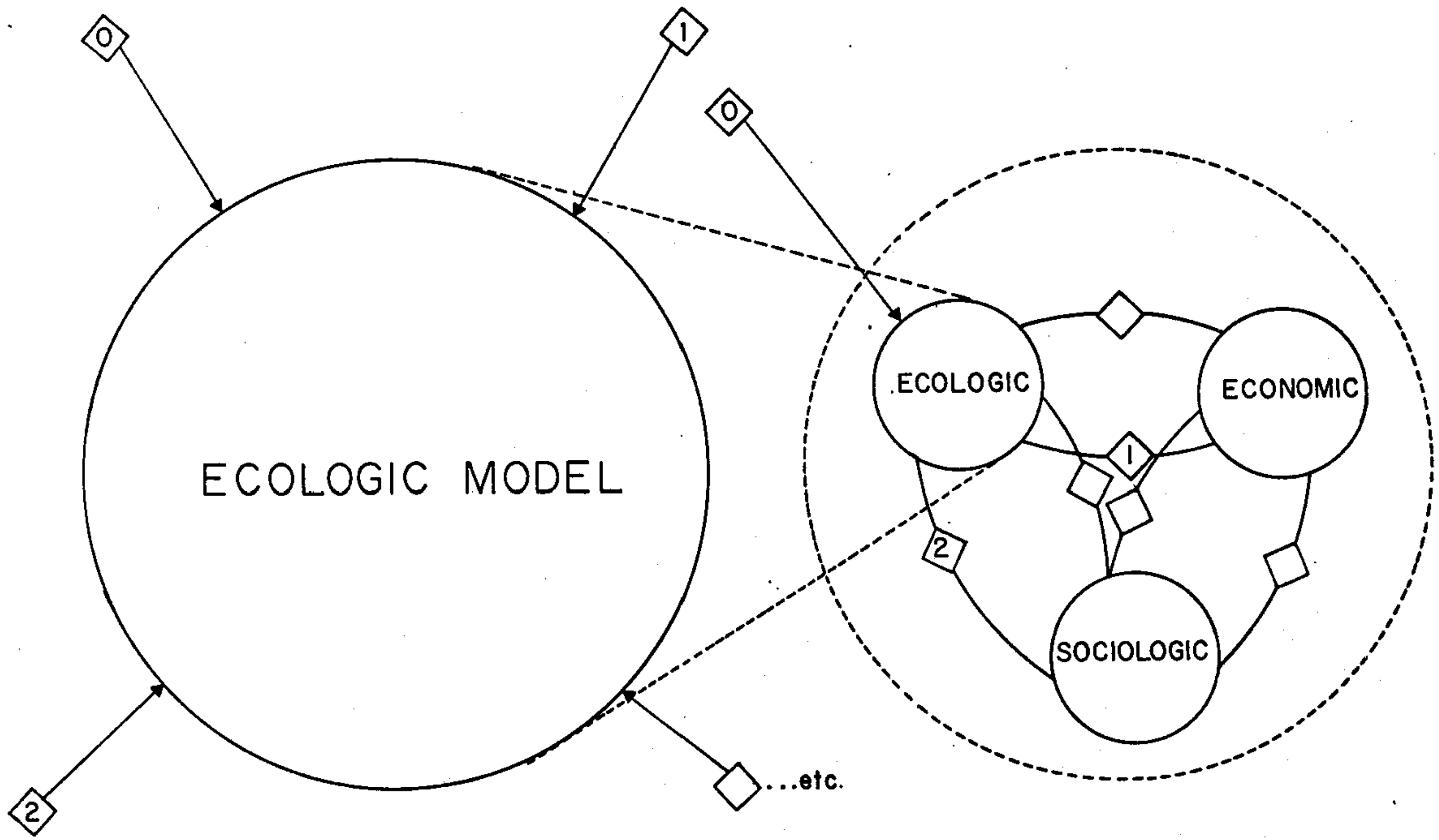
Form 1 of Appendix Fig. 1 shows the ecologic model, its driving variables, and output. Form 2 shows a way in which two of the auxiliary systems couple with the ecologic system in a hierarchical organization. To uncouple these, as in Form 1, requires identification of coupling vectors 1 and 3 as vectors of driving variables.

There must be *trade-offs in models between resolution and the temporal and spatial scope* of the model (Appendix Fig. 2a). Model resolution is increased in general as the degree of mechanism in the model processes increases, as the spatial scale decreases, and as the temporal scale decreases. In the process of aggregation, one may group individual components into a single component to retain the same level of complexity (e.g., group individual plant species into a single producer component) as one increases the temporal and spatial scope (see Appendix Fig. 2b).

The requirement that the management model be hierarchical imposes the requirement on each of the systems models that *coupled models be of compatible resolution and scope*. This is not to say that coupled models must be of identical resolution or scope, but that these must be compatible. These restraints, together with the observation that the ecological system is driving the other systems, makes the uncoupled form of dubious value. The uncoupled form is of value in the structuring of the coupled form, but as a final product is useful only on the short time scale where the lack of feedback loop closure is unimportant. It is unlikely that appropriate driving variables can be generated, short of modelling the associated systems, and even less likely that they will be realistic if the feedback loops are not included.

B. Interrelationship of Model Components and Hierarchical Levels

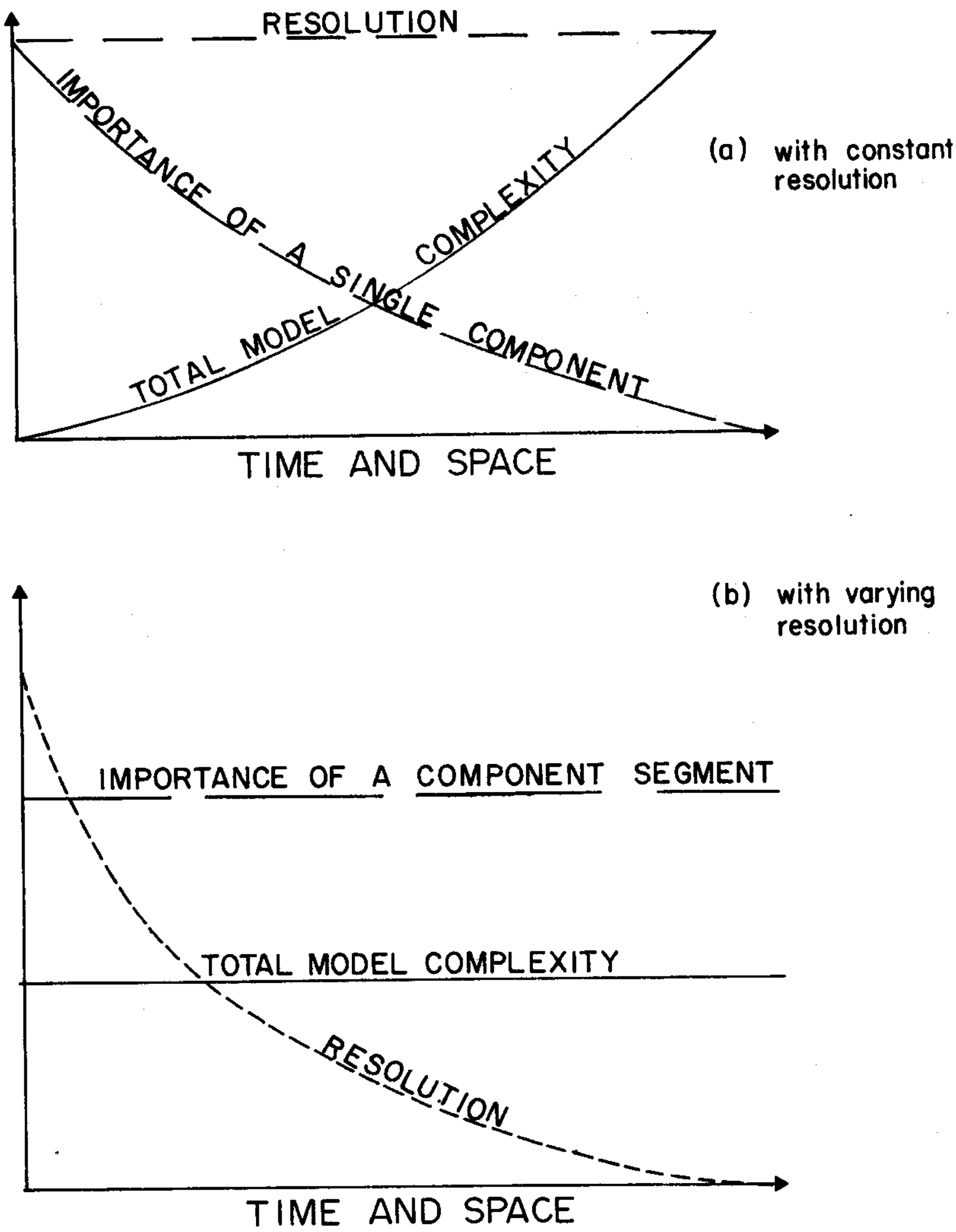
Environmental models may be thought of as having broad subsystems such as biotic components, physical-environmental components, economic components,



Form 1. The ecological system is the system of concern, and all other systems are "outside." The variables ⟨1⟩, ⟨2⟩, ..., are *driving* variables from exogenous systems such as the economic, the sociologic, ...

Form 2. The ecologic, economic, and sociological systems are "inside" a coupled system. The variables ⟨1⟩, ⟨2⟩, ..., are *coupling* variables within the endogenous sectors of the coupled system.

Appendix Fig. 1. Two ways of defining systems. Variable ⟨0⟩ is a driving variable (solar radiation, for example) in both forms.



Appendix Fig. 2. Effect of holding constant or allowing model resolution to vary while the model's temporal and spatial scope increases.

sociological components, and political components. Not all of these components would necessarily enter into models at different echelons in the hierarchy, whether the hierarchy was based on ecological emphasis or management emphasis (Fig. 4). Because of the "*embedding effect*" of developing a hierarchical structure, certain components enter at different levels. For example, biotic components and physical-environmental components probably would exist in models at all echelons of both kinds of hierarchies, that is, those based on ecological or management emphasis.

Within the scope of models based on management emphasis, economic components would enter in early at the individual corporation level of modelling. Sociological components and political components would enter in at the regional level and continue up to the global levels of models with management emphasis.

Appendix Fig. 3 again starts with the building block being the "community type" model which itself is built of submodels of trophic levels. Each trophic level model is built of physical, physiological, and ecological processes.

C. The State Variable Approach to a Hierarchical Framework

The state variable approach to modelling dynamic systems adapted to ecological modelling requires recognition of the following components:

i. *Driving variables* are those variables which are exogenous to the system being modelled and which may vary over time.

ii. *State variables* are those variables which are endogenous to the system.

iii. *Rate processes* are those phenomena which account for the movement of matter or energy from one part of the system to another.

iv. *Descriptors* are parameters which identify the particular site or locality being modelled.

A generalized state variable formulation expressed in matrix and vector algebra is shown below:

$$\dot{\underset{\sim}{x}} = \underset{\sim}{A}\underset{\sim}{x} + \underset{\sim}{B}\underset{\sim}{z}$$

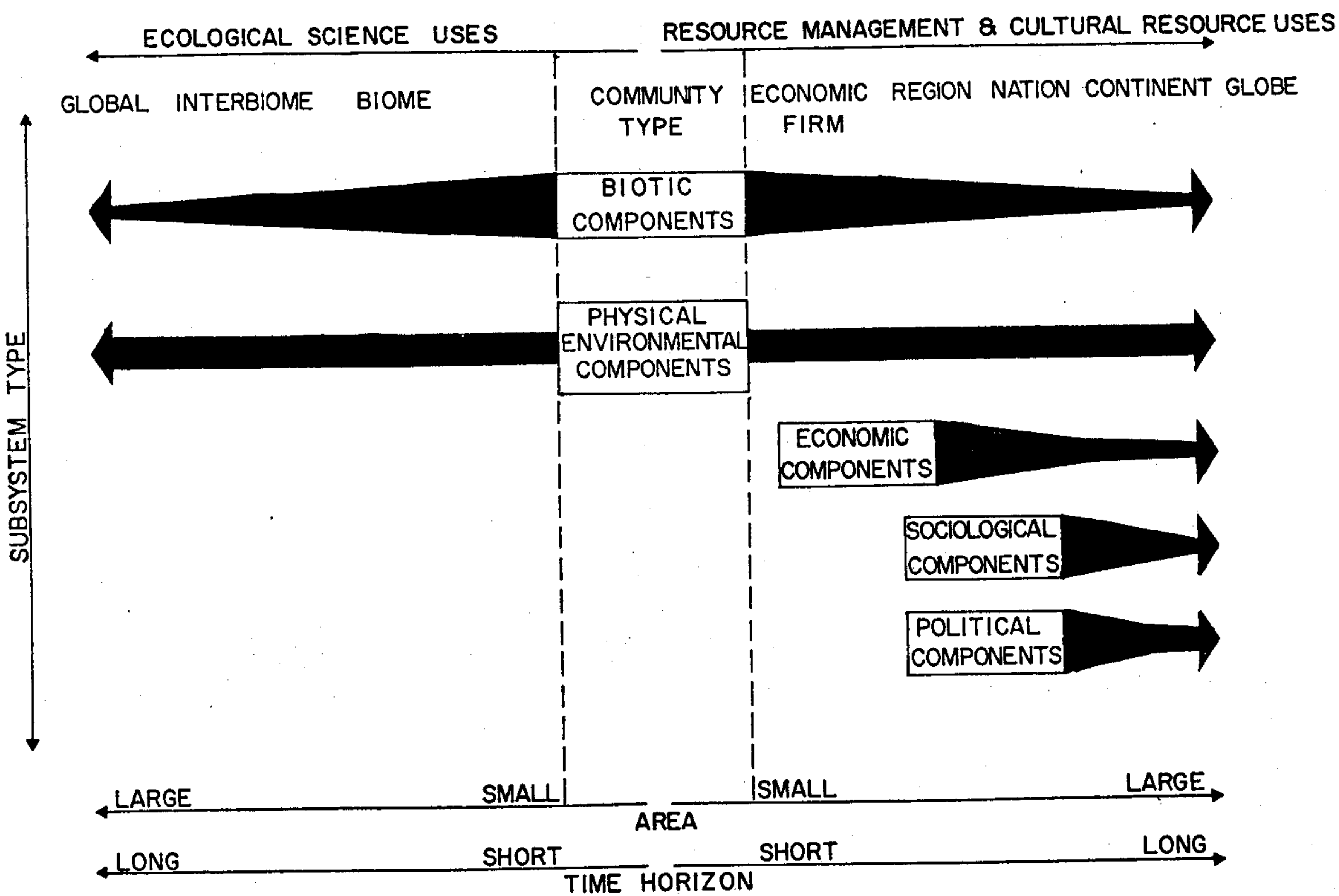
$$\underset{\sim}{y}(t) = \underset{\sim}{C}\underset{\sim}{x} + \underset{\sim}{D}\underset{\sim}{z}$$

$\underset{\sim}{x}$ = State vector

$\underset{\sim}{z}$ = Driving vector

$\underset{\sim}{y}$ = Output vector

$\underset{\sim}{A}, \underset{\sim}{B}, \underset{\sim}{C}, \underset{\sim}{D}$ { Matrices of functions of $\underset{\sim}{x}$, $\underset{\sim}{z}$, and $\underset{\sim}{t}$ (may be nonlinear)



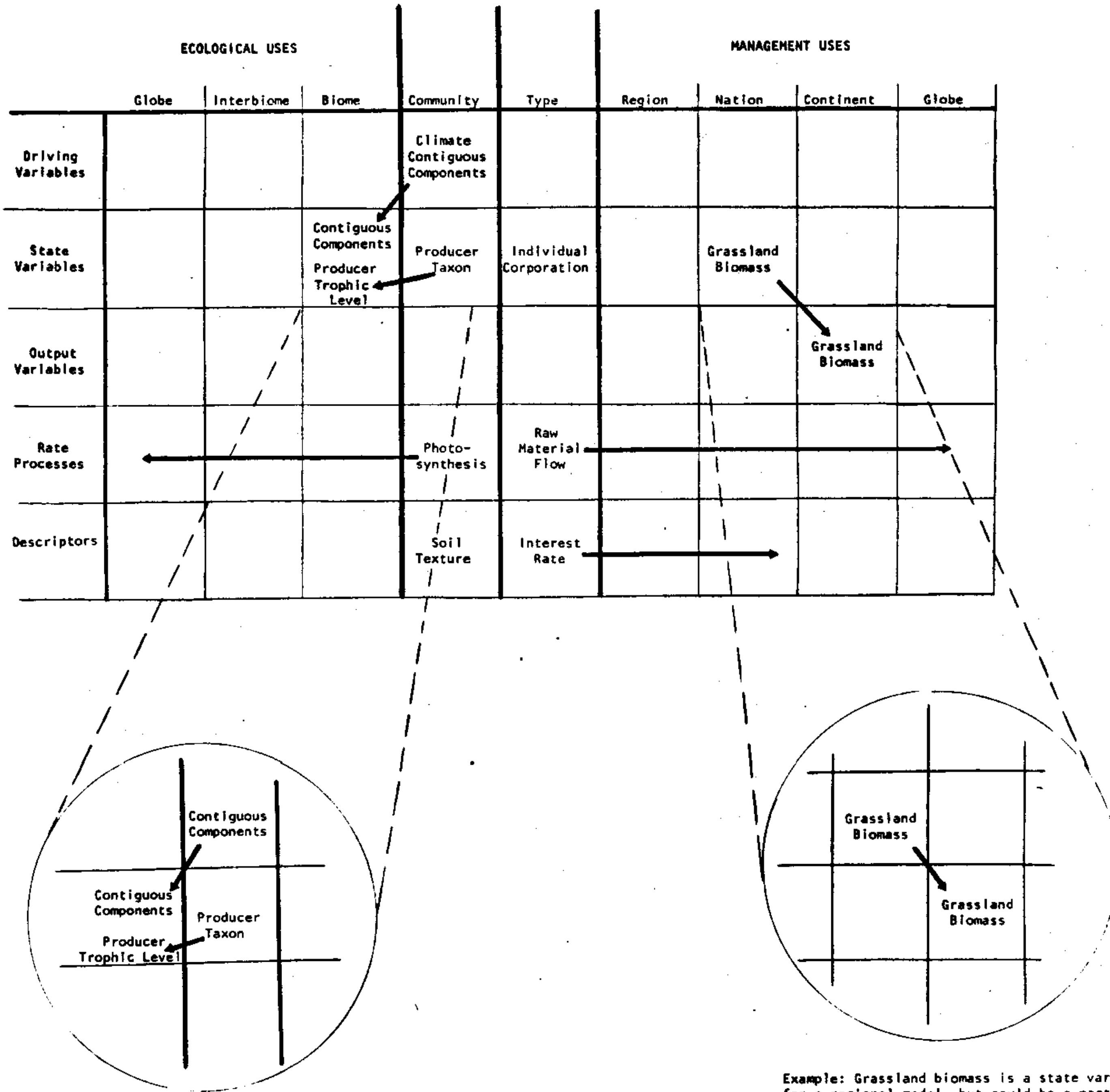
Appendix Fig. 3. Hierarchical integration of ecological systems and resource management systems. Some components, particularly social infrastructure elements, enter at a higher level of integration than do others. Increasing or decreasing width of arrows denotes relative importance of different components going away from the center of the figure, i.e., the "community type" model. Both the time horizon and geographic area scales are logarithms.

Appendix Fig. 4 shows examples of driving variables, state variables, . . ., within the hierarchies of ecosystem-oriented and management-oriented models as described earlier. Several features can be illustrated by this diagram which lists *only selected examples* in any given row or column.

Driving variables in one echelon may become state variables in another echelon of the model. As one goes through the levels of echelons (Appendix Fig. 4), state variables may become output variables to be used as input variables in other submodels. Similarly, a phenomenon which expresses a rate process at one hierarchical level may not be needed at another hierarchical level. Descriptors required at one hierarchical level may be changed at another, or they may no longer be required. Most of these modelling phenomena relate to the concept of aggregation.

As one develops hierarchies of models, it is possible to *aggregate the systems either organizationally or spatially* over the heterogeneity of the system. To aggregate organizationally might be shown by reducing the number of plant taxa that would be carried as state variables in a given echelon as compared to the echelon below it. Aggregating spatially might be demonstrated by integrating over subsystems in a larger system model or a higher level of organization. Thus, instead of considering four or five different individual microwatersheds, an entire watershed might be modelled.

It is important to note that *simply coupling contiguous ecosystems is not equivalent to aggregation* of ecosystems. The aggregation process, such as to be found in moving from the community type of Appendix Fig. 4 to the right or to the left, generally would reduce the number of variables used to describe any one portion of the system.



Example: In the study of a community its contiguous components are exogenous or driving variables to the model, whereas in the study of a biome these contiguous components become state variables. A community model might focus on a particular taxon, whereas a biome model might examine the trophic level.

Example: Grassland biomass is a state var for a regional model, but could be a part of national output.

Appendix Fig. 4. Examples of hierarchical integration of ecological systems and resource management systems. Some of the driving variat state variables, rate processes, and descriptors appropriate for consideration at each level of aggregation are shown. Emphasis is given to the changing nature of the driving variables, state variables, etc., as one progresses outward through each set of hierarchies from the "community type" model at the center of the table.

APPENDIX III

A NATIONAL MODEL

This appendix contains a description of *a simplified national modelling effort* that the biome personnel (with the help of some non-biome participants) could conduct. Successful completion of such a model would demonstrate the applicability of biome researches to questions of national concern and import.

A. Objectives

The objectives of this modelling effort will be *to investigate the impact of abiotic factors, population growth and shifts, and land use policies on production of food and fiber in the United States.*

The abiotic factor of interest is precipitation, and the model should address questions of manipulation of the national precipitation regime. Other abiotic factors, such as temperature and air-borne pollutants, are of secondary interest.

Population growth and shifts will result in a reduction in the arable land available for production. This reduction will result in pressure to increase the intensity of agricultural practices on the remaining arable land. These shifts will, in turn, increase agricultural prices and transportation costs (as production centers are moved further from consumers). Similarly, land use policies will shift land out of production and into other uses.

This initial model will be designed to address the following questions:

i. What are the effects on production (food and fiber) of large-scale weather modification (precipitation)?

ii. What are the effects on production and population pattern of population growth?

iii. Are transportation costs (from farm to market) a significant consideration in population distribution?

To address these questions the model should contain three major subsections--*population*, *production*, and *economics*. An outline of each of these submodels is presented below. A (gross) spatial grid will be established covering the country and obtained by intersecting biome boundaries with "states." (Some grouping of the states into larger units may be advisable.)

B. Population Submodel

The input to the population submodel will be net population as a function of time for the U.S. The output of this model will be a sequence of population maps showing the distribution of population in the country at different times. Appendix Fig. 5 is a diagram of the population submodel for each spatial cell.

The population source is exogenous, and net increases are due to birth minus death. These population classes are identified for each cell: POP1 is not employable because of age or physical incapacity; POP2 is employed (full time); and POP3 is employable but not working. There are flows within the population structure of a given cell (as indicated in Appendix Fig. 5) and also flows to other cells.

C. Production and Land Use Submodel

This submodel will use community type models as developed within the biome studies to simulate production where appropriate. Intensive agriculture models will be developed for the farmlands. The output of these models will be the kilocalories and weight of human consumables per cell of the grid. The dollar value of the consumables will be assumed proportional to their energy content. The cost of transporting them will be assumed proportional to their weight. Appendix Fig. 6 shows a diagram of the production and land use subsystem.

As Appendix Fig. 6 displays, food and fiber production will depend on the land available for such production (LU1, LU2, LU5, LU6) and on the driving variables. Consumption and export of these products depend on local economy (cash) and population.

In the second part of Appendix Fig. 6 the land is subdivided into eight uses. It is assumed that land can be urbanized but not "deurbanized." The urbanization (and other changes of land use) depend on local population, cash, and land use policy.

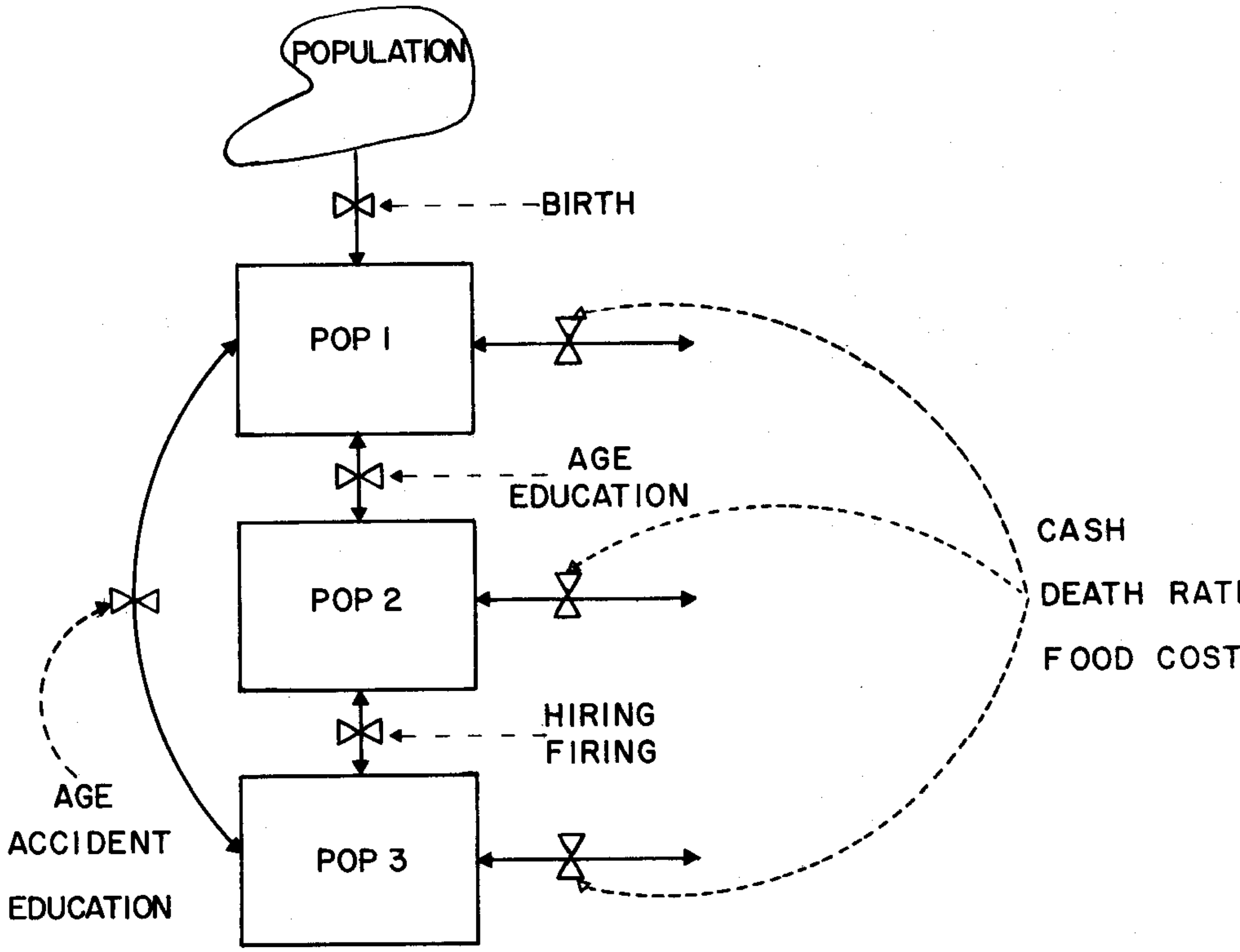
D. Economic Submodel

The economic submodel is diagrammed in Appendix Fig. 7. For each cell, the input of cash will depend on exports, subsidies, and population influx. Also, some portion of the population will participate in the transportation industry and will have income therefrom. Cash will leave a cell to purchase commodities, to pay transportation costs for imports, and to handle population influx.

The desire to investigate the effects of transportation costs on the economy and population distribution demands that transportation show explicitly as part of the economy. Transportation income results from commodity and population distribution. Transportation expenses include salaries paid to employees and equipment costs including maintenence, fuel, vehicles, etc. All of these costs will be assumed proportional to the number of ton-miles expended in distribution.

E. Some Model Characteristics

The size of this preliminary model is indicated in Appendix Fig. 8. However, note that there are only about 32 distinct flows each replicated 100 times. These flows would vary from cell to cell only in their parameterization.

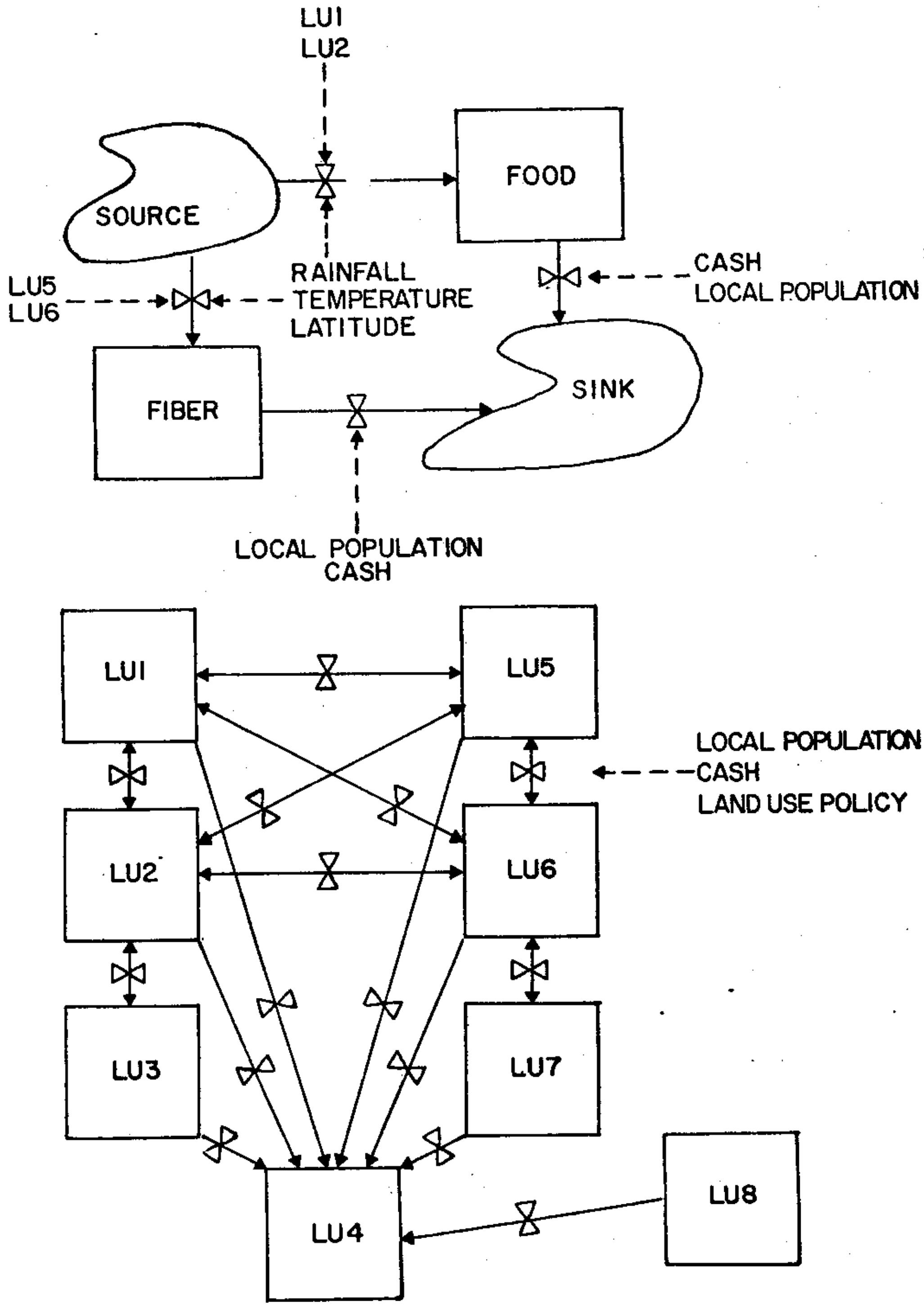


POP 1 = NOT EMPLOYED

POP 2 = EMPLOYED

POP 3 = EMPLOYABLE BUT NOT WORKING

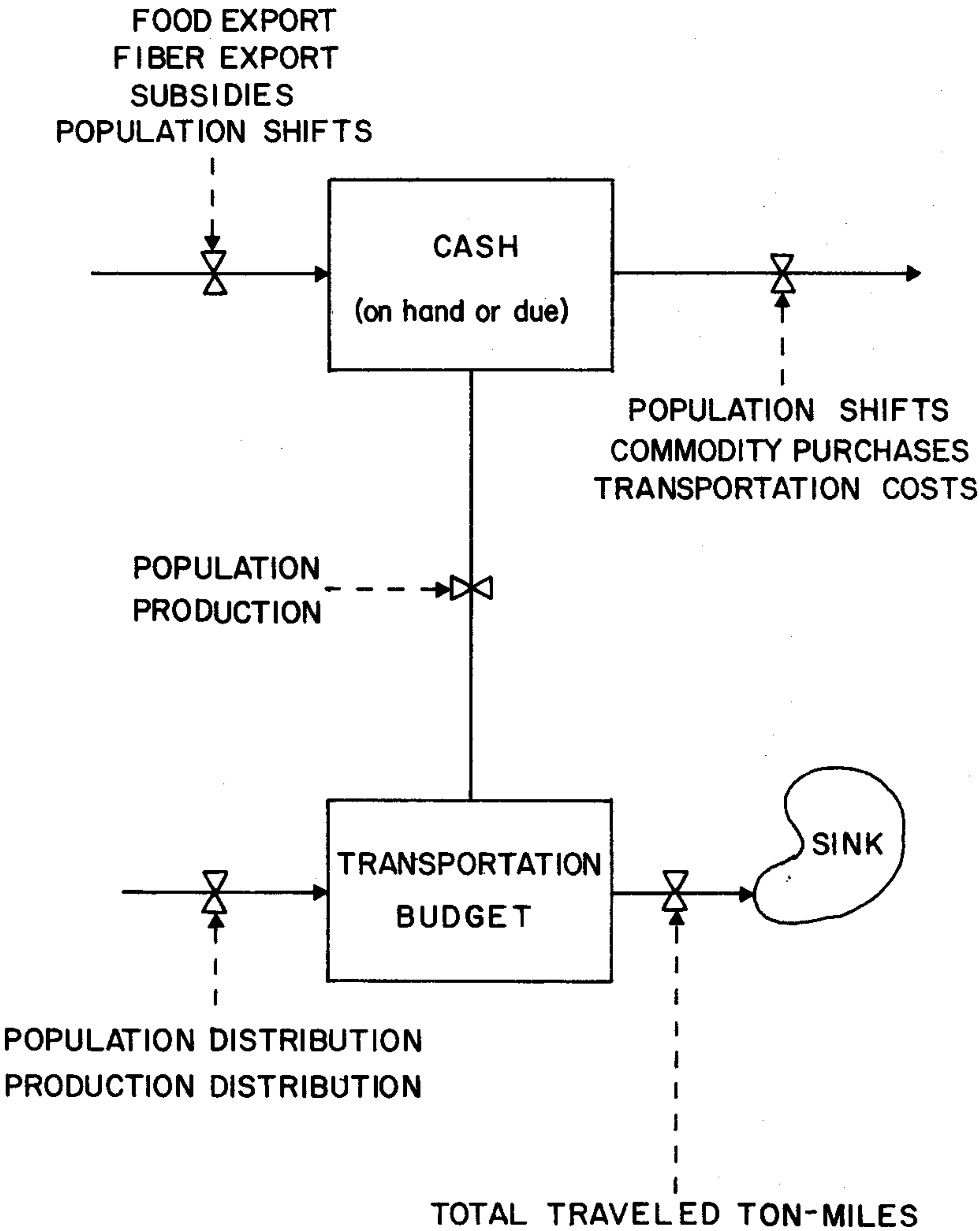
Appendix Fig. 5. Population submodel.



LU1 = acreage used for intensive food farming
LU2 = acreage used for extensive food farming
LU3 = acreage available for food farming, but not currently tilled
LU4 = urban acreage
LU5 = acreage used for intensive fiber production
LU6 = acreage used for extensive fiber production
LU7 = acreage available for fiber production, but not currently tilled
LU8 = non-urban, non-tillable acreage

These areas are mutually exlusive. The sum of LU1 through LU8 is the total acreage in the cell.

Appendix Fig. 6. Production and land use submodel.



Appendix Fig. 7. Economic submodel.

Submodel	No. of State Variables	No. of Flows		
		Internal	Coupling	Total
Population	3	4	3	7
Production and Land Use	10	23	0	23
Economics	2	0	5	5
Total for 100 Cells	1500	2700	800*	3500

* All coupling flows are into a common pool, thereby eliminating a large number of potential coupling flows.

Appendix Fig. 8. Numbers of state variables and flows by submodel and totals.

Given these state variables and flows, the objective could be attained and the questions addressed. The output of the model would be a series of time sequential maps for population, land use, production, etc. Various strategies for management of the system could be applied to the model. For example, the combined effects of weather modification and population redistribution could be investigated. Graphic output as described in Shostack and Eddy (1971) would be used to display the results. I would be advantageous if such efforts could capitalize on the skills of groups such as the National Center for Atmospheric Research which has generated color-coded maps of global atmospheric circulation (see Washington et al. 1968). Such a product as a computer generated model output film would need to be developed on a short-range basis. It would be of primary value to demonstrate the combination of inputs from the different biomes into a single effort.

For the *very simple type of model* outlined above, the *minimum* estimates would include:

i. 2 man-years of senior analysts' time;

ii. consultants in biology, demography, economics, transportation, etc., totalling approximately 2 man-years time;

iii. output design and implementation aid from experienced groups for 2 man-years;

iv. computer time estimated at $15,000;

v. miscellaneous support in report development including secretarial and drafting personnel and materials--$10,000; and

vi. travel and communication to get feedback and evaluation during the operation with biome groups--$15,000.

The minimum time for this very simplified product, assuming simultaneous availability of personnel and budget, would be 2.5 years. Even with this investment, the product would have to be considered as preliminary. It would certainly not address all of the myriad of facets of the natural resource or human resource systems that are discussed above. It *would constitute a point of departure* and a reasonable demonstration. And during its development, the background work for improving the representation of the human and natural resource segments could be carried out as described early in the recommendations of section VI.