MONTANA STATE UNIVERSITY

System analysis of the environmental impact of recreation : the dynamics of the fishing ecosystem
by Ardine Leslie Bjerke

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of
MASTER OF SCIENCE in Industrial and Management Engineering
Montana State University
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Abstract:
Indications are that today's environmental crisis cannot be solved by looking at one problem at a time. Nor can man continue to act on the environment as if his actions had simple consequences. Interrelationships within the environmental-human system are so complex and subtle that any single change introduced could affect many aspects of the whole system. The complexity of the whole system thus demands a comprehensive multidisciplinary understanding of what complex effects could possibly result from any proposed action. A technique which allows an adequate, comprehensive view of the system's complex behavior is systems dynamics, using computer simulation.

A particular environmental problem is developing in the northwestern United States, which decisions will soon have to be made about, that is, the marked increase in population in areas being developed for recreation. In Montana, specifically, Big Sky's recreational development will substantially increase the population in the Gallatin Canyon and, in complex ways, disturb the canyon's present state.

The action of recreational activities on the Gallatin Canyon's pristine environment could be modeled and simulated on a computer using the systems dynamics approach. With the ability thus to trace the complex implications of introducing this recreational population into the delicate ecosystem, researchers could offer tangible data to decision makers. With this data, decision makers should be able to select the best course of action to effect desirable long range goals.

In this thesis project, the researcher has developed a basic framework for systems modeling and simulation of an ecosystem using systems dynamics. This was done by modeling and simulating the fishing ecosystem for a segment of the Gallatin Canyon, one of the systems that will be affected by this increased canyon population. The effects of numerous potential decisions were simulated so that the results of different actions, in such areas as sewage treatment capability, sediment deposition, planting of hatchery fish, and fishing pressure, could be seen as they could possibly affect the fishing ecosystem. Notably, the subsystem most sensitive to change, and crucial to survival of the fish population, was aquatic vegetation and insects.

This model illustrates the effective use of the systems approach and specifically systems dynamics as a method for developing further understanding of the piscatorial system. But most important, the model indicates the potential use of systems dynamics for developing an adequate understanding of the complex environmental problems generally.

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SYSTEMS ANALYSIS OF THE ENVIRONMENTAL IMPACT OF RECREATION: THE DYNAMICS OF THE FISHING ECOSYSTEM

by

ARDINE LESLIE BJERKE

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree

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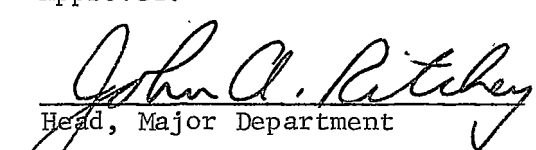
Approved:



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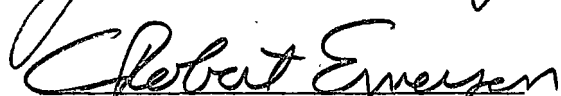

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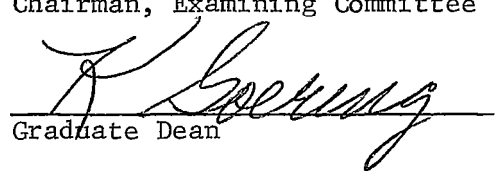

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MONTANA STATE UNIVERSITY
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ABSTRACT

Indications are that today's environmental crisis cannot be solved by looking at one problem at a time. Nor can man continue to act on the environment as if his actions had simple consequences. Interrelationships within the environmental-human system are so complex and subtle that any single change introduced could affect many aspects of the whole system. The complexity of the whole system thus demands a comprehensive multidisciplinary understanding of what complex effects could possibly result from any proposed action. A technique which allows an adequate, comprehensive view of the system's complex behavior is systems dynamics, using computer simulation.

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Chapter 1

INTRODUCTION

Environmental Issues

Many writers claim that environmental problems around the world have become critical. Others, though, contend that these are only subjective fears, that there is nothing to worry about. Which extreme is true, if either? Can either extreme be wholly and exclusively true? And if the environment is truly in a crisis, by what means is it to be saved? Are there technological solutions to its problems? Or must the "scientists" of human nature work to change our cultural myths and hence our habitual ways of behaving towards the environment? Surely both approaches must be taken, in a real crisis. Technology, which must work with the world's exhaustible resources, cannot in spite of popular belief, solve all problems. Yet, it is hoped that this thesis and the study from which it has emerged will contribute a small share to the understanding of what can be done by a humanistically enlightened technology.

In order to reach a clear understanding of the intention behind this study, let us first consider some of the problems that prompt the ecologist to search for answers and methods. Views conflict on whether the planet will support the expanding world population even in the immediate future. Forecasting the need to limit the population is not new. Malthus, writing in 1798, believed that a limited food

supply would control population, as it, in fact, has in some countries. Dr. Dennis L. Meadows and associates have recently built models to investigate five major trends of global concern; accelerating industrialization, rapid population growth, widespread malnutrition, depletion of non-renewable resources, and a deteriorating natural environment. They used the computer to a large extent to determine the effects of the present trends continuing. Meadows' study defines an imminent environmental ceiling beyond which growth in population and industrialization cannot be supported by the environment. The other side of the issue is represented by Yale economist and author, Henry C. Wallich, who does not believe that an environmental ceiling will be reached for at least another two or three centuries in the future. Wallich believes that the information on which the models were constructed was inaccurate. Wallich at least admits a ceiling exists. Many others do not. Those others have been lead to believe there is no ceiling because, so far, in the United States technology has been able to develop fast enough to provide for all commodity and energy needs. Will it be poisoning of the environment or simply starvation that finally limits our growth, as something must, or even destroys the human race? Where behavior is constant, population size determines how much waste is discarded into the environment and the amount of natural resources consumed. Many people contend that population must grow at a drastically slower pace if the world is to continue the quality of life, or standard of

living, it now has. Population can be viewed as one of the first and very basic environmental problems, since it clearly accelerates and maximizes consumption of the environment.

Environmental concern is really not new. In England, sewage has been a problem since London was of any size, and the problem of water pollution from industry has been recognized since the early 1800's. The United States, too, had water pollution problems caused by mills and aggravated by human waste by the mid 1800's. This water pollution resulted in the development of filtering systems for sewage treatment plants at the turn of the century which are still used today (Ridgeway, 35). The need for conservation has also been recognized and supported since the mid 1800's in the United States with the protection of many northwestern forests and the creation of parks and wildernesses.

Exploitation of our natural resources can be quick and deadly without some governmental control; the history of the northern midwest forest, explained by Richard T. Ely and George S. Wehrwein (12), is a case in point. This is especially true when a resource is a common resource (not owned by any one individual or group); just look at the state of water and air resources today in heavily populated areas. Environmental degradation is a reversible process, but new social values and scientific techniques must be developed, before the United States and the world approach the "limit of reversibility," where there is no possibility of reversing this degradation.

Most of America's northwestern states have not felt the onslaught of pollution, because they have been behind the national rates in both population and economic-industrial growth. So most of the area, and all of Montana, where this thesis project has been carried out, has until now kept its high quality collective resources: clean air, clear water, living space, beautiful landscape, and wildlife. These resources themselves, because they create pleasant living conditions, stimulate development. Recreational developers are searching for unspoiled environments for an economic end. Individuals are also demanding a higher quality environment, so that many leave big cities to settle in Montana. This increase in population and developments has an impact on the very resources desired.

Montana also has an abundance of certain mineral resources, like coal, which are especially in demand now. The current search for such extractive resources has stimulated resource-consuming industrial developments, which inevitably brings population and its effects. Montana is highly dependent on extractive industries which always cause environmental problems.

Montana's "crisis" has caused administrators to search for at least an understanding of the development process and the subsequent environmental impact, if not for real solutions to Montana's environmental problems. The purpose of this thesis has been, in part, to find a method for adequately perceiving and predicting the effects of the

kind of agents being discussed in this paper, and ultimately to reach for the real solutions that the administrators have not yet found.

It seems, as Paul W. Barkley would agree, that Montana has been trying to "catch up" with the national industrial growth level by trying to get industry into the state for some time. In March of 1972, a large group of state government officials, including Governor Anderson, visited California to recruit industry. A previous recruiting trip had gone to Minneapolis, Minnesota. The establishment of agencies, such as the Industrial Development Center and the various economic development agencies, signifies the strong push for economic growth in the state.

Economic growth is questioned by some Montanans and economists because it necessitates environmental degradation and resource consumption. Will Montana push economic growth at the expense of the environment, or will economic and environmental interests compromise and finally reach a balance? What approach can be used to help guide Montana to the desired balance? This balance can only be reached with a broad study of all the elements that could be affected by any decision about whether to develop, so that rational choices can be made about "trade-off" priorities. A plan and control of that plan must be comprehensive. Comprehensiveness in any environmental study points out the need for a systems approach, whether analyzing the world system or a small geographic area.

Ecology is basically a systems science studying diverse and

complex relations between organisms and their environments. It does not involve only a single discipline, for many diverse disciplines are working on ecology-related research. The effects of man's actions in most cases cannot be merely figured out by common sense, as pointed out by Barry Commoner in Science and Survival (9) and Rachel L. Carson in Silent Spring (7). Understanding the network of events which crosses disciplinary lines may be the key to determining which are the critical factors to be controlled. Man's efforts to develop the natural resources of any area must be carefully examined to determine exactly what chain of events is going to follow each action.

Any ecological or systems study must consider all factors--environment, economy, sociology, even intangible portions of these factors. In order to consider all factors, interdisciplinary studies are required. These combined sources of knowledge must be integrated into an effective whole to render the total system available for study. To construct the complex (multidisciplinary) model of any ecosystem, engineers, economists, behaviorists, and life scientists must work together, translating their data into the common language of mathematics, each contributing findings from his own discipline. But the final assimilation of their information must be done by an interdisciplinary researcher, a systems analyst.

The environmental crisis demands a comprehensive approach to the problem. This approach must be capable of considering the dynamic

characteristics of population, industrialization, and depletion of the natural, non-renewable resources. A dynamic behavior and an enormous number of interrelationships make any ecosystem, and especially that of man and his environment, extremely complex. The extremely complex nature of ecosystems demands, in ecological crisis, an approach that can adequately comprehend and guide the system.

The contribution of this thesis study will be the following: to present a method for approaching an environmental system for the purpose of modeling, simulating, and forecasting the actions of the system as it would respond to different policies. This method would lead to a better understanding of the system and of how to guide it. Before discussion of the model developed in this thesis, a word will be added about simulating or modeling. Models are classified as either physical (as a reproduction to scale) or abstract. Concepts and verbal symbols are abstract models that we constantly use as tools to deal with real life in our thought processes. Thus, the ecosystem is generated as an abstract model, and progresses from the general ambiguous verbal model to the more precise mathematical model. The real system can thus be represented clearly and concisely.

Thus, simulation is used to facilitate understanding of the complex interrelations. Simulation is done, too, because the real system cannot be experimented with and even if possible, the "real" cost would be prohibitive. Computer simulation is used because the

human mind cannot think out the complex interrelations of symbols in any model and even if it could, the manpower cost would be extremely high. With computer simulation, one can easily examine the hypothetical results in the system, of shifts in the assumptions on which it is based.

It is hoped that the results of this thesis study--the dynamic model and its tentative predictions along with specific recommendations for managing what have been found here to be crucial control points--can be used with further development by people in the position to influence the system. In this project, the modeling and simulation of an ecosystem is applied to a particular area to facilitate testing the model's performance by measurement in the real system.

A small geographic portion of the Gallatin Canyon of Montana will be used as the ecosystem under study. The Gallatin Canyon system runs north and south with arbitrary boundaries starting fifteen miles south of Bozeman, Montana, and running forty miles south to the northwest boundary of Yellowstone Park. This area is currently under study by a multidisciplinary group of faculty members from Montana State University sponsored by the National Science Foundation. The main reasons for such interest in the Canyon are the canyon's pristine environment and the imminent development of a large recreational facility by Big Sky Inc. of Montana, causing an expected dynamic increase in people and, therefore, in pressure on or by the environment. Since

the canyon can be watched and measured in the very process of change, the canyon provides a perfect case study for application of a comprehensive simulation model.

Initially, the effort was to model and simulate the actions of the entire canyon system drawing on the multidisciplinary study group for data and assistance. But this project proved too extensive. To some extent, the researcher did condense a considerable amount of complex data into an organized and logical system, easily understood and yet, as far as it went, true to the ecologic reality being modeled. In this way, he analyzed the general system as a context to understanding the sub-system he finally chose: the fishing ecosystem. This particular sub-system was chosen because of the data available and because of its apparent importance as a recreational activity in this area. This format for analysis and modeling should be usable to study the effects of the kind of factors causing environmental impact discussed above, like recreational and industrial development. But, in fact, the approach used to analyze this sub-system can be expanded to study entire ecosystems.

Chapter 2

REVIEW OF FORMATIVE LITERATURE

The following is a selective account of the many works consulted in acquiring a broad view of environmental issues and of how various disciplines perceive these issues. There are few articles or books written about a truly multidisciplinary approach, which seems to be the only approach that can adequately analyze an ecosystem.

Aldo Leopold (23) provides a very positive approach to our environmental crisis. He believes that once people can be educated to perceive the beauty of nature, they will naturally develop a love for the land, a different land ethic. This simplified and optimistic solution is not realistic when confronting such a complex problem where economics plays such a large part.

The conservation movement historically in this country has been mainly concerned with the economic benefits of conservation rather than with a high quality environment (Burch, 5; Parson, et.al., 30). The goals of conservation are gradually shifting from economic benefits towards a policy that reflects a set of value goals the public wants for their environment. These value goals reflect the desire for high quality common natural resources like air, water, and living space.

The economists (Ayres & Kneese, 2; Barkley & Wiseckler, 3; Crocker & Rogers, 10; Dolan, 11) view the problem as a matter of aligning the cost of products to the public's real expense for the

damages to their common natural resources, which could then be repaired or compensated for. Paul Barkley (3) sees a need for a no-growth economy. The classical economic thought, growth, dollar measures and supply and demand, in his opinion, will inevitably lead to the earth's destruction. Paul Barkley's no-growth economy depends on a basic change in American social values and myths.

William R. Burch (5) stresses the need for revolutionary change in these American social values and myths. More value must be put on the natural environment that we have to continue living in. To institute revolutionary changes, the following pervasive concepts must be reconsidered: "there is always a technological solution to the problem"; "linear and upwards"; "all progress is good"; "always better through time"; "there is always a frontier"; and "rising expectations." Most of these have developed with the unique history of the United States. We must, Burch insists, face up to the environmental crisis here and now or our daydreams that reflect our ever increasing expectations will certainly turn into nightmares.

James Ridgeway (35) would pose the question, can our values be changed, keeping the present power structure in control of industrial and governmental concerns? Ridgeway points out the inadequacy of our political structure to handle the environmental crisis. He contends that the real polluters are the corporations which are really profiting from the environmental crisis by manufacturing pollution devices and,

further, projecting a public image as opponents to pollution when they are concerned with only getting by.

Lynton Keith Caldwell (6) contends that we can change the power structure of industry and government by the creation of administrative bodies backed by laws so that some worthwhile action can result. Caldwell is concerned with the conceptual development and administration of an environmental policy based on comprehensive planning. He is one of the few writers who really approaches the problem in a comprehensive manner; he believes there is a critical need to bridge the gap between many disciplines because every action of any kind effects the whole. " . . . a systems approach examines not only what is intended, but what happens throughout the system (Caldwell, 6:106)." He believes that ecology is the science that should be able to bridge the gaps and tie the existing information into a basic knowledge of man and his environment. Caldwell's comprehensive approach is developed from a problem-solving concept, "spaceship earth" as a closed input-output system. Caldwell's policy of comprehensive environmental administration, which is really radical, is incrementally implemented, based on applied science, the goals of the public administration, and the individual ethic.

Walter Isard (20) also views the problem in a comprehensive manner. He constructed an open input-output model to deal with economics, social, and ecological interrelationships.

The National Science Board (39), too, points out the need for multidisciplinary systems analysis and its ability to predict complex effects of man's action.

Luna B. Leopold (24) has constructed a matrix for the purpose of examining how alternative actions differently affect important components of the environment. These matrix relationships can be used to help understand the complex ecosystem, considering many environmental components. His matrix method can help in determining the preferable alternative.

The following reviews are concerned specifically with system analysis and system dynamics. C. West Churchman (8) describes the meaning of systems analysis and the usual approaches to it. He examines four different system approaches or ends: the "optomization" of efficiency experts; the "modeling" of scientists; the attention to "human feelings" of humanists; the value placed on experience and reactions and not "rational" plans by the antiplanners. He presents the book as a debate pointing out the advantages and disadvantages of all four approaches.

Churchman stresses the importance of the scientific approach as the basis for any system study. It requires determining the "real problem" first and includes these five basic considerations: the system's goal and the measurement of the whole system's performance; the system's resources; the system's environment or its fixed constraints;

the system's components or subsystems; and the management of the system (8:29-30). These five considerations in the scientific approach should be combined with what is most valuable in the other approaches to do a good systems analysis. In this project, the shortcomings of the scientific approach that Churchman pointed out have been included: obvious objectives might be mistaken for the real objectives; intangibles, like human behavior, must be considered but may not be measurable, and this cannot be dealt with by the historically objective scientific approach.

Churchman's approach begins when first you see the world through the eyes of another; "the systems approach goes on discovering that every world view is terribly restricted (8:231)." This really implies the need for interdisciplinary system studies. A truly worthwhile system analysis can be developed only when each discipline can begin to see the other disciplinary views and when each discipline accepts the fact that its own "world view" is restricted. This statement, in my opinion, is especially true for environmentally related system studies.

Jay W. Forrester has contributed very significantly to the field of modeling complex dynamic systems. Modeling and simulation with system dynamics is based on his findings. There are numerous possibilities for applying Forrester's system dynamics, including the study of ecosystems. His books cover all aspects, from start to finish

of system dynamics. Principles of Systems by Forrester (16) is a thorough and formative introduction to system dynamics. The book gives the basic principles of system dynamics modeling which involves the feedback loop relationships, applicable to any system. The approach of Churchman and Forrester together lead to an excellent understanding of systems. Using Churchman's scientific system analysis approach, which helps structure the verbal model, one can build a feedback loop system as Forrester describes it.

In his first book, Industrial Dynamics, Forrester (15) developed an applied system dynamics. The purpose of writing the book was to provide a better way to deal with top management problems by advancing the art of management more towards a science. The facts acquired using scientific techniques, like system dynamics, would give management a more sound basis for policies to guide or manage the ecosystem. Forrester outlines the steps towards structuring a system (industrial) dynamics approach, following Churchman's scientific approach rather closely for the first few steps. System dynamics has developed historically along four lines, each of which he incorporates in his method: information-feedback control theory; decision making processes; experimental approach to systems analysis; and digital computing.

Forrester (15) introduces the industrial system to illustrate the characteristics common to a system dynamics approach. He works with industrial subsystems to show clear application of feedback modeling

principles which then lead to experimentation and simulation with these subsystems, or the whole system on the computer. The appendixes contain important information about solution intervals for the model and other information to forestall difficulties in using system dynamics.

Forrester (17) provides an excellent illustration of a social system in Urban Dynamics. All social systems are complex systems, that is, high order, multi-loop, nonlinear feedback structures. As Forrester explains:

> Complex systems (1) are counterintuitive; (2) are remarkably insensitive to changes in many system parameters; (3) are stubbornly resistant to policy changes; (4) contain influential pressure points often in unexpected places, from which forces will radiate to alter system balance; (5) counteract and compensate for externally applied corrective efforts by reducing the corresponding internally generated action (the corrective program is largely absorbed in replacing lost internal action); (6) often react to a policy change in the long run in a way opposite to how they react in the short run; (7) tend toward low performance (17:109).

These characteristics are just as applicable to any ecosystem as they are to a social system.

Forrester also pointed out the need for interdisciplinary study groups; he believes that in order to construct the actual systems, the conventional intellectual disciplinary lines must be erased.

Forrester stated that enough information exists for structuring systems, "The barrier to progress in social systems is not lack of data (17:113)." He goes on to explain:

> The barrier is the lack of willingness and ability to organize the information that already exists into a structure that represents the structure of the actual system and, therefore, has an opportunity to behave as the real system would. (17:114)

This statement is especially pertinent to ecosystems. We need to use the information we now have available to generate a system dynamics model to further our understanding and point out needed research. Relationships do not need to be based on elaborate statistical analysis in order to be useful--even using what is now available is better than not considering the relationship at all.

The fishing-ecosystem model is computer simulated with all assumptions stated to test its reality. Further understanding of the system is developed by experimentally changing the assumptions and/or exciting the system in a realistic manner. Urban Dynamics is an excellent example of a social system with characteristics similar to a conceptual ecosystem. This book is an excellent reference for setting up flows, and auxillary equations, some of which account for intangibles.

Forrester (13) also wrote an article "Counterintuitive Behavior of Social Systems," which summarizes the need for models like those developed in Urban Dynamics (17). In his article, Forrester illustrates with flow charts and computer forecasting his world dynamics model, which simulates potential environmental effects of various trends.

H. R. Hamilton and his co-authors (18) used Forrester's modeling technique to analyze a regional river basin plan. Trying many simulation

techniques, they found continuous simulation the least expensive and also the best method for modeling a non-linear system. The system dynamics approach, developed by Forrester, is found to be the best technique available at this time. It is his methodology and philosophy which has determined the approach used through this thesis project.

Chapter 3

SYSTEMS

Systems Framework

The process of describing a system as complex as the man-nature system must be by necessity logical and comprehensive. Two different approaches may be taken. First a definition of the elements of the system in detail can be followed by modeling until a workable system has been described. The second approach, and the one used here, is to start from a very general description of the system, follow with general relationships or a general model, and lastly construct a specific model. The two approaches are not in conflict and can indeed benefit the overall process.

Before proceeding with the system analysis, it may be helpful to identify the process suggested by Churchman (8) as the five-step scientific approach. The first step would be a statement of the problem and the objective of the system under study. This would be followed by a listing of the fixed elements (environment) of the system, that is, those properties that the system has little or no ability to alter in the larger sense. The third step is an identification of the resources of the system which "are the means that the system uses to do its jobs (8:37)." A careful examination of the components follows. The last step is identification of the management process. These distinctive steps become a little difficult to deal with when a

man-nature system is under consideration. However, it is felt that much guidance and understanding can be gained by dealing with the so-called systems approach by describing the on-going process in any man-nature system.

The Churchman approach helps to define the composition of the system. What is needed beyond that is a technique that would easily relate the interactions that exist in the system. The circle diagramming technique is a graphic method used for this purpose. A matrix is also used to help understand the system.

The system analysis that is documented here starts generally with an incomplete ecosystem analysis and then completes an extensive system analysis of the fishing ecosystem in Chapter 4.

Ecosystem

What are the problems and objectives associated with an ecosystem? There are conflicts between the environment and man and also among the elements of each. The conflicts must be well balanced to preserve the environment and ultimately man. These conflicts have to do with the many and varied objectives of system or resource uses. Some general objectives stand out. The first group of objectives would center around man. The term "man" in any ecosystem can be pragmatically defined as the present and future potential users of the area. These users might never physically use the area but are interested enough in it to influence the system with some outside force. Recognizing the impossible

nature of defining any one man's objectives, let it suffice to say that the objective is to obtain maximum benefit from the area. What the maximum benefit is, is partly dependent on who you ask to define it--the industrial and business concern, or the concerned preservation groups who have different goals. Another objective expounded by many persons and supported by the natural laws is to protect and maintain the natural order of the environment. There can be little question that as the environment reacts, it does so by what are called the laws of nature. Nature's process is to move along in time on a course of natural succession working by set policies, many of which man does not understand or, in some cases, even know about.

Man might structure his environment, but he is also influenced significantly by his natural surroundings. It appears that man must, therefore, try to bring his objectives and values, what we have called his "benefit," more in line with the environment he is part of through greater understanding of that environment.

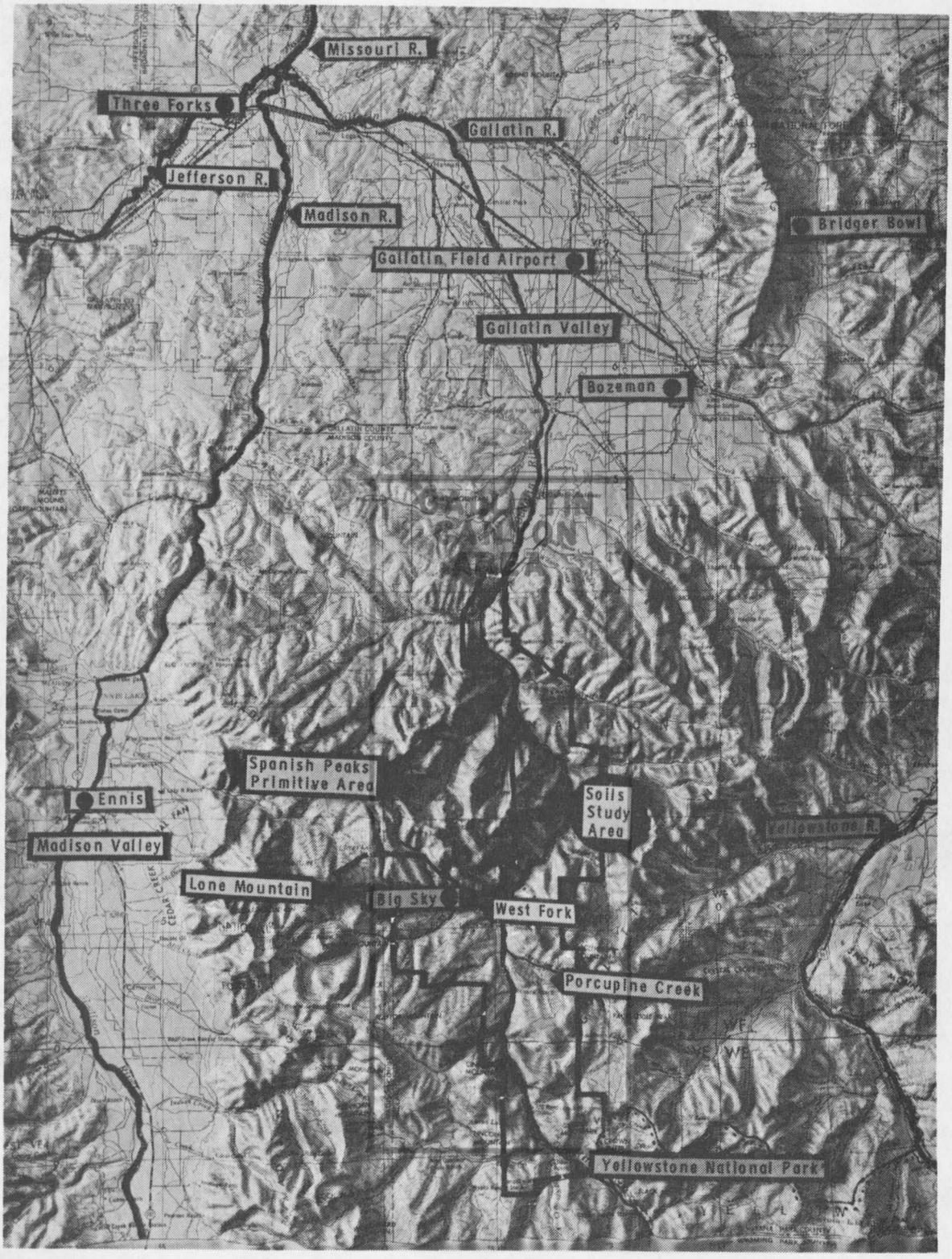
Only be measuring the system's performance can you determine whether man's objectives are working out. One measure of the system's performance will be the potential users' satisfaction over the long run. Another such measurable factor is how many of the present options for resource use will exist for future generations.

Man and nature are both necessary and inseparable, but one factor distinguishes man. Man can influence his own destiny by being

able to perceive his impact on his environment where most other living beings cannot perceive their impact on their natural environment or on man. Even with science, man still has great difficulty perceiving all of the complex reactions of nature caused by a single action. The technique described in this thesis is designed to help improve this perception with the aid of a model, extensive information from other disciplines, and computer calculation. Man is the controlling force and can thus affect the action of both man and nature to attain their greatest benefit.

The boundaries of the system needs to be explicit to insure a good systems analysis. The physical boundaries are drawn as an example for Gallatin Canyon in Figure 1. This physical boundary encloses the physical features and forces within the system but there are some outside influences that must be considered, particularly human influence. This influence will include the potential user's needs and demands and the demands of the governmental agencies in control even if these factions are not in the canyon at the time. The human elements will be restricted to those that will affect the area.

What are the fixed elements of an ecosystem? What is fixed for one scientific field is not fixed for another. Nevertheless, there are certain properties of the canyon which in general terms the system cannot alter a great deal. Three properties of the canyon which man will likely only have minor impact upon are the basic geology,


Missouri R.
Three Forks
Gallatin R.
Jefferson R.
Madison R.
Bridger Bowl
Gallatin Field Airport
Gallatin Valley
Bozeman
Spanish Peaks Primitive Area
Ennis
Soils Study Area
Yellowstone R.
Madison Valley
Lone Mountain
Big Sky
West Fork
Porcupine Creek
Yellowstone National Park

climate, and present state of technology. To be sure the system can alter a hillside and maybe change the average temperature of a small area but in a general ecosystem of any size (such as the Gallatin Canyon) these properties become descriptive inputs in a model, not highly variable ones.

The resources of a pristine ecosystem, like the Gallatin Canyon, are generally aesthetics, land, wildlife, fish, vegetation, water, soil, and minerals. These resources are basically what man uses to accomplish his goals.

The variable interests and needs of man within the ecosystem are recreational activities, industrial activities, cultural, political users' demands and needs, and governmental agencies like the forest service. The industrial activities include such things as logging, farming, ranching, and mining. The recreational activities include such things as hunting, fishing, sightseeing, backpacking, camping, and snowmobiling. Urbanization includes construction of any man-made structure, from homes to billboards. These interests guide the resources toward particular goals. So, man's management of the system is full of special interest and conflicts.

Churchman's approach has brought us to this point, where we can better understand the makeup of the system. But it does not explain explicitly, how the components are related. To clarify the relationships, the circle diagraming technique was developed. The relationships are

described in this model in terms of flows of information or material that have definite effects. Circle diagrams allow graphic representation of interrelationships among man's resources and natures' resources and their cross relationships.

The two fundamental components of an ecosystem are nature and man being in the ecosystem as a potential user or influencer. Each component is then composed of resources or, as follows, subsystems.

Components:	Nature	Man
Resources:	Atmosphere Earth Water Animals Vegetation	culture economics techniques

Some liberty has been taken with the scientific definition of these resources, but this general classification still applies. The analysis of an ecosystem can be generally represented by Figure 2, page 26. It is important to note the reasoning behind the figure. Dynamic increase in the activities of man will significantly change the system. Man, nature, and the interaction of the two components will significantly influence the resources of the system. The resources of the system will in turn directly affect the activities of man, nature, and their interaction. Illustrating these factors with graphic diagrams, man can evaluate the system and then try to modify his activities. This methodology will, hopefully, ultimately help to evaluate and predict the activities of the ecological system and to thus clarify the systems'

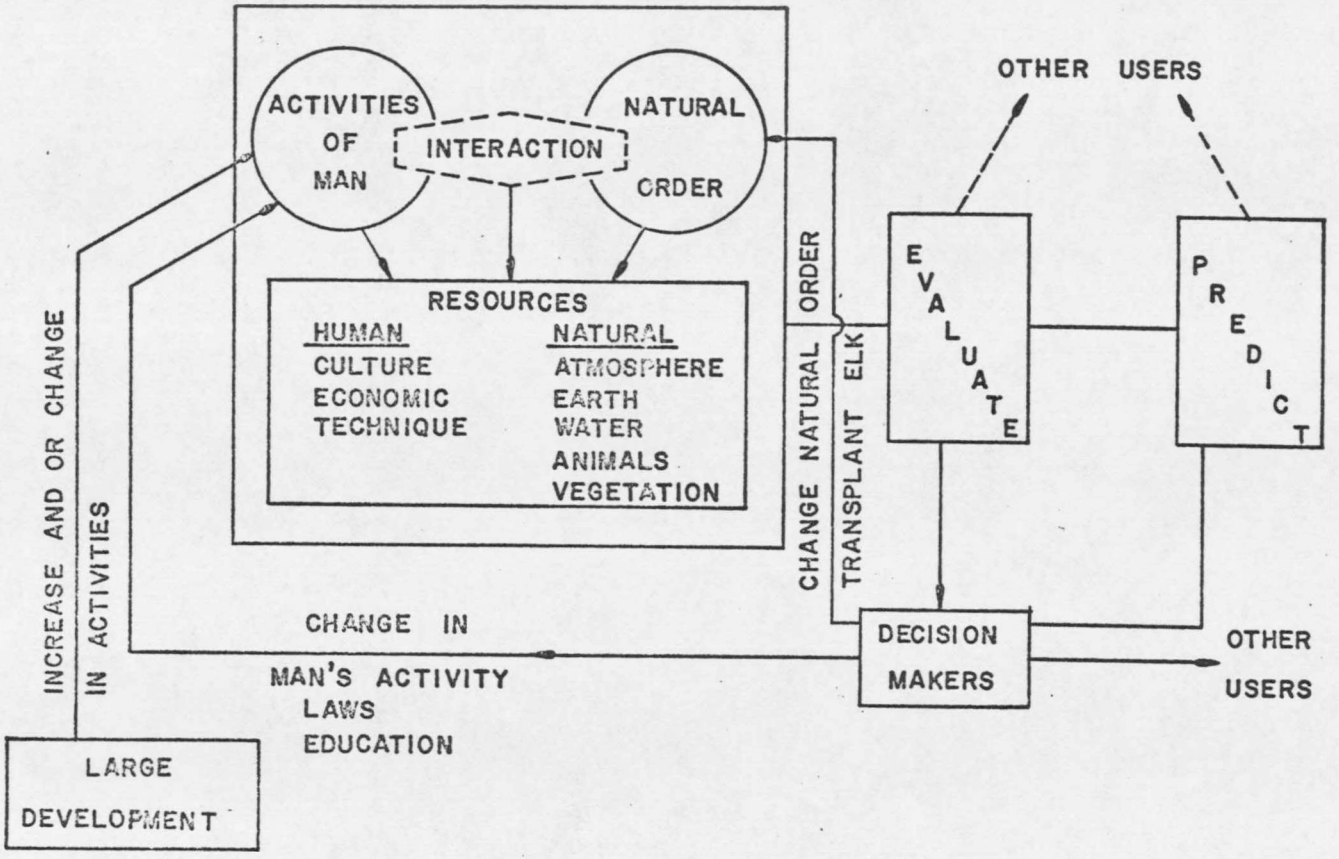


FIG. 2

A DYNAMIC SYSTEM

behavior for the decision makers.

The circle diagramming technique is explained further in Appendix A where figures show the relationships within many of man's recreational activities. Others of man's activities must still be included to complete the circle diagramming for an ecosystem.

The makeup of the other component of the ecosystem, nature, is shown in Figure 3, page 28. Many of the basic resources were broken down into their important elements. The fixed elements are included in the figure because they significantly affect the other elements or resources. The circle diagramming can have elements added or subtracted to fit any particular system as shown in Figure 4, page 29, which represents a pristine environment like the Gallatin Canyon. This figure also shows how water quality was considered apart from the resource of water. Soil was also split from geology. This flexibility in the model makes it easier to represent the real system. How can the relationships among different elements be illustrated with the circle diagrams? The easiest method is to draw arrows showing one element influencing another. Specific types of flows were discovered and were categorized as the following: life needs, life style, biological, psychological, chemical, and material requirements, consumption, physical force, and physical limitation. These flows are defined and explained in Appendix A. These categories are used to label the flow relations. One class of flow for the components of nature is

FIG. 3
PRISTINE ECOSYSTEM

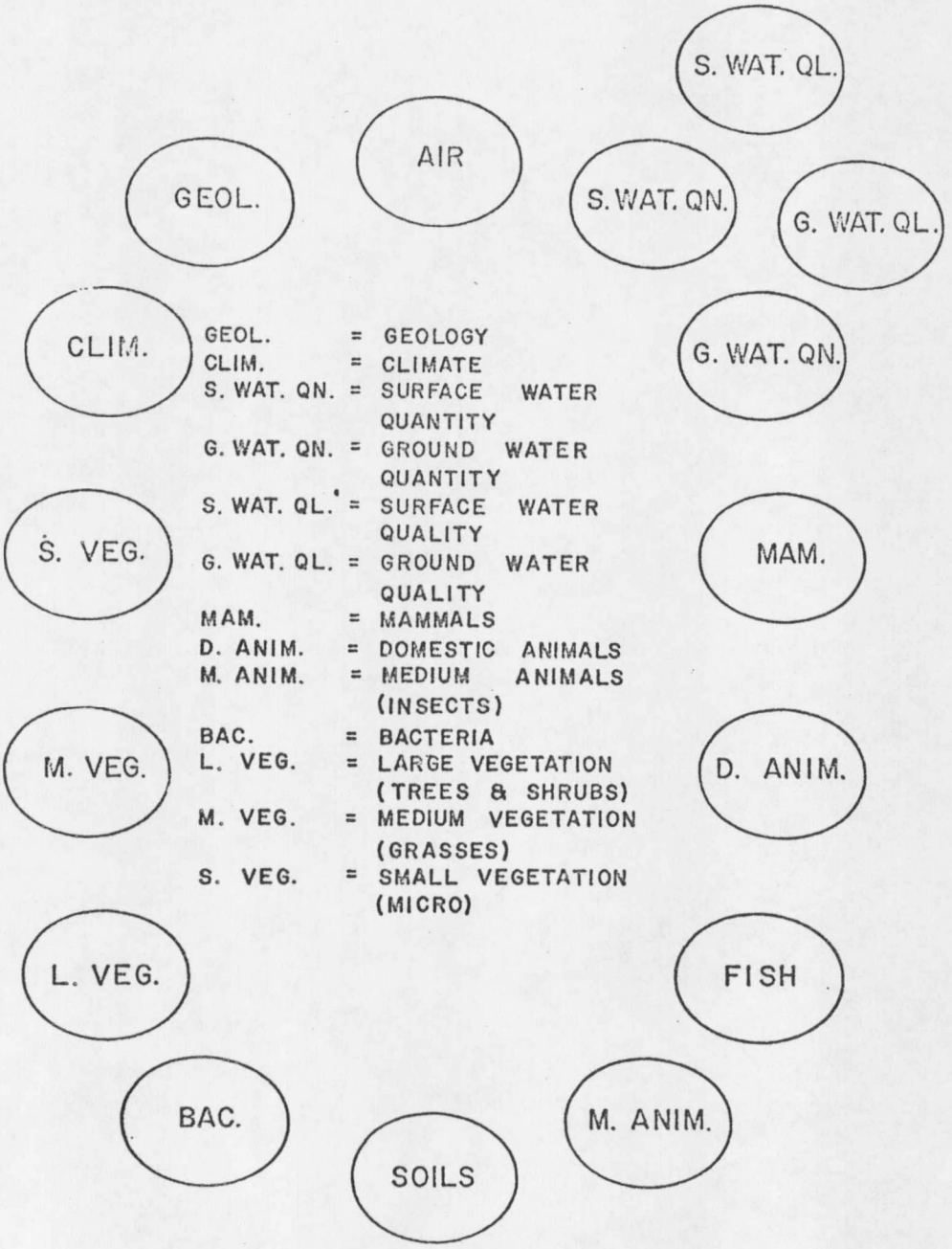


FIG. 4
MODIFIED ECOSYSTEM
(GALLATIN CANYON)

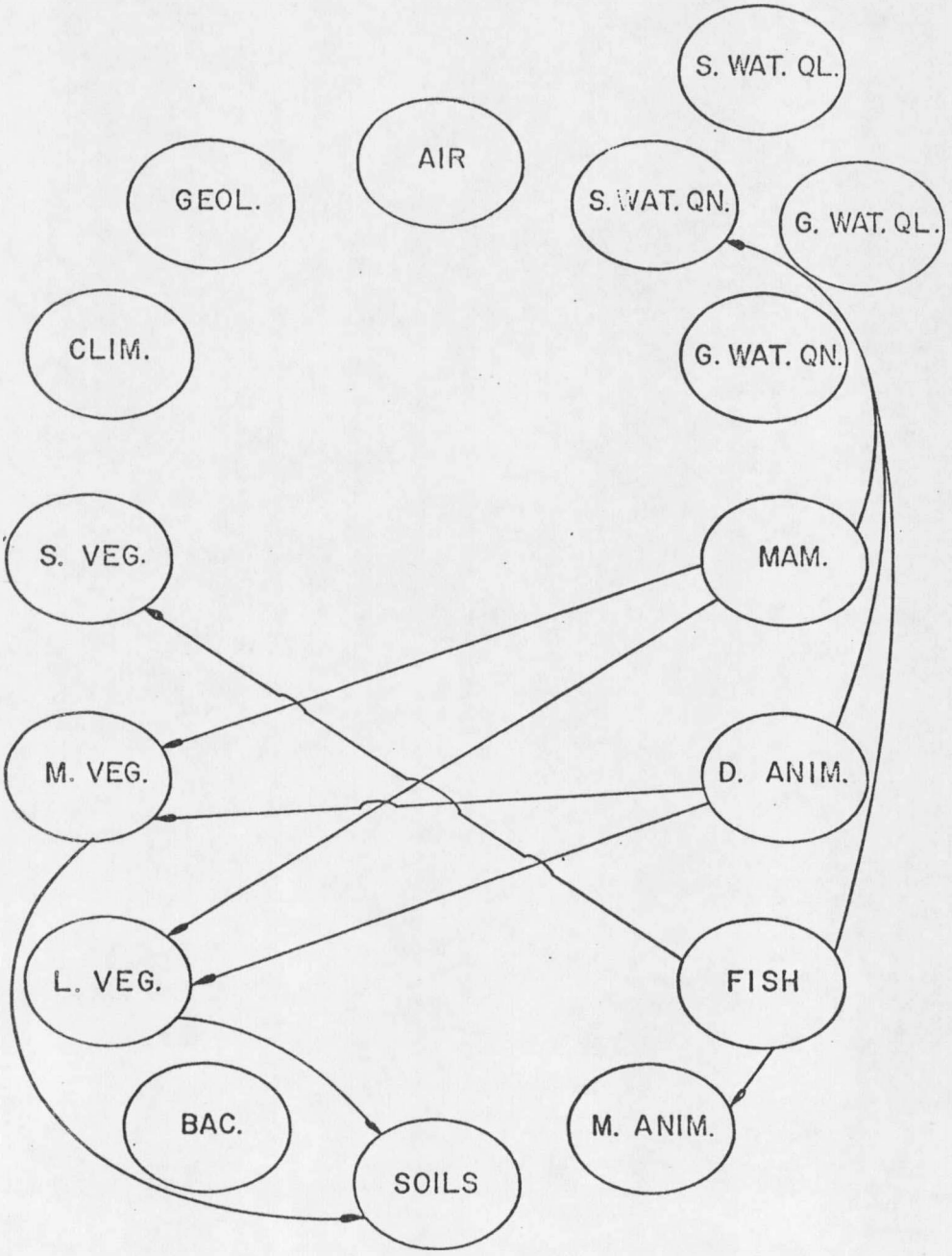


FIG. 5
CONSUMPTION

illustrated in Figure 5, page 30.

The flow categories fit easily into Forrester's information feedback system so that a system dynamics model can be developed. The material flow as described here can be the controlled flow that takes place between a rate and its level. The rest of the classified flows are really the information flows within a subsystem or from one subsystem to another.

The circle diagrams for man, Figure 6, page 32, show important human resources, illustrating the uncertain dividing lines between one resource and another and provides for development of better flow relationships which are not explained in this paper.

The natural circle diagram is now changed by adding man into the picture. Man is represented primarily by recreational activities because of their effect in any area which is a pristine environment. An example is shown with snowmobiling in Figure 7, page 33. The circle diagrams allow scholars from the other disciplines to easily understand the relationships and effects. The flow relations can be drawn in by anyone and then explained and categorized. Additional circle diagrams are in Appendix A. To construct a total ecosystem model, the circle diagramming should be completed for all activities that use the resources and not just for recreation. The diagram stage is only one aspect of modeling.

A type of impact matrix (Leopold, 24) was also used to help

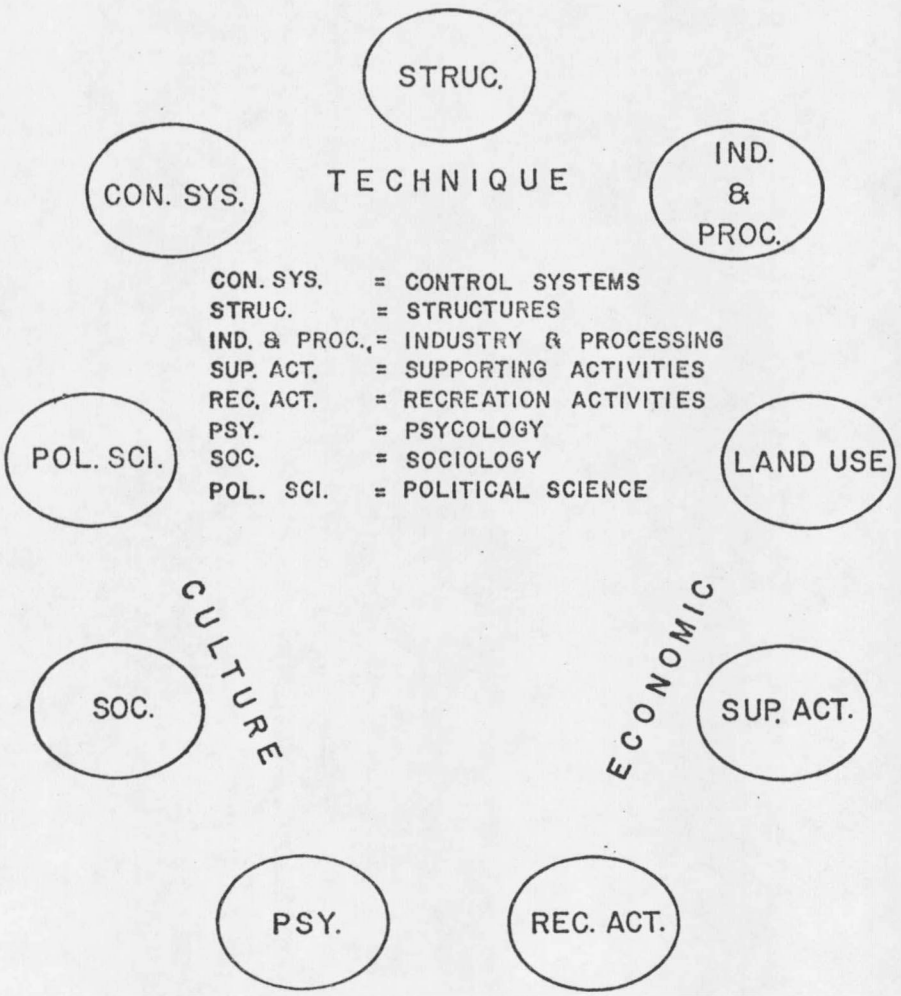


FIG. 6

SYSTEM OF MAN

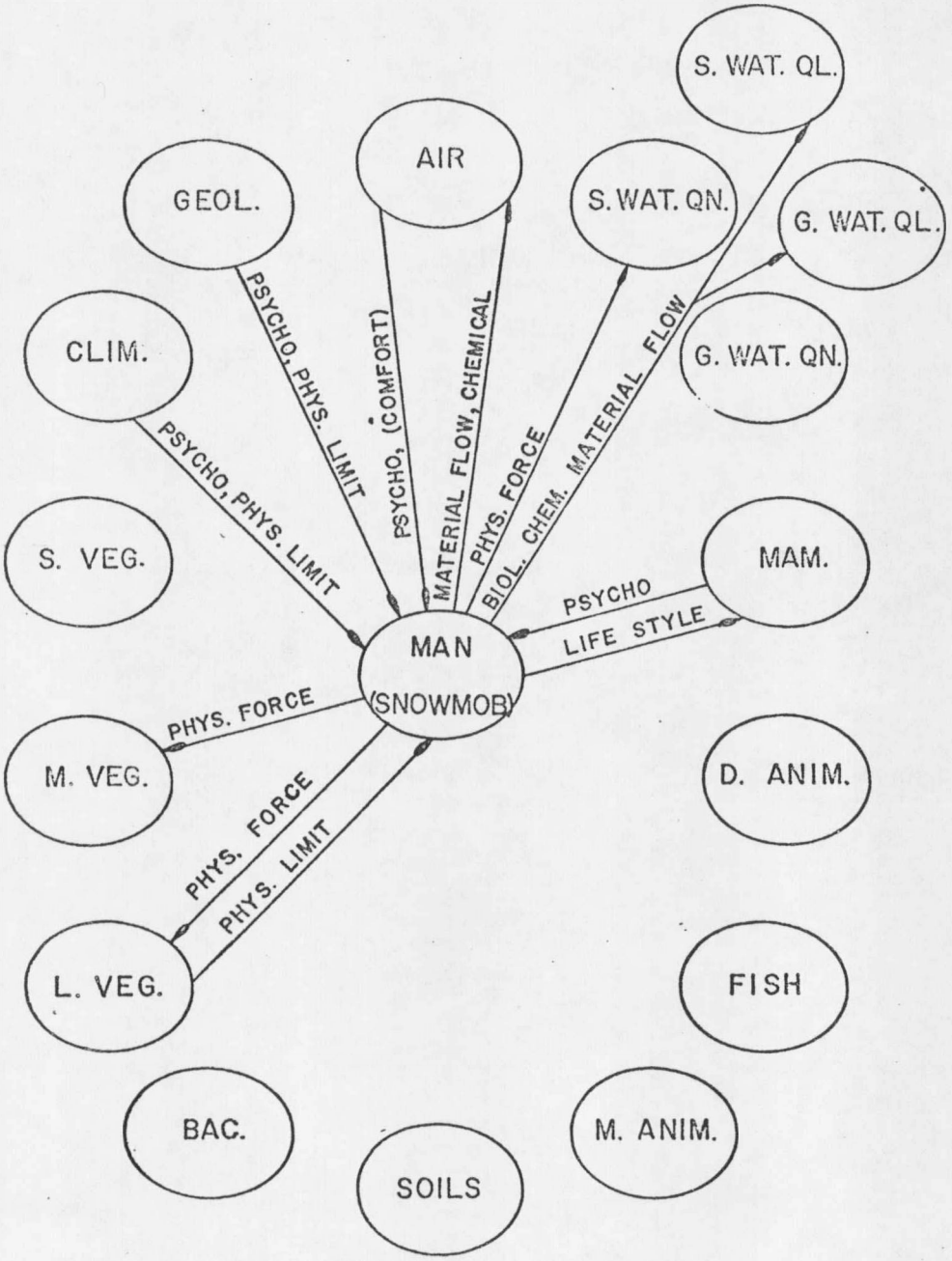


FIG. 7
SNOWMOBILING

structure the interrelations, the important factors to be considered in any area. Appendix B gives a more detailed description of the environmental impact matrix.

The system analysis in the method being described, thus, consists of the Churchman approach, the circle diagramming, and the impact matrix. Together, these constitute a major start for a complex verbal model of an ecosystem.

These approaches and structuring methods lead to a basic, general understanding of an ecosystem. The general model can be built to develop a detailed systems analysis for a sub-system: fishing-ecosystem dynamics. The extended and complete methodology (verbal model, math model, flow diagrams, computer simulation, implementation) used in the dynamic fishing-ecosystem model can be used to complete the detailed analysis of the larger ecosystem and all recreational activities given the proper resources of time and manpower.

Chapter 4

FISHING-ECOSYSTEM DYNAMICS

The information provided to this point gives an idea of the complexity and multiple feedback loop characteristics of the ecosystem. The system dynamics approach for a total ecosystem or a fishing-ecosystem is based on the following premises, which seems logical and true for the system considered. These premises are structured after those given in Industrial Dynamics:

1. The system behaves counterintuitively.
2. Man cannot think out the complex interrelations of an ecosystem or fishing-ecosystem; a computer is needed.
3. Simulation will take the place of judgment to determine the action needed by decision makers.
4. There exists enough information, even if not all of it is quantitative, to realistically model the system.
5. Many relations do not depend on very precise measurements.
6. Policy and structural changes are feasible that will produce substantial improvement of the system, now or in the future.
7. The resulting policies of fishing dynamics are not in conflict with the larger ecosystem. (This is yet to be proven in a completed ecosystem dynamics.) (Forrester, 15:14)

Forrester also identifies the steps to follow in using his Industrial Dynamics or Systems Dynamics approach.

1. Identify a problem.
2. Isolate the factors that appear to interact to create the observed symptoms.
3. Trace the cause-and-effect information-feedback loops that link decisions to action to resulting information changes and to new decisions.
4. Formulate acceptable formal decision policies that describe how decisions result from the available information streams.
5. Construct a mathematical model of the old decision policies, information sources, and interactions of the system components.
6. Generate the behavior through time of the system as described by the model (usually with a digital computer to execute the

lengthy calculations).

7. Compare results against all pertinent available knowledge about the actual system.
8. Revise the model until it is acceptable as a representation of the actual system.
9. Redesign, within the model, the organizational relationships and policies which can be altered in the actual system to find the changes which improve system behavior.
10. Alter the real system in the directions that model experimentation has shown will lead to improved performance.

(The resulting fishing-ecosystem model is at the cyclical steps of 7, 8, and 9.) (15:13)

The first few steps of Forrester's approach are contained in Churchman's scientific systems approach.

Churchman's approach helps to define the problem, the objective of the system and, in general, helps generate a verbal model. Churchman's last step of defining the management process seems to be the main body of Forrester's system dynamics. System dynamics is interested in determining what changes in overall management policies are necessary to drastically improve the system. It seems another step to Forrester's procedure should be added. After identifying the problem, one should list the specific policy questions that the model will be designed to answer. This step really defines the purpose of the model (15). System dynamics, fishing-ecosystem dynamics in this case, will, it is hoped, answer significant policy questions after further development and, therefore, improve the system. Specific questions that fishing dynamics will, hopefully, answer are listed in Table 1, page 39.

System dynamics is based on information feedback loops. Figure 8, page 37, illustrates the simplest form of a feedback system.

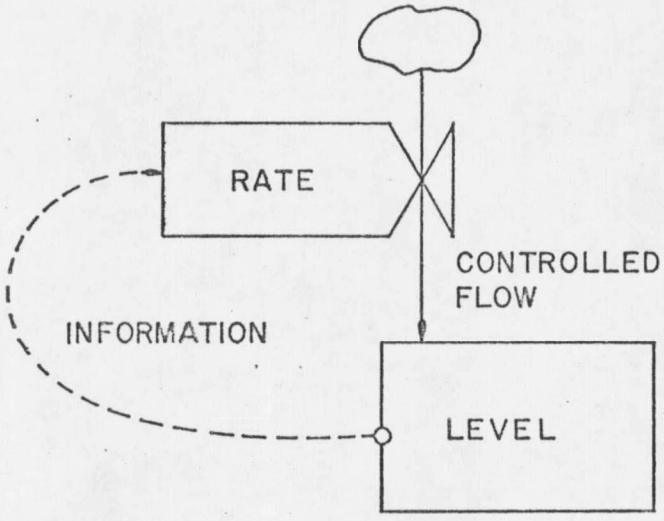


FIG. 8
SIMPLE FEEDBACK SYSTEM

The circle diagram and matrix were also used to help generate a verbal model. The classified flows in the circle diagramming technique are really information feedback that exists in the system.

It seems that the ecosystem dynamics will and should be studied to insure that the "whole" system is optimized instead of optimizing a subsystem like fishing. Some indirect activity conflicts will be considered but will not be given specific categories in the models, so that complexity does not obscure the major relationships.

Verbal Model

A verbal model has been constructed for fishing with the help of Churchman's scientific approach in conjunction with Forrester's first few steps and circle diagramming and matrix relations.

The environmental problem is basically an influx of people into the area. Specifically, the model will hopefully determine what policies are necessary for managing the area to insure a high quality fishing experience for present and future generations. The purpose for developing a model is best illustrated with Table 1, page 39.

The quality fishing experience must be weighted against its real cost which includes conflict with other recreational and industrial activities. The system should be used in such a way that future generations have the same alternatives open to them as the present generation does. The satisfaction of present and future potential fishermen will be the measure of the system's performance. Potential

fishermen are defined as those persons or groups who are able to use the area and/or who are interested to a significant degree so that they affect the area in some manner.

Table 1

TABLE OF POLICY QUESTIONS

(What happens if the following policies or characteristics are changed?)

Aspects	Control Agency
Bag limits, size limits, and method of fishing --this affects fishing pressure indirectly	Montana Fish and Game
License fees--out of state, resident	
Planted fish--amount, when, and where	
Method of paying for planted fish	
Season length and possible out-of-state and resident seasons	
Sediment deposition for spring and summer	Forest Service
Aesthetic value of the canyon	Land owners and county commissioners
Surface water quality	Montana Fish and Game Individuals State Health Dept.
Development in the area	Land owners and county commissioners
Traffic pattern	Highway Department
Fishermen composition of the canyon	None

Churchman's analysis would now consider the fixed elements. The fixed elements of the fishing system are the same as those of the ecosystem: the topography, weather, and man's technology. A four-lane highway is not considered to be part of the topography; it may, however, be included in the model as a policy consideration. The resources of the area are aesthetics, fish, aquatic food, water,

nutrients, security pool, and riffle areas. The agents for converting these resources will be fishermen, state fish and game controls, access, fishermen's needs and desires, cultural, economic and political structures and urbanization. Defining the management of the system is Churchman's last step.

In this project, circle diagramming, illustrated for fishing in Figure 9, page 41, was the next step in constructing the verbal model. The fishing system was also analyzed with regard to feedback levels using Forrester's basic systems concept and then was diagrammed. The important natural and man-made components, which were present and measurable in the system at one chosen moment, have been represented in the circle diagram in Figure 11, page 43, where arrows have been used to show general relationships.

A verbal description of the system has been developed by means of the aforesaid approaches along with significant input from Dr. Richard Graham, Fish biologist at Montana State University; Richard Vincent of the Montana Fish and Game Department; and Ann Williams, sociologist at Montana State University. The following published sources were also extensively used to gain an understanding of the fishing regulations and the fish population: brooks, browns, and rainbows (Hunt, 19; Marcoux, 26; McFadden, 27; Peterson, 32). Information and data were also collected from other members of the Gallatin Canyon research group, along with results from sociologists, economists,

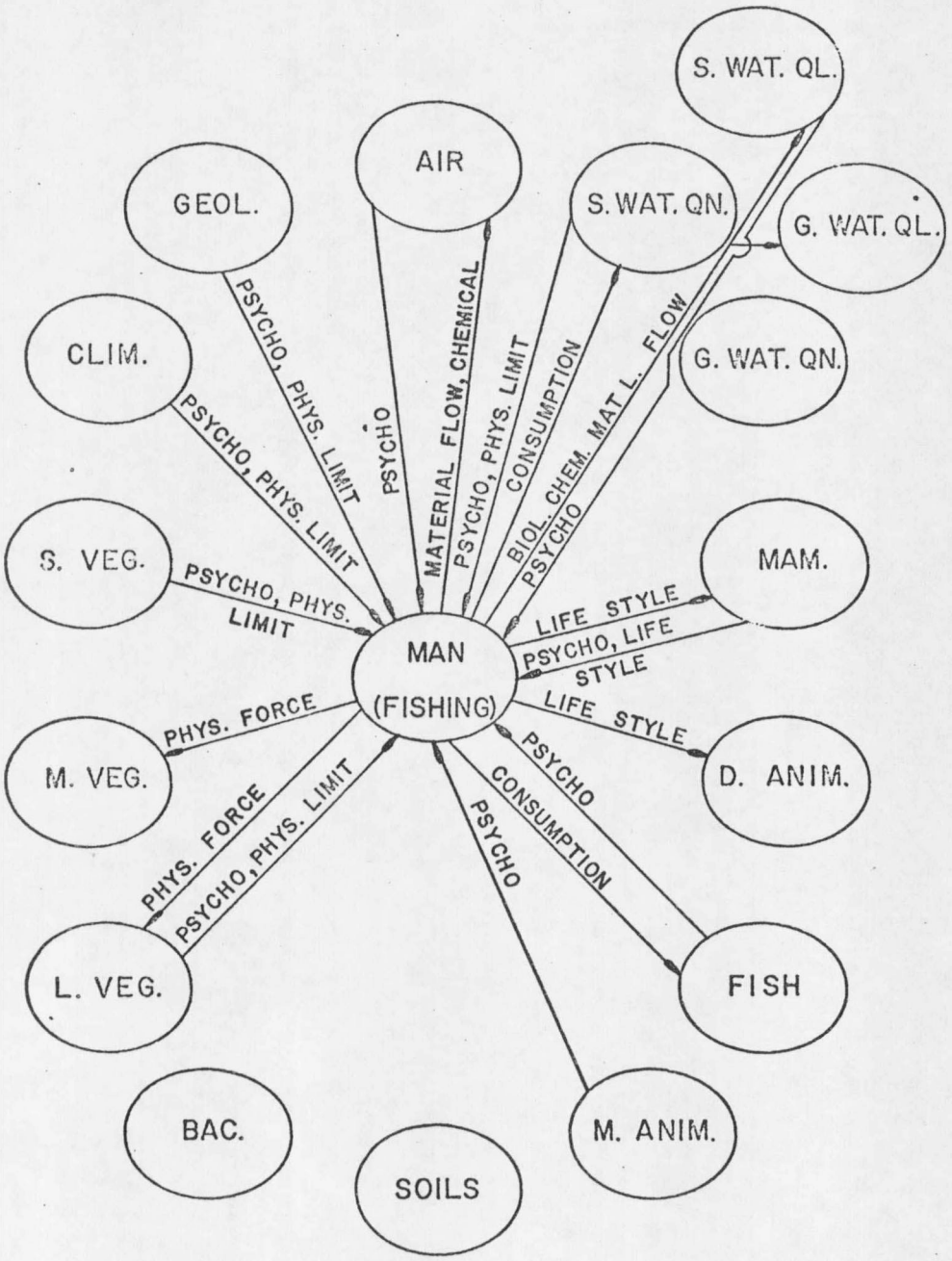


FIG. 9
FISHING

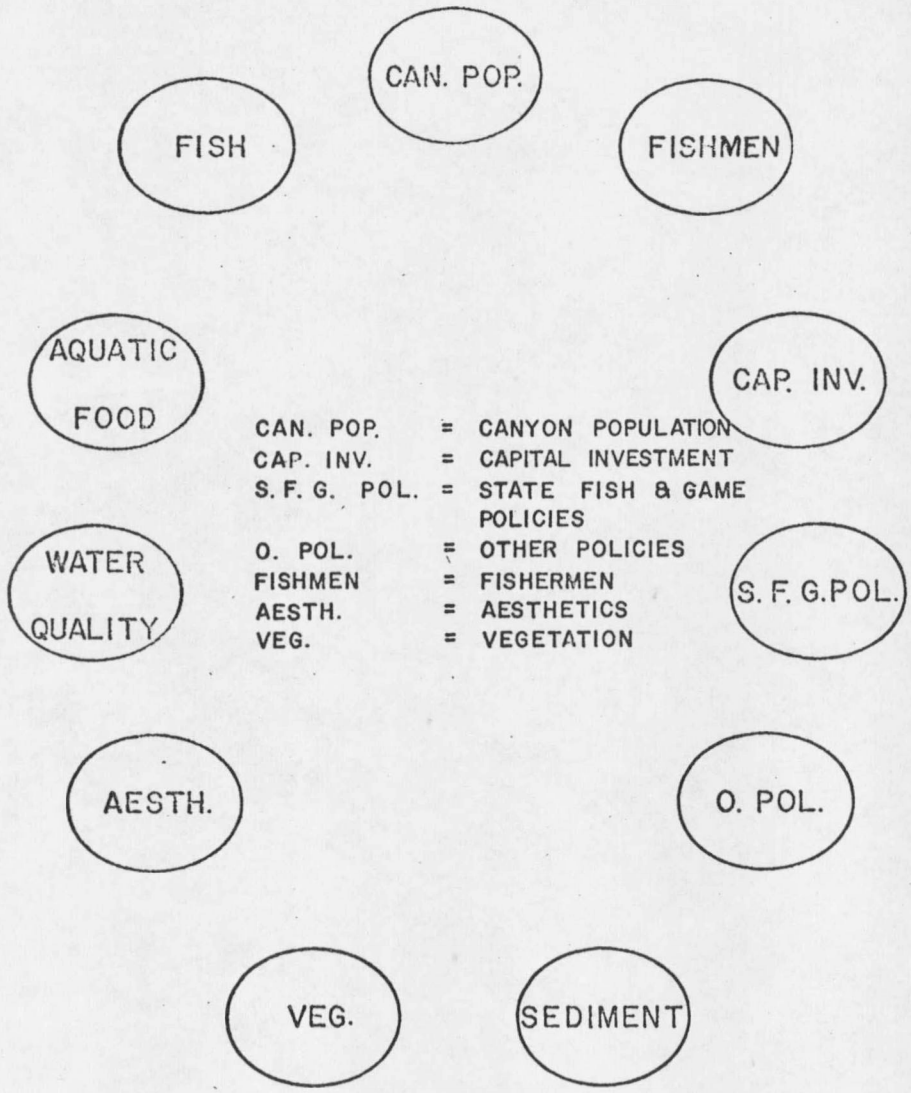


FIG. 10

MAN-NATURE

FISHING SYSTEM

USING SYSTEM DYNAMICS

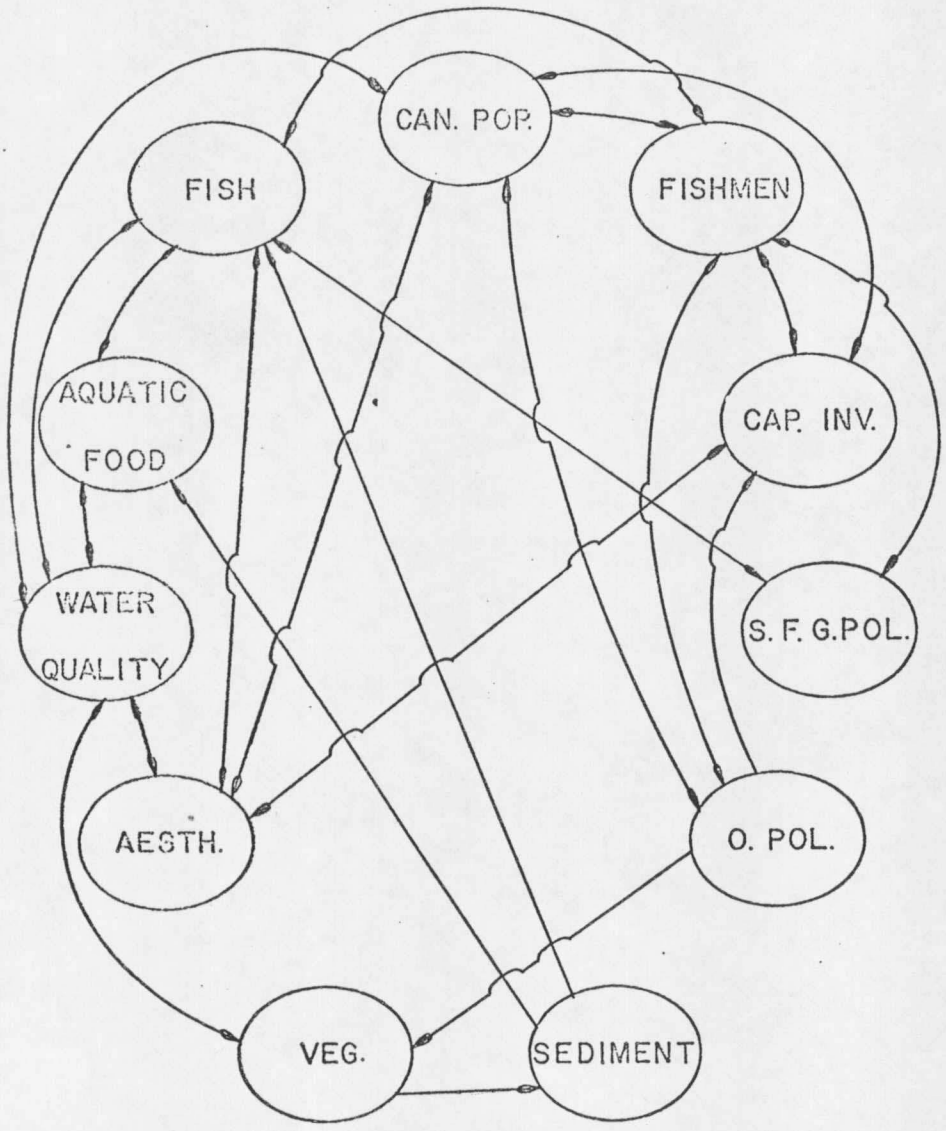


FIG. II

MAN-NATURE

FISHING SYSTEM

USING SYSTEM DYNAMICS

and from a fishing questionnaire.

A systems story was generated to create a deeper understanding of the fishing activity. Depending on where they are from, all fishermen, those from the local area, from Montana, or from elsewhere in the country, have certain needs and desires. The fishermen using the Gallatin Canyon area are classified as "nonresidents," and "Montana residents." Each group has specific characteristics. Some categories in which they have different demands are the level of crowding they will endure, income level, fishing satisfactions, and personal standards for aesthetics and pollution. They enter the area to satisfy these needs.

Fishermen have a clear impact on the area. Although they bring a great deal of equipment with them into the Gallatin Canyon area, they also spend a certain amount for additional equipment in the locality where they fish. The economic activity of the area can be measured by two important factors, the amount of capital investments and tourists' expenditures. These are almost totally dependent on recreational activity in the Gallatin area and, therefore, are significantly influenced by fishing. The economic activity of the Canyon is also influenced by the sheer number of people that use the Canyon for recreation. This also determines the amount of development or urbanization of the canyon which is directly tied to the capital investment. These elements are interrelated. One stimulates the

other. This part of the fishing system has not been included in the model for this study and should be one of the first areas of model improvement.

The fishermen buy licenses as out-of-state or resident fishermen. This payment is used by the State Fish and Game Department to cover some expenses related to fish management. Fishermen enter the Canyon area in differing party sizes bringing with them nonfishing resource users. The nonresident fishermen seem to care less about any damage to the natural environment done by developments, pollution, and crowding. Among other things, they tend to use the easy access areas along the river. These areas comprise a small percentage of the whole river but have a large percentage of the fishing pressure. The fishermen make up a considerable portion of the canyon population and so influence the amount of development and environmental degradation that takes place.

Depending partly on their backgrounds, the fishermen will be differently affected psychologically by their fishing experience. Out-of-state fishermen will be inured to development, crowding, and pollution and may be more tolerant of those things than the men who do not live under those conditions, and so are still sensitive to them. Water pollution is offensive to individuals at various levels. Filamentous algae will be considered a nuisance by some fishermen at a certain level and intolerable at a higher level. Different fishermen

are affected by and place high priority on different aspects of their fishing experience: the setting's natural beauty, the low pollution level, or the number and size of the fish caught. Fishermen are also physically limited and, hence, psychologically affected by the controls used by the State Fish and Game Department. In addition, the fishermen have been drawn into the area for various reasons: "just happened to be in the area," the fishing reputation of the area, the aesthetics, the proximity of Yellowstone National Park, and a variety of others; so they would expect various fishing experiences there.

The aesthetic character of the area, its visual effect, the level of its air and noise pollution, and such factors can be extremely important for fishing activities because they comprise the total fishing experience. Everyone derives his aesthetic pleasure from different complex and indefinable qualities in his environment, so that each individual will interpret the aesthetic value of an area differently. But pollution, which is directly related to the fishermen and general Gallatin Canyon population, undoubtedly interferes with most people's aesthetic pleasure.

The State Fish and Game Department regulates the activities of the fishermen. In conjunction with the legislature, it also determines license fees. Bag limits, size limits, fishing seasons, and fishing methods are also determined by the State Fish and Game Department. Different seasons could be specified for residents and

nonresidents. The criteria could be fly versus bait fishing or non-barb hooks for returning fish versus barbed hooks to keep fish. Through these regulations, the State Fish and Game Department can influence the fishing pressure on an area. Some fish biologists believe that the fishing regulations along with the policy of planting fish, should be variable from one area to another.

It has been discovered that the established standard maximum-catch minimum-size regulations seem to have little effect on fishermen and on fish population (Hunt, 19) so that fishing follows about the course it would take were no regulations imposed at all. However, tighter regulations would, it seems, have an effect when the bag limit is halved and the size limit is increased. The fishermen seem to be psychologically affected; so that even though they catch less than the bag limit, they rarely return to the area (Hunt, 19). Increasing the size limit on fish caught can help to sustain the adult fish population to some degree and thus has virtues; but, again, the regulation seems to discourage most fishermen who prefer to keep their catch.

The recreation activity of fishing depends heavily on the sport-fish population. Water pollution is the pollution that most directly affects fishing. Water pollution increases the nutrients in the river and, in turn, increases the aquatic vegetation and aquatic insects. An increase in aquatic food could possibly help the fish population to expand, but pollution could also become a nuisance to

the fish habitats and at a high enough level could kill the fish. Judging by discussions about Gallatin Canyon on water pollution, excluding sediment deposition, it seems unlikely that the Canyon will attain a level that would be harmful to fish in the foreseeable future. The question of sediment has been separated from that of other water pollution and discussed further on because of its importance.

The particular species of game fish available seems to determine how many sportsmen will be drawn to an area, so the species thus influences fishermen population growth. In the area under study, the makeup is mainly rainbow, with some brown trout. The rainbows lay their eggs in the spring, the browns in the fall, so that the fish populations' reproductive cycles and hence their population size are susceptible to sediment deposition and other harmful natural effects in different seasons. The population of fish and, therefore, fishermen are thus dependent on the season of the year and also on the aquatic food available. The level of aquatic food in the river's food producing areas (riffle areas) is determined by the growth-accelerating nutrients in the water. The fish population also depends on the basic stream topography: the fish need both riffle areas and security pools for cover. A perfect combination of riffle and security areas is their equal (50-50) and even distribution along the river's length. For the Gallatin Canyon area, it is about 75 per cent riffle areas and only 25 per cent security pool areas, a situation which limits the fish

population.

The trout population can be divided into four groups: the adults, which spawn; the immature trout or non-spawners; the fingerlings; and the planted trout. A trout can spawn only if it is old enough or big enough. The growth rate of the fish thus also acts on the population size, since it determines the number of breeders. The fish's chances of coming to maturity for spawning depend on all the factors above and even on water temperature.

Trout eggs themselves can be destroyed by the deposition of sediment, if it is in a sufficient quantity to cut off the oxygen needed by the eggs. The spring spawners, like Gallatin County's rainbows, thus have problems with their eggs because of spring runoff. Sediment deposition can also affect the food production in riffle areas in the summer and fall. But, not all muddy water is damaging to fish food or eggs. The muddy water is helpful if it is turbulent enough to suspend the particles and/or wash away sediment deposits that already exist. The problem with turbulent muddy water occurs when it is saturated with particles. Developers, the United States Forest Service, the State government agencies like the State Highway Department, and the state water resources agency, and possibly the State Fish and Game Department can influence sediment loads by construction activities, road, or structures, allowing certain timbering techniques in specified amounts and the structural changes of river banks.

The fish population needs a critical number of adult fish to sustain an adequate fishery. A drastic reduction will occur in the fishery when the population drops below this critical level (McFadden, 27). This critical level could also be referred to as the self-sustaining level. Some people in management also desire to have a buffer stock to ensure a good fishery, that is, a fish population that can support the fisherman population to its satisfaction, even when natural mortality severely limits any one or two age groups.

The adult population can lay too many eggs. There is an optimum number of eggs that should be layed to meet the constraints of any area. Too few eggs or too many eggs both decrease the number of progeny. The natural mortality rate is usually quite high for trout, somewhere between 30 and 60 per cent. In the Montana area, the winter kill itself is quite significant. The winter kill and general mortality rate depend on fish population density and the condition of the host environment. The mortality rate of a particular brook trout stream could be as high as 64 per cent without affecting the high-quality fishery, which is made up of a considerable number of fish with an adequate percentage of young spawners and large spawners (McFadden, 27).

An important element included in the model is fishing's effect on a fish population's size. In this regard, fishing must be considered in the context of the natural process of population equilibrium.

Any natural river environment can only sustain a limited number of fish. The fish population establishes an equilibrium in relation to the environment. The point of equilibrium is the optimum level of population in that environment, neither more nor less than can be sustained. To maintain equilibrium, death balances birth and growth. A certain proportion of the fish population would have to die because of natural pressures related to population and other causes, the proportion being determined by the conditions in the host environment. As the environmental pressures related to population size are thus lowered, the rest of the population's survival is facilitated.

The total population may be thought of in terms of the functional percentage, that is, the percentage that survives and the moribund percentage, that is, the percentage which is going to die in the natural course of maintaining population equilibrium. Except for those fish in a moribund condition physically, the moribund figure does not refer to any particular fish, but to a percentage that will be taken from the population.

Suppose that a segment of a river contains 1000 fish, and that the number that are going to die--the moribund figure--is 10 per cent or, in this case, 100 fish. If the number of fish extracted by fishermen from the total population of 1000 is something less than the number of fish that are going to die anyway, then it can be said that

the fish extracted by these fishermen come from the moribund percentage. Some fish are going to die; and if the number extracted is something less than this moribund figure, it does not matter, in respect to maintaining population equilibrium, whether the fish die naturally or from fishing. In this case, then, fishing does not markedly affect population size.

What must be understood is the conceptual distinction between two elements of the moribund percentage, in respect to fishing. Suppose that about 20 per cent (twenty fish) of the moribund percentage, because of physical condition, non-accessible habitat and such factors, cannot be caught no matter what level of fishing pressure exists. This supposed 20 per cent must thus be considered inaccessible and cannot be affected by fishermen's activities. In that case, only about 80 per cent (eighty fish) of the moribund portion would be accessible. Since the 20 per cent would die quite apart from fishermen's activities, their deaths must be allowed for when calculating what percentage of the total fish population fishermen could take without truly influencing the population's size, in this case eighty fish. Because of the inaccessibility of the supposed 20 per cent, fishermen could, in this case, take only up to a possible 80 per cent of the moribund percentage without markedly affecting the total population. Fishing demand that did not exceed the accessible number of the moribund percentage could be called "allowable" fishing pressure. In this case, fishing demands

that went above 80 per cent of the moribund segment would have to be considered as excess fishing pressure.

The effects of different degrees of fishing pressure, including degrees of excess pressure, have been examined, in this project, by computer simulation runs. However, it should be noted further that even excess fishing pressure, although it undoubtedly has an immediate depleting effect on an area's fish population, will not necessarily have a lasting effect. Because environmental pressures related to population are decreased, fish will be drawn in from other areas over time, and also the resident fish population will naturally move again towards its optimum. Thus, even excess fishing pressure of the intensity that can be found at favorite holes with easy access will not necessarily, in the long run, affect the whole fish population in a total river segment.

This systems story gives a summary of the known important and general piscatorial relationships. The verbal systems story has been converted to a concise mathematical model using systems dynamics. Not all of the general descriptive parameters in the systems story were generated into the model, because of limited time.

The Model

The fishing dynamics model has been developed to further the understanding of fishing as a recreational activity from a systems approach. The descriptive model can be used by decision makers as a

tool for understanding the particular system under study. This model illustrates that information can be gained about possible environmental effects, by constructing a model of the relationships believed to exist, many of which are unquantifiable or not backed by significant statistical data. (See Appendix D, pages 143-146) These relationships have been evaded in the past for these last two reasons. This thesis has confronted these relationships and has accomplished a quantified basic model that can lead to further understanding of the fishing ecosystem. The model should be just the first step in a continued fishing-ecosystem study. This model should be improved upon but, as it is, can be used as a basic starting model for any fishing ecosystem. The model requires further information from related scientific, economic, and human science fields. Use of the model in any other particular fishing ecosystem would require close examination of the assumptions on which the model is built, and a study of the structural changes which would have to be made in order to change the model results. It is extremely important to recognize that the model can be changed to fit the assumptions any one desires to examine--even many structural changes could be implemented with some work. This model will not lead to hard and fast final recommendations but will lead to better understanding of the fish ecosystem and, therefore, could facilitate better management policies.

The basic structure of a systems dynamics model is composed of

levels, rates, auxiliaries, and constant input (assumptions).

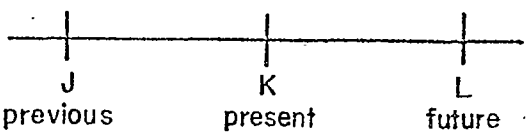
Levels and Rates

The levels of any system describe the important measurable components of the system. A full description of the levels would then adequately describe the state of the system. Materials flow in and out of the levels which are affected by the flows to the extent that they accumulate them. A level equation, which is a mathematical representation of a level being affected by flow, is illustrated with an example, the adult fish population-level equation.

L APOP.K = APOP.J + DT*(AGROW.JK + IMTRA.JK-ADTH.JK)

APOP - Adult fish population (pounds)
AGROW - Adult fish growth (pounds/week)
IMTRA - Immature fish transferred into adult population (pounds/week)
ADTH - Adult fish death (pounds/week)

DT - change in time (1 week)



Computational time scale

FIG. 12

The equation describes mathematically the adult fish population at the present time K and is equal to the previous level at time period J plus the change that has occurred in the time interval DT from time J

to K. Three flow rates affect the level of adult fish population, AGROW, IMTRA, and ADTH. All level equations are constructed by adding to the level existing in the immediately preceding period, time period "J," the flows in and out that occur during the time interval DT, the processes of integration. The adult fish population is measured in pounds to give some indication of both number and size of the population.

Rates are constructed for each respective level which must be dimensionally balanced and also reflect the action of the system. The adult growth rate is an example of a rate equation:

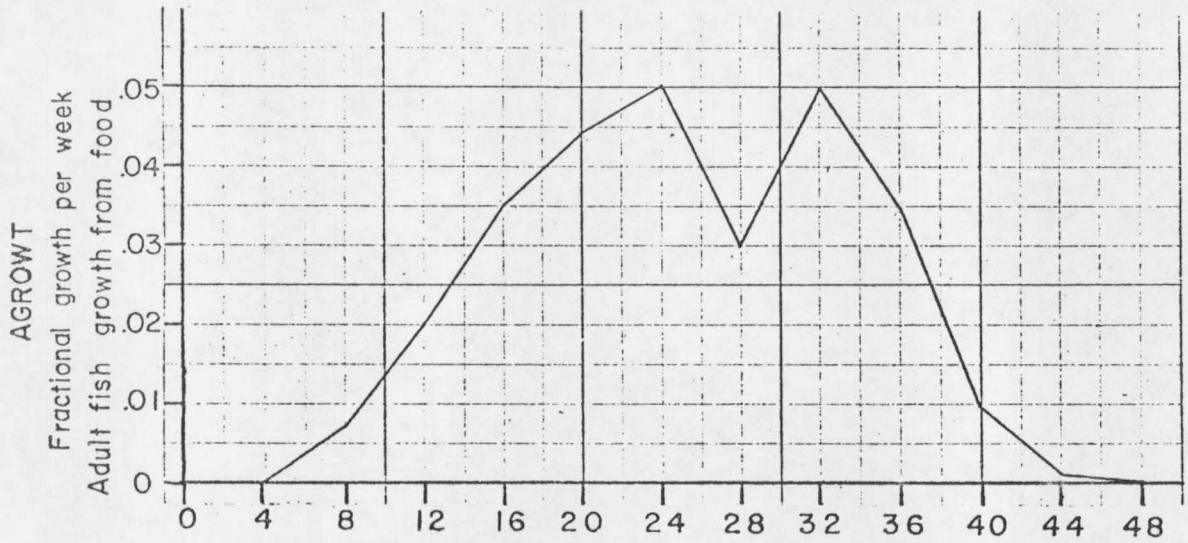
R AGROW.KL = AGROWT.K * GRWFDR.K * Clip (APOP.K, 0, APOP.K,0)

AGROW - Adult fish growth (pounds/week)
GRWFDR - Growth multiplier from food ratio (dimensionless)
AGROWT - Adult fish growth table fraction (1/week)
APOP - Adult fish population (pounds)
Clip - A function used to prevent negative growth

The adult growth rate reflects the pounds of adult fish that will be added to the adult population during the interval DT. The fractional growth (AGROWT) is dependent upon the season of the year, as fish growth is highly influenced by the temperature of the water. When the water is too hot or too cold, it causes very slow or no growth. Figure 13 illustrates the table function relationship between the forty-eight-week seasonal year, starting in January, and the fractional growth that occurs per week. A table function for Dynamo, the computer-simulation language used for systems dynamics, can be used in two variations, TABLE and TABHL (Forrester, 16; Pugh, 34). These two

functions determine the value to be used dependent upon the value of the independent variable. In Figure 13, if the value of the independent variable SEASON is 24, the value of the adult fractional growth per week is .05. The following two equations are needed to use this table function:

```
A AGROWT.K=TABLE(AGRTAB,SEASON.K,0,48,4)  ADULT GROWTH  VS SEASON
T AGRTAB=0.0/0.0/.0075/.02/.035/.044/.05/.03/.05/.035/.01/.001/0.0 PERWK
```



AGRTAB TABLE
FIG. 13

The normal growth is affected by the amount of aquatic food that is available. The growth multiplier from food ratio (DRWFDR) is related to the need-availability ratio as Figure 14 illustrates. This figure illustrates the use of the function name TABHL. The function

name TABHL means that if the value of the independent variable goes below its lower value or above its highest value, the dependent value is assigned its value at these respective limits. As in the case of Figure 14, if the need availability ratio (NAFDGR) could drop below 1, the dependent variable, GRWFDR would be assigned a value of one and when NAFDGR, however, is larger than 51, GRWFDR is assigned to a value of five.

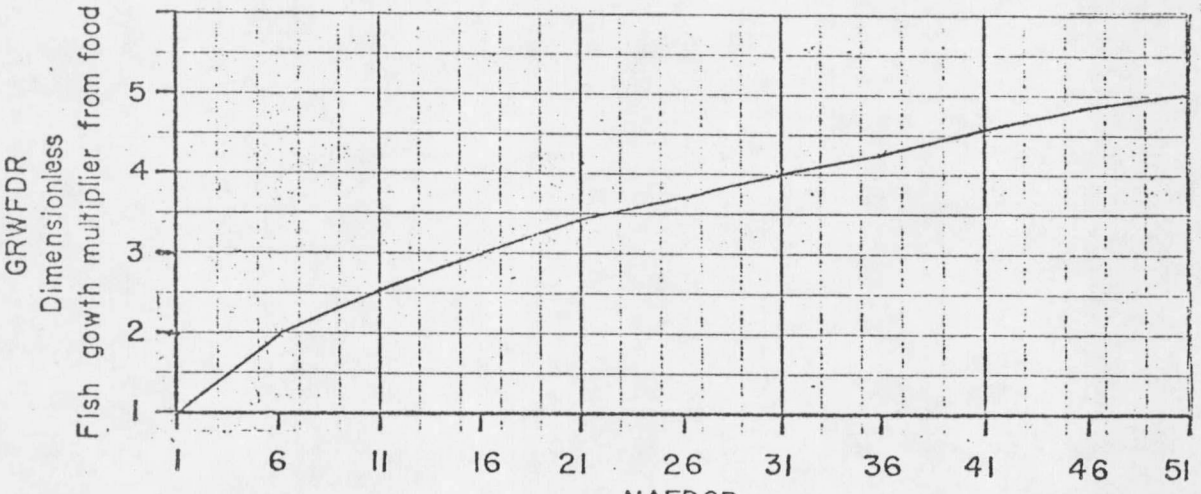


FIG. 14

These tables represent assumptions that the model is based on, which help in determining the flow into a particular level, adult fish population.

The following is a list of the important levels of the fishing-

ecosystem model, as shown in Table 2.

Table 2

IMPORTANT LEVELS OF THE FISHING-ECOSYSTEM MODEL

Fingerling Population (FINPOP)	The fingerlings are newly hatched fish that stay in this category till they are reclassified into the immature population approximately one year after birth.
Immature Fish Population (IMPOP)	The immature fish are usually between one and two years of age. These fish are unable to spawn because of either age or size (pounds).
Adult Fish Population (APOP)	The adult fish are able to spawn and, therefore, sustain the wild fish population (pounds).
Planted Fish Population (PLPOP)	The planted fish are those fish grown in a hatchery by man. The Montana Fish and Game Department directly determines the number planted in the river (pounds).
Aquatic Food (AQFD)	The aquatic food is composed of both aquatic vegetation and aquatic insects (pounds).
Potential Resident Fishermen-User Pool (PRFUP)	This pool is composed of those Montana residents that use or plan to use the Gallatin Canyon for fishing.
Potential Nonresident Fishermen-User Pool (PNRFUP)	The non-Montana residents that use or plan to use the Gallatin Canyon at some time for fishing make up this user pool.

What rates flow in and out of the foregoing listed levels? The following table, Table 3, gives a summary of the system's rates and an idea of the factors affecting each rate. A more precise understanding can be achieved by examining the systems flow charts and the equations

Table 3

RATES OF THE FISHING-ECOSYSTEM MODEL

Eggs Hatched Rate (EGGHAT) The number of eggs that actually hatch are dependent on the adult fish population. The eggs that hatch flow into the fingerling population. The rainbow and brown trout eggs are hatched only at certain times of the year. The eggs are also affected by sediment.

Fish Death Rates - Fingerling (FNDETH), Immature (MDETH), Adult (ADTH), and Planted (PLDTH). All of the fish death rates are dependent upon their respective population size upon the lack of aquatic food, and upon the water pollution beyond critical levels.

Fish Growth Rates - Immature (IMGROW), Adult (AGROW), and Planted (PLGROW). Their rates are also dependent on their respective population levels, the availability of food, and the season of the year, which determines the water temperature. The fingerlings also grow but they are measured in numbers and, therefore, do not increase in numbers even though they do increase in weight.

Fish Transfer Rates - Fingerlings are transferred to the immature population (FINTRAD), (TRADNR), and the Immature are transferred to the adult population (IMTRA). The only difference between FINTRAO and TRAFNR is the criteria measurement number of fish/week and pounds of fish/week respectively. The immature transfer is also measured in pounds per week. The transfers are influenced only by the size of the population which they originate from.

Fish Planted By Man Rate (PLANTED) The fish planted in the river depend on the Montana Fish and Game Department, which has a policy of planting a specified number at a specified time.

Aquatic Food Growth Rate (AQFDGR) The aquatic food growth is influenced by the amount of nutrients in the water, or pollution, and the season of the year.

Table 3 (Continued)

Aquatic Food Death Rate (AQFDDT) The aquatic food death rate is influenced by the season of the year, consumption by fish, the water pollution beyond a critical level, and the sediment deposition that can destroy the food producing areas.

Entering Rate of Fishermen Into the User Pools Resident Pool (ERFP) and Nonresident Pool (ENRFP) These entering rates are influenced by the level of their respective pools and by the social characteristics of each pool, such as their permitted crowding of the fishing area, fishing success, and the general aesthetics of the area, which is directly reflected in the number of total "people-days" during which the canyon is used. A "people day" is defined as one individual's being in the canyon for a twenty-four hour period.

Rate at Which Fishermen Leave the User Pools Both Resident Pool (LRFP) and Nonresident Pool (LNRFP). The leaving rates from these pools are influenced by the level of their respective pools and by the same social characteristics that result in people being allured to the area. Fishermen will be driven away if the environment of the canyon is bad enough. Both population pools have different demographic characteristics and also have a different turnover which is reflected in the level of the normal fractional leaving and entering rates.

Important Auxiliaries

Sediment deposition, water pollution, and total canyon population are three very important auxiliaries structured in this model. The system is excited with an increase in sediment deposition (Figure 17, page 72) and an increase in the canyon population (Figure 15, page 68). These two auxiliaries have no systems feedback, which should be added for any extended ecosystem analysis. The sediment significantly affects the fish eggs and the aquatic food. The population is increased in two separate segments--the Big Sky population and the rest of the canyon population. The Big Sky population causes winter-peak use of the canyon to approach the summer-peak use. The population was separated into these segments because of critical differences in sewage treatment facilities. The water pollution is influenced by the two populations and by the inefficiencies of their respective sewage treatment facilities. The population is assumed to directly reflect the environmental degradation of the area and, therefore, influence the fishermen by a "people pollution" ratio auxiliary. The water pollution affects the fish, fishermen, and aquatic food. Its influence on the fish and fishermen is harmful only after a critical level of pollution is achieved. The aquatic food growth rate increases as more pollution or nutrients are added to the water. There is, however, a critical level at which the aquatic food is also harmed by pollution.

Constants and Parameter

The fishing-ecosystem model is based on numerous constants or parameters. The information in Table 4, pages 64 and 65, list some of the more important constants that the model is based on. Again, a more thorough understanding can be achieved by examining the flow charts and the equations in Appendices C, pages 128-142, and F, pages 151-164. A small portion of the following constants were experimented with in this model.

The parameters in Table 5, page 66, can be changed but they should be consistent with other directly related factors. For example, the food needs of the fish population are directly related to the aquatic food available and their relationship here must reflect a realistic proportionality.

The model also required the following initial values that can only forestall model equilibrium. Most values were generated to create model equilibrium in the first year.

FINPOP	= 5,000 fingerlings	AQFD	= 5,000 pounds
IMPOP	= 500 pounds	PRFUP	= 70,000 people
APOP	= 3,500 pounds	PNRfup	= 30,000 people
PLPOP	= 200 pounds		

These initial values are very rough estimates and need further critical evaluation by experts. The values, however, do seem fairly realistic. The level of the model which most needs expert information and assessment of its initial value is the aquatic food level.

Table 4

IMPORTANT CONSTANTS

Constant Name	Definition
NMEGKIL = .15	Normal fraction of eggs killed per week by sediment.
ACATMOD = .8	The "allowable" segment of the moribund percentage of the total adult fish population (see pages 51 through 53).
MODCOM	The excess fishing pressure permitted in the model, being an arbitrary percentage of the excess demand by fishermen.
PLACATMO = .9	The "allowable" segment of the moribund percentage of the total planted fish population.
PLMODCM = .9	The excess fishing pressure permitted in the model, being an arbitrary percentage of the excess demand by fishermen.
LUFDSR = .33	The limit of usable aquatic food according to the pool-riffle areas ratio.
MDFDTH = .549	Modifies the aquatic food death table.
FATE = .8	The food that fish consume that would die naturally.
TTRI = .15	Inefficiency of Big Sky tertiary sewage treatment plant.
STTRI = .90	Inefficiency of septic tank sewage treatments in the rest of the canyon.
PNUSS = 50	The water pollution ratio level at which fishermen are affected adversely (means 50 times the maximum present level of water pollution).
PKILST = 100	The water pollution ratio level at which fish are adversely affected (means 100 times the maximum present level of water pollution).
RCMD = .20	Facilitates the increase or decrease on the rest of the canyon population growth without changing numerous tables.
BSCONR = table	Big Sky resort contributes to a fractional increase in the rest of the canyon population which varies during the season.
NRER = .008	Normal fraction/week of resident fishermen entering the fishermen pool.
NLVR = .0007	Normal fraction/week of resident fishermen leaving the pool. (Difference between the two fractions determines the growth, while the magnitude

Table 4 (Continued)

Constant Name	Definition
	determines the turnover.)
NRENR = .002	Normal fraction/week of nonresident fishermen entering the fishermen pool.
FLUN = .0025	Normal fraction/week of nonresident fishermen leaving the pool. Again, the difference helps determine the growth and the magnitude the turnover.
BG11-BG84	These constants can be changed to effect the projected user population growth of the Big Sky Resort.

Table 5

PARAMETERS

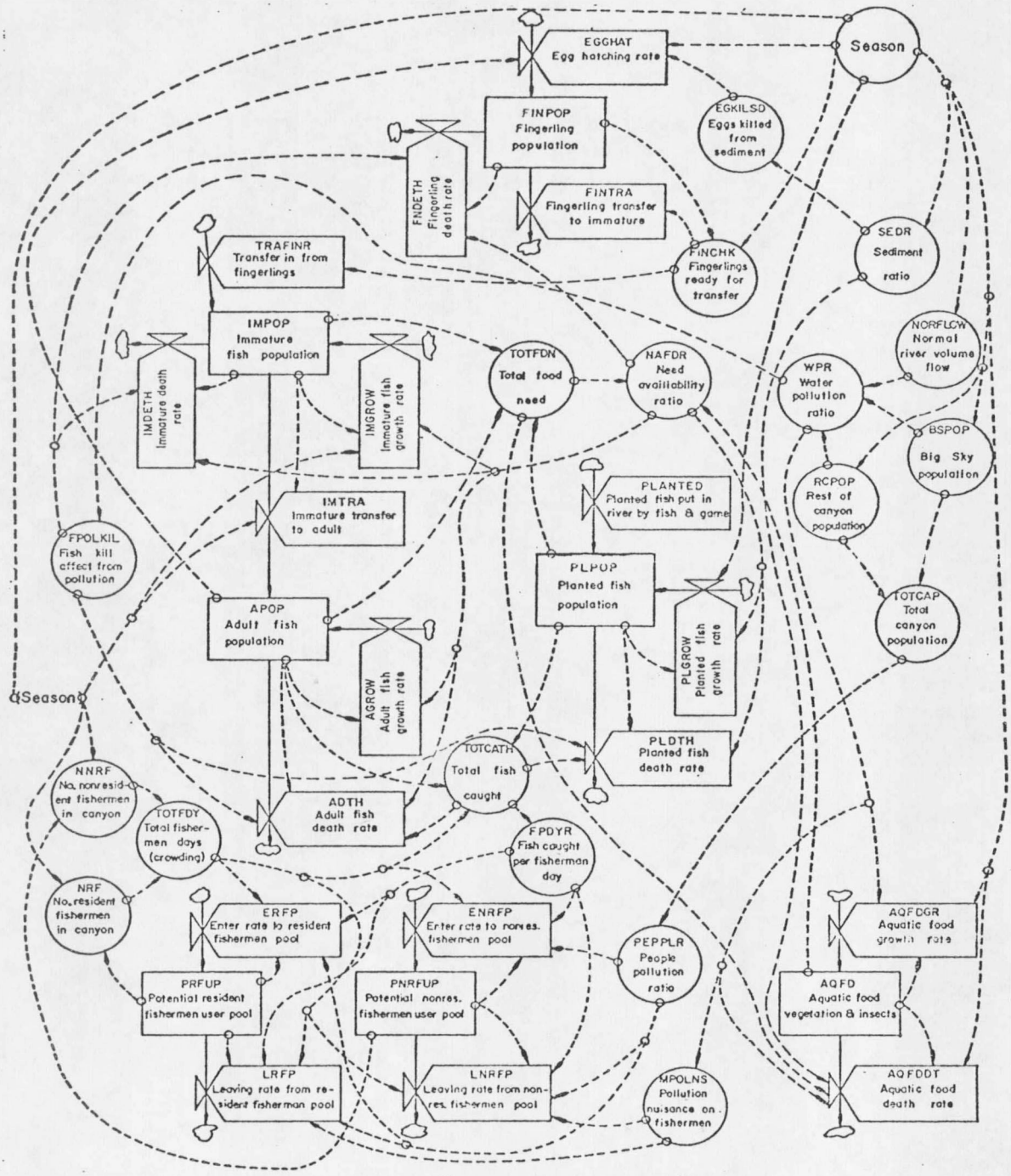
Constant Name	Definition
EGGPLB = 1400	Eggs per pound of adult fish produced
PLFNED = .015	Pounds of aquatic food needed/week for planted fish
AFNED = .02	Pounds of aquatic food needed/week for adult fish
IMNED = .01	Pounds of Aquatic food needed/week for immature fish
POLPMP = .10	Pollution units per modified untreated "population people" day
POPVOL = 140	The normal water volume of 1 in January can disperse 140 pollution units or 1400 "people days" (i.e., 24-hour units of canyon use) of untreated human waste (called in this study "untreated population") generated from inefficient sewage treatment.
BLWP = 1700	Base line water pollution should agree with TTRI, STTRI, and POPVOL, to create a maximum present water pollution ratio equal to 1.
FATM = 1	The number of fishermen days per man fishing in the canyon (a fishermen day equals three hours)

Flow Chart

The appendix contains the complete flow chart for the fishing model. Figure 15 illustrates a condensed version of this flow chart. The purpose of Figure 15 is to show the general structure of the model and information flow that exists between related subsystems. The simple structure and symbols of a flow diagram can be examined on Figure 8, page 37. A circle in a flow chart not illustrated in Figure 8 is an auxiliary which, in most cases, is a subdivision of the respective rates which they influence. Auxiliaries make a model easier to follow. This flow chart graphically relates most of the systems story written earlier. In fact, the important aspects of the verbal model dictate the structure of the flow chart.

Computer Simulation

The first step in running the model with the computer is to establish model equilibrium, with no outside influence or excitement. The two variables that provide the excitement for this system are sediment and canyon population. To establish equilibirum these two variables were held constant at normal 1973 levels. The system's action was then examined to determine which subsystem was not performing in a state of equilibrium. The aquatic food was the subsystem that had to be modified to achieve model equilibrium. This was done by modifying the normal death rate of aquatic food. The equilibrium is reflected as it exists in the initial year of simulation, 1973. The



CONDENSED FLOW CHART
FIG. 15

model is now ready to experiment with by changing the model assumptions. This initial equilibrium is important for comparing the simulated dynamic changes of the system caused by excitation or changes in basic model assumptions (constants and tables).

The ecosystem's performance can be estimated by the degree of the fishermen's satisfaction and by the resource-use options open to future generations. Both of these measurements are reflected in the simulation runs: satisfaction is reflected by the number of fishermen in the canyon and the resource-use options available are shown by the level of resources in the system such as fish populations and aquatic food.

The basic or standard simulation run is illustrated in Figure 16, page 70. To read the computer output, one must examine the left-hand margin of the run to determine the variable name and the symbol that represents it in the run. The scales for each variable are also presented on the left-hand side; one has to match up the symbol, scale, and variable. The "T" beside each scale number means that the number is given in thousands. An example is in Figure 16: the variable APOP, the adult fish population, is equal to the symbol "A" in the simulation run. The symbol "A" is represented by the scale which goes from 100 to 8.00T or from 0 to 8000. The symbol "W" represents the water pollution ratio (WPR) and is represented by a scale that goes from 0 to 2. The more important variables in each run are also labeled.

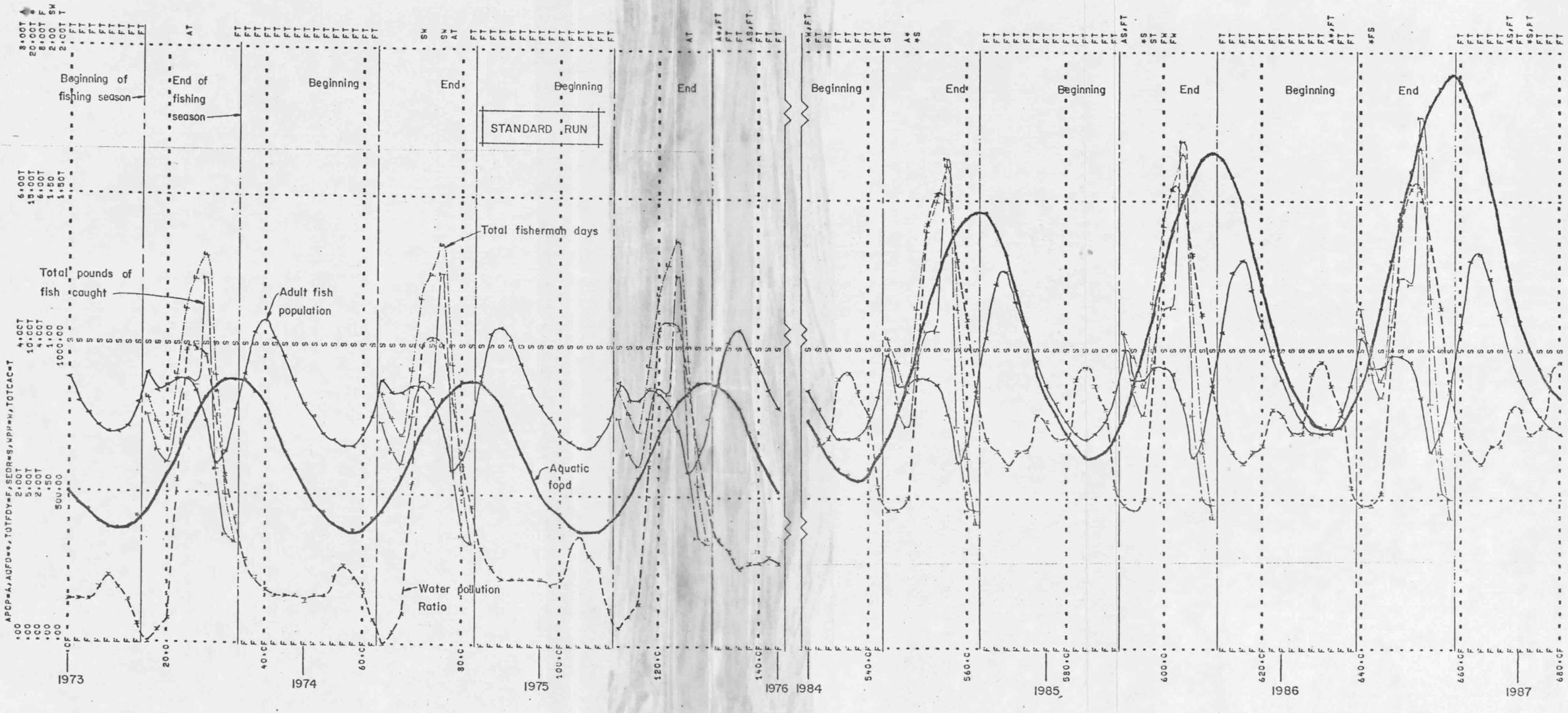

Beginning of fishing season
End of fishing season
Beginning
End
Beginning
STANDARD RUN
End
Beginning
End
Beginning
End
Beginning
End
Total pounds of fish caught
Adult fish population
Total fisherman days
Aquatic food
Water pollution Ratio
1973
1974
1975
1976
1984
1985
1986
1987

FIG. 16

The scales of these variables may change from one run to another and must, therefore, be carefully examined. Symbol representation may overlap, too, from one run to another as "S" does, which represents the sediment ratio (SEDR) in Figure 16 and amount of fish caught per resident fishermen-day (RFPDY) in Figure 17, page 72.

The basic run is excited with an increase in canyon population starting in 1974. The simulated increase in population seems realistic, being constructed from present trends and a delay in projected Big Sky use, caused by unforeseen setbacks. This realistic increase in canyon population causes for 1986, a predicted 50 per cent increase from the 1973 level in the water pollution ratio for the peak summer months and a predicted five-fold increase from the very low 1973 level for the peak winter ski season. The water quality during the winter of 1986 is approximately the same pollution ratio as that of the summer peak-use during that year. The simulated increase in water pollution has resulted in a new aquatic food level that is almost double that in the original balance. The assumptions related to water pollution do not reflect any harmful effects in this model until the pollution increases by fifty times its original peak ratio of one, at equilibrium, mainly because of the relatively pure status of the present water quality. A better understanding of these critical water pollution ratio values can be achieved with help from water biologists and other experts along with experimentally changing the constants involved in this model.

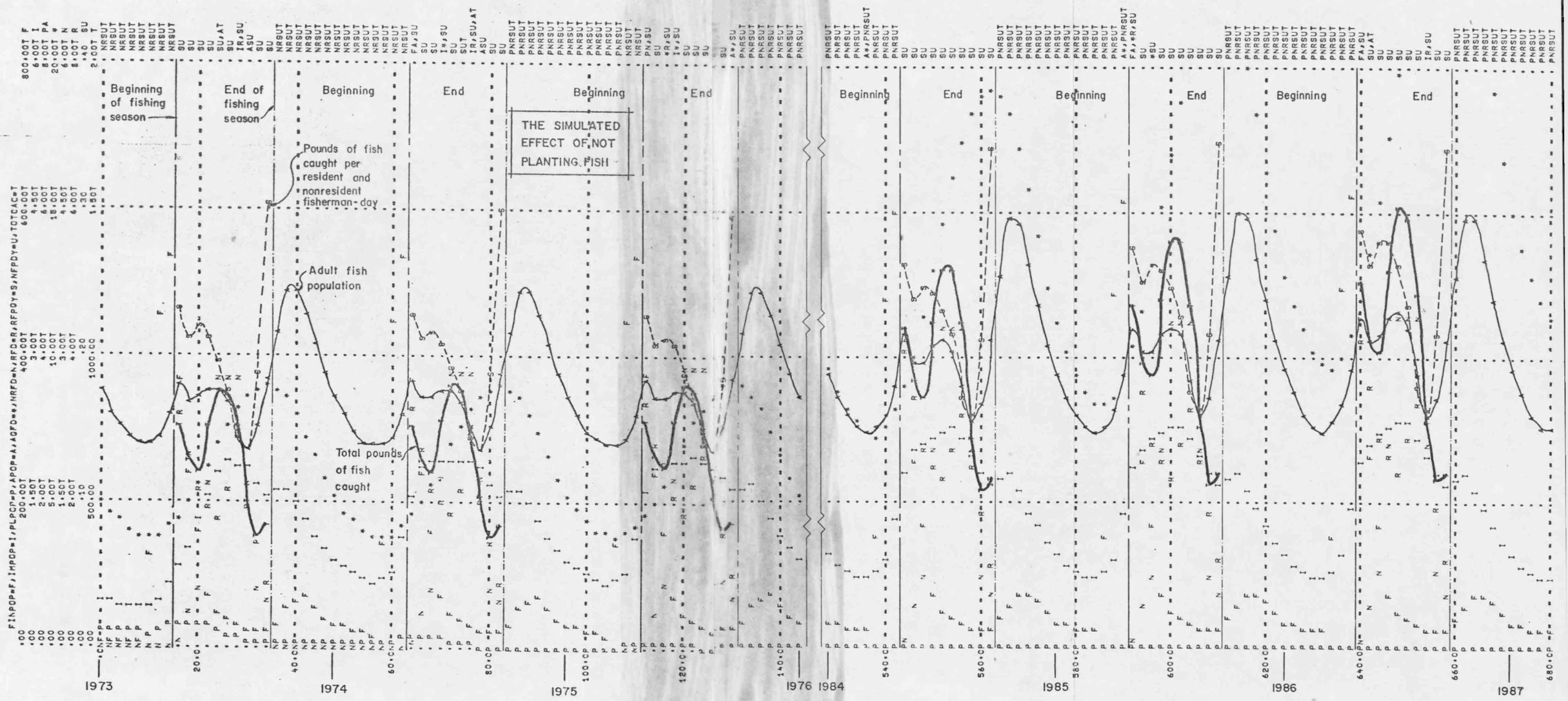

Beginning of fishing season
End of fishing season
Beginning
End
Beginning
End
Beginning
End
Beginning
End
Beginning
End
THE SIMULATED EFFECT OF NOT PLANTING FISH
Pounds of fish caught per resident and nonresident fisherman-day
Adult fish population
Total pounds of fish caught
1973
1974
1975
1976
1984
1985
1986
1987

FIG. 17

The following four sample simulation runs include an increase in sediment deposition and changes in some of the more important constants or assumptions in the system. These examples serve as limited illustrations of the many possible simulated changes in the system and the resultant simulation runs that can lead to a deeper understanding of the system. The examples are compared to the standard run for interpretation of the results.

Figure 17 illustrates the possible effects of not planting any fish in the Gallatin River. It seems most fishermen can distinguish between the planted and wild trout that are caught. Most fishermen value the wild trout more than the planted fish because of their potentially larger size and a difference in taste claimed by some fishermen. To a fisherman, a pound of planted fish caught is, therefore, assumed to be equivalent to half a pound of any wild fish caught in this sequence of simulation runs. It is felt that this is a realistic value for planted fish; however, if this value were increased significantly, the following simulated results could be modified. The simulated policy of not planting fish results in an increase in the total fish caught, as the wild fish are allowed to prosper without the invasion of large concentrated populations of planted fish along the river. This results in an increase in overall fisherman satisfaction directly related to an increase in total catch. This also leads to a small increase in the fisherman population compared to the standard

run since the area becomes more attractive. Another effect in the simulation run model of not planting fish is a significant simulated increase in the level of aquatic food due to a lack of consumption by planted fish. This remarkable increase points out the model sensitivity of aquatic food.

What would happen if public policies or construction activities increased the sediment deposition? Figure 18, page 75, illustrates the simulated result of such action. The sediment is gradually increased starting in 1974 till approximately a seven-fold increase occurs in 1981, at which time most of the aquatic food has died and the fingerling population has decreased by one-seventh of its balanced spring-season size. The population diminishes because the fish die from a lack of food and not because of an insufficient fingerling population. The fisherman populations do not react to this drastic simulated decrease because of the sustained aesthetics of the area and the relatively uncrowded fishing areas. This model does not reflect a drastic reduction in fishermen some time after all the fish die, which an improved version should. Experimentation with this basic model or an improved version could help answer many of the policy questions related to sediment deposition. A greater understanding can and should be reached by determining the reactions of the system to different system excitation like complete destruction of one year's fingerling population or only sporatic increases in sediment deposition.

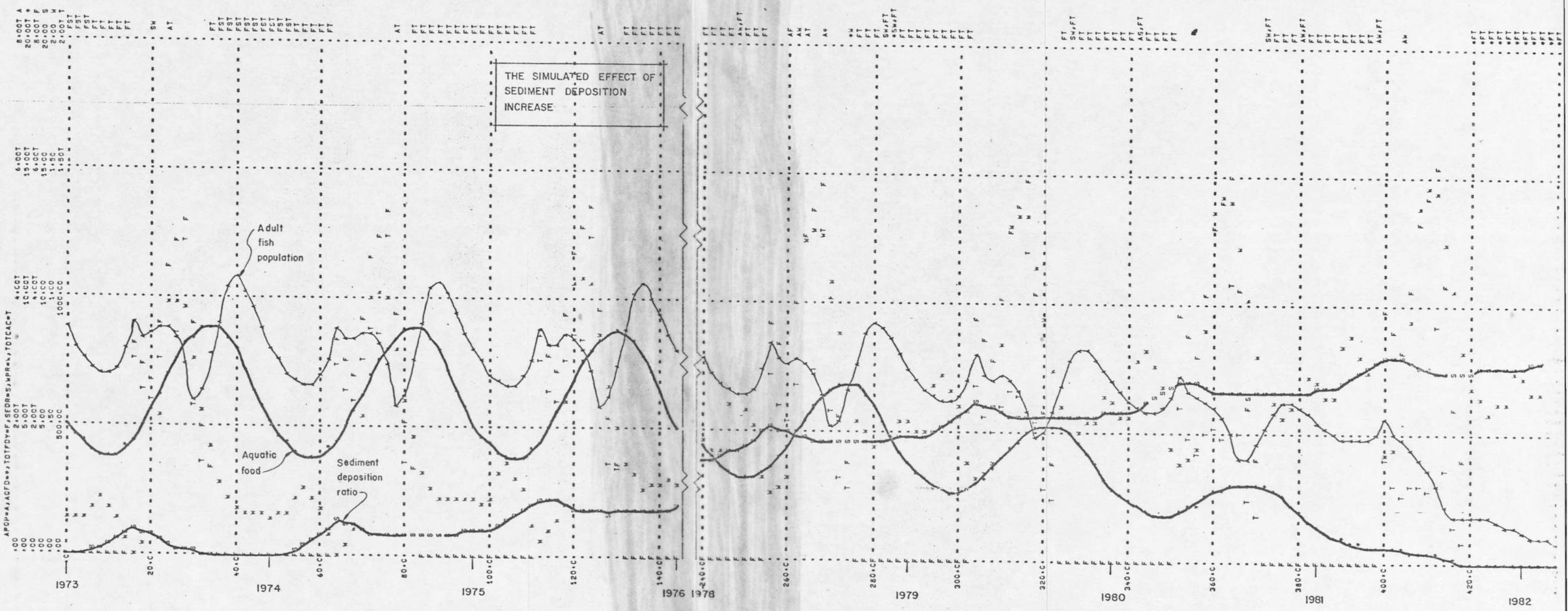

THE SIMULATED EFFECT OF SEDIMENT DEPOSITION INCREASE
Adult fish population
Aquatic food
Sediment deposition ratio
1973
1974
1975
1976
1978
1979
1980
1981
1982

FIG. 18

Let us now simulate the system's dynamic action if the Big Sky tertiary treatment plant were assumed to become 60 per cent inefficient, a four-fold increase from the original run. Figure 19, page 77, illustrates the increasing water pollution ratio, especially high during the peak winter ski season. The simulated water pollution is approximately twice as bad in the summer of 1986 as in 1973; the simulated 1986 winter pollution has increased by almost seven times the winter equilibrium in 1973. This water pollution has resulted in an approximately three-fold increase over 1973 in aquatic food. This means, with an assumed inefficiency of 15 per cent, the aquatic food level is doubled, and it triples when the assumed inefficiency is increased to 60 per cent. In this case, aquatic food increases at an even greater rate than it does when fish are not planted. The simulated increase in aquatic food results in an increase in the fish populations until the populations become limited in the amount of growth possible because of the limited number of security pools. The fish have now developed a new simulated equilibrium level which can only be increased with the development of more security pools. This simulation run again does not reflect any harmful water pollution effects. This run illustrates the need to maintain the efficiency of the tertiary treatment plant at Big Sky to prevent a significant decrease in the water quality during the winter months. This run also points out the need for improved treatment of the sewage in the rest of the canyon which causes most

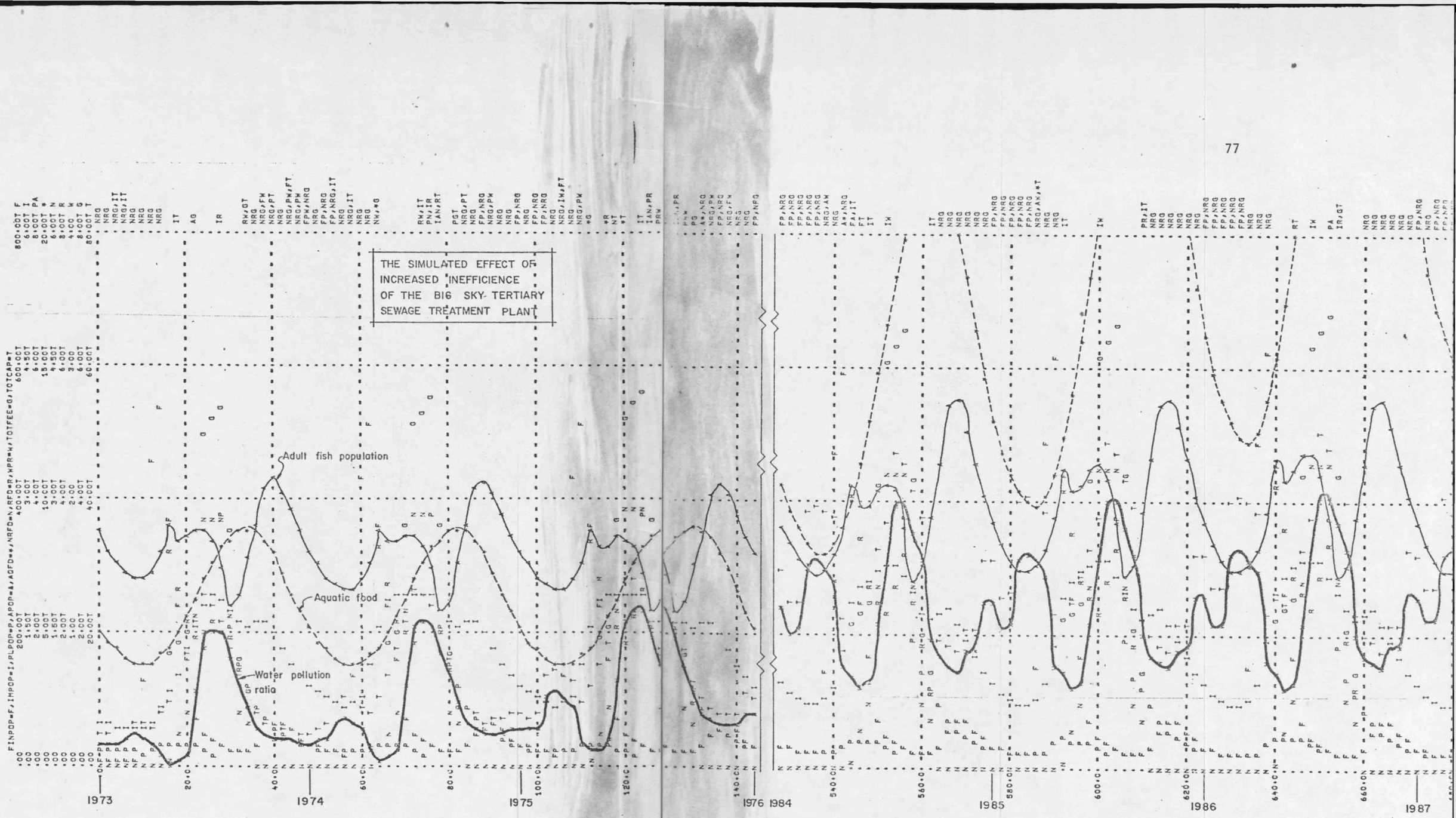

THE SIMULATED EFFECT OF INCREASED INEFFICIENCE OF THE BIG SKY TERTIARY SEWAGE TREATMENT PLANT
Adult fish population
Aquatic food
Water pollution ratio
1973
1974
1975
1976 1984
1985
1986
1987

FIG. 19

of the simulated increase in the water pollution ratio in the summer. The run illustrates that no more benefits occur in an increased fish population after the water pollution ratio gets above approximately 1.5.

The last example, Figure 20, page 79, illustrates the simulated effect of changing five important constants: MDFDTH, PLMDAF, FATE, ACATMOD, and MODCOM. MDFDTH represents the modifier of the aquatic food-growth table. The planting of fish in the river has some adverse effect like increased pressure for available food and also crowding of the security pools in the area of the plant (PLMDAF). In this run, there is no influence (crowded conditions) reflected other than that reflected in the additional food needs of the fish population. Fate influences the amount of food consumed by fish.

ACATMOD represents the "allowable" segment of the moribund percentage as described in a preceding section, pages 51 through 53. Excess fishing pressure, also previously defined, is represented by MODCOM.

In the particular runs made, a very high percentage of the moribund percentage was made accessible. ACATMOD is 80 per cent in the standard run (Figure 16, page 70) and 99 per cent in this run. The researcher has traced the effects of adding to this a 50 per cent excess fishing pressure, MODCOM, in the original run and then a 1 per cent excess fishing pressure in this run. MODCOM is the percentage, permitted in the model, of the excess demanded by the number of

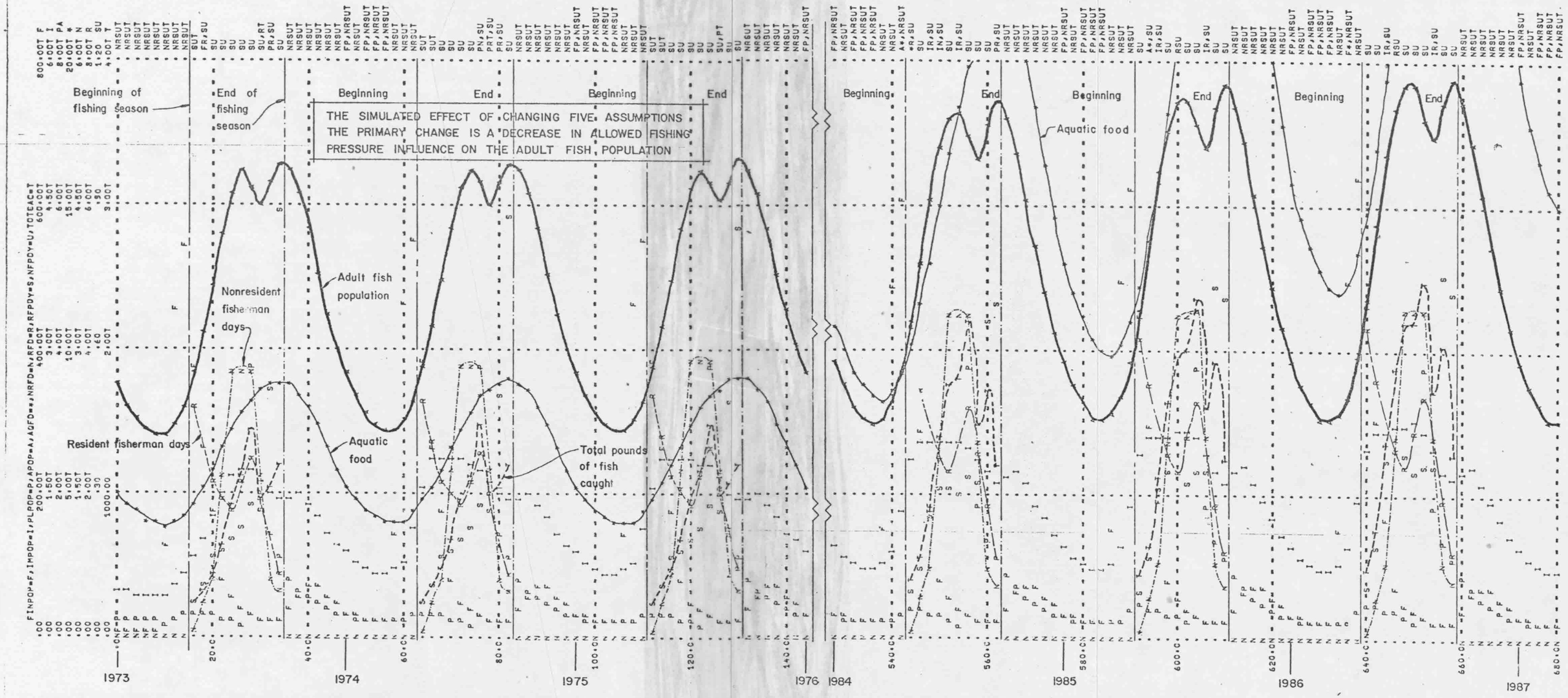

Beginning of fishing season
End of fishing season
Beginning
End
Beginning
End
Beginning
End
Beginning
End
Beginning
End
THE SIMULATED EFFECT OF CHANGING FIVE ASSUMPTIONS
THE PRIMARY CHANGE IS A DECREASE IN ALLOWED FISHING
PRESSURE INFLUENCE ON THE ADULT FISH POPULATION
Adult fish population
Nonresident fisherman days
Resident fisherman days
Aquatic food
Total pounds of fish caught
Aquatic food
1973
1974
1975
1976
1984
1985
1986
1987

FIG. 20

fishermen; excess refers to over and above the "allowable" portion of the moribund percentage. When MODCOM was made 50 per cent, the fish population was radically effected during the fishing season. The 1 per cent excess resulted in a slight increase over the natural death rate, but such permitted excess fishing pressure did not have a significant influence on the fish population. The run represented in Figure 20 and others similar to it also illustrate that as the fishing pressure effect decreases and allows the adult fish population to achieve its natural optimum, the fishing satisfaction increases because of an increase in total fish caught. This run, in regard to the influence of fishing pressure, tends to exhibit more realistic action than seems to be the case with the standard run, Figure 15, page 68. This run also illustrates the effect of lowering the death rate of food, as it exhibits more radical growth in later years than the standard run reflects.

The simulation runs examined here are few in comparison to the runs needed to further understand the system. This model has given only a glimpse of the dynamic fishing ecosystem which it is possible to model with further development; and these model results suggest what considerable understanding can be achieved using systems dynamics. These results are based on many assumptions--the constants and tables. Since continued work with expert assistance to improve many of the assumptions is still necessary, it is more important to recognize the structural development of the model than any particular results.

Model Improvements and Further Research

It must be emphasized again that this model provides the basic framework for a model that can actually be used by decision makers to achieve an understanding of the fishing ecosystem. The improvement of this model can be accomplished in three different areas: the model assumptions, the basic model structure, and further extensions of the model.

The model assumptions are contained in the constants and tables used. These assumptions can be improved with the further assistance of experts in the areas of fish biology, sociology, aquatic life, and sediment to name a few. These experts must be willing to work with the knowledge they now have and be willing to give a professional opinion that is not necessarily backed by elaborate statistical analysis.

The basic model structure can be improved in specific ways. The first improvement would be to cut out a few unnecessary and overlapping auxiliaries to make the model more compact. The next step would be to improve the structure of the model, or its logic, with expert assistance. The structures should also be changed to reflect a more drastic reduction in fishermen when the fish population is destroyed, and the possible self-regeneration of the fish population and the aquatic food when they are destroyed and river conditions improve. Planted fish should be another possible method for regenerating the wild fish population, a

method that is not in the model. The sensitivity of the aquatic food growth also needs further investigation, which might indicate the need for structural improvements. The sediment and canyon populations are used as only an outside influence and, therefore, do not contain any feedback loops that really exist in the total system. These feedback loops should be developed to add further value and reality to the model. The economics of this system are extremely important and should be one of the first structural improvements added. This economic structure could be easily added as it is based on population and fishermen. This improvement would provide additional information that is extremely important in an economically based society.

The model in its present structure could be used to further experiment with the constants and tables. From this, some additional understanding would emerge. But the researcher feels that the improvements above should be implemented before further experimenting, to achieve the optimal use of the fishing-ecosystem dynamics as a management tool for further understanding of the system.

This type of model could be further extended to include all recreational activities in a pristine environment like the Gallatin Canyon, which is badly needed by developers, environmentalists, and government control agencies. This enlarged version could assist anyone interested in better understanding the process of recreational development in any unspoiled area.

The process of model improvement should be a cyclical and never-ending process, as the model is used and improved for and by the decision makers as a practical tool.

This type of system simulation has its greatest value in helping one understand the complex system and its critical control factors. The model could also, however, be used as a basic tool in a dynamic cost/benefit analysis. This economic-analysis tool could be greatly enhanced with the predictions and the dynamic levels that systems dynamics could pass on to the decision maker. This is just another aid to comprehending the system that can be attained through systems analysis.

Another possible area of immediate concern to environmental research is the management of interdisciplinary research teams. This tool equips the members of the research team with a common and very useful language for communicating and representing the system they are studying. The results of such an effort by a group, such as the Gallatin Canyon study group, in regard to a recreation system, could be astounding. All members could model and logically follow through their areas of expertise and examine how and where their areas influence and overlap other areas of expertise, determining the connecting feedback between subsystems. This process could be used as a very valuable guide to determine exactly what information and data or further research is needed. This would prevent or at least control the investigation

of areas that do not contribute to the total overall project's goal, that is, development of a better understanding of the total system.

Systems dynamics could possibly be used to model the actual actions of the research team itself and determine the best management technique for controlling the researchers.

Systems dynamics can be used as a tool for real progress in the fight against environmental degradation by equipping managers with the ability to understand and predict the results of their decisions, and by providing interdisciplinary researchers with the ability to understand and combine the total system under study.

The systems approach and possibly systems dynamics could be used as a tool to determine the best method for implementing any plan or model. This leads to an area of prime concern to any designer--implementation of his designed system.

Implementation

Any research project, plan, or management tool is useless if it sits on the shelf. All designers and especially engineers must include the decision makers in their systems and then design with them in mind to create a worthwhile contribution. Decision makers must feel that they have contributed to the design; they must be informed about using systems analysis as an important tool for improving their management capabilities. The more a decision maker can feel the designed model is really his, the more he will depend on it as a tool.

The systems approach is the management tool of the future, which requires management to effectively strive for long-range systems goals rather than optimizing the system for personal or short-range goals. An example of a systems approach is the program planning and budgeting (PPB) presently being used by the government. However, the effectiveness of this tool is thwarted by its users, who find that the new systems approach is disturbingly contrary to past approaches (Roos, 37) which have tended to optimize for the personal and short-range goals. This will be a problem in implementing any new systems approach like systems dynamics.

Systems dynamics is a particular systems-analysis management tool that will permit a decision maker to examine the total consequences of a decision over the long run. He does not have to know the exact relationships that exist, for he can examine the system's action over a known range of relationships. Once the model has been developed, the potential for improving decision making is endless. Decision makers must be informed how systems analysis can be used as a valuable tool. These administrators must have a basic understanding, in order to be able to participate in the designing process. If these two steps are not followed, the decision maker might expend his energy determining whether the systems analyst is trying to undermine his interest; for unless he understands the systems analysis method, he could suspect its intentions.

This model could be transferable to any fishing stream, with the modifications indicated in the previous section. This model could become a very valuable tool for the Montana Fish and Game Department in making policies concerning any game-fishing area. A Montana State Fish and Game fish biologist was consulted in constructing this model and has shown interest in the possibility of experimenting with the model. The limited time that is available on a master's thesis prevents the investigator from doing as much work in this area as he desires. However, the model is well documented and flow charted to make it easily accessible to others interested in it.

It is hoped that further implementation will be carried on after this thesis project is completed. The Montana Fish and Game Commission could get involved in improving the design of the model and thence in informing administrators, using the model. Dick Vincent, the Montana Fish and Game biologist at Bozeman, is interested in understanding and using the model and, therefore, he, or another Fish and Game fish biologist, must be involved in the process of improving the model. This technique has great potential not only in fish management but also in game management. Only making the required improvements on this model and then implementing it will allow this extensive project to reach its true value. If this project is not implemented, it could become just another neglected academic exercise. The model will hopefully serve another purpose by providing the groundwork for the

development of a recreational systems dynamics model by the Gallatin Canyon research team. The total worth of this designed model or any design depends on the implementation and use of the design and on no other factor.

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

The researcher conceives of this model as an essential beginning in the study of fishing ecosystems. It is recognized that potential faults may exist in the model, and that there may still be problems that have not yet emerged. The methodology of systems dynamics is a cyclical process of using and improving the dynamic model.

This model illustrates that the systems approach can be used to achieve a better understanding of environmental problems and specifically the piscatorial system in this thesis. This specific model represents the successful use of systems dynamics to model and simulate complex environmentally related problems. The example simulations in this thesis are valuable examples of how fish, fishermen, aquatic food, water pollution, human populations and sediment can be combined into a logical and dimensionally balanced system.

The following example recommendations have been developed from the level of understanding possible through the systems approach. These example recommendations reflect the results of the model and simulation runs. This model is dependent on many assumptions made by the researcher that need further review by experts in various disciplines and it is therefore stressed again that these are only examples of recommendations that are possible.

1. The systems approach indicates that fishing regulations

and policies should be variable from one area to another.

2. Fishing regulations or policies, based upon the understanding achieved by the model and the resulting simulation runs, for the Gallatin Canyon might be:

a. year round fishing (assuming minimal effect of fishing pressure on the fish population)

b. not planting any fish in the Gallatin Canyon

c. keeping the present bag limits even if they only serve as a psychological control of fishermen

d. using the bag limits to effect fishing pressure only when the fishery is in poor condition--caused from natural or man-made action

3. The systems approach indicates that in streams that require planted fish to maintain a fishery, determine cost/benefit of developing natural breeding grounds for a self-sustaining fish population.

4. The model suggests the need for controlling and monitoring the generation of sediment and the resulting effects on both fish eggs and aquatic food, to improve the model and as a result, the management of any similar fishing area.

5. The model also suggests the need for controlling and monitoring the water pollution and the resulting effects on fish, fishermen, and aquatic food, to improve the model and as a result to improve the model and as a result to improve the understanding of the water

pollution problem.

6. The model also suggests that sewage treatment facilities in the canyon should be investigated to maintain water quality levels above those indicated in the simulation runs.

The sensitivity of aquatic food to changes in the system is quite astonishing. A water pollution ratio increase from one to two does not seem bad when one examines the river's present relatively pure condition. The increase in water pollution has a multiplying effect on the aquatic food growth, and because of this could have an adverse effect on fishermen at a much lower critical level than is assumed in the model. It is also recognized that if the sensitive aquatic food growth along with canyon population growth were to maintain their trends in 1986 the growth could have a significant adverse effect on the performance measures of the system, that is, fisherman satisfaction and resource-use options. This could be estimated with additional runs. The recreational activity of fishing seems in the model to generally improve as a result of increased canyon population and, therefore, of water pollution. The general fisherman population has increased, which reflects a general fisherman satisfaction, but not necessarily an increase in average catches. One must, however, keep in mind that certain people have been displaced because of the increase in the canyon's use.

The critical factors in the fishing ecosystem model seem to be those that affect the aquatic food in the river. Water pollution,

which stimulates aquatic food growth, and sediment deposition which acts destructively on food-producing areas seem to be the critical influences on whether the main subsystem, aquatic food, will be maintained. If these two effects balance each other out, the food supply could, in fact, stay at equilibrium from 1973 through 1987.

This model has illustrated the possible results of systems dynamics being applied to a practical environmental problem and the method's possible use as a management tool. This technique, systems dynamics, developed by Jay W. Forrester (15, 16, 17) can advance the management of fishing ecosystems from an art to a science and might eventually allow scientific management of the entire ecosystem, the whole earth.

This example demonstrates that systems dynamics is a possible approach for increasing understanding of the recreational activity of fishing, eventually all recreational activities and possibly the dynamics of our environmental crisis. This model shows the results of confronting conditions that may be unknown from a lack of statistical data; items unquantified because of lack of a technique; and the combination of various dimensions to produce a logical and realistic systems simulation model.

Montana's "crisis" must be approached with a systems concept that will provide a better understanding of its environmental problems caused by agents like recreational and extractive industrial developers.

This practical application proves that systems dynamics can help people understand the problem areas related to our environment. The state must first develop the ability to use this technique and, for the best results, make use of an interdisciplinary team. The State laws then might be changed to reflect a systems concept of environmental impact. Conceiving problems in terms of systems requires consideration of not only the first direct results of a development but all resulting effects including increased population and possible synergistic effects. The laws might also reflect the use of logical predictions from this technique, even if the model is only a descriptive model, not backed by elaborate statistics. This lack of statistical data does not affect this technique's usefulness, as it can examine the effect on the system as a variable is changed, ranging over known possible values.

Some Montana governmental agencies are willing to admit a lack of understanding about the environmental impact of various developments because of "unknowns" and unquantifiable relationships. Other agencies do not acknowledge this problem. Whatever category a governmental agency fits, this technique would help it to document its assumptions, to relate unquantitative items, and to at least consider the range of experts' opinions about unknowns. Governmental agencies, Montanans, and developers would all have a better understanding of the development process because of this technique.

Can the systems approach, if used in Montana, solve the

environmental crisis? One must think of the system in terms of the United States and, finally, the world. The United States has had a unique history and, therefore, has developed a unique environmental crisis. The people of the United States consume from twenty to fifty times more natural resources than do people in developing countries (Forrester, 13:66). One can imagine the implications of a world-wide United States population in view of the demands we now make on our environment. Yet the United States is trying to "export" our way of life, "the good life," to every country in the world. The prospects of such a large demand on our "spaceship earth" (Caldwell, 6) suggest a very grim future. The systems concept of "spaceship earth" as a closed input-output system points out the need for a slow-growth or no-growth economy. Could the United States' free enterprise society survive such a drastic change in our values and myths? This necessary change will come about if the present trends lead to a catastrophe or if enough insight and understanding into the possible results of our present trends can change general American goals.

Systems analysis implies controls that might limit some personal freedoms but might, considering the intensity of current environmental pressures, prevent excessive encroachments on other people's freedoms. And, finally, these controls might initiate more freedom of a different kind for the human race as a whole, which might then escape inevitable extinction.

APPENDICES

APPENDIX A

CIRCLE DIAGRAMING

Circle diagraming allows graphic representation of the inter-relationships among a system's important elements. This technique also allows persons of various disciplines to each contribute his own data and to see the effects on the total system.

Appendix Outline

1. Flow Classification of Circle Diagrams
2. Circle Diagrams of the Natural Environment
3. Man's Structural Environment
4. The Total Environmental Relationships: Man-Nature

RELATIONSHIP

1. Flow Classification of Circle Diagrams

Flow refers to the influence of one element on other elements of the system. The influence is a relationship flow. Flows are classified by first generating numerous relationships and identifying their common characteristics. The classification was done with the intention of approximating the real system as much as possible. Many of the flows are not easily measured, but it is better to take into account what is known about the relationships, in whatever manner possible, than to toally ignore them. The following classes of flows

are not laws for diagraming flow relationships but are tentative guides.

Classifications: Life-needs flows, life-style flows, biological, psychological, chemical, and material flows, consumption flows, physical-force flows, physical-limitation flows, commercial, and population flows.

Definitions and examples are given on the following pages.

Definitions and Examples of Relationship Flows

Life-needs flows are those factors that affect the life-sustaining needs of living things. Living things are affected by the presence of an extremely bad quality or the absence of a quantitative item that will cause death of living cells. These types of influence are life-need relationships.

Examples: The quantity and quality of air, water, and vegetation that is necessary to maintain mammal life. The influence of the quality and quantity of these elements on mammals is a life-need flow.

Life-style flows occur whenever something causes living things to change the existing patterns of their life.

Examples: The grazing of cattle in a certain area in most cases, pushes deer or elk out of that area. If man uses a primitive area, often he will push the animals

out of their home area and thus change their life styles. The action of these forces are life-style flows.

Biological flow can introduce organic substances to cause changes in organic composition of any living or material substance.

Examples: Mammal's excretions affect the biological composition of water and, thus, its quality. The quality of air and water affect the composition of an animal's cells and its biological processes.

Psychological flow occurs whenever anything affects the psychological state of mind of an individual.

Example: The ugly appearance of polluted water may affect the state of a person's mind.

The chemical composition of any material or living being may be affected by the Chemical flow from other substances.

Example: The soil's chemical composition directly affects the chemical makeup of the surface and ground water.

Material flow is the movement of any substance or being from one location to another or the transportation of something from one environment to another.

Examples: The movement of precipitation to surface water and hence to ground water is a good example of material flow.

Consumption flow occurs when material is consumed by other living substance and the material's biological and chemical makeup is changed and used by another living substance.

Example: Animals' consuming vegetation and water is consumption flow.

Physical-force flows when it is applied to change the shape or structure of another substance or being.

Example: The geology and climate of an area are physical forces that help determine the air quality.

Physical-limitations flows occur when living beings or activities are limited by certain natural conditions or man-made policies.

Example: Extreme temperatures can eventually cause death to living beings. Skiing is physically limited by the slope of mountains, that is, by geology.

Population flow occurs mainly as a segment of material flow. People move around, changing the environment around them.

Example: Tourists enter and leave a pristine environment from an outside origin.

Commercial flow occurs as part of the conversion process of natural resources.

Example: Tourists pay money for services in the canyon which is, in turn, paid out for business resources.

2. Circle Diagrams of the Natural Environment

The natural environment contains many elements. Which elements must be included to provide a realistic and usable model? Figure 21, page 100, shows the important elements that have developed into a pristine ecosystem. Figure 22, page 101, shows the probable elements of a modified pristine ecosystem which, in this case, is the Gallatin Canyon. In Figure 22, the elements of birds and protozoa have been excluded because they are not visibly influential to the ecosystem in the area. They are not being measured by the National Science Foundation Study Group either. Interactions in the natural environment are illustrated in Figures 23 through 30, pages 102 through 109. The figures relate to each class of flow. It is important to point out that not all potential relationships have been diagrammed, but the diagram is still a reasonable basis for study.

3. Man's Structural Environment

Man, as an environmental force, can be divided into important elements, each element having its own makeup and its own specific influence. These elements overlap in many ways. There are no definite breaks between many of man's economic, technical, or cultural activities. Figure 31, page 110, illustrates some kinds of overlap and the circular structure.

Man's own interrelationships are not shown because they are so complex: each element influences most all of the other elements.

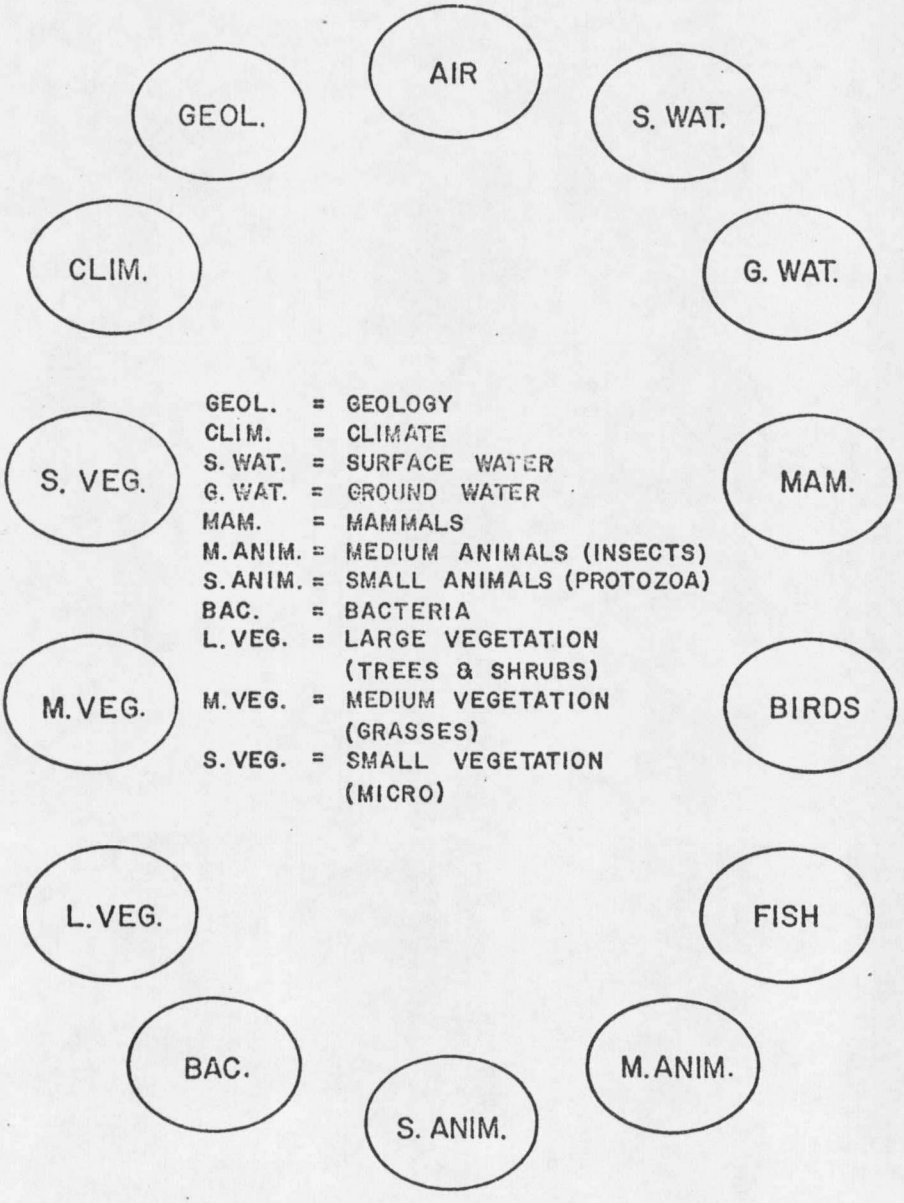


FIG. 21
PRISTINE ECOSYSTEM

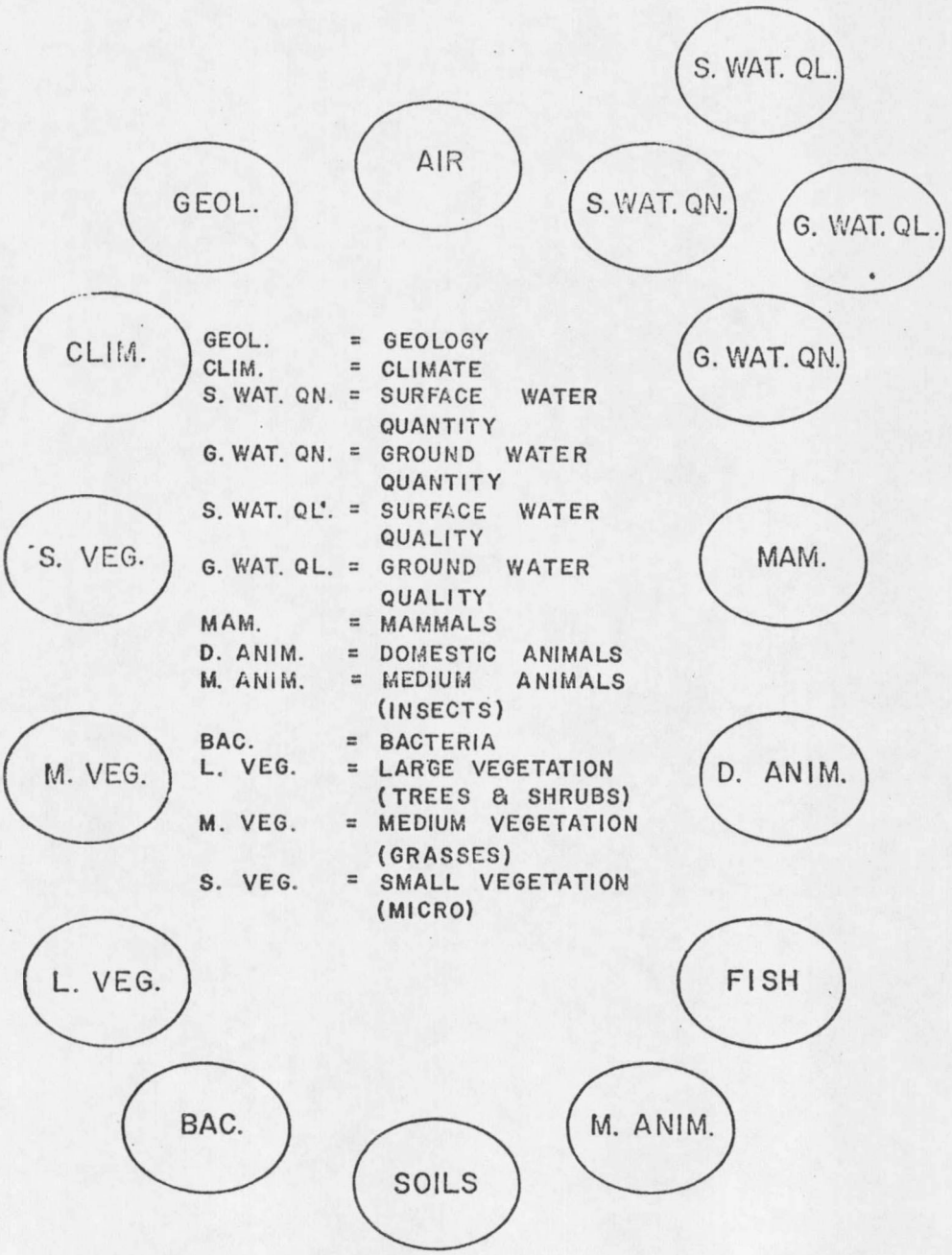


FIG. 22
MODIFIED ECOSYSTEM
(GALLATIN CANYON)

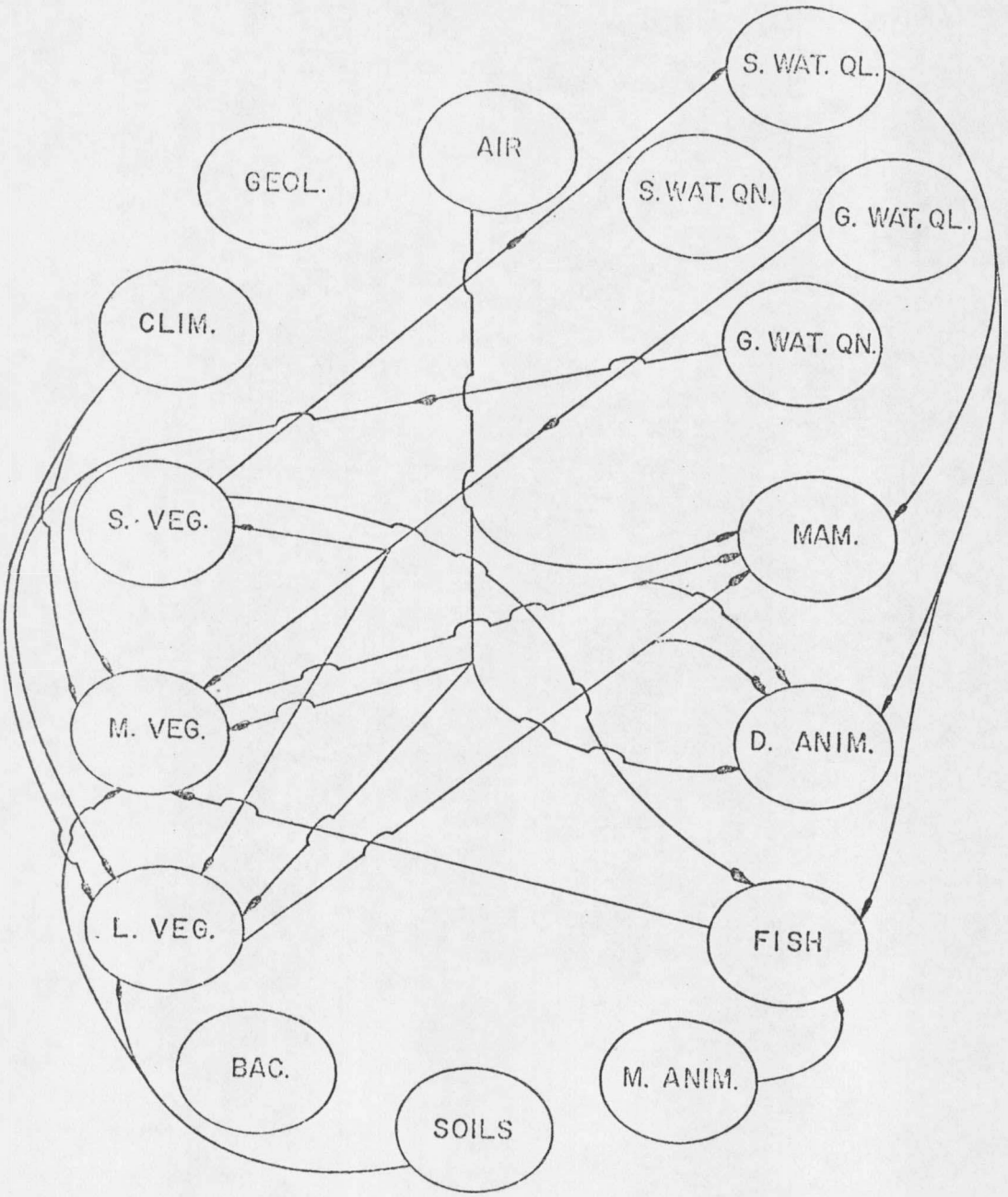


FIG. 23
LIFE NEEDS

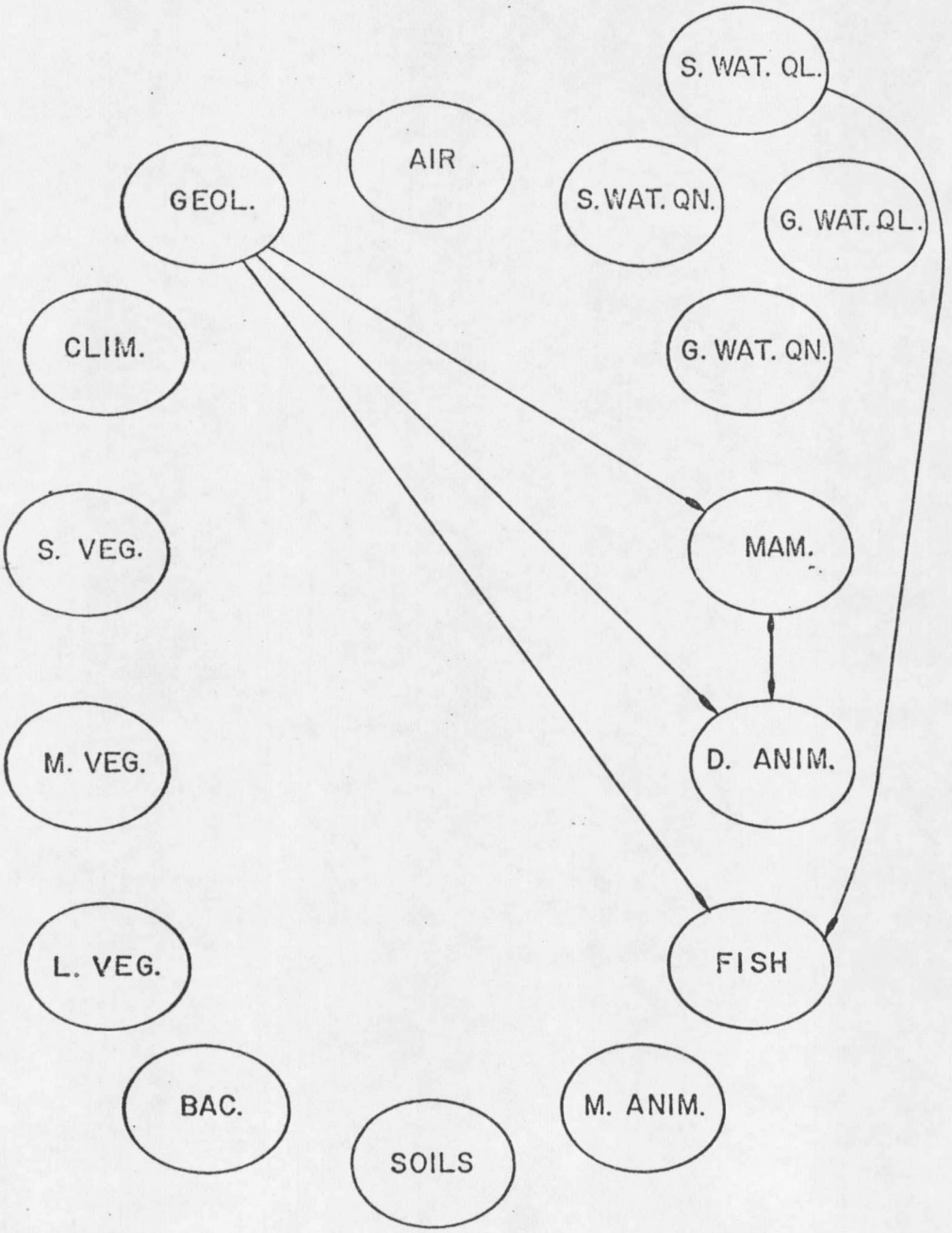


FIG. 24
LIFE STYLE

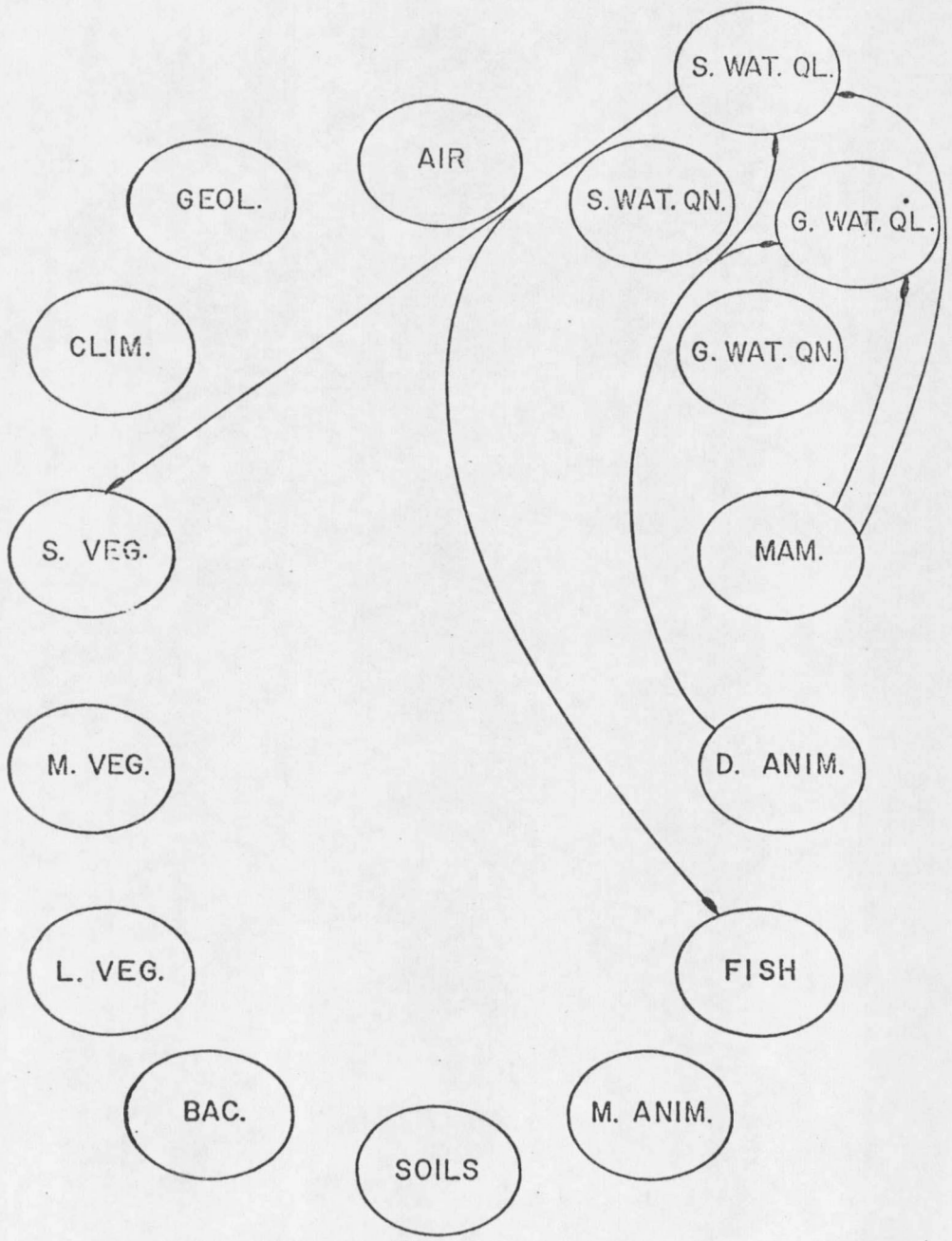


FIG. 25
BIOLOGICAL

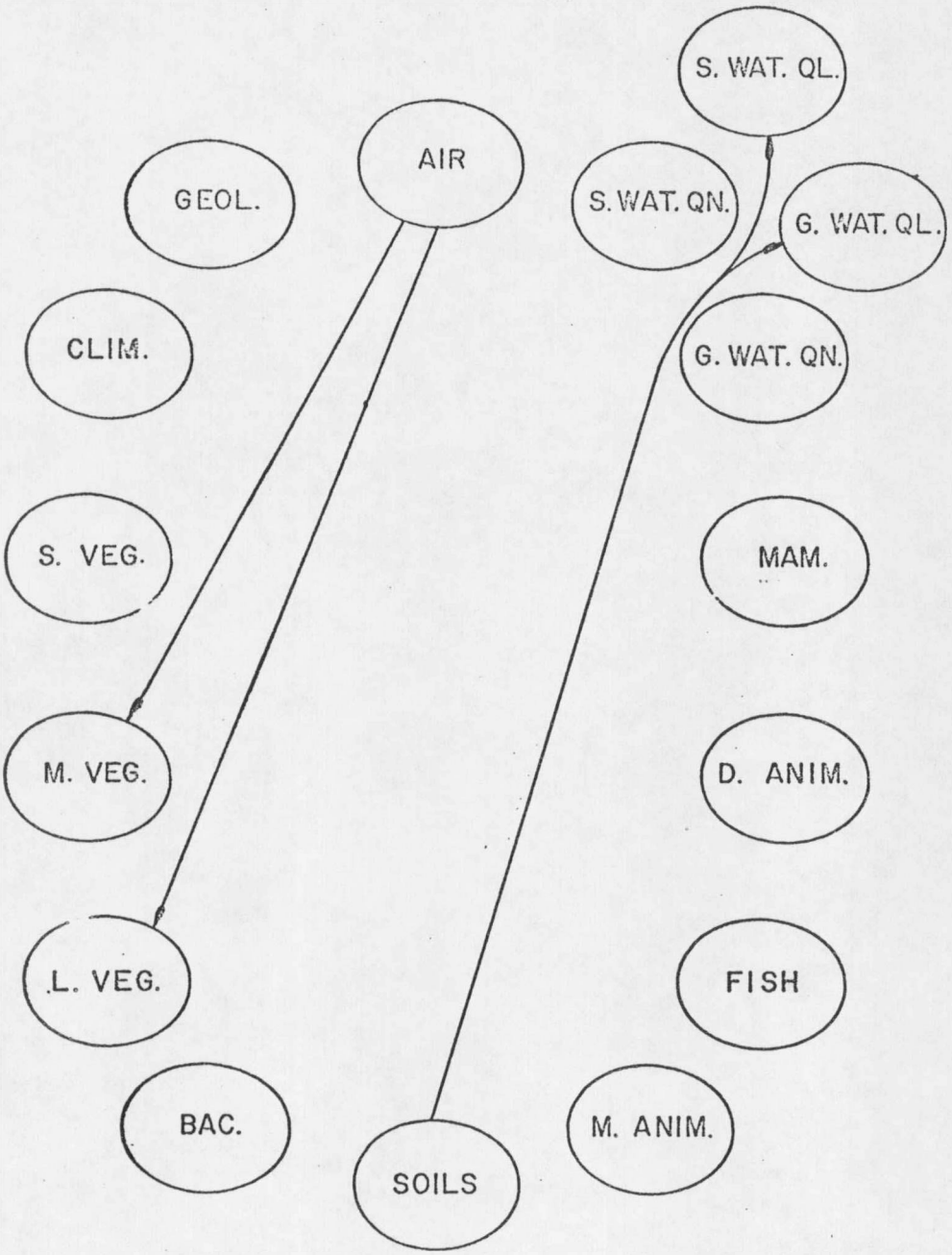


FIG. 26
CHEMICAL

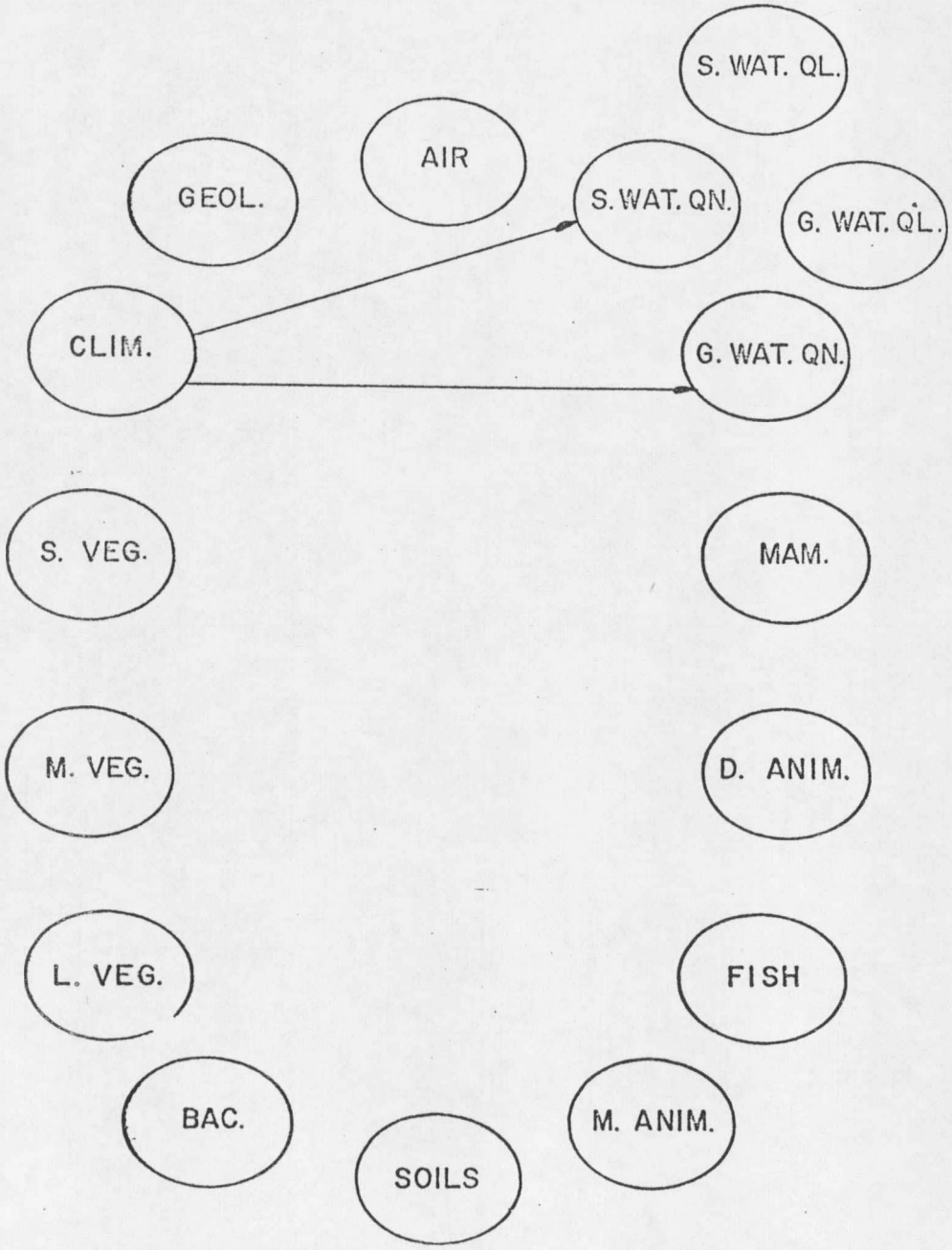


FIG. 27
MATERIAL FLOW

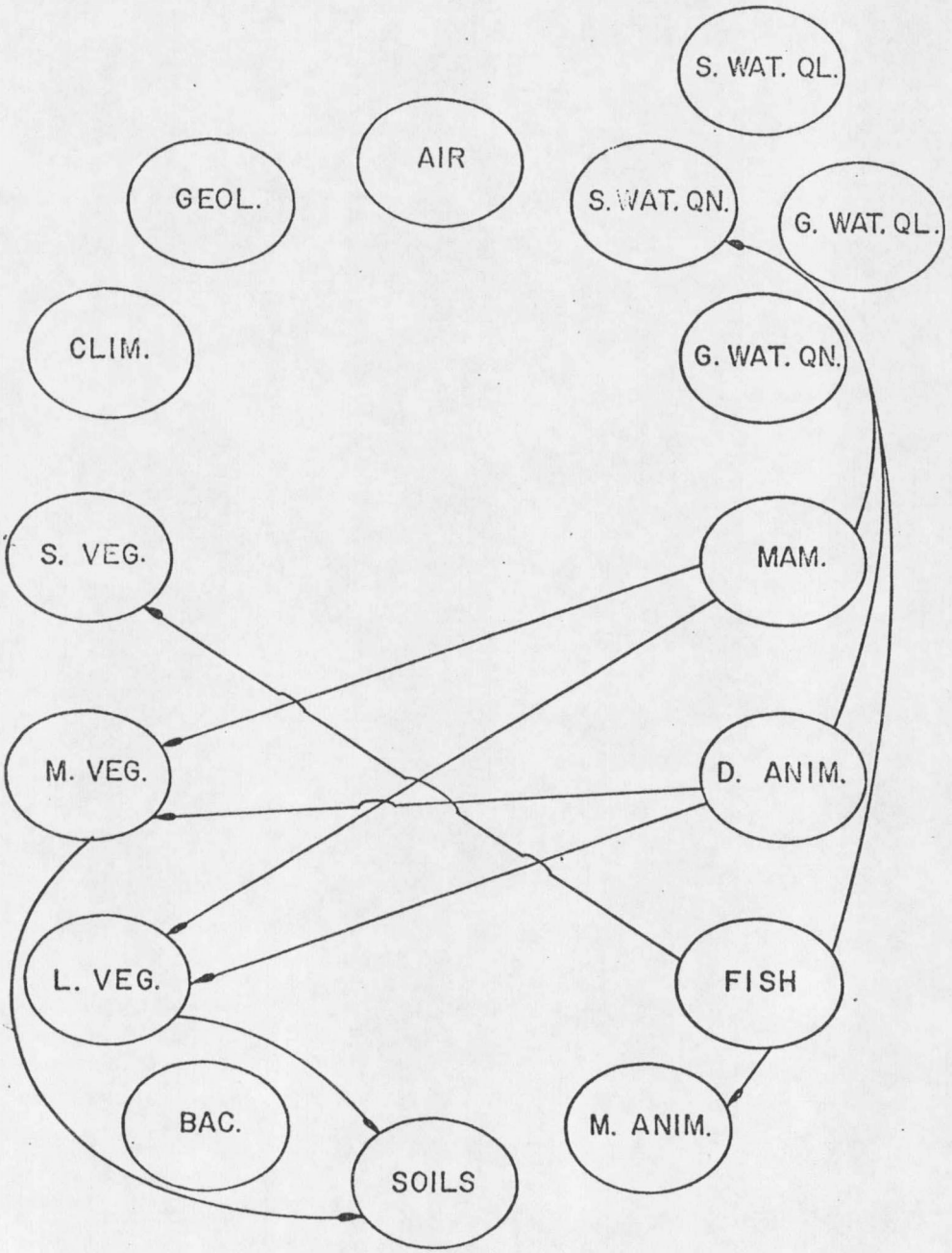


FIG. 28
CONSUMPTION

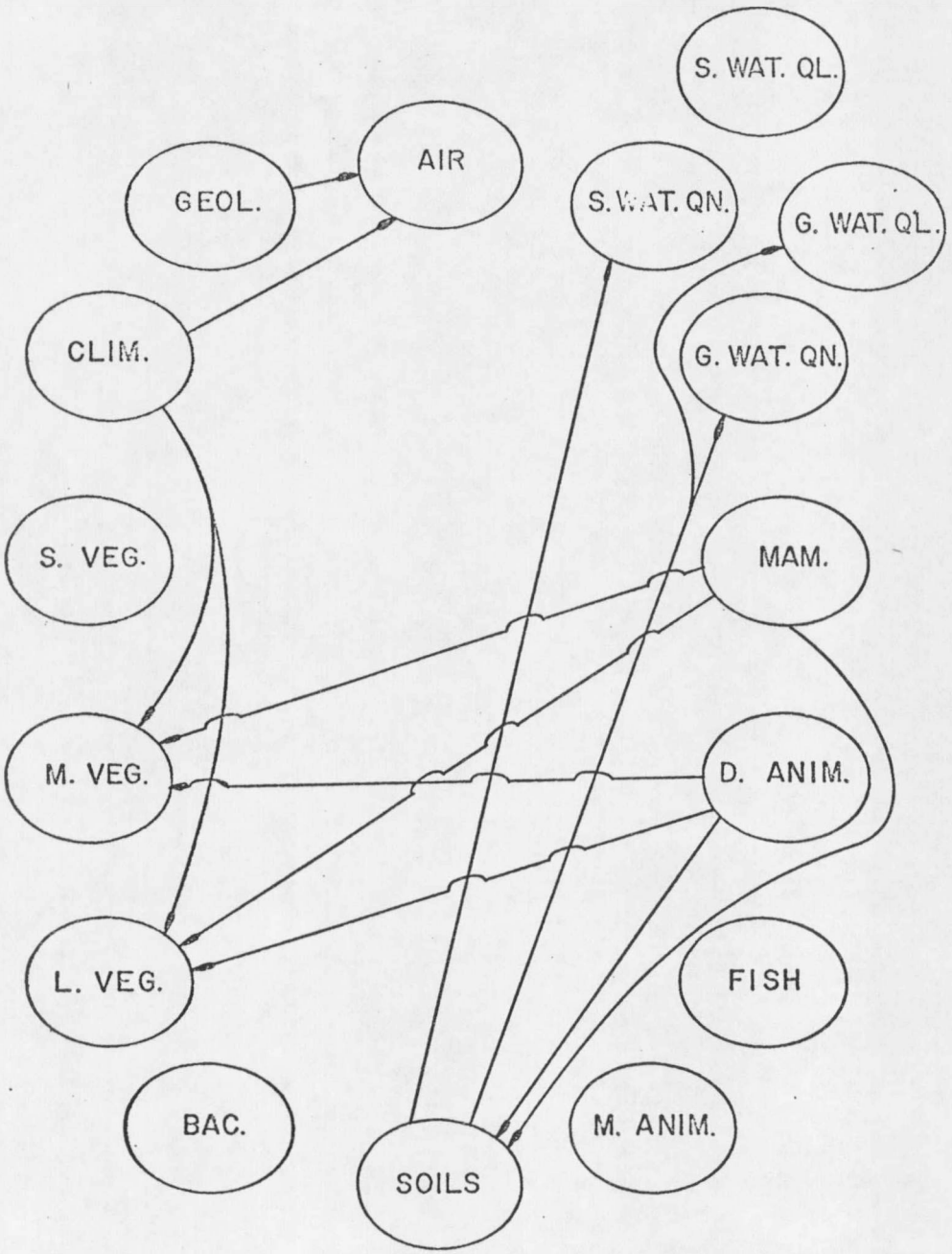


FIG. 29
PHYSICAL FORCE

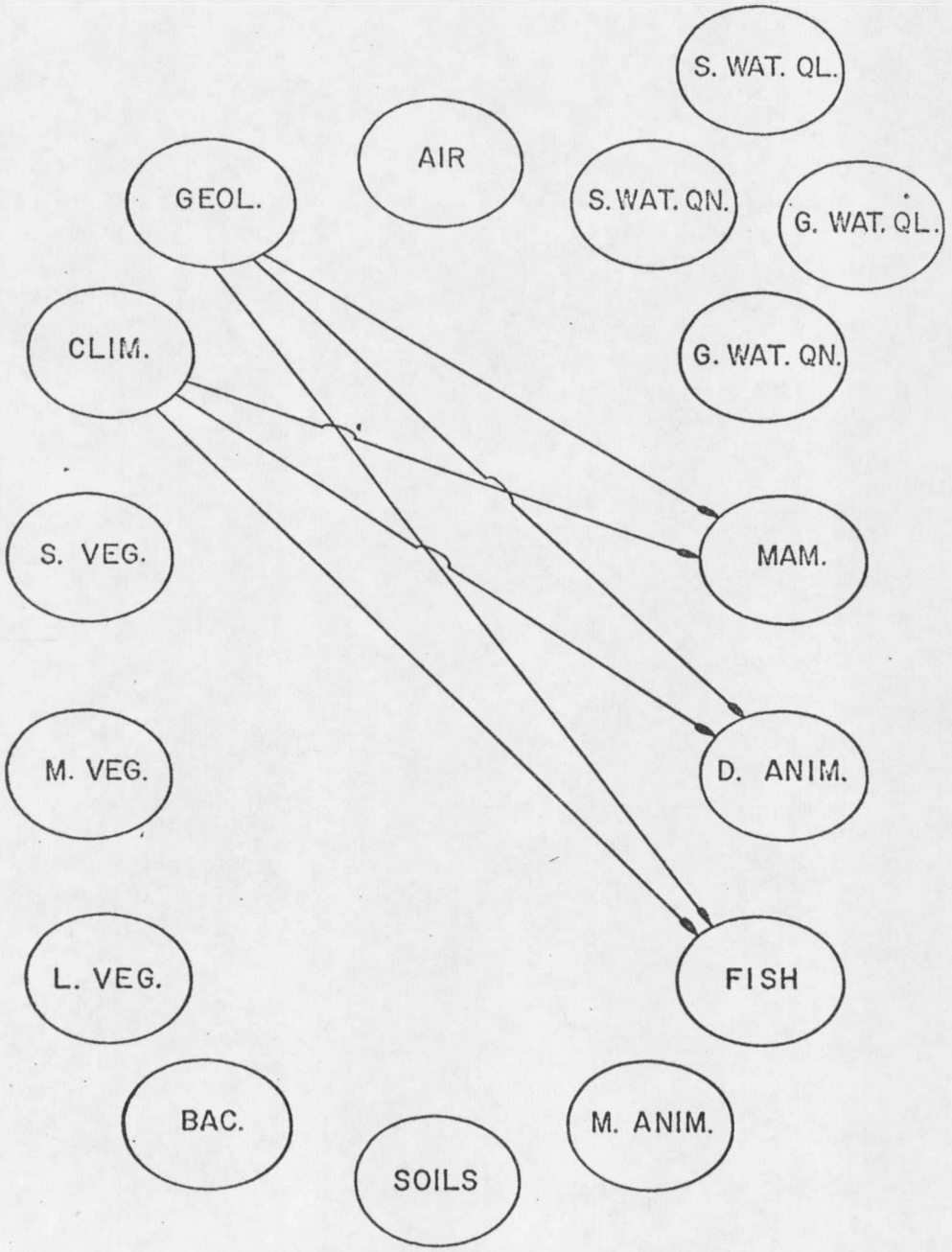


FIG. 30

PHYSICAL LIMITATIONS

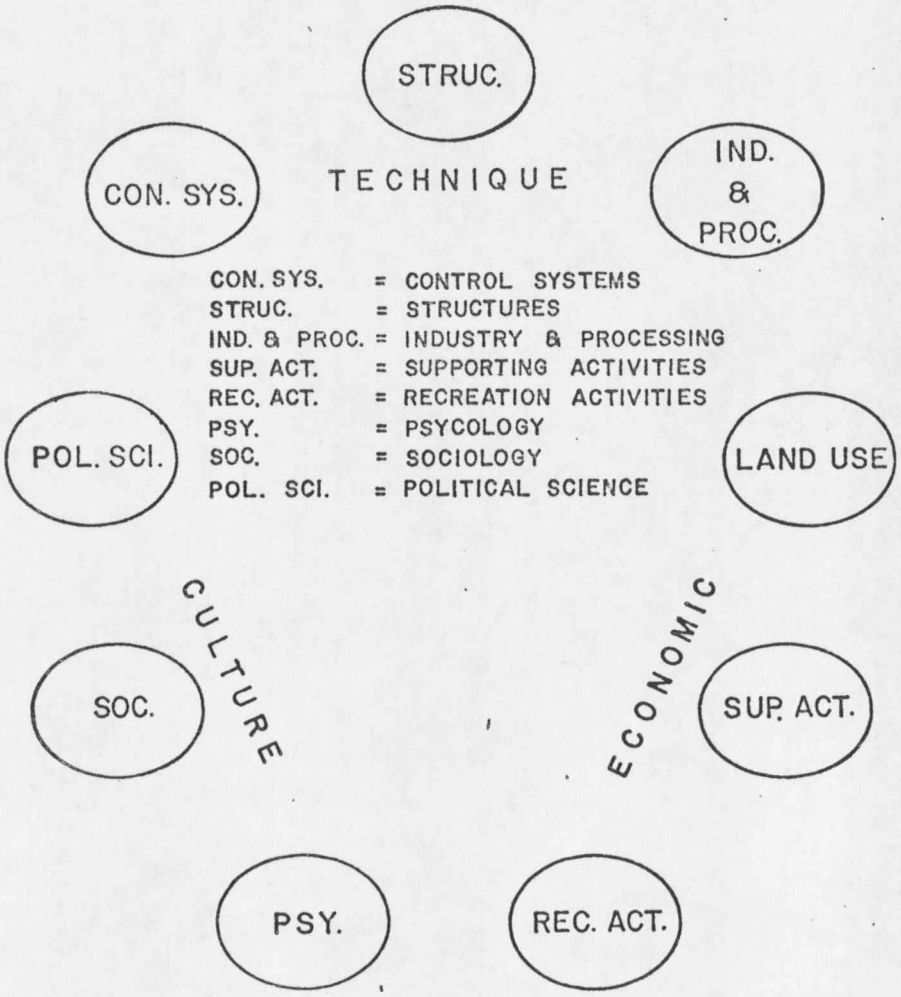


FIG. 31

SYSTEM OF MAN

4. The Total Environmental Relationships: Man-Nature

To understand the system, it is extremely important to see the relationship between man and nature. Figures 32 through 35, pages 112 through 115, represent the impact of various recreational activities on the natural environment. The recreational activity also includes the human supporting elements like the political and economic elements. Many more circle diagrams would have to be included to complete the ecosystem analysis.

Another type of man-made circle diagram was developed and used as illustrated in Figure 37, page 117. The flow in this case, however, is not labeled. This figure illustrated the use of circle diagraming with the levels or important auxiliaries of the fishing system, as a step in using the system dynamics analysis.

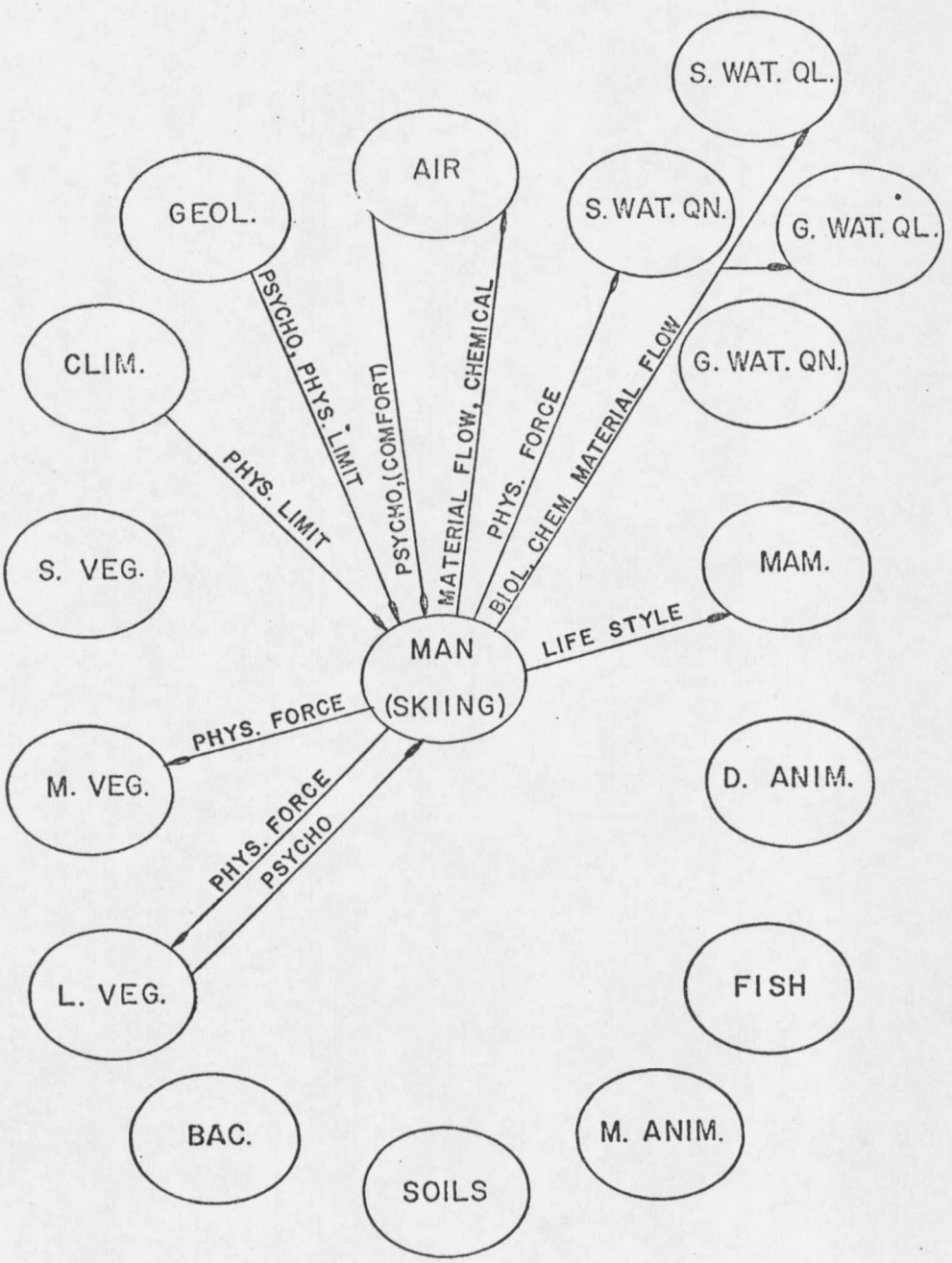


FIG. 32
SKIING

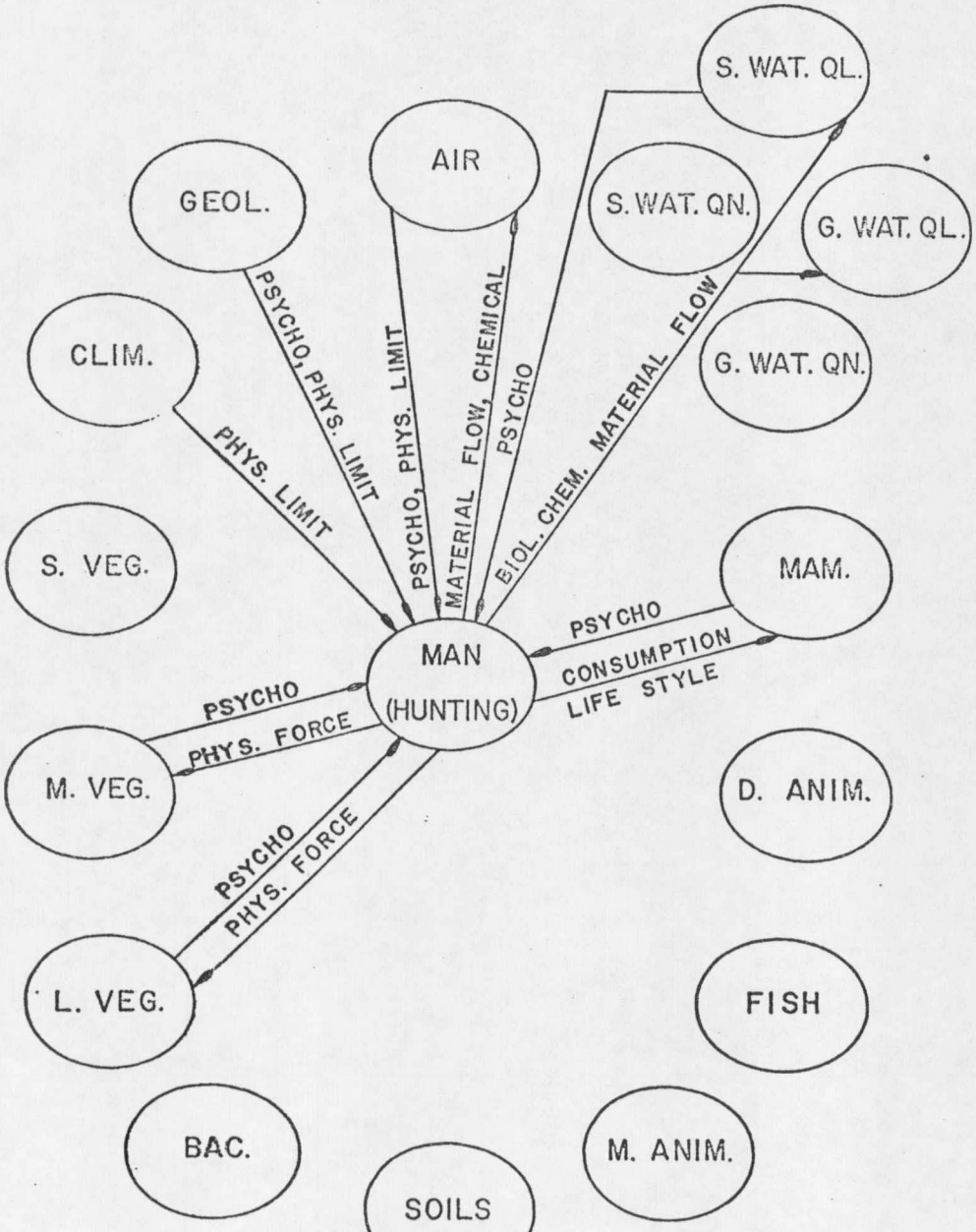


FIG. 33
HUNTING

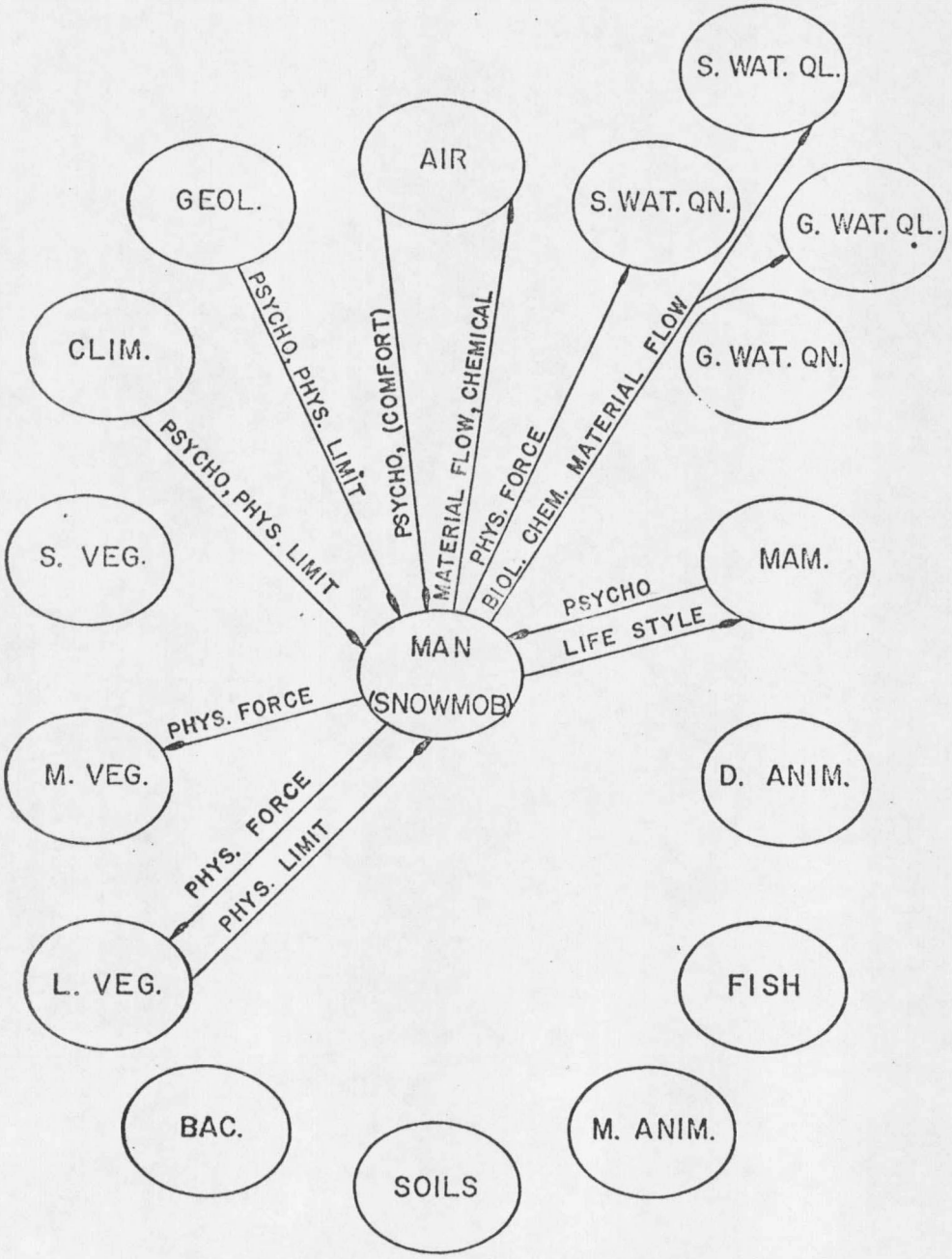


FIG. 34
SNOWMOBILING

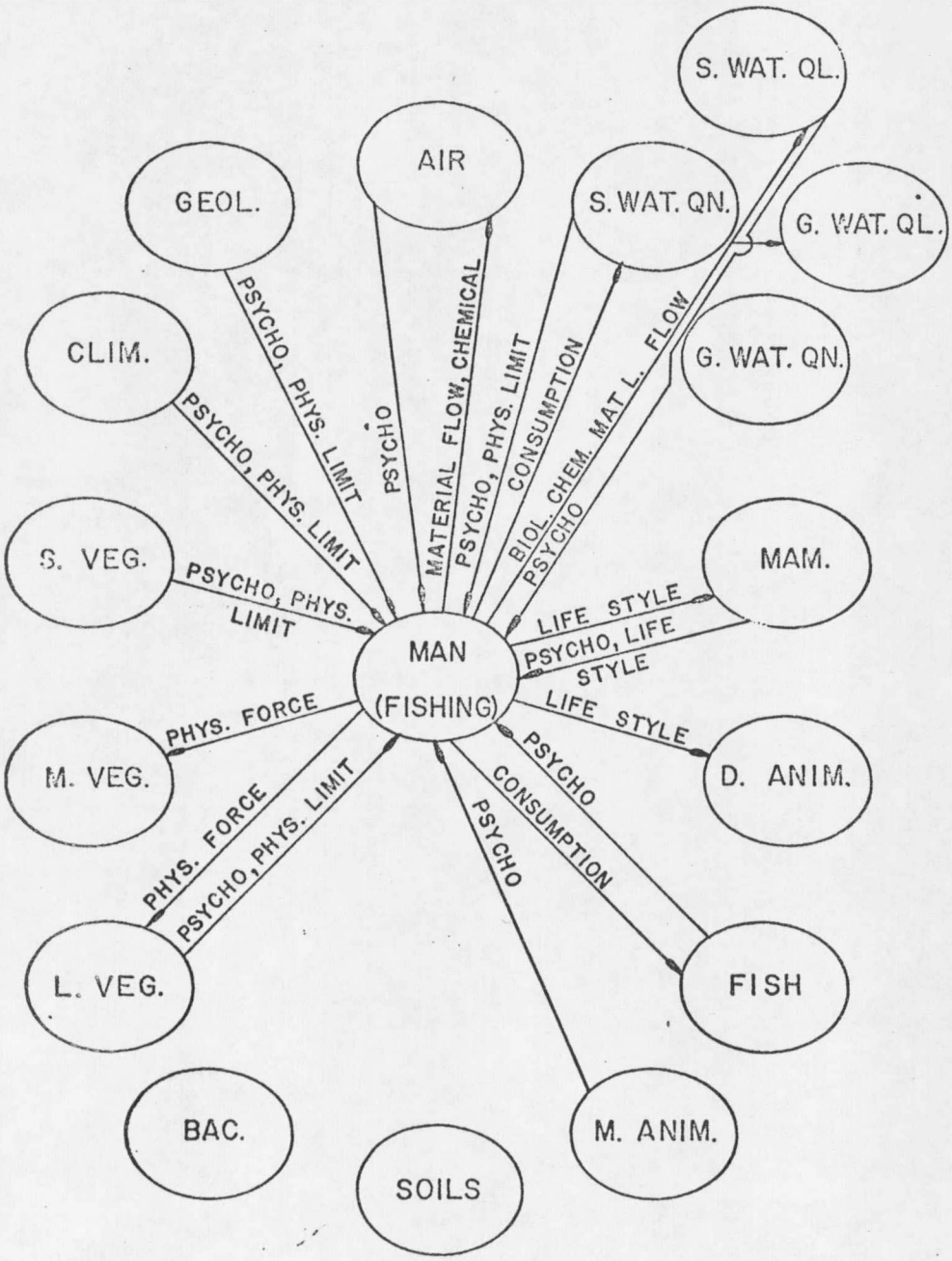


FIG. 35
FISHING

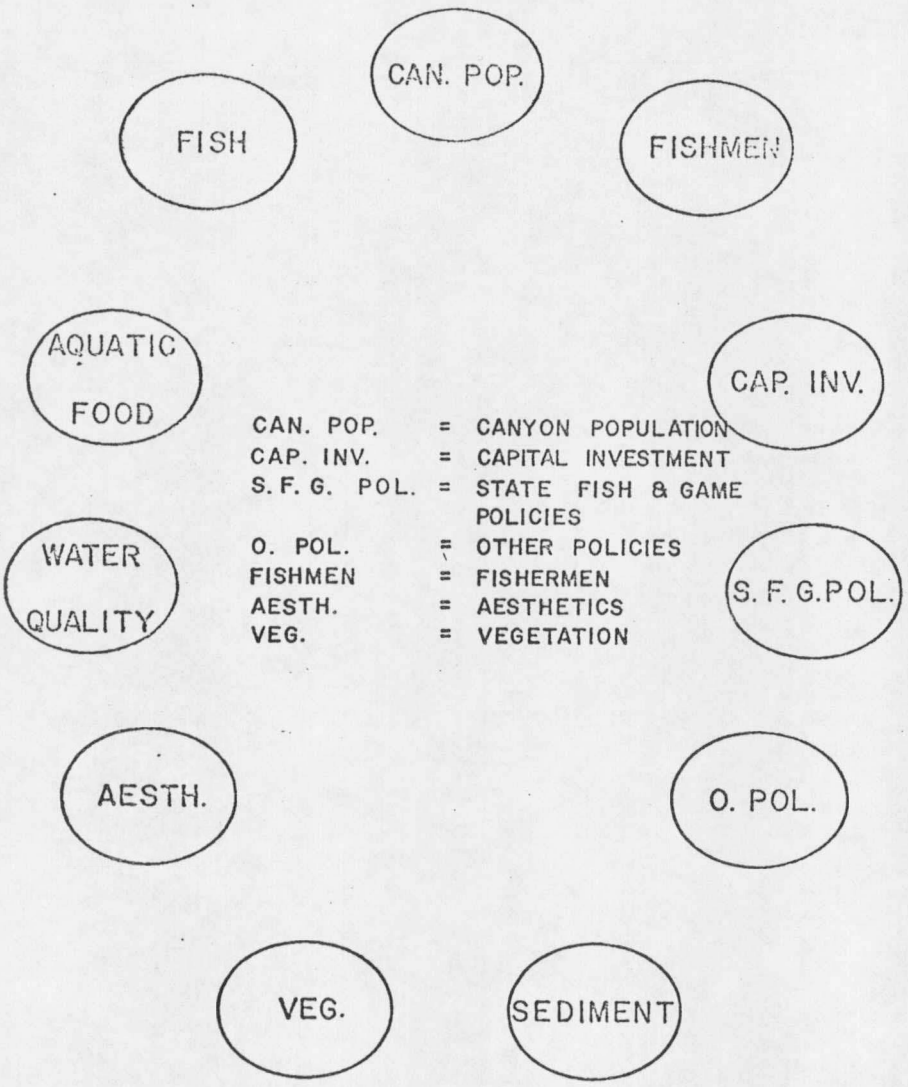


FIG. 36

MAN-NATURE

FISHING SYSTEM

USING SYSTEM DYNAMICS

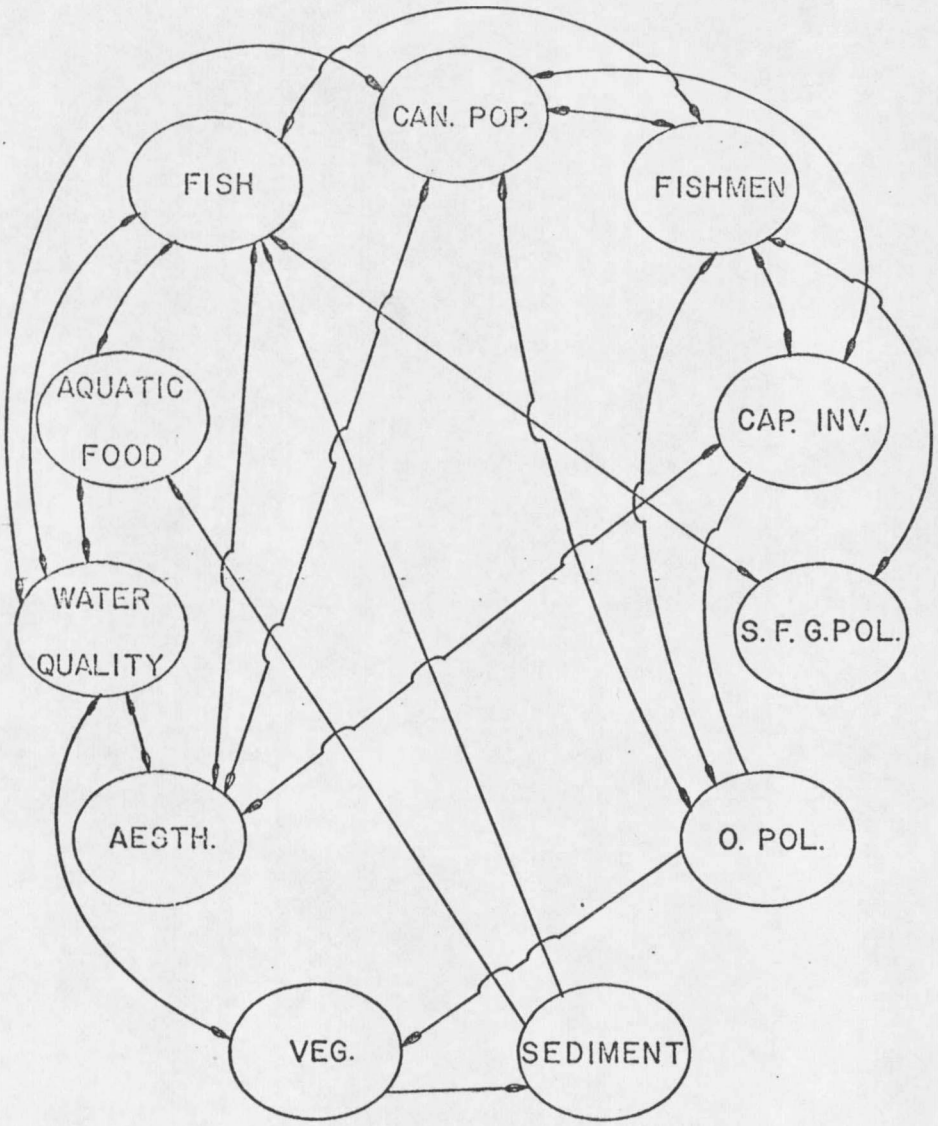


FIG. 37

MAN-NATURE

FISHING SYSTEM

USING SYSTEM DYNAMICS

APPENDIX B

MATRIX DEVELOPMENT

Luna B. Leopold (24) developed an impact matrix to determine the critical elements being affected by man's actions. Another important step in Leopold's matrix was to generate numerous alternatives and then use the matrix to determine the best alternative with respect to impact on an area. This technique is valuable but one must question how complete it is. It might be that this technique also falls into the trap of looking only at direct first-stage reactions to man's proposed action. The proposed matrix represents three additional areas of impact besides the man-nature impact. These three additional areas are nature-nature, man-man, and nature-man impacts. The matrix is structured as illustrated in Figures 38 and 39, pages 119 and 120. All elements and characteristics of man and nature are used on both axes. The matrix relationships are evaluated, as Leopold has suggested, accounting for both their magnitude and importance. Another factor could possibly be added by also setting down the classes of flow relations that exist. Following Figure 39 is a list of characteristics and elements used in both axes. This list needs to be condensed if it is to be used effectively as a tool for system dynamics. However, all listed elements have some significant effects on any ecosystem. Working with so many elements is very cumbersome, but also quite comprehensive.

MATRIX

IMPACT OF

	NATURE	MAN
NATURE	Natural Relationships: Nature's Impact on Nature	Man's impact on nature
MAN	Nature's Impact on Man: Aesthetics, or specifically, fish or elk required for fishing and hunting	Man's Impact on Man: The multiplier effect, or man's social and psychological action related to man's original action

FIG. 38

ENVIRONMENTAL IMPACT MATRIX

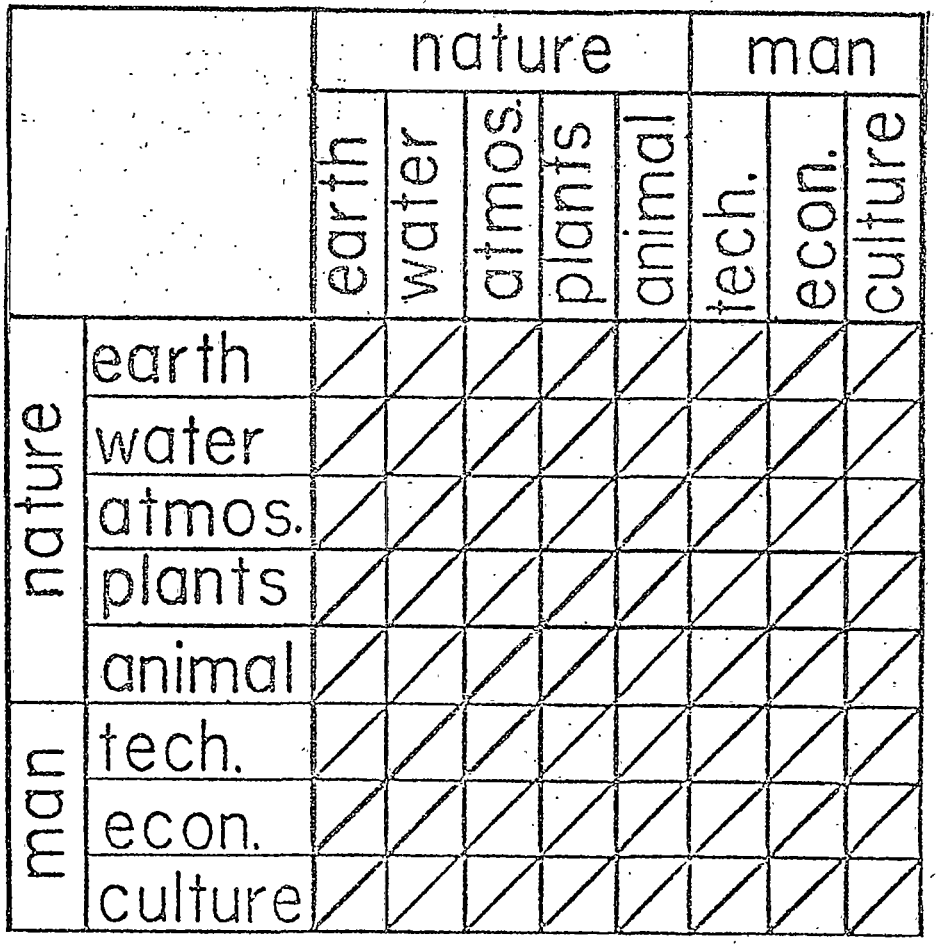


FIG. 39

The matrix is a valuable tool and could be developed with further research.

Another "environmental matrix" was developed in To Live On Earth (copyright 1972 by The John Hopkins University Press). This particular matrix is very comprehensive with regard to environmental problems and the possible human controls or solutions available to solve these problems. The next step in using the matrix is to develop a system dynamics model reflecting the problems, their importance, and the possible solutions suggested by this comprehensive matrix. The dynamic system model could reflect the end result of the matrix's apparent solutions to the environmental problems, but under dynamic conditions which the matrix cannot automatically reflect. The system dynamics has another advantage in being able to simulate the proposed control action and testing its effectiveness by model performance. The matrix can be used as a valuable tool to develop a system dynamics model.

Suggested List of Elements to be Considered
in Any Environmental Impact Matrix

NATURE

I. Earth

A. Geology

1. structure
2. rock type
3. surficial processes
4. porosity

I. A. 5. permeability
6. slope
7. slope aspect
8. N-S valley
9. E-W valley
10. elevation

B. Soils

1. minerals
2. nutrients
3. compaction
4. horizons
5. horizons depth
6. horizon color
7. clay
8. silt
9. loam
10. gravel
11. stones
12. bedrock
13. PH
14. depth of free lime
15. soluable salt
16. soil temperature
17. soil H_2O content
18. percolation rate
19. liquid limit
20. plastic limit
21. erosion potential index
22. oxygen soil states

II. Water

A. Surface Water Quantity

1. peak volume
2. low volume
3. channel
4. water rights

B. Surface Water Quality

1. chemical
2. biological
3. turbidity

II. B. 4. temperature
5. depth
6. velocity
7. bedding
8. PO_4
9. channel
10. vegetation

C. 1. level
2. peak level
3. low level

D. Ground Water Quality

1. chemical
2. biological
3. PO_4
4. flow level
5. flow direction

III. Atmosphere

A. Air Quality

1. gaseous composition
2. large ions
3. large particulates
4. oxyeous nitrates
5. sulfur oxides

B. Climate (Macro, Micro)

1. precipitation
2. temperature
3. wind direction
4. wind velocity
5. humidity
6. solar radiation
7. temperature strata

IV. Plants

A. Large Plants and Trees

1. number of species
2. percentage ground covered

IV. A. 3. percentage wilderness covered
4. quality
5. diseases
6. growth rate

B. Small Plants

1. amount filamentous algae
2. number special
3. percentage fungus cover
4. percentage algae cover

C. Bacteria

1. number types
2. amount

V. Animals

A. Mammals

1. number species
2. amount
3. amount elk
4. life style

B. Fish

1. number species
2. number species of sport fish
3. population sport fish
4. average size sport fish
5. population scavengers

C. Birds

1. number species
2. population

D. Medium Animals

1. number species
2. number bothersome species

MAN

I. Technological Man

A. Structures

1. wells
2. distance to surface water
3. number fireplaces
4. number structures
5. number road structures
6. structure density
7. number structures in wilderness
8. number septic tanks
9. number structures of primary sewage treatment
10. number structures of secondary sewage treatment
11. number structures of tertiary sewage treatment
12. heating source

B. Industry and Processes

1. timbering
2. ranching
3. farming
4. lumber mills

II. Economic Man

A. Land Use

1. wilderness
2. forestry
3. grazing
4. residential
5. commercial
6. private
7. public

B. Activities

1. education
2. church
3. playground
4. utilities
5. liquor store
6. grocery store

II. B. 7. auto store
8. sporting goods
9. motels
10. construction
11. hunting
12. fishing
13. skiing
14. picnicing
15. sight seeing
16. shopping
17. snowmobiling

C. Traffic

1. going to and from West Yellowstone
2. going to and from Bozeman
3. going to and from Ennis
4. commercial to and from West Yellowstone
5. commercial to and from Bozeman
6. commercial to and from Ennis
7. air travel
8. trails
9. back roads

III. Cultural Man

A. Human Interest

1. parks
2. monuments
3. uniqueness

B. Sociology

1. population
2. number tourists
3. average income
4. health
5. safety
6. employment
7. employers

III. C. Political

1. clubs
2. leadership
3. local government
4. state government
5. fish and game
6. forest service

APPENDIX C

FLOW CHARTS OF FISHING-ECOSYSTEM DYNAMICS

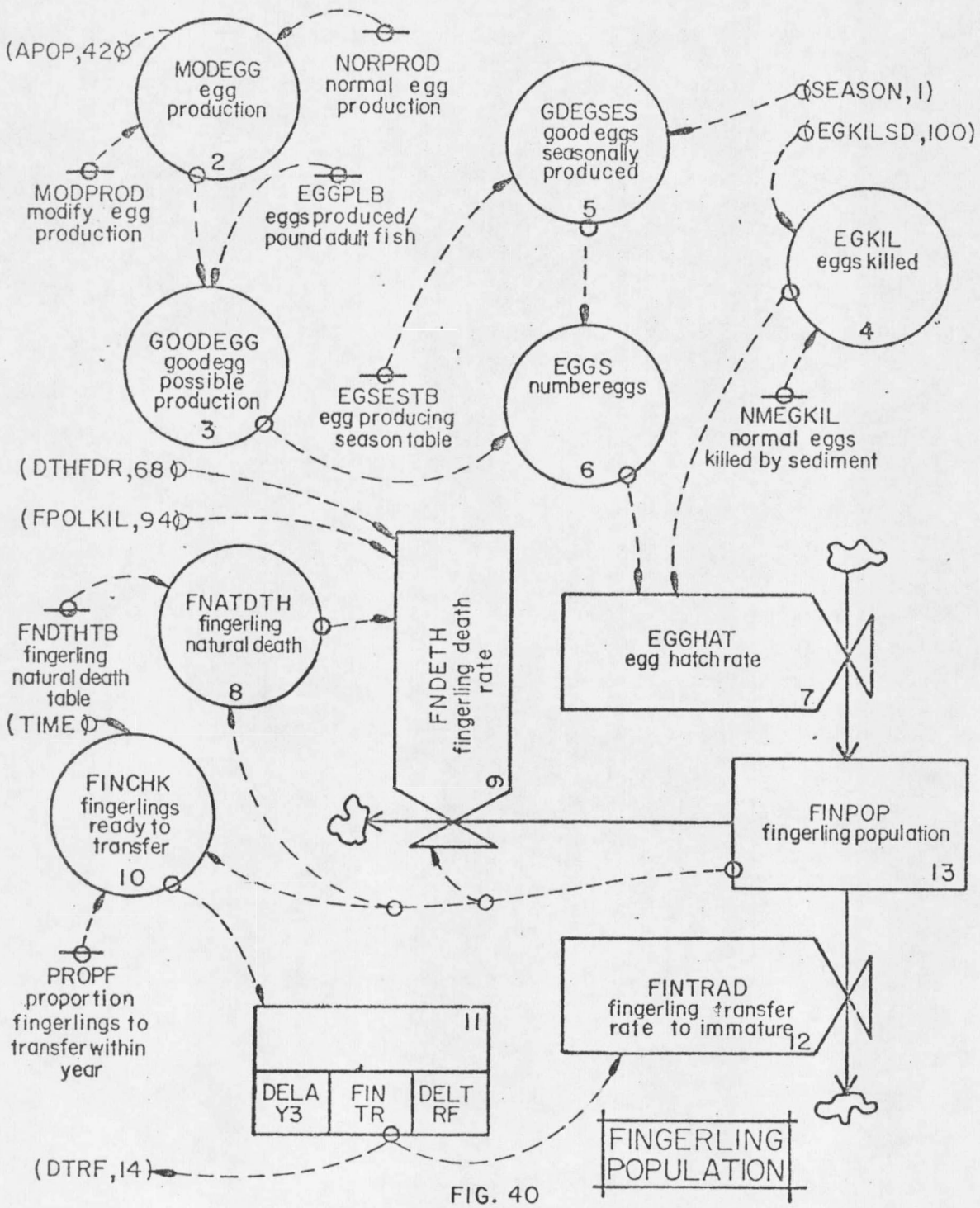

(APOP,42)
MODEGG
egg
production
2
NORPROD
normal egg
production
MODPROD
modify egg
production
EGGPLB
eggs produced/
pound adult fish
GDEGSES
good eggs
seasonally
produced
5
(SEASON,1)
(EGKILSD,100)
EGKIL
eggs killed
4
GOODEGG
good egg
possible
production
3
EGSESTB
egg producing
season table
EGGS
number eggs
6
NMEGKIL
normal eggs
killed by sediment
(DTHFDR,68)
(FPOLKIL,94)
FNATDTH
fingerling
natural death
8
FNDTHTB
fingerling
natural death
table
FNDETH
fingerling death
rate
9
EGGHAT
egg hatch rate
7
(TIME)
FINCHK
fingerlings
ready to
transfer
10
FINPOP
fingerling population
13
PROPF
proportion
fingerlings to
transfer within
year
11
DELA
Y3
FIN
TR
DELT
RF
FINTRAD
fingerling transfer
rate to immature
12
(DTRF,14)
FINGERLING
POPULATION

FIG. 40

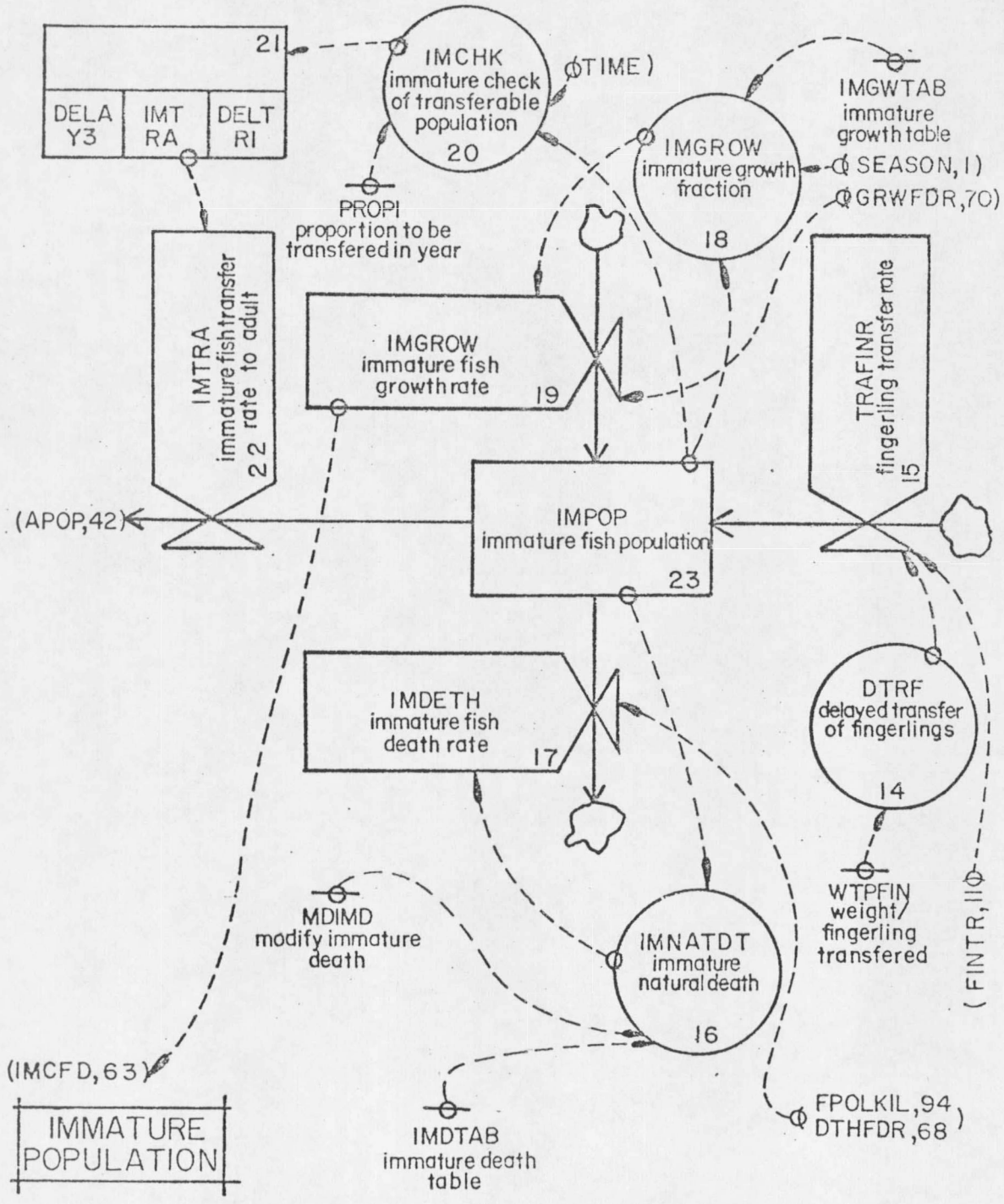

21
DELA Y3
IMT RA
DELT RI
IMCHK immature check of transferable population 20
ΦTIME)
PROPI proportion to be transfered in year
IMGROW immature growth fraction 18
IMGWTAB immature growth table
ΦSEASON,1)
ΦGRWFDR,70)
IMTRA immature fish transfer 22 rate to adult
IMGROW immature fish growth rate 19
TRAFINR fingerling transfer rate 15
(APOP,42)
IMPOP immature fish population 23
IMDETH immature fish death rate 17
DTRF delayed transfer of fingerlings 14
WTPFIN weight/ fingerling transfered
(FINTR,11Φ
MDIMD modify immature death
IMNATDT immature natural death 16
(IMCFD,63)
IMMATURE POPULATION
IMDTAB immature death table
FPOLKIL,94
DTHFDR,68)

FIG. 41

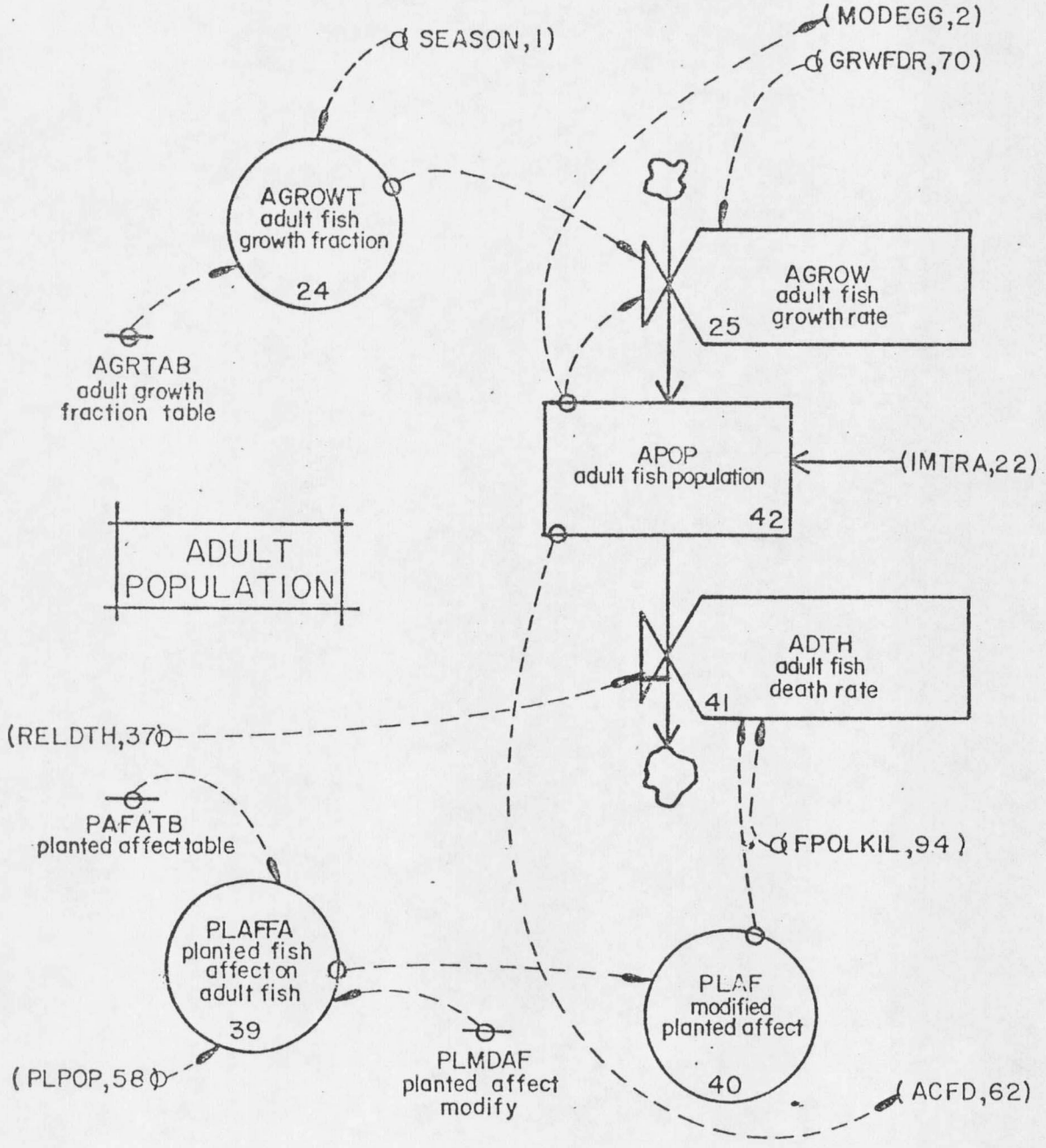

(SEASON, 1)
(MODEGG, 2)
(GRWFDR, 70)
AGROWT
adult fish
growth fraction
24
AGROW
adult fish
growth rate
25
AGRTAB
adult growth
fraction table
APOP
adult fish population
42
(IMTRA, 22)
ADULT
POPULATION
ADTH
adult fish
death rate
41
(RELDTH, 37)
PAFATB
planted affect table
(FPOLKIL, 94)
PLAFFA
planted fish
affect on
adult fish
39
PLAF
modified
planted affect
40
(PLPOP, 58)
PLMDAF
planted affect
modify
(ACFD, 62)

FIG. 42

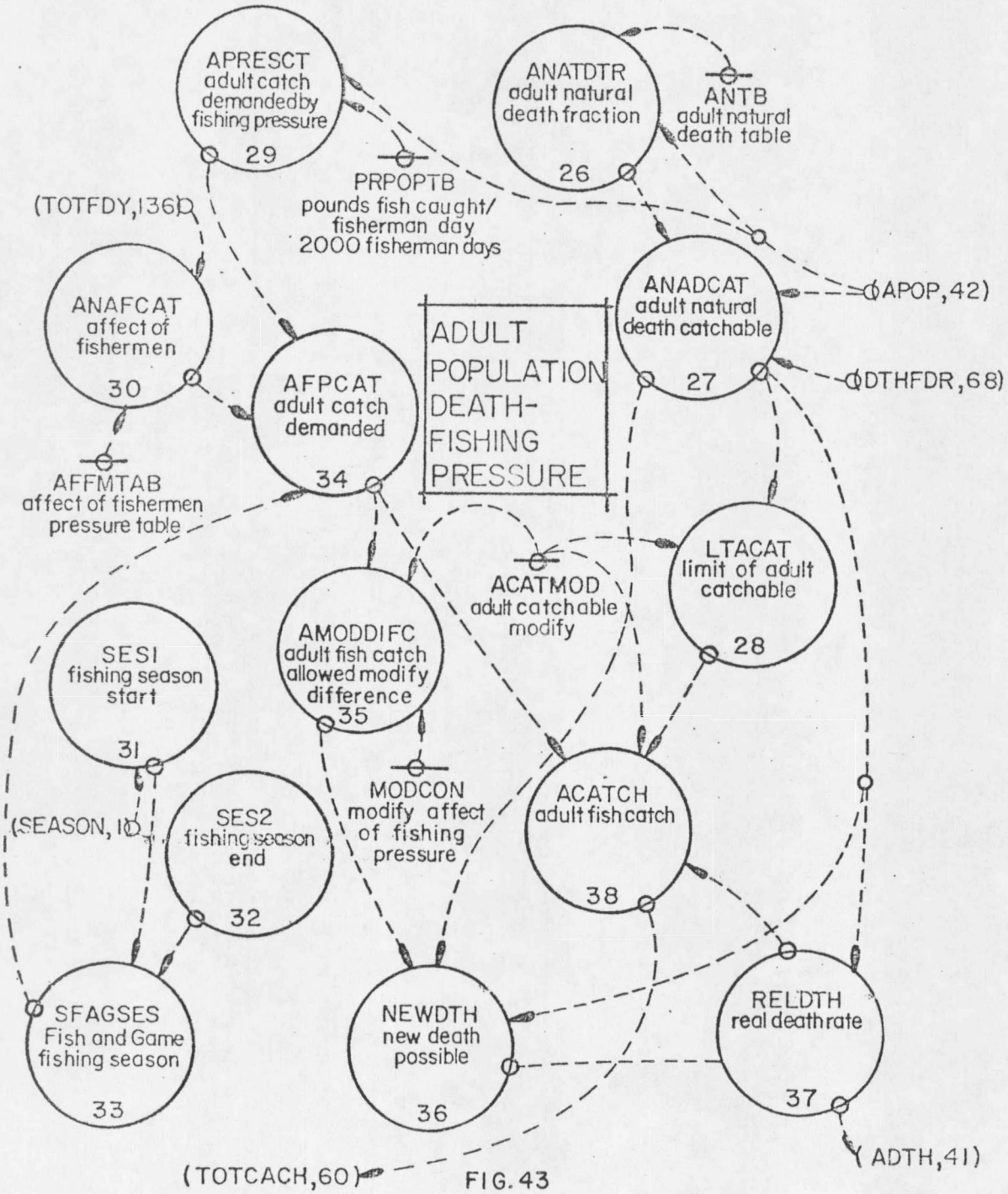

APRESCT
adult catch
demanded by
fishing pressure
29
ANATDTR
adult natural
death fraction
26
ANTB
adult natural
death table
PRPOPTB
pounds fish caught/
fisherman day
2000 fisherman days
(TOTFDY,136)
ANAFCAT
affect of
fishermen
30
ANADCAT
adult natural
death catchable
27
(APOP,42)
(DTHFDR,68)
ADULT
POPULATION
DEATH-
FISHING
PRESSURE
AFPCAT
adult catch
demanded
34
AFFMTAB
affect of fishermen
pressure table
ACATMOD
adult catchable
modify
LTACAT
limit of adult
catchable
28
AMODDIFC
adult fish catch
allowed modify
difference
35
SESI
fishing season
start
31
MODCON
modify affect
of fishing
pressure
ACATCH
adult fish catch
38
(SEASON,1)
SES2
fishing season
end
32
SFAGSES
Fish and Game
fishing season
33
NEWDTH
new death
possible
36
RELDTH
real death rate
37
(ADTH,41)
(TOTCACH,60)

FIG. 43

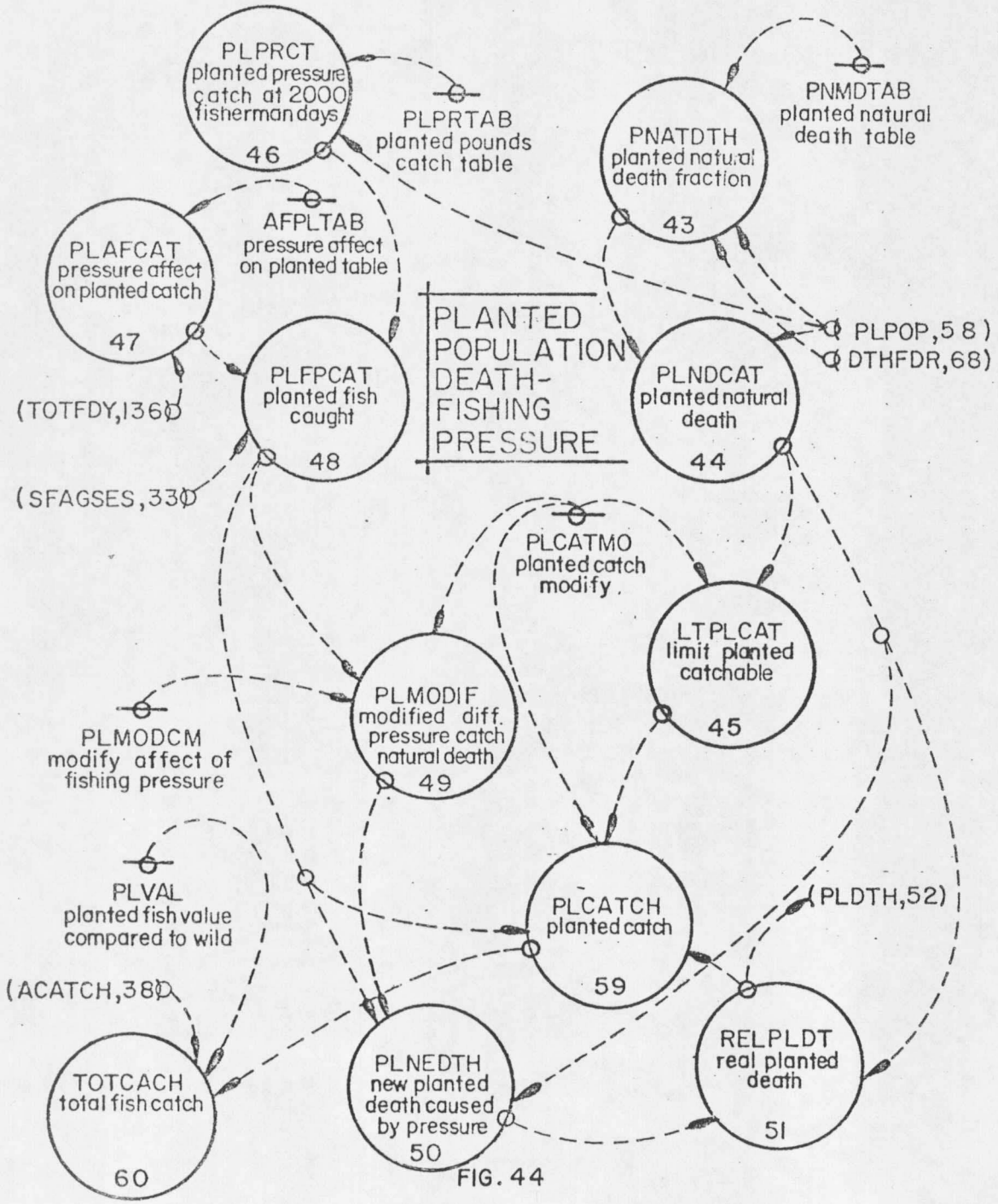

PLPRCT
planted pressure catch at 2000 fisherman days
46
PLPRTAB
planted pounds catch table
PNATDTH
planted natural death fraction
43
PNMDTAB
planted natural death table
AFPLTAB
pressure affect on planted table
PLAFCAT
pressure affect on planted catch
47
PLANTED POPULATION DEATH-FISHING PRESSURE
PLPOP,58)
DTHFDR,68)
(TOTFDY,136)
PLFPCAT
planted fish caught
48
PLNDCAT
planted natural death
44
(SFAGSES,33)
PLCATMO
planted catch modify
LTPLCAT
limit planted catchable
45
PLMODIF
modified diff. pressure catch natural death
49
PLMODCM
modify affect of fishing pressure
PLVAL
planted fish value compared to wild
(ACATCH,38)
PLCATCH
planted catch
59
(PLDTH,52)
TOTCACH
total fish catch
60
PLNEDTH
new planted death caused by pressure
50
RELPLDT
real planted death
51

FIG. 44

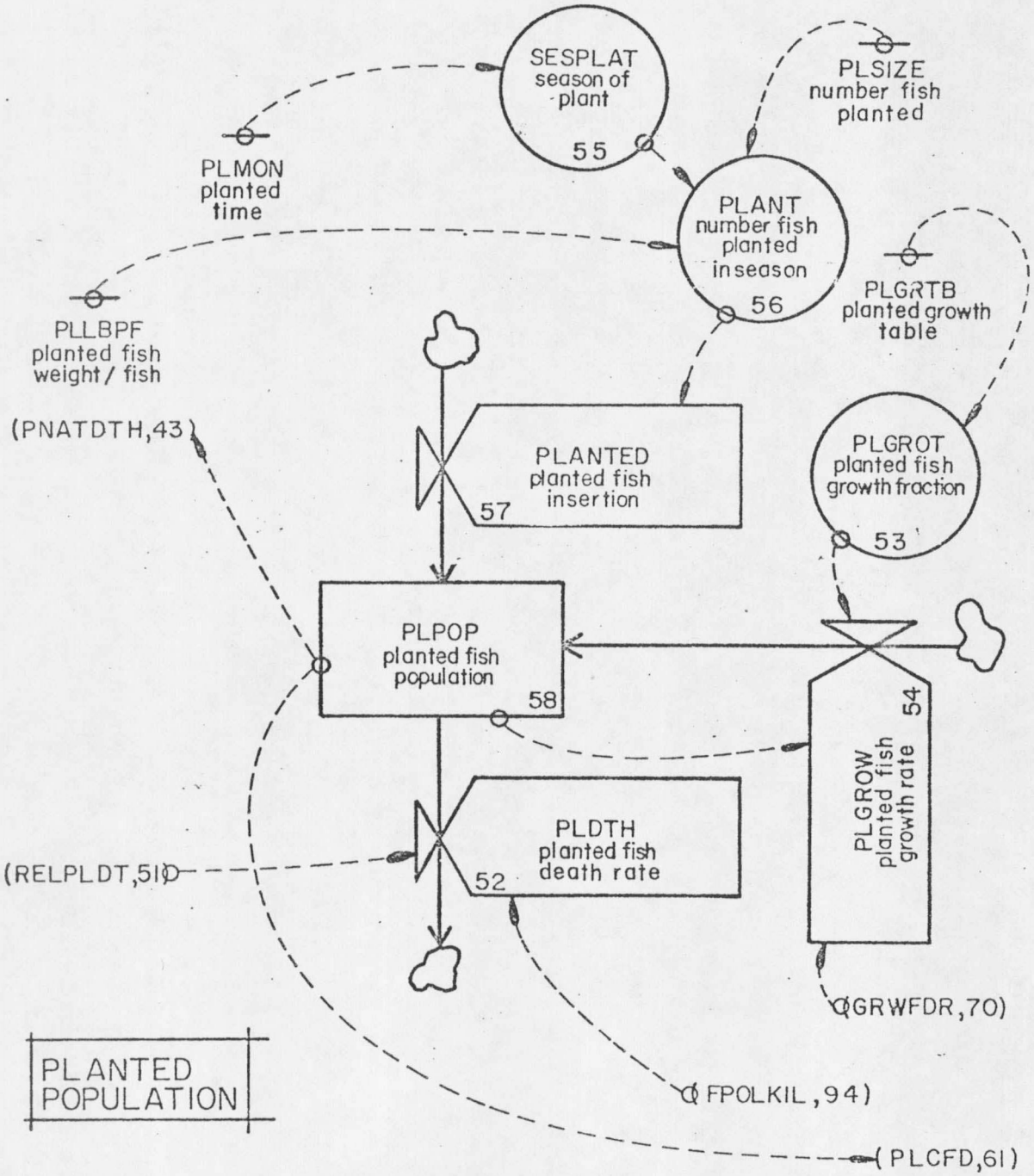

SESPLAT
season of plant
55
PLSIZE
number fish planted
PLMON
planted time
PLANT
number fish planted inseason
56
PLGRTB
planted growth table
PLLBPF
planted fish weight / fish
(PNATDTH,43)
PLANTED
planted fish insertion
57
PLGROT
planted fish growth fraction
53
PLPOP
planted fish population
58
54
PLGROW
planted fish growth rate
PLDTH
planted fish death rate
52
(RELPLDT,51)
(GRWFDR,70)
(FPOLKIL,94)
(PLCFD,61)
PLANTED POPULATION

FIG. 45

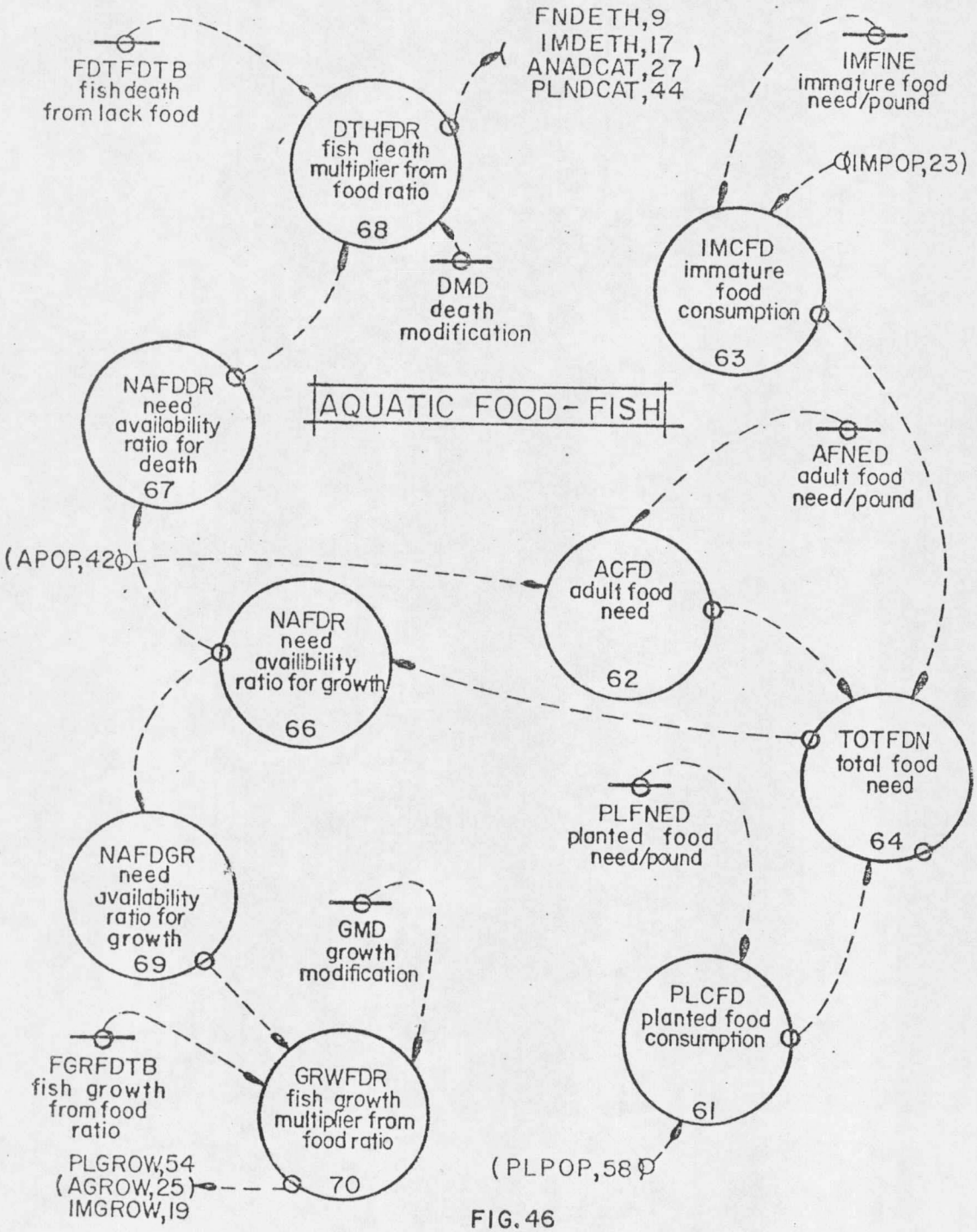

FDTFDTB
fish death
from lack food
FNDETH,9
IMDETH,17
ANADCAT,27
PLNDCAT,44
DTHFDR
fish death
multiplier from
food ratio
68
DMD
death
modification
IMFINE
immature food
need/pound
(IMPOP,23)
IMCFD
immature
food
consumption
63
NAFDDR
need
availability
ratio for
death
67
AQUATIC FOOD-FISH
AFNED
adult food
need/pound
(APOP,42)
ACFD
adult food
need
62
NAFDR
need
availibility
ratio for growth
66
TOTFDN
total food
need
64
PLFNED
planted food
need/pound
NAFDGR
need
availability
ratio for
growth
69
GMD
growth
modification
PLCFD
planted food
consumption
61
FGRFDTB
fish growth
from food
ratio
GRWFDR
fish growth
multiplier from
food ratio
70
PLGROW,54
(AGROW,25)
IMGROW,19
(PLPOP,58)

FIG. 46

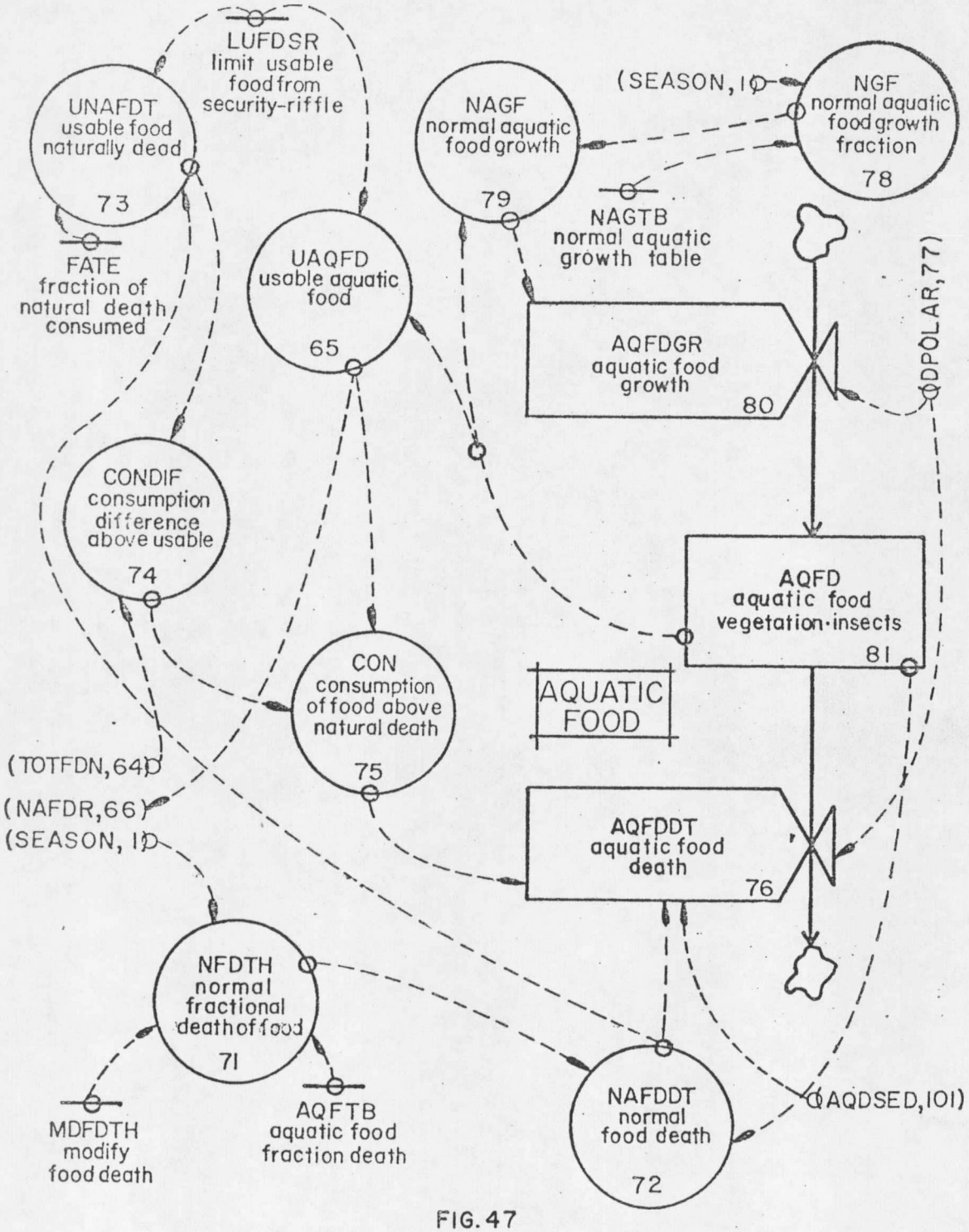

LUFDSR
limit usable
food from
security-riffle
UNAFDT
usable food
naturally dead
73
FATE
fraction of
natural death
consumed
UAQFD
usable aquatic
food
65
NAGF
normal aquatic
food growth
79
(SEASON,1)
NGF
normal aquatic
food growth
fraction
78
NAGTB
normal aquatic
growth table
AQFDGR
aquatic food
growth
80
(DPOLAR,77)
CONDIF
consumption
difference
above usable
74
AQFD
aquatic food
vegetation-insects
81
AQUATIC
FOOD
CON
consumption
of food above
natural death
75
(TOTFDN,64)
(NAFDR,66)
(SEASON,1)
AQFDDT
aquatic food
death
76
NFDTH
normal
fractional
death of food
71
MDFDTH
modify
food death
AQFTB
aquatic food
fraction death
NAFDDT
normal
food death
72
(AQDSED,101)

FIG. 47

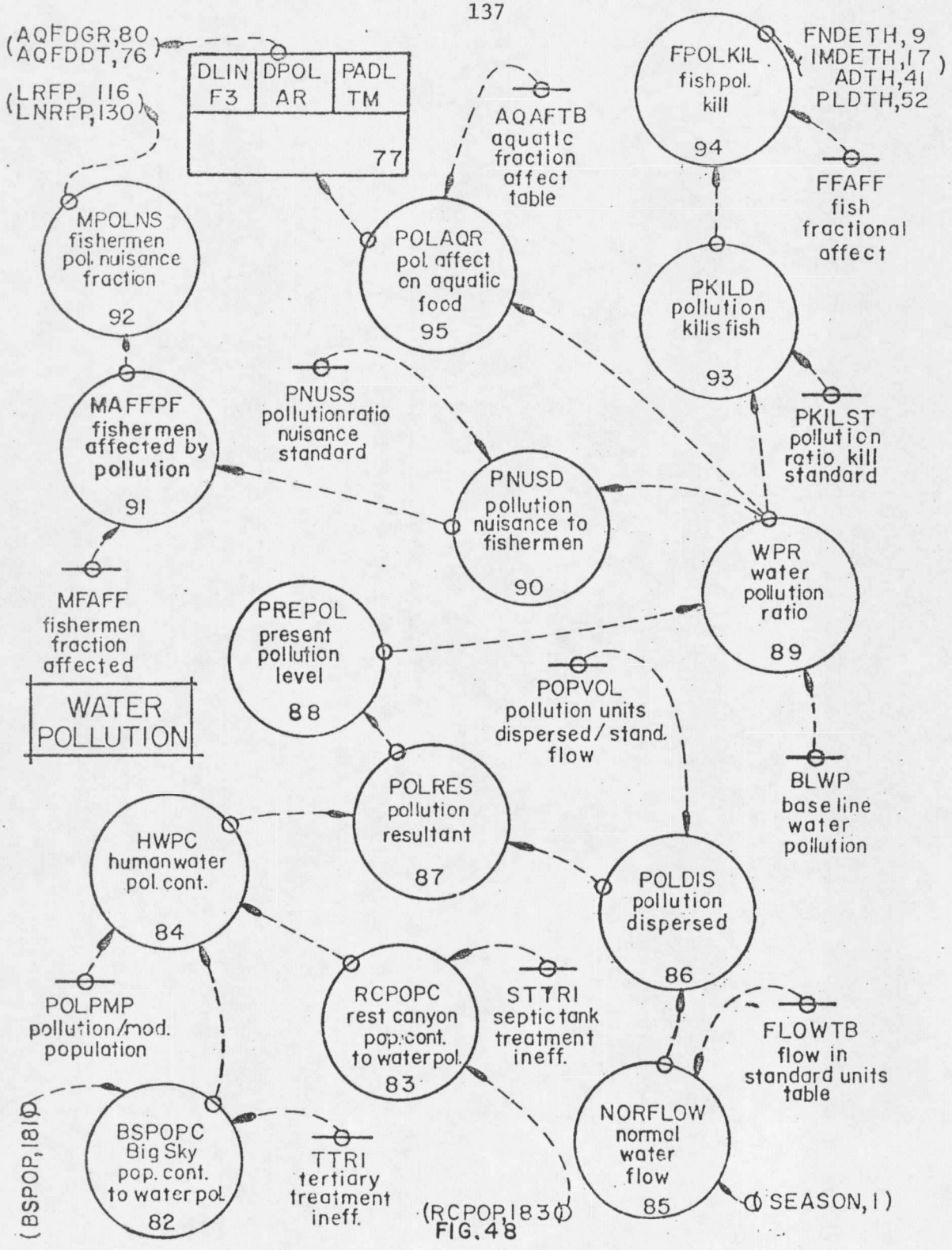

(AQFDGR,80 AQFDDT,76)
(LRFP, 116 LNRFP,130)
DLIN F3
DPOL AR
PADL TM
77
AQAFTB aquatic fraction affect table
FPOLKIL fish pol. kill 94
FNDETH, 9 IMDETH,17 ADTH,41 PLDTH,52
FFAFF fish fractional affect
MPOLNS fishermen pol. nuisance fraction 92
POLAQR pol. affect on aquatic food 95
PKILD pollution kills fish 93
PKILST pollution ratio kill standard
PNUSS pollution ratio nuisance standard
MAFFPF fishermen affected by pollution 91
PNUSD pollution nuisance to fishermen 90
WPR water pollution ratio 89
MFAFF fishermen fraction affected
PREPOL present pollution level 88
POPVOL pollution units dispersed / stand. flow
WATER POLLUTION
BLWP base line water pollution
POLRES pollution resultant 87
HWPC human water pol. cont. 84
POLDIS pollution dispersed 86
POLPMP pollution/mod. population
RCPOPC rest canyon pop. cont. to water pol. 83
STTRI septic tank treatment ineff.
FLOWTB flow in standard units table
(BSPOP,181)
BSPOPC Big Sky pop. cont. to water pol. 82
TTRI tertiary treatment ineff.
NORFLOW normal water flow 85
(SEASON,1)
(RCPOP,183)

FIG. 48

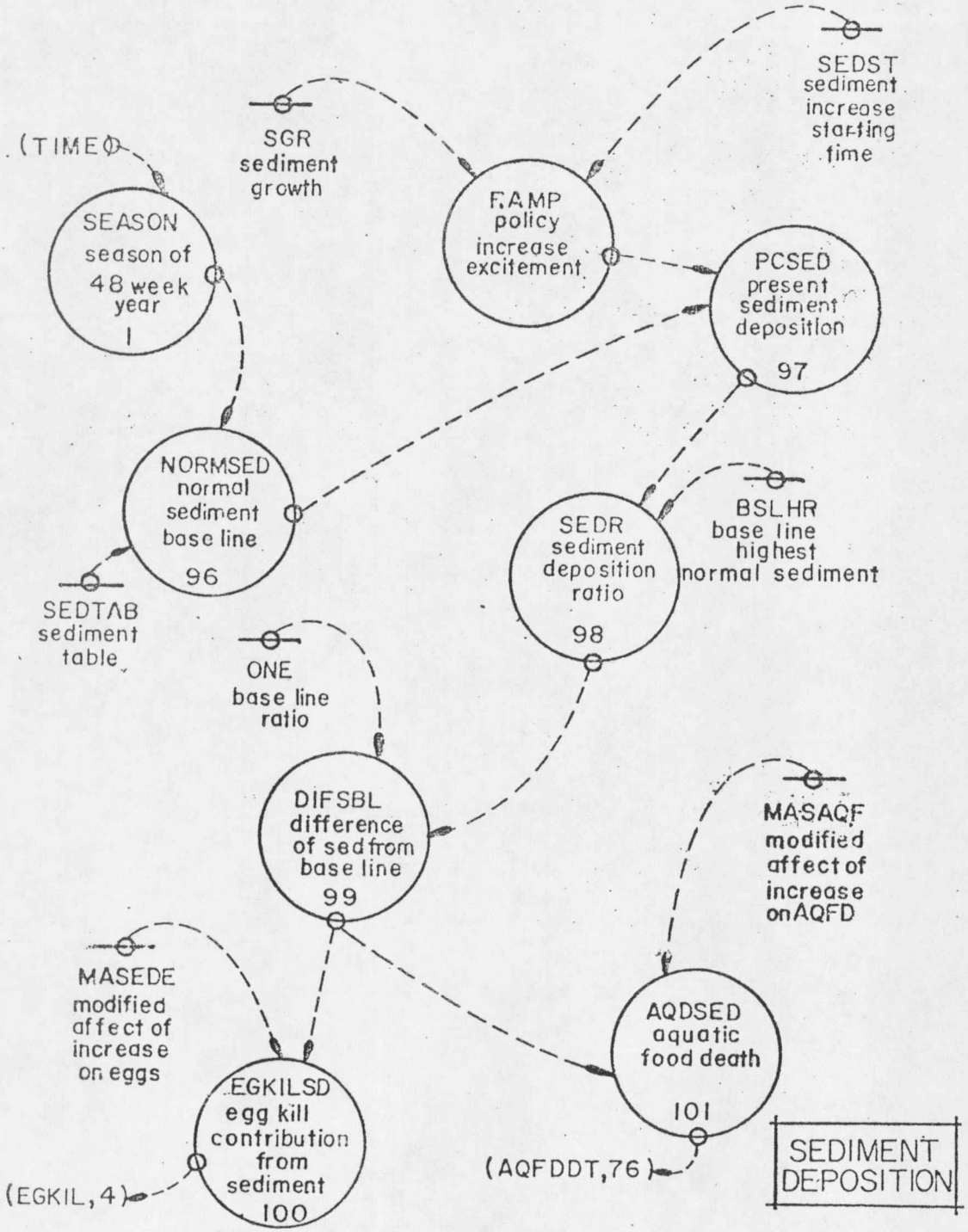

(TIME)
SEASON
season of 48 week year
1
SGR
sediment growth
FAMP
policy increase excitement
SEDST
sediment increase starting time
PCSED
present sediment deposition
97
NORMSED
normal sediment base line
96
SEDTAB
sediment table
SEDR
sediment deposition ratio
98
BSLHR
base line highest normal sediment
ONE
base line ratio
DIFSBL
difference of sed from base line
99
MASAQF
modified affect of increase on AQFD
MASEDE
modified affect of increase on eggs
AQDSED
aquatic food death
101
EGKILSD
egg kill contribution from sediment
100
(EGKIL,4)
(AQFDDT,76)
SEDIMENT DEPOSITION

FIG. 49

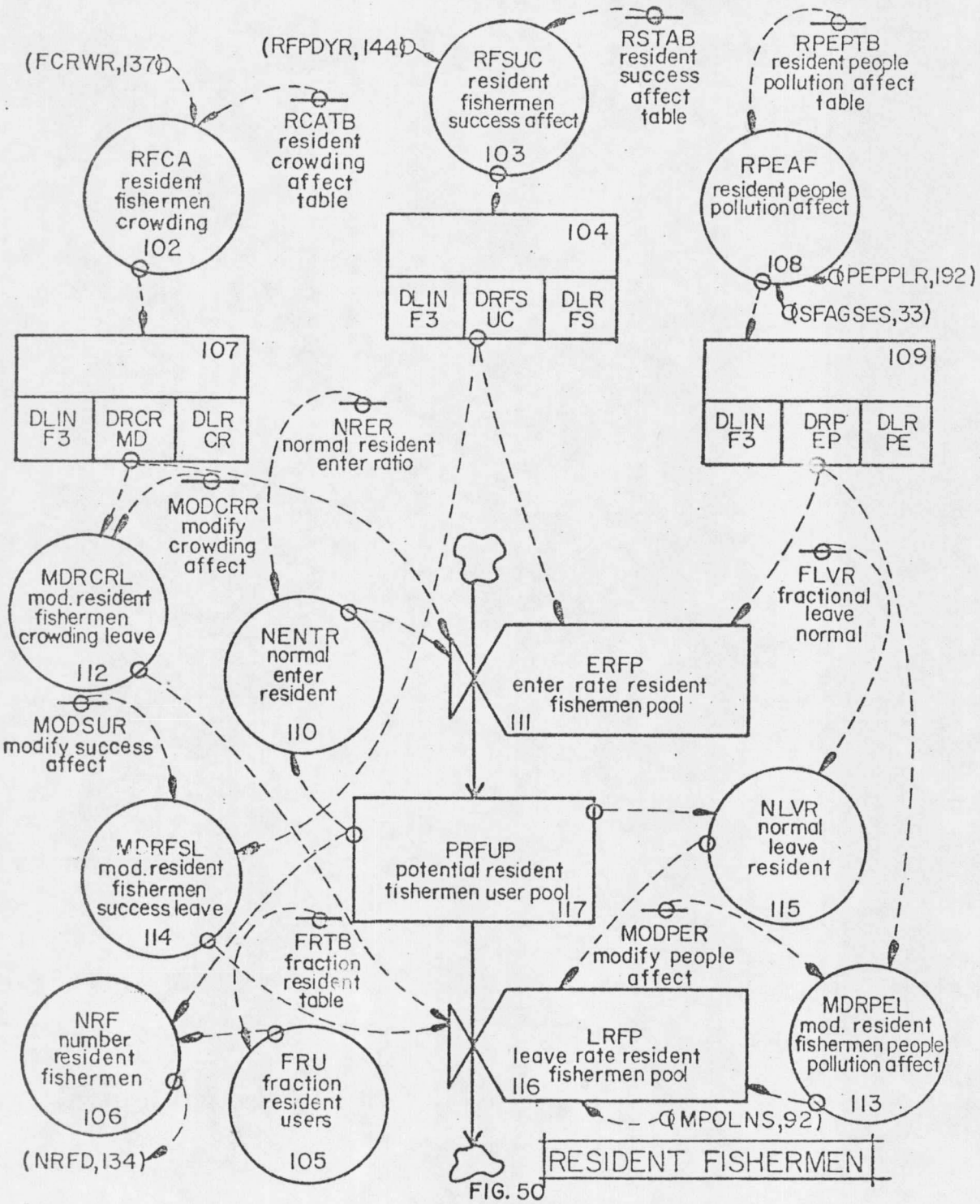

(FCRWR,137)
RFCA
resident
fishermen
crowding
102
RCATB
resident
crowding
affect
table
(RFPDYR,144)
RFSUC
resident
fishermen
success affect
103
RSTAB
resident
success
affect
table
RPEPTB
resident people
pollution affect
table
RPEAF
resident people
pollution affect
108
(PEPPLR,192)
(SFAGSES,33)
104
DLIN F3
DRFS UC
DLR FS
107
DLIN F3
DRCR MD
DLR CR
109
DLIN F3
DRP EP
DLR PE
NRER
normal resident
enter ratio
MODCRR
modify
crowding
affect
MDRCRL
mod. resident
fishermen
crowding leave
112
NENTR
normal
enter
resident
110
ERFP
enter rate resident
fishermen pool
111
FLVR
fractional
leave
normal
MODSUR
modify success
affect
MDRFSL
mod. resident
fishermen
success leave
114
PRFUP
potential resident
fishermen user pool
117
NLVR
normal
leave
resident
115
FRTB
fraction
resident
table
MODPER
modify people
affect
NRF
number
resident
fishermen
106
FRU
fraction
resident
users
105
LRFP
leave rate resident
fishermen pool
116
MDRPEL
mod. resident
fishermen people
pollution affect
113
(MPOLNS,92)
(NRFD,134)
RESIDENT FISHERMEN

FIG. 50

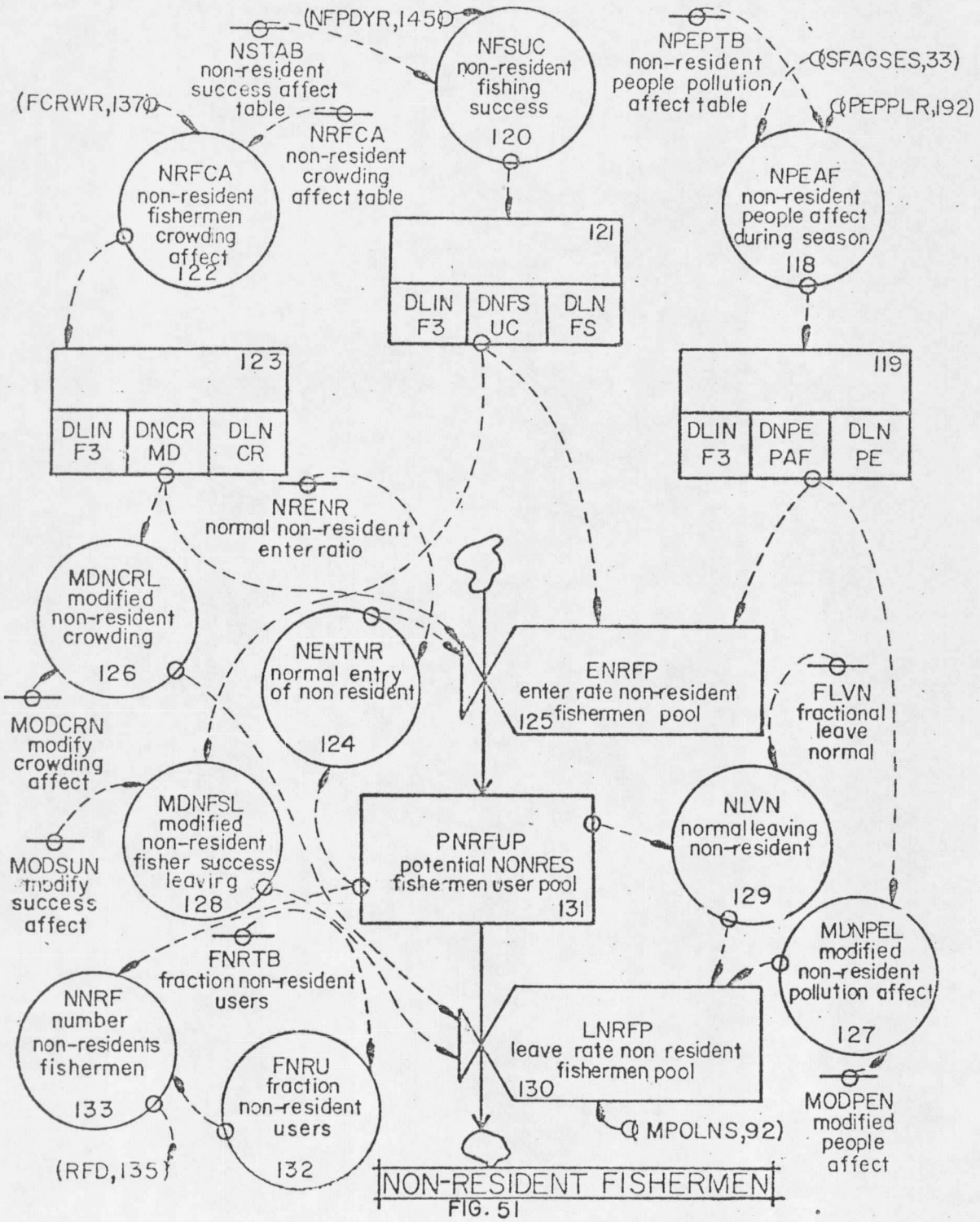

(NFPDYR,145)
NSTAB
non-resident
success affect
table
NFSUC
non-resident
fishing
success
120
NPEPTB
non-resident
people pollution
affect table
(SFAGSES,33)
(PEPPLR,192)
(FCRWR,137)
NRFCA
non-resident
crowding
affect table
NRFCA
non-resident
fishermen
crowding
affect
122
NPEAF
non-resident
people affect
during season
118
121
DLIN F3
DNFS UC
DLN FS
123
DLIN F3
DNCR MD
DLN CR
119
DLIN F3
DNPE PAF
DLN PE
NRENR
normal non-resident
enter ratio
MDNCRL
modified
non-resident
crowding
126
NENTNR
normal entry
of non resident
124
ENRFP
enter rate non-resident
125 fishermen pool
FLVN
fractional
leave
normal
MODCRN
modify
crowding
affect
MDNFSL
modified
non-resident
fisher success
leaving
128
PNRFUP
potential NONRES
fishermen user pool
131
NLVN
normal leaving
non-resident
129
MODSUN
modify
success
affect
FNRTB
fraction non-resident
users
MDNPEL
modified
non-resident
pollution affect
127
NNRF
number
non-residents
fishermen
133
LNRFP
leave rate non resident
fishermen pool
130
FNRU
fraction
non-resident
users
132
(MPOLNS,92)
MODPEN
modified
people
affect
(RFD,135)
NON-RESIDENT FISHERMEN

FIG. 51

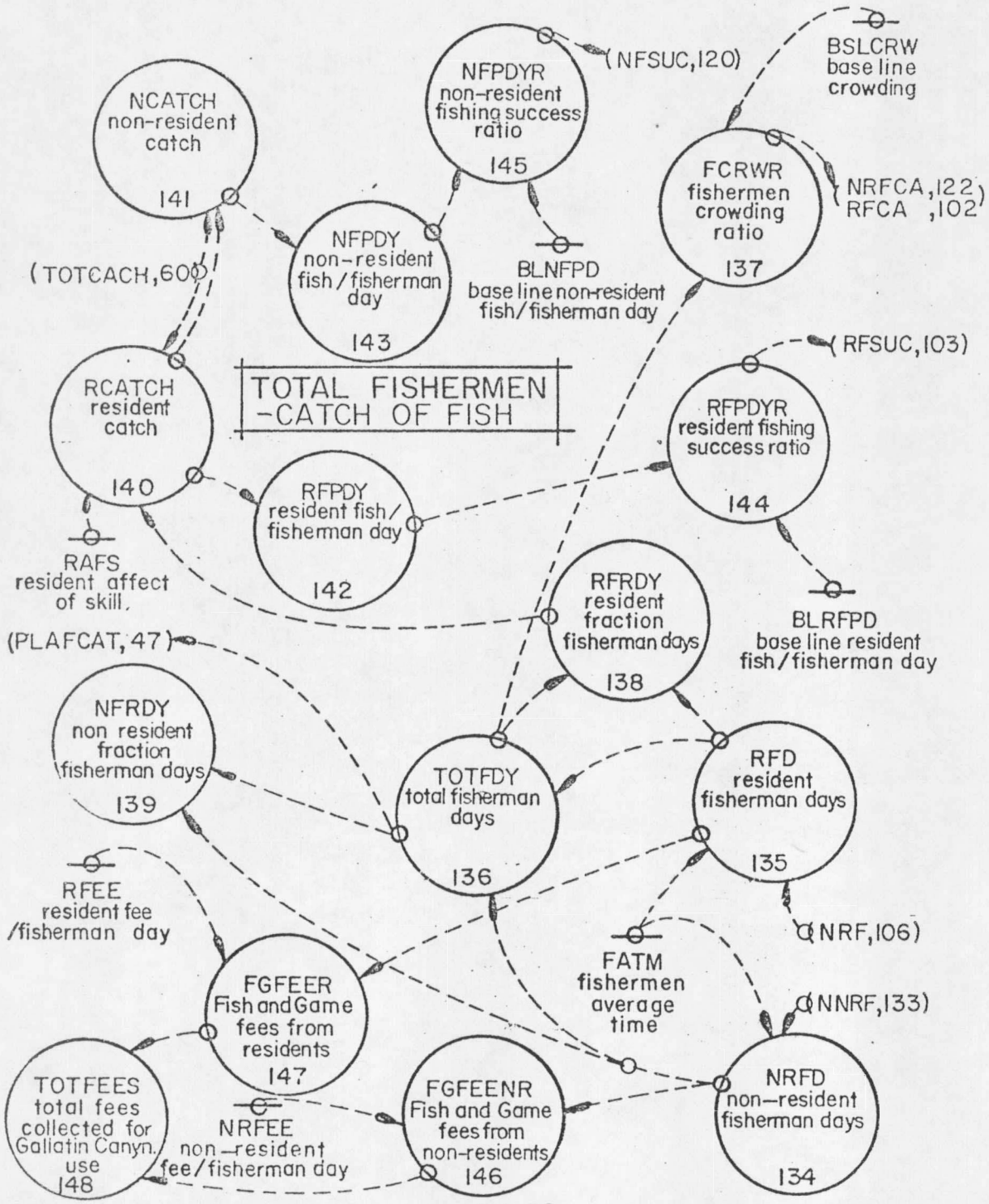

TOTAL FISHERMEN -CATCH OF FISH
NCATCH non-resident catch 141
NFPDYR non-resident fishing success ratio 145
(NFSUC,120)
BSLCRW base line crowding
FCRWR fishermen crowding ratio 137
(NRFCA,122) (RFCA ,102)
NFPDY non-resident fish/fisherman day 143
BLNFPD base line non-resident fish/fisherman day
(TOTCACH,60)
RCATCH resident catch 140
(RFSUC,103)
RFPDYR resident fishing success ratio 144
RFPDY resident fish/fisherman day 142
RAFS resident affect of skill
RFRDY resident fraction fisherman days 138
BLRFPD base line resident fish/fisherman day
(PLAFCAT,47)
NFRDY non resident fraction fisherman days 139
TOTFDY total fisherman days 136
RFD resident fisherman days 135
RFEE resident fee /fisherman day
(NRF,106)
FATM fishermen average time
(NNRF,133)
FGFEER Fish and Game fees from residents 147
TOTFEES total fees collected for Goliatin Canyn. use 148
NRFEE non-resident fee/fisherman day
FGFEENR Fish and Game fees from non-residents 146
NRFD non-resident fisherman days 134

FIG.52

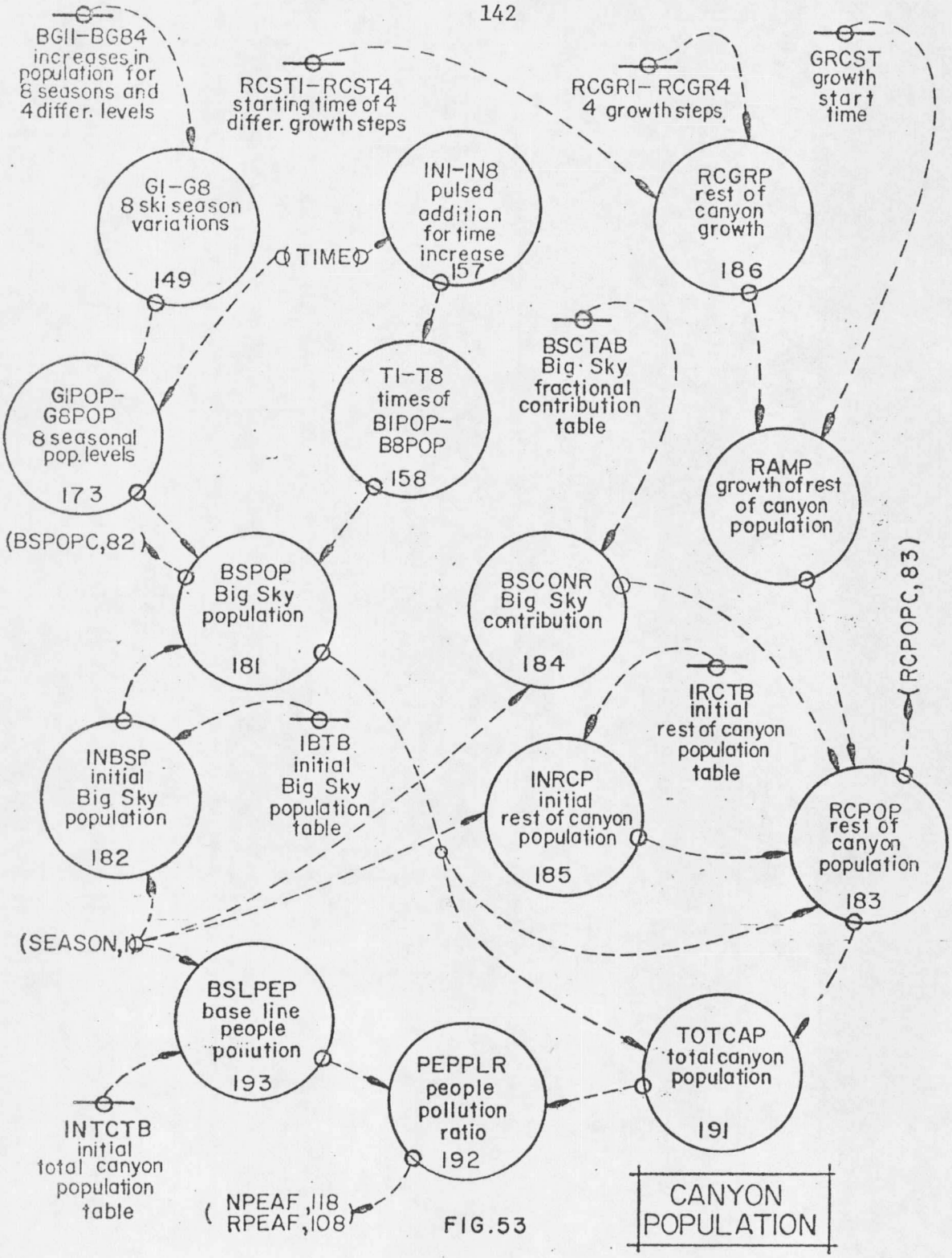

BGII-BG84 increases in population for 8 seasons and 4 differ. levels
RCSTI-RCST4 starting time of 4 differ. growth steps
RCGRI-RCGR4 4 growth steps.
GRCST growth start time
GI-G8 8 ski season variations 149
INI-IN8 pulsed addition for time increase 157
RCGRP rest of canyon growth 186
TIME
BSCTAB Big Sky fractional contribution table
GIPOP-G8POP 8 seasonal pop. levels 173
TI-T8 times of BIPOP-B8POP 158
RAMP growth of rest of canyon population
(BSPOPC,82)
BSPOP Big Sky population 181
BSCONR Big Sky contribution 184
(RCPOPC,83)
IRCTB initial rest of canyon population table
INBSP initial Big Sky population 182
IBTB initial Big Sky population table
INRCP initial rest of canyon population 185
RCPOP rest of canyon population 183
(SEASON,I)
BSLPEP base line people pollution 193
TOTCAP total canyon population 191
PEPPLR people pollution ratio 192
INTCTB initial total canyon population table
(NPEAF,118 RPEAF,108)
CANYON POPULATION

FIG.53

APPENDIX D

TECHNIQUES FOR MODELING PROBLEMS

Researchers analyzing and modeling almost any complex system, and specifically environmental systems, encounter seeming unknowns, unquantifiable items, and dimension problems. These problem areas stem from a lack of statistical data, of general information and of a technique which could provide solutions. These solutions must be found to adequately model and simulate the system's action in order to further our understanding of the system under study.

Unknowns are those relationships in the system that are believed to exist but whose magnitude is very unclear. Confronting unknowns often points out areas for further research necessary to provide at least some general information. Gathering information from experts will point out these areas and can often help the model builder or builders to determine the assumptions that are needed to solve this problem. Once the assumptions are made one can experiment with the model over their possible range of magnitudes. One must, however, try to find experts who are willing to give personal opinions; these opinions could help to solve the problem of not knowing how to represent an unknown in the model. An example of an unknown in this model is the relationship between sediment deposition and fish eggs. There is not enough information even to generate a professional opinion in regard to the

effect of doubling the sediment deposition in the Gallatin Canyon. Therefore, an assumption (constant or table) had to be made based on common sense. This assumption could then be experimented with to determine the most realistic effect or relationship.

Unquantifiable items are those relationships or abstract variables that are known to exist, but for which units of measurement have not been devised. Information must again be collected from experts who are willing to discuss the general structural makeup of the item and how it influences related items in the system. Assumptions (constants and tables) are then generated from these opinions. These assumptions can then be experimented with to determine the effect on the system. An unquantifiable item often occurs when numerous variables combine to make up an item, variables such as aesthetics or fisherman satisfaction. Ann Williams, sociologist, along with the sociology fisherman questionnaire, was consulted to determine factors affecting fisherman satisfaction. It seems the satisfaction that a fisherman derives from an area determines the fisherman's attitude and use of that area. It is also known that the aesthetics of the area, the number and size of fish caught, and the amount of crowding influences the fisherman's satisfaction.

A representation of fishermen's satisfaction was constructed in the following manner. Aesthetics is closely related to environmental degradation, which directly depends on the amount of use or "people

pollution" of the area. Number and size of fish caught will be reflected by the pounds of fish caught. The number of fishermen using the area at any one time will reflect the crowding in the area. How these factors are combined or how they mathematically influence related factors then becomes a problem in dimensions. All the factors that make up fisherman satisfaction are converted into a dimensionless ratio of present level over baseline level, which is then converted to a fractional effect based on a table function. The following illustrates this technique in relation to "people pollution," referring to the environmental degradation that an increase in Canyon population causes. The present level of total canyon population is divided by a baseline population constant which becomes the "people pollution" ratio. This ratio then becomes the variable which the fractional effect on fishermen is dependent on. Many dimensionless ratios and multipliers are used to relate different subsystems to dimensionally balance the system.

A unit measurement often used in this model to measure variables given in complicated and cumbersome dimensional units is referred to as standard units. Standard units were used in river flow, sediment deposition, and water pollution. The relative magnitude is used as a basis for determining the arbitrary standard unit. An example of this procedure is the process whereby river flow was calculated and then the smallest flow month, January, was used as the arbitrary standard unit, which is divided into all other monthly flow values to determine the

number of standard units of flow. This technique still maintains a proportional magnitudinal difference.

Another interesting procedure was the development of the systems representation of an effect that depends on two different factors, as in this model the amount of fish caught depends on both the fish population and the fishing pressure. The technique was to develop in the model an effect dependent on one variable, in this case fish population, while holding the other variable, fishing pressure, constant. Then as fishing pressure changed from this constant level, it determined a modifying multiplier. The original effect and the modifying multiplier was then multiplied to get the resulting effect.

These are some suggested techniques used to solve the above problems encountered in this model.

APPENDIX E

SUGGESTED TECHNIQUES FOR RUNNING A SYSTEMS DYNAMICS MODEL

The ability to program in the Dynamo II language comes with experience. It is first necessary to acquire a basic understanding of Forrester's systems dynamics principles, available in Principles of Systems (Forrester, 16). The ability to flow-chart is also needed to adequately model a system using this technique. At first, the Dynamo language seems rigid compared to extended Fortran, but it becomes more flexible with use. This language can easily be learned with little previous programming experience.

If a complex system is undertaken with multiple subsystems, it is necessary to logically divide the system into individual subsystems or groups of subsystems. Experience indicates that each subsystem or group of subsystems should be comprised of approximately 90 to 120 equations to give an idea of its size. These subdivisions are to be programmed as individual disc files and then run individually with contant influence from outside the system's subdivision. This is accomplished by using an initial equation (N) for all values that must be included for the influential variables from other subsystems. They, however, should be deleted from the completed and finished program. Each subdivision should be built on a file and edited with the UTS edit subsystem which enables fast editing of the errors that are listed

by Dynamo. These individual subdivisions should be run by themselves until operating problems are worked out and the system acts approximately as it should with constant outside influence.

The length of the run or number of simulation periods should be only as long as is necessary to determine if the system is behaving in a logical manner. In this model, ninety-six week-long periods were simulated, representing two years. A significant increase in cost occurs as the runs get longer. It is also important to select the greatest DT (change in time) to prevent unnecessary costs. DT depends on the shortest delay in the system and should be between half and a quarter of the delay time (Forrester, 6:6-10). Many of the assumptions (constants and tables) about magnitude are dependent on DT.

The subdivisions are then combined by merging the disc files, making minor corrections for the first control card and then editing the print, plot, and spec cards to fit the newly combined program. This type of building and merging is done until a complete model or program is constructed. A concentrated effort should be made to balance the whole completed model and not its subdivisions. Balancing the model can be done by determing the variable that is causing problems and then experimenting with the model by changing the assumptions (constants and tables). This experimentation should be done systematically to effectively use each run. In this model it was found that aquatic food would not balance and, therefore, numerous assumptions were experimented

with. It was found that aquatic food growth was a very sensitive control on aquatic food. This factor (MDFDTH) was then used to balance the system.

The Fortran Program that is generated by the Dynamo Compiler can be used to help solve problems, too. One mistake that neither Dynamo nor Fortran will recognize as an error is the multiplication of a function times another variable, as for example: Table (IMDTAB, IMPOP.K,0,2500,250)MDIMD. Leaving out the multiplication sign (*) between the function and MDIMD will not be recognized as an error, and yet it will distort the table and any related variables.

Many more functions remain to be used for the first time at the Montana State University Computer Center and, therefore, not all of the operating problems have been worked out yet. One that does exist is a problem with the function SAMPLE which can be corrected by the computer center personnel. Other functions may have similar problems.

It seems that the use of time-dependent functions like switch, pulse, and step, in conjunction with other equations, must be generated at the time period immediately previous to the one under calculation. In this model, fish were to be planted in the river the twenty-eighth week of the season and, therefore, the number twenty-seven had to be used. Similar problems, at this point unaccountable, occurred in the canyon population subsystem.

Dynamo II is an easy and versatile simulation language to use once an ability to use it has been acquired. Almost anything can be simulated using systems dynamics. It can easily simulate traffic, populations, and numerous other simple areas of application. However, this technique's value lies in the simulation of complex systems to improve our understanding of them.

The facilities are available on the Montana State University computer, which has the potential to assist researchers in every discipline.

APPENDIX F

LISTING OF THE FISHING-ECOSYSTEM DYNAMO PROGRAM

```
*    FISH DYNAMO
NOTE SEASONAL VARIATIONS ARE BASED ON A 48 WEEK YEAR
L SEASON.K=SEASON.J+DT*PULSE(=48,47,48)                                    1
N SEASON=0                                                                 1.1
NOTE
NOTE
NOTE
NOTE
NOTE  FINGERLING POPULATION
NOTE
NOTE
NOTE
NOTE  EGG HATCHING RATE
A MODEGG.K=CLIP(MODPROD,NORPROD,APOP.K,6000)   MODIFY EGGS FROM APOP       2
C NORPROD=1,MODPROD=.75                NORMAL, MODIFY                      2.1
A GOODEGG.K=APOP.K*EGGPLB*MODEGG.K   GOOD EGGS LAYED                       3
C EGGPLB=1400                          EGGS PER LB OF FISH                 3.1
A EGKIL.K=NMEGKIL+EGKILSD.K      NORMAL KILL MOD BY SED                    4
C NMEGKIL=.15                     % NORMAL EGG KILL FROM SEDIMENT           4.1
A GDEGSES.K=TABLE(EGSESTB,SEASON.K,0,48,4) GOOD EGGS ACCORDING TO SEASON   5
T EGSESTB=0/0/0/.15/.05/0/0/0/0/.0025/.0025/0/0 EGGSEASON=RAIN & BROWN     5.1
A EGGS.K=GOODEGG.K*GDEGSES.K     NUMBER EGGS                               6
R EGGHAT.KL=EGGS.K=(EGGS.K*EGKIL.K)      EGGS HATCHED                      7
NOTE     AN THE SEDIMENT KILLS PART OF OR ALL OF THE EGGS
NOTE THE DEATH RATE OF THE FINGERLINGS FROM HATCHING TO ONE YEAR OLD
A FNATDTH.K=TABHL(FNDTHTB,FINPOP.K,0,4E5,1E5)   FINGERLING NATURAL DEATH   8
T FNDTHTB=0,.25,.45,.75,.85                                                8.1
R FNDETH.KL=CLIP(FINPOP.K,0,FINPOP.K,0)*FNATDTH.K*FPOLKIL.K*DTHFOR.K       9
NOTE                                   FINGERLING DEATH
NOTE TRANSFERE OF FINGERLINGS INTO IMATURE
A FINCHK.K=PROPF*PULSE(FINPOP.K,8,48),  FINGERLINGS READY TO TRANSFER      10
C PROPF=.90                            PROPORTION READY TO TRANSFER        10.1
A FINTR.K=DELAY3(FINCHK.K,DELTRF)       TRANSFER FING.OUT TO IMATURE       11
R FINTRAO.KL=CLIP(FINTR.K,0,FINPOP.K,0) TRANSFER BUT NONE WHEN NO FING.    12
C DELTRF=8 WKS              DEL.TRANS.TIME                                 12.1
L FINPOP.K=FINPOP.J+DT*(EGGHAT.JK-FNDETH.JK-FINTRAO.JK)                    13
NOTE                                    FIN POPULATION PULSE=TRAN
N FINPOP=5000                                                              13.1
NOTE
NOTE
NOTE
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NOTE
NOTE IMMATURE TROUT===== CANT SPAWN AND YET OVER 1YR OLD,SLOW GROWTH MAY
NOTE
NOTE
NOTE
NOTE  MAKE THEM OLDER WHEN TRANSFERED
A DTRF.K=FINTR.K*WTPFIN                    TRANSFER  FIN. BY WEIGHT          14
C WTPFIN=.10                               WEIGHT PER FINGERLING TRANSFER    14.1
R TRAFINR.KL=CLIP(DTRF.K,0,FINPOP.K,0) TRANSFER IN FROM FINGERLING           15
A IMNATDT.K=TABHL(IMDTAB,IMPOP.K,0,2500,250)*MDIMD    IMAT.NATURAL DEATH    16
T IMDTAB=0,.02,.03,.04,.06,.09,.12,.17,.25,.30,.35    NATURAL DEATH TAB     16.1
C MDIMD=1                                  MODIFY IMAT.NAT.DEATH             16.2
NOTE IMMATURE NATURAL DEATH
R IMDETH.KL=IMNATDT.K*DTHFDR.K*FPOLKIL.K*CLIP(IMPOP.K,0,IMPOP.K,0)          17
NOTE                                       RATE OF DEATH FOR IMMATURE POP.
A IMGW.K=TABLE(IMGWTAB,SEASON.K,0,48,4)      IMATURE GROWTH RATIO           18
T IMGWTAB=0/0/.0125/.04/.05/.06/.065/.05/.025/.045/.015/.005/0 PERWEEK      18.1
R IMGROW.KL=CLIP(IMPOP.K,0,IMPOP.K,0)*IMGW.K*GRWFDR.K  IM. GROWTH RATE      19
A IMCHK.K=PROPI*PULSE(IMPOP.K,8,48)        IMATURE READY TO TRANSFER         20
C PROPI=.93                                PROPORTION TRANSFERABLE           20.1
A IMTR.K=DELAY3(IMCHK.K,DELTRI)            TRANSFERABLE IMMATURE POP         21
C DELTRI=10 WKS                            DELAY IN TRANSFER OF IMMATUR TOA  21.1
R IMTRA.KL=CLIP(IMTR.K,0,IMPOP.K,0)        NO TRANS WHEN NO IMPOP.           22
L IMPOP.K=IMPOP.J+DT*(TRAFINR.JK+IMGROW.JK-IMDETH.JK-IMTRA.JK) IM  LEVEL     23
N IMPOP=500                                                                  23.1
NOTE
NOTE
NOTE
NOTE
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NOTE ADULT•FISH POPULATION =WILD
NOTE
NOTE
NOTE
NOTE IMMATURE   TRANSFER INTO  ADULT    POP•  SAME RATE AS IMTRA•KL
NOTE  THE GROWTH RATE OF ADULT FISH
A AGROWT•K=TABLE(AGRTAB,SEASON•K,0,48,4)  ADULT GROWTH  VS SEASON          :24
T AGRTAB=0•0/0•0/•0075/•02/•035/•044/•05/•03/•05/•035/•01/•001/0•0 PERWK  :24•1
R AGROW•KL=AGROWT•K*GRWFDR•K*CLIP(APOP•K,0,APOP•K,0)  ADULT GROWTH RATE   :25
NOTE  THE DEATH RATE OF ADULT FISH  = THE DTH CONSIDERING THE FISHMEN PS
A ANATDTR•K=TABHL(ANTB,APOP•K,0,10E3,1E3)    ADULT NATURAL DEATH           :26
T ANTB=0,•01,•02,•03,•05,•07,•10,•17,•25,•30,•35                           :26•1
A ANADCAT•K=ANATDTR•K*DTHFDR•K*CLIP(APOP•K,0,APOP•K,0)  NAT DEATH OF ADU   :27
A LTACAT•K=ACATMOD*ANADCAT•K          LIMIT OF NAT•DTH CATCHABLE           :28
C ACATMOD=•8      % FISH CAUGHT WOULD DIED ANYWAY                          :28•1
NOTE ACATMOD=1•0 MEANS ALL NATURAL DEATH FISH ARE CATCHABLE
NOTE    FISHERMEN PRES• AFFECT ON THE DEATH RATE
A APRESCT•K=TABHL(PRPOPTB,APOP•K,0,2E4,1E3)  CATCH VS FISH   APOP          :29
NOTE LBS•FISH CAUGHT/FISHMEN=DAY VS APOP  CONSTANT FISHING PRES=2000FMPY
T PRPOPTB=•00/•05/•10/•20/•30/•40/•50/•60/•70/•80/•90/1•0/1•1/1•2/1•3/1•  :29•1
X 4/1•5/1•8/1•9/2•0/2•2                  LBSFISH CAUGHT=FMDAY VS APOP
NOTE THE AFFECTIVENESS OF FISHING IS ALSO INFLUENCED BY TOTAL FISHERMEN
NOTE TO REPROPORTION CATCHES AMONG MORE FISHERMEN AS PRES INCREASES
A ANAFCAT•K=TABHL(AFFMTAB,TOTFDY•K,0•0,2E4,2E3) AFFECT• MOD CATCH NO SES  :30
T AFFMTAB=1•2/1•0/•90/•8/•7/•6/•5/•3/•2/•1/•05    AFFECT VS FISHERMEN     :30•1
A SES1•K=CLIP(1,0,SEASON•K,16)         FIRST PART OF FISHING SEASO        :31
A SES2•K=CLIP(0,1,SEASON•K,36)         NO SEASON PAST WEEK 36             :32
A SFAGSES•K=CLIP(SES2•K,SES1•K,SEASON•K,36)  THE FISHING SEASON REGULATI  :33
A AFPCAT•K=APRESCT•K*ANAFCAT•K*SFAGSES•K*TOTFDY•K LBFISH CAUT FROM PRES   :34
A AMODDIFC•K=((AFPCAT•K/ACATMOD)=ANADCAT•K)*MODCOM   ADULT MODIFIED DIFF.  :35
NOTE MODCOM=1•0 MEANS FISHING PRESS• COMPLETELY DETERMINES DEATH ABOVE
NOTE   NATURAL DEATH
NOTE MODCOM=0  MEANS  NOTHING CAUGHT THAT WOULDNOT DIE NATURAL
C MODCOM=•5            RATIO OF HOW MUCH DIF IS INCLUDED,HALF PRES ALLOWD  :35•1
NOTE USE A MODIFING COMPROMISE OF 50% =THE ACATMOD CAN ALSO AFFECT DEATH
A NEWDTH•K=ANADCAT•K+AMODDIFC•K          NEW LEVEL DEATH=PRESS CAUSED      :36
A RELDTH•K=MAX(ANADCAT•K,NEWDTH•K)        DETER•WHICH RATE IS MAX•         :37
NOTE ADULT FISH CAUGHT                   DEPENDENT ON ACATMOD AND MODCOM
A ACATCH•K=CLIP((RELDTH•K/ACATMOD),AFPCAT•K,(AFPCAT•K=LTACAT•K),0)         :38
NOTE            **  PLANTED FISH TEND TO KILL OFF THE ADULT FISH
A PLAFFA•K=TABHL(PAFATB,PLPOP•K,0,5E3,500) PLANTED AFFECT ON ADULT POP•    :39
T PAFATB=0•0/0•03/0•05/0•08/0•11/0•15/0•20/0•25/0•33/0•40/0•50             :39•1
A PLAF•K=PLMDAF*PLAFFA•K                 MODIFY PLANTED AFFECT ON ADULT    :40
C PLMDAF=1                               PLANTED AFF• MODIFIER             :40•1
R ADTH•KL=(RELDTH•K*FPOLKIL•K)+(RELDTH*PLAF•K)   ADULT FISH DEATH          :41
L APOP•K=APOP•J+DT*(AGROW•JK+IMTRA•JK=ADTH•JK)          LEVEL ADULT POP.   :42
N APOP=3500                                                               :42•1
NOTE
NOTE
NOTE
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NOTE   THE PLANTED FISH POPULATION
NOTE
NOTE
NOTE
NOTE   PLANTED DEATH RATE
A PNATDTH.K=TABHL(PNMDTAB,PLPOP.K,0,1E4,1E3)        PLANTE NATURAL DTH      43
T PNMDTAB=0,.16,.22,.27,.33,.40,.45,.50,.55,.60,.65                         43.1
A PLNDCAT.K=PNATDTH.K*DTHFDR.K*CLIP(PLPOP.K,0,PLPOP.K,0) NAT DEATH PLAN     44
A LTPLCAT.K=PLCATMO*PLNDCAT.K          LIMIT OF NAT. DTH CATCHABLE          45
C PLCATMO=.9          % FISH CAUGHT COULD DIE ANYWAY                        45.1
NOTE   FISHMEN PRES  AFFECT DEATH RATE = VERY HARD TO DO CAUSE HIGH NAT.
A PLPRCT.K=TABHL(PLPRTAB,PLPOP.K,0,1E4,1E3)       2000FM DAYS/MONTH         46
T PLPRTAB=0/.05/.10/.15/.20/.25/.30/.35/.40/.45/.50 LBSFISH VS PLPOP        46.1
NOTE AFFECTIVENESS IF THE FISHING USER PRES INCREASE ABOVE 2000
A PLAFCAT.K=TABHL(AFPLTAB,TOTFDY.K,0,0,2E4,2E3) AFFECTIVE CATCH VS FMUSE    47
T AFPLTAB=1.2/1.0/1.0/1.0/.95/.90/.85/.80/.75/.70/.68   AFFECT CATCH        47.1
A PLFPCAT.K=PLPRCT.K*PLAFCAT.K*SFAGSES.K*TOTFDY.K LBSFISH CAUT FROM PRES    48
A PLMODIF.K=((PLFPCAT.K/PLCATMO)=PLNDCAT.K)*PLMODCM  PLANTED MODF DIFF      49
C PLMODCM=.9      RATIO OF DIF TO INCLUDE AS CAUGHT =90% EASYLY CAUT        49.1
A PLNEDTH.K=PLNDCAT.K+PLMODIF.K          NEW LEVEL DEATH=PRESS CAUSED       50
A RELPLDT.K=MAX(PLNEDTH.K,PLNDCAT.K)        DET.MAX FOR DTH                 51
R PLDTH.KL=RELPLDT.K*FPOLKIL.K               PLANTED DETH RATE              52
NOTE PLANTED GROWTH RATE
A PLGROT.K=TABLE(PLGRTB,SEASON.K,0,48,4)  GROW RATIO VS SEASON              53
T PLGRTB=0/0/.002/.05/.04/.038/.035/.005/.025/.008/.002/G/O RATIO/WK        53.1
R PLGROW.KL=PLGROT.K*GRWFDR.K*CLIP(PLPOP.K,0,PLPOP.K,0)  PL.GROWTH          54
C PLMON=27                              WEEK OF PLANTING JULY 1ST           54.1
A SESPLAT.K=SEASON.K=PLMON              DETERMINE PLANT TIME                55
A PLANT.K=SWITCH(PLSIZE,0,SESPLAT.K)    CAUSES  PLANT                       56
C PLSIZE=11000                          NUMBER PLANTED                      56.1
R PLANTED.KL=PLLBPF*PLANT.K             LBS OF PLANTED FISH                 57
C PLLBPF=.33                            WEIGHT OF EACH PLANTED FISH         57.1
L PLPOP.K=PLPOP.J+DT*(PLANTED.JK+PLGROW.JK=PLDTH.JK)                        58
N PLPOP=280                                                                 58.1
NOTE
NOTE
NOTE ** PLANTED FISH CAUGHT **          DEPEDENT ON PLCATMO AND PLMODCM
NOTE                                    PLMODCM=0 MEANS NOTHING CAUGHT
NOTE                                    THAT WOULDNOT DIE NATURAL
NOTE                                    PLMODCM=1 PRESS IS ALL IMPORTANT
NOTE                                CATCH DEPENDENT ONLY ON PRESS TABLES
A PLCATCH.K=CLIP((RELPLDT.K/PLCATMO),PLFPCAT.K,(PLFPCAT.K=LTPLCAT.K),0)     59
A TOTCACH.K=ACATCH.K+(PLVAL*PLCATCH.K)  TOTAL CATCH OF FISH  (WORTH)        60
C PLVAL=.5                              PLANTED CATCH VALUE                 60.1
NOTE
NOTE
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```
NOTE
NOTE          ****   AQUATIC FOOD   ****
NOTE
NOTE
NOTE
NOTE   ****  FOOD CONSUMPTION  ****
A PLCFD.K=PLFNED*PLPOP.K                    PLANTED FOOD CONSUMPTION          61
A ACFD.K=AFNED*APOP.K                       ADULT   FOOD CONSUMPTION          62
A IMCFD.K=IMFNED*IMPOP.K                    IMMATUR FOOD CONSUMPTION          63
C PLFNED=.015 LB.FOOD/LB.FISH/WK            PLANTED NEED                      61.1
C AFNED=.02  LB.FOOD/LB.FISH/WK             ADULT NEED                        62.1
C IMFNED=.01 LB.FOOD/LB.FISH/WK             IMMATURE NEED                     63.1
A TOTFDN.K=PLCFD.K+ACFD.K+IMCFD.K LB.FOOD/LB.FISH/WK.  TOTAL FOOD NEEDED      64
A UAQFD.K=LUFDSR*AQFD.K                     USABLE AQUATIC FOOD               65
C LUFDSR=.33                                LIMIT USABLE FOOD FROM SECURITY   65.1
NOTE                                        RIFFLE AREAS
A NAFDR.K=UAQFD.K/TOTFDN.K                  NEED AVAILABILITY RATIO           66
NOTE DEATH CONTRIBUTION TO FISH  FROM AQUATIC FOOD
A NAFDDR.K=CLIP(1,NAFDR.K,NAFDR.K,1)                                          67
A DTHFDR.K=TABHL(FDTFDTB,NAFDDR.K,0,1,.1)*DMD  FISH DEATH FROM LACK OF F      68
T FDTFDTB=10,5,2.5,1,1.85,1.70,1.55,1.35,1.20,1.10,1                          68.1
C DMD=1                                     DEATH MODIFS TABLE                68.2
NOTE GROWTH CONTRIBUTION TO FISH FROM AQUATIC FOOD
A NAFDGR=CLIP(NAFDR.K,1,NAFDR.K,1)                                            69
A GRWFDR.K=TABHL(FGRFDTB,NAFDGR.K,1,51,5)*GMD FISH GROWTH FROM OVER AB.F      70
C GMD=1                                     GROWTH MODIFIER                   70.1
T FGRFDTB=1,2,2.5,3,3.4,3.7,4.0,4.3,4.6,4.8,5                                 70.2
NOTE  ***  DEATH RATE OF AQUATIC FOOD  **
A NFDTH.K=TABLE(AQFTB,SEASON.K,0,48,4)*MDFDTH NORMAL FRACTION DEATH           71
C MDFDTH=.549                               MODIFY FOOD DEATH FRACT.          71.1
T AQFTB=.10,.10,.10,.08,.05,.05,.05,.08,.09,.10,.13,.15,.13 D/WK              71.2
A NAFDDT.K=CLIP((NFDTH.K*AQFD.K),0,(NFDTH.K*AQFD.K),0)    NORM     FOOD      72
A UNAFDT.K=FATE*LUFDSR*NAFDDT.K             USABLE FOOD DIED ANYWAY           73
C FATE=.8                                   FRACTION OF NAT.DEATH FOOD CONSM  73.1
A CONDIF.K=CLIP((TOTFDN.K-UNAFDT.K),0,(TOTFDN.K-UNAFDT.K),0)  CONSUMP         74
A CON.K=CLIP(CONDIF.K,UAQFD.K,(UAQFD.K-CONDIF.K),0) CONSUMPTION BY FISH       75
R AQFDDT.KL=NAFDDT.K+CLIP(CON.K,0,CON.K,0)+(NAFDDT.K*AQDSED.K)+(NAFDDT.K      76
X *CLIP(0,DPOLAR.K,DPOLAR.K,0))             AQUATIC FOOD DEATH=NORM+EXCESS
NOTE                                          CONSUMPTION+SEDIMENT AFFECT
A DPOLAR.K=DLINF3(POLAQR.K,PADLTM)          DELAYED AFFECT OF POLLUTION RATI  77
C PADLTM=2 WK                               CONSTANT TIME DELAY IN AFFECT     77.1
A NGF.K=TABLE(NAGTB,SEASON.K,0,48,4)        NORMAL AQUATIC FOOD GROWTH FRACT  78
T NAGTB=.02,.02,.04,.08,.09,.10,.08,.07,.06,.04,.03,.02,.02                   78.1
A NAGF.K=CLIP((NGF.K*AQFD.K),0,(NGF.K*AQFD.K),0)    NORMAL AQUT. GROWTH       79
R AQFDGR.KL=NAGF.K+(NAGF.K*CLIP(DPOLAR.K,0,DPOLAR.K,0)) AQUATIC FOOD GWH      80
L AQFD.K=AQFD.J+DT*(AQFDGR.JK-AQFDDT.JK)  AQUATIC FOOD LEVEL                  81
N AQFD=5000                                                                   81.1
NOTE
NOTE
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NOTE
NOTE                *****   WATER POLLUTION RATIO   *****
NOTE
NOTE
NOTE
A BSPOPC.K=BSPOP.K*TTRI                    BIG SKY POPUL. CONT. TO POL.H2O    .82
C  TTRI=.15 D                              BIG SKY TERTIARY TREAT.INEFF       .82.1
A RCPOPC.K=RCPOP.K*STTRI                   REST OF CANYON  CONT TO POL H2O    .83
C STTRI=.90 D                              SEPTIC TANK INEFF. FOR REST OF C   .83.1
A HWPC.K=(BSPOPC.K+RCPOPC.K)*POLPMP        HUMAN WATER POL. CONT              .84
C POLPMP=.10 POLUNT/POP                    POLLUTION PER MODIFIED POP.        .84.1
A NORFLOW.K=TABLE(FLOWTB,SEASON.K,0,48,4) FLOW NORM UNITS                     .85
T FLOWTB=1,1.016,1.009,1.659,5.933,9.489,4.157,1.929,1.607,1.474,1.257,       .85.1
X 1.062,1.0
NOTE JANUARY   FLOW IS USED AS NORM
A POLDIS.K=POPVOL*NORFLOW.K POL.           POLLUTION DISPERSED                .86
C POPVOL=140                               1 STAND VOL WILL DISPERSE 1400     .86.1
NOTE                                        PEPDAYS IN EACH WEEK
A POLRES.K=CLIP((HWPC.K=POLDIS.K),0,(HWPC.K=POLDIS.K),0) RESULTANT POLLN      .87
A PREPOL.K=CLIP(POLRES.K,.0001,POLRES.K,.0001)  PRESENT POL. TO ENSURNO=      .88
A WPR.K=PREPOL.K/BLWP                      WATER POL. RATIO                   .89
C BLWP=1700                                BASE LINE WATER POLLUTION          .89.1
A PNUSD.K=CLIP((WPR.K=PNUSS),0,(WPR.K=PNUSS),0) POL.NUISANCE TO FISHMEN       .90
C PNUSS=50 POL.RATIO                       POLLUTION NUISANCE STANDARD        .90.1
A MAFFPF.K=PNUSD.K*MFAFF                   FRACTION FMEN AFFECTED BY H2O P1   .91
C MFAFF=.02 D                              MEN FRACTION AFFECTED PER UNITDI   .91.1
NOTE FISHING STOPS ABOUT SAME TIME FISH ARE STARTED TO BE KILLED
A MPOLRS.K=CLIP(MAFFPF.K,1,PNUSD.K,0)      FISHERMEN FRACTIONAL AFFECT FR P   .92
A PKILD.K=CLIP((WPR.K=PKILST),0,(WPR.K=PKILST),0) POL.KILL OF FISH            .93
C PKILST=100                               POLLUTION KILL STD. =STARTSHARM F  .93.1
A FPOLKIL.K=(PKILD.K*FFAFF)+1              AFFECT OF POLL.ON FISH             .94
C FFAFF=.10 FR/UNITPOL                     AFFECT/POLUNIT DIFF. 110POL=ALLK   .94.1
NOTE                                       KILL ALL FISH  .05 =AT 120
NOTE POLLUTION AFFECT ON AQUATIC FOOD
A POLAQR.K=TABHL(AQAFTB,WPR.K,1,301,20)     POL.AFF.ON AQFD                   .95
T AQAFTB=0,1,2,3,4,5,4,3,2,1,0,-1,-2,-3,-4,-5                                 .95.1
NOTE
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NOTE
NOTE          ****   SEDIMENT RATIO   ****
NOTE
NOTE
NOTE
NOTE  SEDIMENT BELOW NORM WILL IMPROVE HATCHING VERY LITTLE IF ANY=IGNOR
A NORMSED.K=TABLE(SEDTAB,SEASON.K,0,48,4) SED NORMAL BASED ON AVG          96
T SEDTAB=.05/.10/1.5/3.0/5.0/4.0/2.0/1.0/.50/.15/.10/.09/.05               96.1
A PCSED.K=NORMSED.K*RAMP(SGR.K,SEDST.K)   PRESENT SEDIMENT DEPOSITINS      97
NOTE                                      WITH POSSIBLE GROWTH
C SGR.K=.00                               INCREASE IN SEDIMENT GROWTH       97.1
C SEDST=48                                START TIME OF GROWTH              97.2
A SEDR.K=PCSED.K/BSLHSR                   SEDIMENT RATIO=PRESENT/BASELINE    98
C BSLHSR=5                                BASE LINE HIGH NORM SED           98.1
A DIFSBL.K=CLIP((SEDR.K=ONE),0,(SEDR.K=ONE),0)  DIF.FROM BSL SEDIMENT RA    99
C ONE=1                                   BASE LINE RATIO                   99.1
A EGKILSD.K=MASEDE*DIFSBL.K               FRACTIONAL INCREASE IN EGG KILL  100
C MASEDE=.10                              MODIFID AFFECT OF SED.INCREAS    100.1
NOTE MASEDE=.10 MEANS AN INCREASE TO SEDR =1.1  TOTAL DEATH OF ALL EGGS
NOTE       =.01                             =101  TOTAL DEATH
NOTE SEDIMENT AFFECT ON AQUATIC FOOD
A AQDSED.K=DIFSBL.K*MASAQF D              SEDIMENT AFFECT ON AQ.FOOD       101
C MASAQF=.01                              FRACTIONAL AFFECT MODIFY AFFECT  101.1
NOTE
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NOTE
NOTE   ***  FISHERMEN POPULATION  ***
NOTE
NOTE
NOTE
NOTE                  **  RESIDENT FISHERMEN  **
A RFCA.K=TABHL(RCATB,FCRWR.K,0,10,1)      RES CROWDING AFFECT                 102
T RCATB=1,.05,.005/0/=.010/=.05/=.10/=.30/=.50/=.75/=1.0                      102.1
A RFSUC.K=TABHL(RSTAB,RFPDYR.K,0,3,.25) RES FISHMEN SUCCESS AFFECT            103
T RSTAB=-.20/=.03/=.02/=.01/0/.01/.02/.03/.05/.07/.09/.10/.12                 103.1
A DRFSUC.K=DLINF3(RFSUC.K,DLRFS)          DELAY RES FISHING SUCCESS           104
C DLRFS=48 WK                        DELAY TIME RES SUC                       104.1
A FRU.K=TABHL(FRTB,SEASON.K,0,48,4)*SFAGSES.K FRACTION RES USERS              105
T FRTB=0,.0005,.0150,.03,.045,.03,.025,.035,.02,.005,.0005,.0002,0            105.1
A NRF.K=FRU.K*PRFUP.K                     NUMBER RES FISHERMEN                106
A DRCRMD.K=DLINF3(RFCA.K,DLRCR)           DELAY IN RES CROWDING AFFECT        107
C DLRCR=48 WK                             DELAY TIME CROWDING                 107.1
A RPEAF.K=TABHL(RPEPTB,PEPPLR.K,0,10,1)*SFAGSES.K  PEP AFF ONLY DUR SESN      108
T RPEPTB=1,.02,.005/0/=.005/=.05/=.10/=.30/=.40/=.60/=.90                     108.1
NOTE  3X IS CRITICAL LEVEL OF PEOPLE POL  AFF ON RES
A DRPERAF.K=DLINF3(RPEAF.K,DLRPE)         DELAY RES AFFECTED BY PEOPLE POL    109
C DLRPE=48 WK                             DELAY TIME FOR PEOPLE AFFECT        109.1
A NENTR.K=NRER*CLIP(PRFUP.K,0,PRFUP.K,0)      NORM ENTER RESIDENT             110
C NRER=.0008                              NORM FRACTION FISHERMEN ENTERRES    110.1
R ERFP.KL=NENTR.K+(NENTR.K*DRCRMD.K)+(NENTR.K*DRPERAF.K)+(NENTR*              111
X DRFSUC.K)                               ENTER RATE RESIDENTS
A MDRCRL.K=MODCRR*CLIP(0,DRCRMD.K,DRCRMD.K,0)  MODIF RES CROW LEAVE AFF       112
C MODCRR=1                                MODIFY CROWDING AFFECT ON RES       112.1
A MDRPEL.K=MODPER*CLIP(0,DRPERAF.K,DRPERAF.K,0) MOD RES PEOPL POL LEAVE       113
C MODPER=1                                MODIFY PEOPLE AFFECT ON RES         113.1
A MDRFSL.K=MODSUR*CLIP(0,DRFSUC.K,DRFSUC.K,0)   MOD RES FISH SUCCESS LEV      114
C MODSUR=1                                MODITY SUCCESS AFFECT ON   RES      114.1
A NLVR.K=FLVR*PRFUP.K                     NORMAL LEAVING RESIDENT FISHMENP    115
C FLVR=.0007                              NORMAL FRACTION RES LEAVING POL     115.1
R LRFP.KL=NLVR.K=(NLVR.K*MDRCRL.K)=(NLVR.K*MDRPEL.K)=(NLVR.K*MDRFSL.K)        116
X +(NLVR.K*MPOLNS.K)                      LEAVE RATE RES FISHMEN FROM POOL
L PRFUP.K=PRFUP.J+DT*(ERFP.JK=LRFP.JK)    POTENTIA  RES FISHMENPOOL           117
N PRFUP=7E4                               INITIAL RES POOL                    117.1
NOTE
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NOTE
NOTE              ** NONRESIDENT FISHERMEN **
NOTE
NOTE
NOTE
A NPEAF.K=TABHL(NPEPTB,PEPPLR.K,0,10,1)*SFAGSES.K  PEP AFF NRES DUR.SESN 118
T NPEPTB=1,.02,.005,0,=.005,=.05,=.10,=.30,=.40,=.60,=.90                 118.1
NOTE  3X IS CRITICAL LEVEL OF PEOPLE POL  AFF.ON NONRES
A DNPEPAF.K=DLINF3(NPEAF.K,DLNPE)        DELAY PEOPLE POL AFF ON NONRES   119
C DLNPE=48                               DELAY TIME PEOPLE POL AFF  NONR  119.1
A NFSUC.K=TABHL(NSTAB,NFPDYR.K,0,3,.25) NONRES FISHMEN SUCCESS            120
T NSTAB=-.20,=.03,=.02,=.01,0,.01,.02,.03,.05,.07,.09,.10,.12             120.1
A DNFSUC.K=DLINF3(NFSUC.K,DLNFS)         DELAY IN NONRES FISHING SUCCESS  121
C DLNFS=48                                  DELAY TIME NONRES SUC         121.1
A NRFCA.K=TABHL(NRCATB,FCRWR.K,0,10,1)  NONRES FISHERMEN CROWDING AFFECT  122
NOTE  CRITICAL CROWDING POINT IS 3X PRESNONRES CRITICAL CROWDING=NEG AFF
T NRCATB=1,.05,.005,0,=.010,=.05,=.10,=.30,=.50,=.75,=1.0                 122.1
A DNCRMD.K=DLINF3(NRFCA.K,DLNCR)         DELAY IN NONRES CROWDING AFFECT  123
C DLNCR=48 WK                            DELAY TIME NONRES CROW           123.1
A NENTNR.K=NRENR*CLIP(PNRFUP.K,0,PNRFUP.K,0)       NORMAL ENTER OF NONRS 124
C NRENR=.002                             NORM ENTER RATIO                 124.1
R ENRFP.KL=NENTNR.K+(NENTNR.K*DNCRMD.K)+(NENTNR.K*DNPEPAF.K)+(NENTNR*     125
X DNFSUC.K)                              ENTER RATE = NORMAL*CROWD*PEOPLE
NOTE                                        AFFECT+FISHING SATISFACTION
A MDNCRL.K=MODCRN*CLIP(0,DNCRMD.K,DNCRMD.K,0)   MODIFIED NONRES CROW LEV  126
C MODCRN=1                               MODIFY CROWDING AFFECT ON NONRES 126.1
A MDNPEL.K=MODPEN*CLIP(0,DNPEPAF.K,DNPEPAF.K,0) MOD NONRES PEOPL POL LEV  127
C MODPEN=1                               MODIFY PEOPLE AFFECT ON NONRES   127.1
A MDNFSL.K=MODSUN*CLIP(0,DNFSUC.K,DNFSUC.K,0)  MOD NONRES SUCCESS AFLEV  128
C  MODSUN=1                              MODIFY SUCCESS AFFECT ON  NONRES 128.1
A NLVN.K=FLVN*PNRFUP.K                   NORMAL LEAVING NONRES.FISHMEN PL  129
C FLVN=.0025                             NORMAL FRACTION NONR LEVE POOL   129.1
R LNRFP.KL=NLVN.K=(NLVN.K*MDNCRL.K)=(NLVN.K*MDNPEL.K)=(NLVN.K*MDNFSL.K)   130
X +(NLVN.K*MPOLNS.K)                     LEAVING RATE NONRES FISHMEN POOL
L PNRFUP.K=PNRFUP.J+DT*(ENRFP.JK=LNRFP.JK)     POTENTIAL NONRES.FISHMEN.  131
N PNRFUP=3E4                             INITIAL NONRES POOL              131.1
NOTE
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NOTE
NOTE    ACTUAL FISHERMEN IN CANYON
NOTE
NOTE
NOTE        CATCH PROPORTIONED
A FNRU•K=TABHL(FNRTB•SEASON•K,0,48,4)*SFAGSES•K FRACTIONAL NONRES U      132
T FNRTB=0,0,0,•001,•002,•02,•09,•09,•02,•010,0,0,0                      132•1
A NNRF•K=FNRU•K*PNRFUP•K                  NUMBER NONRES FISHERMEN       133
A NRFD•K=NNRF•K*FATM                      NONRES FISHERMEN DAYS         134
C FATM=1  FISHMENDAY = 3HRS               TIME SPENT BY AVG•FISHERMEN   134•1
A RFD•K=NRF•K*FATM                        RES•FISHERMEN DAYS            135
A TOTFDY•K=NRFD•K+RFD•K                   TOTAL FISHERMEN DAYS          136
A FCRWR•K=TOTFDY•K/BSLCRW                 FISHMEN CROWDING RATIO        137
C BSLCRW=4500                               BASE LINE CROWDING FISM     137•1
A RFRDY•K=RFD•K/TOTFDY•K                  FRACTION RESIDENT DAYS        138
A NFRDY•K=NRFD•K/TOTFDY•K                 FRACTION NONRES•  DAYS        139
A RCATCH•K=RFRDY•K*TOTCACH•K*RAFS         RES•CATCH                     140
C RAFS=1•0                                RESIDENT AFFECT OF SKILL      140•1
A NCATCH•K=TOTCACH•K-RCATCH•K             NONRES•CATCH                  141
A RFPDY•K=RCATCH•K/RFD•K                  RESIDENT LBS FISH PER FISHDAY 142
A NFPDY•K=NCATCH•K/NRFD•K                 NONRES•  LBS FISH PER FISHDAY 143
A RFPDYR•K=RFPDY•K/BLRFPD                 RES FISH PER FDAY/BASE LINE CATH 144
C BLRFPD=•40                              BASE LINE RES•CATCH           144•1
A NFPDYR•K=NFPDY•K/BLNFPD                 NRES FISH PER FDAY/BASE LINE CATH 145
C BLNFPD=•35                              BASE LINE NONRES CATCH        145•1
A FGFEENR=NRFD•K*NRFEE                    NON RESIDENT FEES CAUSE GALLATIN 146
C NRFEE=1•5                               FEE=$1•50 FOR EACH FISHERMENDAY 146•1
A FGFEER=RFD•K*RFEE                       RESIDENT FEES COLLECT BECAUSE GL 147
C RFEE=•50                                FEE=50¢ EACH AVG RES•FISHDAY  147•1
A TOTFEES=FGFEENR•K+FGFEER•K              TOTAL FISHING FEES            148
NOTE
NOTE
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NOTE
NOTE                CANYON POPULATION
NOTE   BIG SKY SEASONS VARY AT 8 DIFFERENT RESORT USE LEVELS
NOTE   THESE ARE TAKEN FROM PROJECTED USE LEVELS BY BIG SKY
NOTE THE GROWTH AT BIG SKY IS VERY SKI SEASONAL
NOTE    THE MAKE UP OF THE POPULATION EQUATIONS ARE NOT FLOW
NOTE        CHARTED BECAUSE THEY ARE USED ONLY FOR THE GENERATED
NOTE          POPULATIONS = THE CONSTANTS ARE EXPLAINED TO CHANGE
NOTE            THE GROWTH
NOTE
NOTE
NOTE
NOTE                ****   BIG SKY POPULATION=USER DAYS  ****
NOTE
NOTE
A G1.K=STEP(BG11,S1)+STEP(BG12,S2)+STEP(BG13,S3)+STEP(BG14,S4)          149
A G2.K=STEP(BG21,S1)+STEP(BG22,S2)+STEP(BG23,S3)+STEP(BG24,S4)          150
A G3.K=STEP(BG31,S1)+STEP(BG32,S2)+STEP(BG33,S3)+STEP(BG34,S4)          151
A G4.K=STEP(BG41,S1)+STEP(BG42,S2)+STEP(BG43,S3)+STEP(BG44,S4)          152
A G5.K=STEP(BG51,S1)+STEP(BG52,S2)+STEP(BG53,S3)+STEP(BG54,S4)          153
A G6.K=STEP(BG61,S1)+STEP(BG62,S2)+STEP(BG63,S3)+STEP(BG64,S4)          154
A G7.K=STEP(BG71,S1)+STEP(BG72,S2)+STEP(BG73,S3)+STEP(BG74,S4)          155
A G8.K=STEP(BG81,S1)+STEP(BG82,S2)+STEP(BG83,S3)+STEP(BG84,S4)          156
N IN1=0                                                                 156.1
N IN2=0
N IN3=0
N IN4=0
N IN5=0
N IN6=0
N IN7=0
N IN8=0
NOTE   DETERMINING STEP TIMES ===T1=T8
L IN1.K=IN1.J+PULSE(48,51,48)                                           157
A T1.K=48+IN1.K                                                         158
L IN2.K=IN2.J+PULSE(48,59,48)                                           159
A T2.K=52+IN2.K                                                         160
L IN3.K=IN3.J+PULSE(48,63,48)                                           161
A T3.K=60+IN3.K                                                         162
L IN4.K=IN4.J+PULSE(48,71,48)                                           163
A T4.K=64+IN4.K                                                         164
L IN5.K=IN5.J+PULSE(48,79,48)                                           165
A T5.K=72+IN5.K                                                         166
L IN6.K=IN6.J+PULSE(48,87,48)                                           167
A T6.K=80+IN6.K                                                         168
L IN7.K=IN7.J+PULSE(48,91,48)                                           169
A T7.K=88+IN7.K                                                         170
L IN8.K=IN8.J+PULSE(48,95,48)                                           171
A T8.K=92+IN8.K                                                         172
L G1POP.K=PULSE(G1.K,95,48)+G1POP.J                                     173
L G2POP.K=PULSE(G2.K,51,48)+G2POP.J                                     174
L G3POP.K=PULSE(G3.K,59,48)+G3POP.J                                     175
L G4POP.K=PULSE(G4.K,63,48)+G4POP.J                                     176
L G5POP.K=PULSE(G5.K,71,48)+G5POP.J                                     177
L G6POP.K=PULSE(G6.K,79,48)+G6POP.J                                     178
L G7POP.K=PULSE(G7.K,87,48)+G7POP.J                                     179
L G8POP.K=PULSE(G8.K,91,48)+G8POP.J                                     180
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N  G1POP=700                                                              180.1
N G2POP=0
N G3POP=0
N G4POP=0
N G5POP=0
N G6POP=0
N G7POP=0
N G8POP=0
A BSPOP.K=STEP(G1POP.K,T1.K)+STEP(G2POP.K,T2.K)+STEP(G3POP.K,T3.K)        181
X +STEP(G4POP.K,T4.K)+STEP(G5POP.K,T5.K)+STEP(G6POP.K,T6.K)
X +STEP(G7POP.K,T7.K)+STEP(G8POP.K,T8.K)+INBSP.K
C BG11=700,BG12=700,BG13=600,BG14=670                                     181.1
C BG21=3000,BG22=200,BG23=2000,BG24=550
C BG31=450,,BG32=450,,BG33=400,,BG34=415
C BG41=300,,BG42=140,,BG43=200,,BG44=190
C BG51=1240,BG52=340,BG53=150,BG54=440
C BG61=350,,BG62=140,,BG63=260,,BG64=190
C BG71=550,,BG72=330,,BG73=380,,BG74=415
C BG81=1900,BG82=110,BG83=1210,BG84=610
C S1=48,S2=144,S3=384,S4=624                                              181.2
A INBSP.K=TABLE(IBTB,SEASON.K,0,48,4)   INITIAL BIG SKY POP =73           182
T IBTB=700,1100,1300,700,800,900,800,800,700,600,500,700,700              182.1
NOTE
NOTE
NOTE                  ****   REST OF CANYON POPULATION=USER DAYS   ****
NOTE
NOTE
NOTE   BIG SKY POPULATION AFFECT USE OF THE REST OF THE CANYON
NOTE     ACCORDING TO THE BSCTAB =TABLE
A RCPOP.K=INRCP.K+(RCMD*RAMP(RCGRP.K,GRCST))*(BSCONR.K*BSPOP.K) USEROA/W 183
C GRCST=49                                  START FOR REST CAY GROWTH     183.1
C RCMD=.20                                  REST CAY GROWTH MODIFIER
NOTE                                         MEANS NO CHANGING OF TAB
NOTE REST CANYON POPULATION WITH GROWTH AND BIG SKY INFLUENCE
A BSCONR.K=TABLE(BSCTAB,SEASON.K,0,48,4)  BIG SKY CONTRIBUTION TO RESTCA 184
T BSCTAB=.10,.10,.10,.05,.05,.02,.01,.01,.02,.03,.05,.10,.10              184.1
A INRCP.K=TABLE(IRCTB,SEASON.K,0,48,4) USER DAYS/WK INITIAL RC POP.       185
T IRCTB=4E3,4E3,5300,4900,8900,16E3,25E3,21100,13E3,7300,5100,4600,4E3    185.1
A RCGRP.K=STEP(RCGR1.K,RCST1)+STEP(RCGR2.K,RCST2)+STEP(RCGR3.K,RCST3)+ST 186
X EP(RCGR4,RCST4)
C RCST1=48 WK                                                             186.1
C RCST2=144 WK
C RCST3=384 WK
C RCST4=624 WK
A RCGR1.K=TABLE(RG1TB,SEASON.K,0,48,4)  GROWTH 1ST PERIOD                 187
A RCGR2.K=TABLE(RG2TB,SEASON.K,0,48,4)  GROWTH 2ND PERIOD                 188
A RCGR3.K=TABLE(RG3TB,SEASON.K,0,48,4)  GROWTH 3RD PERIOD                 189
T RG1TB=40,75,100,45,50,75,200,180,150,75,55,75,40                        189.1
T RG2TB=20,25,25,20,5,4,4,20,20,4,4,20,20
T RG3TB=-50,-85,-100,-60,-50,-75,-200,-180,-150,-75,-55,-85,-50
A RCGR4.K=TABLE(RG4TB,SEASON.K,0,48,4)  GROWTH 4TH PERIOD                 190
T RG4TB=0,0,0,0,0,0,0,0,0,0,0,0,0                                         190.1
NOTE
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NOTE
NOTE        ****   TOTAL CANYON POPULATION INPEOPLE DAYS ****
NOTE
A TOTCAP.K=BSPOP.K*RCPOP.K                  TOTAL CANYON POPULATION          191
A PEPPLR=TOTCAP.K/BSLPEP.K                  PEOPLE POLLUTION RATIO           192
A BSLPEP.K=TABLE(INTCTB,SEASON.K,0,48,4)    BASE LINE PEOPLE IN TOTAL CAY    193
T INTCTB=4700,5100,6400,5600,9700,16900,25800,21900,13700,7900,5600,5200 193.1
X ,4200                                     BASE LINE TOTCAP
PLOT APOP=A(0,8E3)/AGFD=*(0,20E3)/TOTFDY=F/SEDR=S/WPR=W/TOTCACH=T
PLOT FINPOP=F(0,8E5)/IMPOP=I(0,6E3)/PLPOP=P(0,8E3),APOP=A/AGFD=*(0,20E3)
X /NRFD=N(0,6E3),RFD=R/WPR=W/TOTFEES=G/TOTCAP=T
PLOT FINPOP=F(0,8E5)/IMPOP=I(0,6E3)/PLPOP=P(0,8E3),APOP=A/AGFD=*(0,20E3)
X /NRFD=N(0,6E3),RFD=R/RFPDY=S/NFPDY=U/TOTCACH=T
SPEC DT=1/LENGTH=700/PRTPER=0/PLTPER=2
RUN STANDARD
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LITERATURE CITED

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