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

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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Date May 4, 1973

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

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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.[1] 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 north-west 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 <u>will</u> 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,