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THE CLUB OF ROME  
PROJECT ON THE PREDICAMENT OF MANKIND

PRELIMINARY DRAFT

PHASE ONE

DYNAMICS OF GLOBAL EQUILIBRIUM

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Given the present outlook, only the faithful who believe in miracles from heaven, the optimistic who anticipate superwonders from science, the parochial fortunate who think they can continue to exist on islands of affluence in a sea of world poverty and the naive who anticipate nothing can look to the future with equanimity.

--- Philip M. Hauser  
Director of the Population  
Research and Training Center  
and Professor of Sociology,  
University of Chicago

## PREFACE

Three convictions unite the members of the Club of Rome.

1. The long term prospects of our global society are poor at the moment, and the situation appears to be deteriorating.
2. The only viable solutions to global problems will be those with a transnational perspective and a planning time horizon much greater than those currently exhibited by any state.
3. Scientific attempts to identify the fundamental interactions which determine the rate and direction of global evolution, realistic assessments of our feasible options, and concerted efforts to achieve a more satisfactory global situation can lead to a substantial improvement over our current situation.

Within the context of those convictions, the M.I.T. team has been engaged in a set of empirical research and simulation modeling studies to identify the long term global prospects and to evaluate alternative policies in the context of their impact over the next 50 to 200 years. The following material briefly describes the global model, World3, and the twelve sub-studies which relate to it. No attempt is made to explain each model in detail, but references are given to the more complete reports. Policy recommendations, where already justified by the research, are briefly summarized.

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## INTRODUCTION

For some four thousand years the condition of the human race has been characterized by growth and change. Technological development has accelerated. Natural resources have been depleted. Our environment has been polluted at an ever-increasing rate. Population has multiplied at least 50-fold and may double again within this century. Now there is evidence that growth is occurring too quickly to permit adaptation by the planet's social institutions and its ecological systems.

Growth cannot continue indefinitely on a finite planet. We are faced with an inevitable transition from world-wide growth to global ecological equilibrium. Because of the time delays inherent in social system change, decisions made now are already influencing the nature of that future equilibrium. Will it be an equilibrium of poisoned lakes, of oppressive crowding, of food shortage and a declining standard of living? Or will we choose a different mode of equilibrium characterized by a more desirable set of conditions? The shift from growth to dynamic balance may be initiated by a catastrophe such as war or starvation. Alternatively, transition could result from an enlightened, concerted, international effort to adopt new values and define new goals.

The predicament of mankind is that we can perceive the individual symptoms and the components of profound social problems, but we are stymied in our efforts to comprehend the total situation and develop

global solutions. While perceptive individuals everywhere have begun to recognize the inevitability and the dangers of transition to equilibrium, thinking and action have been confined to individual problem areas. Demographers press for effective birth control measures. Ecologists seek an end to the destruction of our natural environment. Agricultural experts search for more efficient food production. All would admit that there are important interactions among their various approaches, but the conceptual framework, the analytical methodologies and the vocabulary to unite the different fields have been lacking.

Recognition of these deficiencies by Dr. Aurelio Peccei and others led to the formation of the Club of Rome and to its plans for an action-oriented program on the 'Predicament of Mankind' to develop a formal basis for concerted action on global problems. Phase One of that program will evaluate the present world situation and the policy options available to mankind as we move toward the equilibrium phase of our development.

### THE CLUB OF ROME

The Club of Rome is a group of individuals deeply concerned about the future of the world and the looming problems which threaten human society. The Club is informal, multinational and non-political. Its members include scientists, humanists, economists, educators and business leaders. None of its members are involved in current political decisions, nor has the Club itself any ideological, political or national commitments.

Many organizations, national and international, have been formed in response to global problems. The special strength of the Club of Rome lies in its flexibility. It is not pre-committed to any doctrine or to the welfare of any particular nation or group. Its membership, though limited, is being deliberately extended to include representatives of all cultures, and it is expected that the funds for its projects will be derived from organizations and individuals in several different nations.

To carry out its program, the Club of Rome has been incorporated in Geneva as a non-profit association under the Swiss Civil Code. It has established numerous contacts with key people in Ottawa, Moscow, Washington, Tokyo, Buenos Aires, Stockholm, Berne, Vienna and other capitals, as well as in international organizations. While this high-level exchange of views will continue, the Club of Rome believes that it can

now undertake a program of research that will succeed in penetrating and describing the complex nature and dimensions of the world's problems.

As a small organization, the Club recognizes its limitations in directly affecting significant global change. It views its role rather as that of a catalyst. It realizes that its program can succeed only if its achievements are sufficiently new and important that they attract a lasting group of adherents from different cultures and various branches of scientific and political activity. To do that the Club seeks to identify a new class of global problems and to provide the language, the methodologies and the criteria of success appropriate for their solution.

### THE CLUB OF ROME PROGRAM: PHASE ONE

Before initiating the first phase of its program, the Club of Rome undertook a search for formal analytical methods which could integrate rationally the many disciplines required for any overall assessment of the current world situation. Meetings in Berne, Switzerland and Cambridge, Massachusetts in June and July of 1970 led to selection of one specific method, System Dynamics<sup>1</sup>, as the foundation of Phase One.

An important part of the conference work in Cambridge involved formulation and analysis of a preliminary model (World2) developed through the System Dynamics approach and incorporating many of the global relationships underlying the complex of critical global problems previously identified by the Club. Most of these problems, such as malnutrition and pollution, result from the exponential growth of population and industrialization. Phase One thus focuses explicitly on the dynamics of growth in population and production. Hunger, pollution and other environmental factors are already acting to limit that growth. Thus an important objective of the project has become the study of problems

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1. System Dynamics is a theory of system structure and a set of tools for representing complex systems and analyzing their dynamic behavior. Originally developed at M.I.T. by Professor Jay W. Forrester for application to industrial problems, these tools are widely known as Industrial Dynamics. However that name is a misnomer since the method has been applied to over a hundred different systems ranging from internal medicine to urban decay and the management of research and development projects.

inherent in negotiating a deliberate transition from world-wide growth to global equilibrium.

Development of appropriate models, identification of relevant data and conduct of preliminary analyses are the most important tasks of the first phase. The research will be conducted by an international group under the direction of Professor Dennis L. Meadows at the Massachusetts Institute of Technology.

Later phases which extend the research initiated in Phase One, diffuse knowledge about the critical problems, and propose appropriate solutions will require a sustained, decentralized effort involving the participation of many peoples and organizations. The effort must be multinational and, therefore, Phase Two, the design of a decision making testing laboratory (DEMATEL) based on the models developed at M.I.T., will begin in Geneva, Switzerland in June 1971. The global simulation work will continue at M.I.T. in support of the Club of Rome effort, but funding will be sought from other sources.

## METHODOLOGY OF PHASE ONE

### History of System Dynamics

The field of System Dynamics has been developed at the Massachusetts Institute of Technology through more than thirty years of continuous effort directed toward the analysis and control of complex system behavior. From its birth in the study of relatively simple mechanical systems it has grown to provide a single framework for understanding the behavior of all electronic, chemical, biological and social systems whose elements interact through time to produce system changes. Four lines of historical development prior to 1956 led to Industrial Dynamics and then to System Dynamics. They are:

- the theory of information-feedback systems
- a knowledge of human decision-making processes
- the experimental model approach to complex systems
- the digital computer as an inexpensive means to simulate realistic mathematical models

Study of mechanical servo-mechanisms at M.I.T. led to an awareness in the early 1940's that time delays, amplifications and structural relationships among a system's elements could be more important in

determining aggregate system behavior than the individual components themselves. The concepts of information feedback and control were developed to express the relation between structure and behavior. More recent efforts to design automatic self-regulating control systems have extended these concepts and shown them to underlie behavior in all systems.

The potential of competitive advantages obtainable through the automation of data processing and routine decisions in large organizations has focused much attention on the nature of human decision making. Research conducted since the early 1950's suggests that important components of the decision-making process are not entirely "free will" but are strongly conditioned by the information present in the environment. Progress has been made in this field to the point where we are now able to model the basic structure of decision making.

It is not yet possible to derive general analytical solutions for realistic models of systems as complex as those encountered in social systems. The alternative is an experimental approach based on quantitative models of the system. First a mathematical model of the social system is constructed. This model is a detailed description of the decision processes in the system. It indicates how the conditions at one point in time lead to subsequent conditions at later points in time. The behavior of the model is observed and experiments are conducted to answer specific questions about the system that is represented by the model. "Simulation" is the name generally applied to this process

of conducting experiments on a model instead of attempting the experiments with the real system. In simulation studies the goal is not to predict the future, but rather to understand, in a pragmatic way, how alternative changes in the current system are associated with different modes of behavior over time.<sup>2</sup> The simulation approach, a fundamental element of System Dynamics methodology, was developed at M.I.T. in the early 1950's as engineers were forced to analyze systems too complex to solve analytically.

The fourth foundation element of System Dynamics is the electronic digital computer, which made the vast number of calculations required to trace the behavior of a specific system through time economically feasible. In the past fifteen years the cost of arithmetic computation has fallen by a factor of 10,000 or more. Such a cost reduction creates a totally different research environment. Computing machines have become so widely available, and the cost of computation and machine programming is now so low relative to other costs, that the former difficulties in conducting a simulation study no longer determine the rate of progress in understanding system behavior.

A group of individuals from the engineering and social sciences came together in 1956 under Professor Jay W. Forrester at M.I.T.'s Sloan School of Management to exploit these four developments. Their initial

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2. This is an extremely important point. One can imagine many states which could characterize the globe several decades from now: international warfare, rampant epidemics or prosperous tranquility. A System Dynamics study would be less useful in predicting which will exist than in indicating how alternative international agreements would alter the tendency to move toward each of those conditions.

work focused on industrial applications and the field thus came to be called Industrial Dynamics. The first major work was published under that title by Professor Forrester in 1961.<sup>3</sup> It detailed the general principles of complex system analysis and described their applications to inventory-workforce control problems in large industrial organizations. As the perspectives of the Sloan School widened from business administration to the management of broad social systems, the Industrial Dynamics group undertook a larger range of problems. The methodology was extended and refined through application to several hundred problems over the next decade. Studies ranged from the mechanism of homeostasis in the human body, to social problems of drug addiction and predator-prey relationships in animal populations. The general principles and the analytical tools which were developed in the course of these studies are now called System Dynamics.

Several major System Dynamics studies have resulted in books. In Dynamics of Research and Development Professor Edward B. Roberts relates resource allocation, policies, scheduling rules and individual motivation to the performance of large scale research programs.<sup>4</sup> As urban problems involving social unrest and economic decline became important in the United States, Professor Forrester employed the principles of System Dynamics to unify information from the fields of economics, sociology and political science in a radical new theory of urban decay.<sup>5</sup> His

3. Forrester, J.W., Industrial Dynamics, The M.I.T. Press, Cambridge, Massachusetts, 1961.

4. Roberts, E.B., Dynamics of Research and Development, Harper and Row, New York, New York, 1964.

5. Forrester, J.W., Urban Dynamics, The M.I.T. Press, Cambridge, Massachusetts, 1969.

prescriptions for the ills of stagnant cities have brought support to the Sloan School for a broadly based study of urban problems.

Developing countries receive more than ninety percent of their foreign exchange earnings from the export of primary commodities like cocoa and tin. Thus the pronounced instability in the prices of these products has disrupted the development programs of many poorer nations. Using System Dynamics methodology, Professor D. L. Meadows has identified for the first time a general theory relating the factors which make all commodities prone to price fluctuations.<sup>6</sup> Published in The Dynamics of Commodity Production Cycles this theory is being extended now to permit the design of more effective control methods.

The application of System Dynamics to those problems identified by the Club of Rome will be a logical extension of work conducted over the last decade. Implications of the research will be more profound, but the elements of the approach, the underlying methods, will be the same.

#### Application to World Problems


One important advantage of System Dynamics for the Club of Rome program is that it represents real world relationships pictorially or mathematically in terms quickly learned by everyone. Sophisticated mathematical ability is not a prerequisite for understanding and using the results of a System Dynamics study. Thus demographers, economists,

6. Meadows, D. L., The Dynamics of Commodity Production Cycles, Wright-Allen Press, 238 Main Street, Cambridge, Massachusetts, 1970.

governmental leaders and others interested in global problems will be able to apply the Phase One results readily to their own fields.

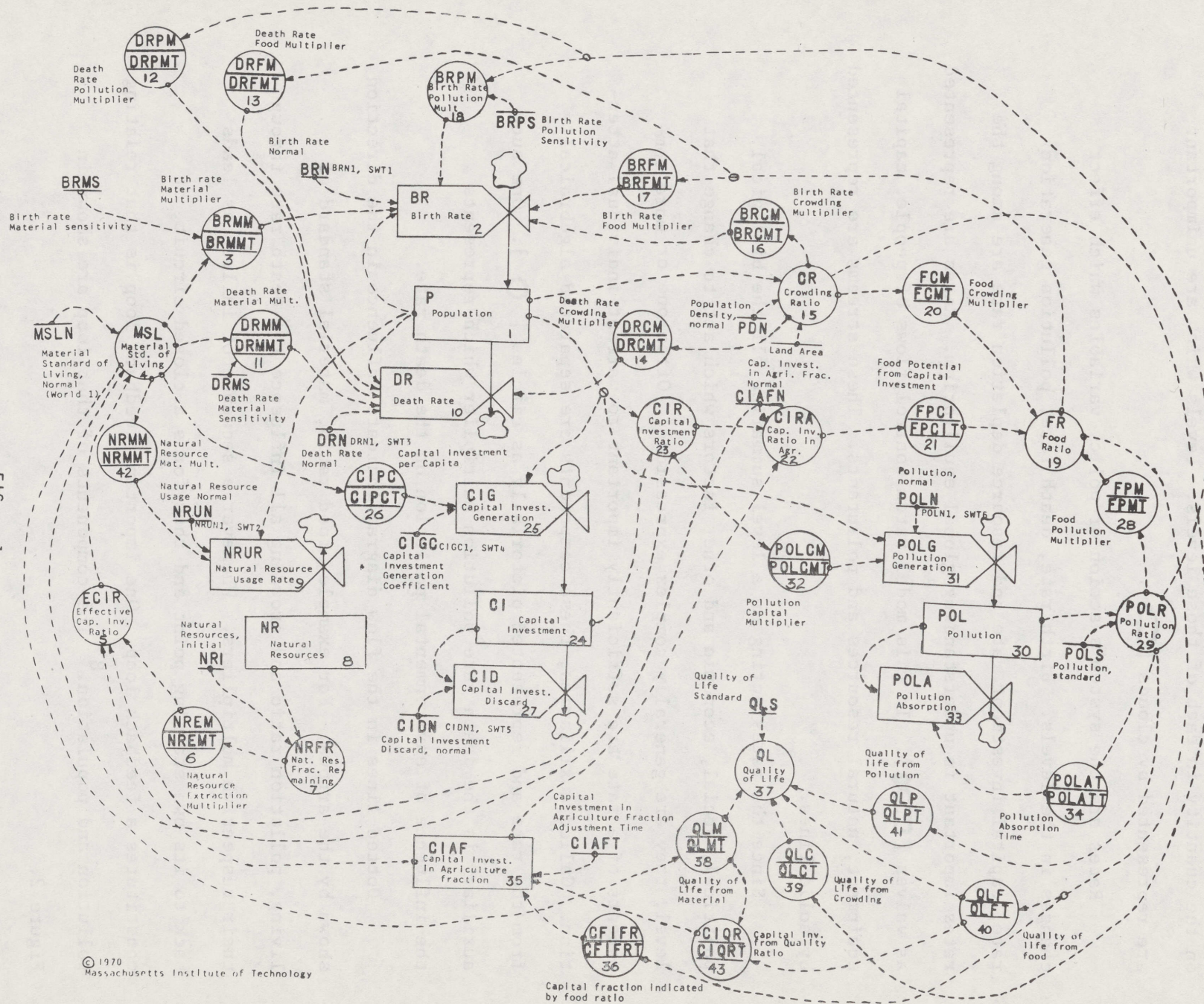
A detailed description of the System Dynamics approach is available in Principles of Systems.<sup>7</sup> A preliminary System Dynamics model of the world, that developed by Professor Forrester for the July 1970 Cambridge meeting, is briefly described here. It will illustrate the use of System Dynamics in understanding the characteristics of global equilibrium. Figure 1 is a flow diagram or pictorial representation of the assumptions in the model. The assumptions deal explicitly with the interrelations among the world's population, economic development, natural resources, pollution and food production capabilities.

These interrelationships depend on many aspects of the real world. Psychological factors influencing desired family size, biological effects of pollutants, physical determinants of capital depreciation and the economic influence of declining natural resource stocks are among the hundreds of factors which were considered in constructing the model.

Using the computer to conduct studies of model behavior requires that each assumption be expressed very precisely. According to the theory of System Dynamics only two types of variables, "levels" and "rates", are necessary to express any relationship in a system. Levels are the state variables which characterize the system at any point in time. Population, pollution, natural resources, capital investment and agricultural capacity (represented by the fraction of capital invested in agriculture) are the five levels in this preliminary model. All levels are represented by rectangles [  ]. Model behavior depends

7. Forrester, J. W. , Principles of Systems, Wright-Allen Press, 238 Main Street, Cambridge, Massachusetts, 1968.

FIG. 1  
FLOW DIAGRAM  
OF WORLD2



on the quantity in each of those levels. Levels which are unimportant are represented by clouds [☁].

Rates are the system's action or policy variables which effect changes in the levels. Birth rate, death rate, pollution generation rate, capital investment rate and resource depletion rate are among the rates important in understanding global equilibrium. Rates are represented as valves [⊗]. In this model rates control flows of people, capital equipment, natural resources and pollutants. These streams are represented by solid lines.

Since the rates acting on a level summarize all the biological, political, social, economic and other factors which act to change that level, they are generally complex expressions. Often one or more components of a rate are sufficiently important to warrant individual attention. Called auxiliaries, these components are separated algebraically from the rate and represented pictorially as circles [○]. One such auxiliary is the death rate pollution multiplier which represents the influence of environmental pollution on the death rate.

Dotted lines in the flow diagram indicate influence in the direction shown by the arrows. For example, food ratio, material standard of living, pollution ratio and crowding all influence the death rate through their respective multipliers. Whenever a sequence of influences leads back to its own starting point and thus forms a closed circuit, it constitutes a feedback loop. One important feedback loop is that relating pollution and population.<sup>8</sup> The components of that loop are shown in Figure 2.

8. The numbers on each element of the loop indicate the element's location in the total flow diagram.

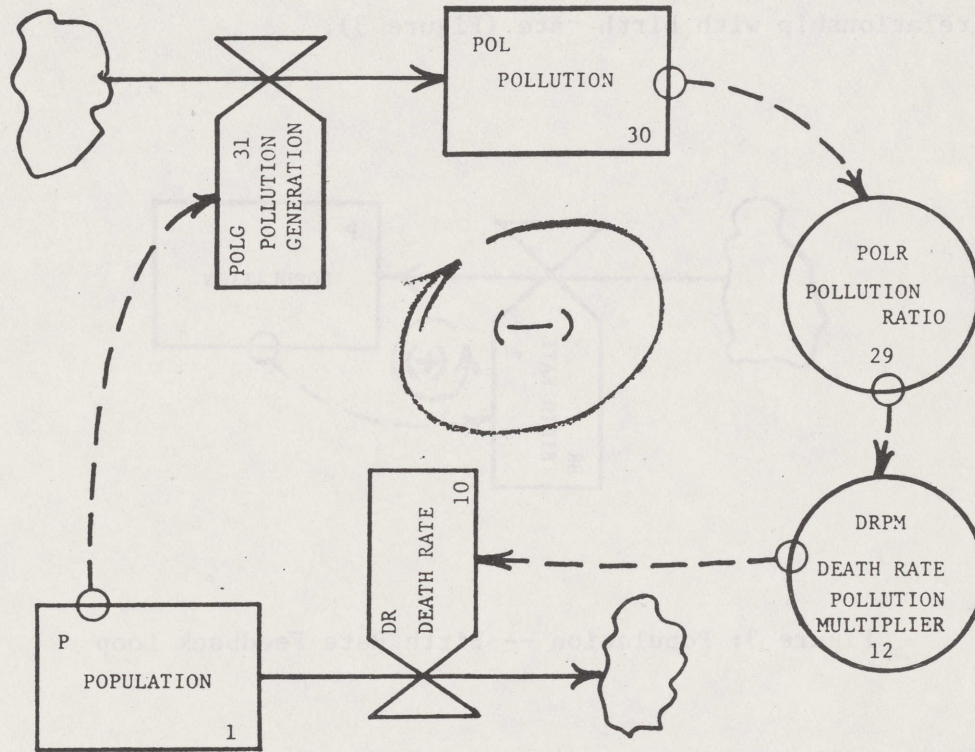


Figure 2: Population -- Pollution Feedback Loop

This particular sequence of influences is a negative feedback loop. In any negative loop a change in one element sets in motion a chain of events around the loop which eventually produces a counter-acting influence on that element. For example, a decrease in population decreases pollution generation and thereby lowers the level of pollution. As a result, the pollution ratio decreases and death rate is lowered, leading ultimately to greater population.

Feedback relations may also be positive. In that case a change in one element is propagated about the loop to result ultimately in a reinforcing change in the same element. Usually each element in a

system will be influenced by several positive and negative loops simultaneously. For example population is also involved in a positive feedback relationship with birth rate (Figure 3).

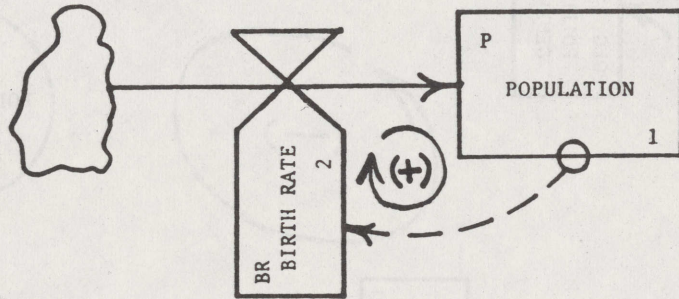


Figure 3: Population -- Birth Rate Feedback Loop

If population were suddenly increased, the number of people born per year would increase and thereby raise population even more.

Feedback loops differ not only in their polarity, positive and negative, but also in the delay with which their responses are propagated around the loop. The delays inherent in the second loop, shown in Figure 3, are about fifteen to twenty years. Delays in the former loop involving pollution and population may be fifty years or more. Thus it is in general very difficult to determine intuitively the exact implications of a given change for a particular level. An initial decrease in population might lead in the model above to either more or less population ultimately than if the decrease had not occurred. The final direction of the response would depend on the strength and the delay of relationships inherent in each loop where population is an element.

The fund of human experience contains much good information on the nature of the individual relationships underlying global problems. However, these relationships constitute feedback loops like those illustrated in Figures 2 and 3. Thus when it is necessary to analyze the probable effects of several simultaneous policy changes, human intuition is completely inadequate. Our failure to control complex social systems is not primarily due to any lack of data about their components. It stems rather from lack of the necessary tools for structuring that data and analyzing its dynamic consequences. Now, however, it is possible to include in formal models all the information available. Any real world relationship which can be expressed verbally can be incorporated in a System Dynamics model. Then computer simulation experiments can provide analyses very quickly and inexpensively.

During Phase One a world model will be constructed which contains the relationships necessary to represent and study many of the critical global problems identified by the Club of Rome. Among them are:

- explosive population growth with consequent escalation of social, economic and other problems.
- widespread poverty.
- generalized malnutrition.
- destructive agricultural practices.
- irrational practices in resource usage.
- increasing pollution.
- limited understanding of what is feasible in the way of corrective measures.

One dimension of our current dilemma is that actions made to alleviate

any of these problems often aggravate the others. Intensive use of fertilizers, for example, does increase food production, but it exacerbates water pollution. Accelerated economic development raises material standards, but increases social tensions, pollution and the depletion of natural resources. There are many alternative policies. Birth control, development of more efficient crops, increased recycling of natural resources and changes in the societal values which govern investment in capital. Some combination of these policies can be effective, but alternatives must be evaluated in the context of their total impact on all elements of our global society. The following simulations with the preliminary world model illustrate the mechanisms of policy studies based on System Dynamics models.

### ANALYSES OF THE PRELIMINARY MODEL

Each of the following simulation runs is essentially an experiment to determine the effect on total system behavior of one or more specific policy changes made in year 1970 of the system's evolution.

- Run STD.S      Standard run provided for reference.
- Run 12S        Technological changes are introduced in 1970 which permit natural resources to be used four times more efficiently.
- Run 22S        Conditions in Run 12 are supplemented by technological change which reduces the generation of pollution by 50% and by a shift in social priorities which increases capital investment generation by 20%

Because these analyses are based on the preliminary model WORLD2 they should be viewed primarily as illustrations of the approach, not predictions of outcomes which could be expected if the policy changes were actually implemented.

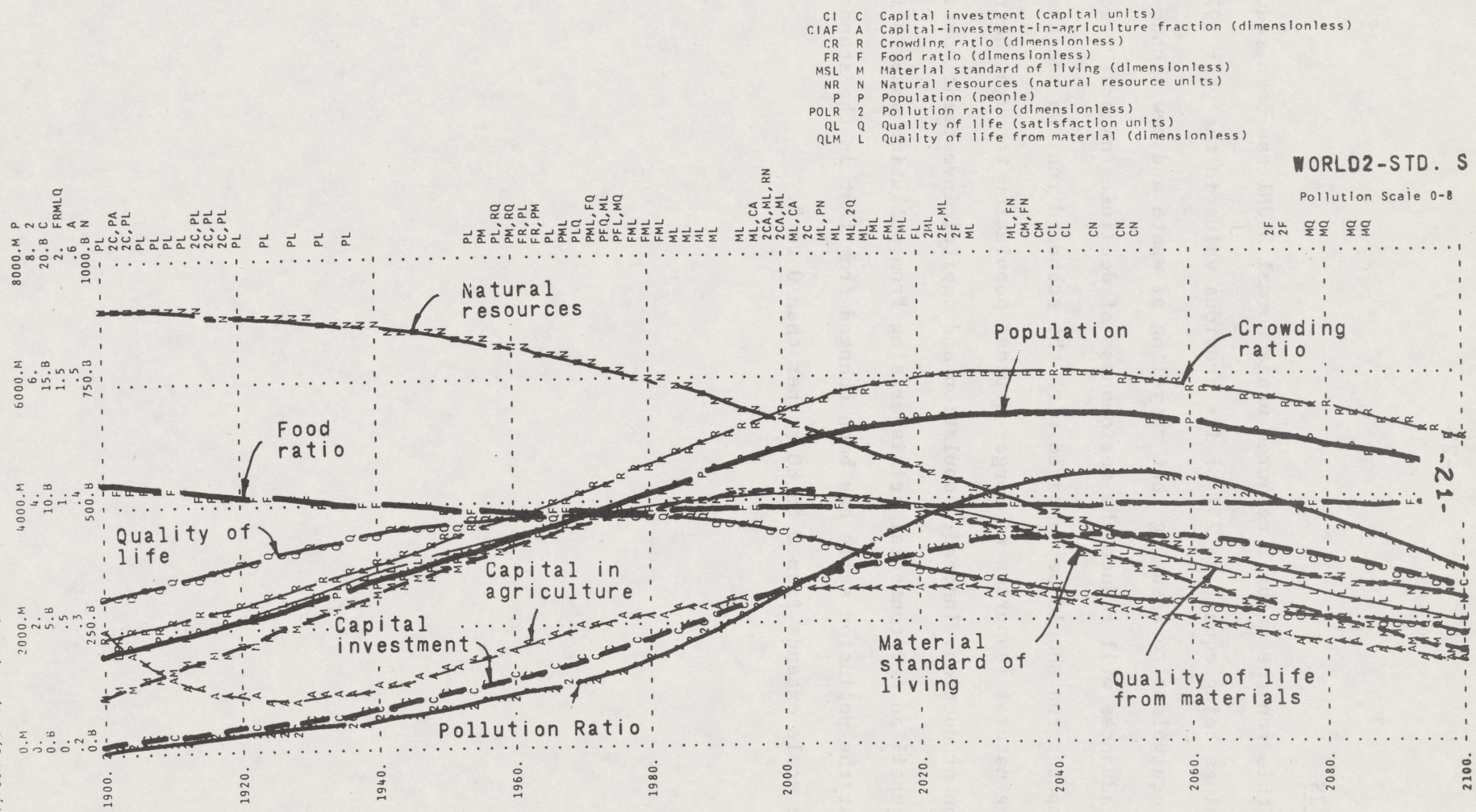
WORLD2-STD. S

This is the standard computer run from the WORLD2 model. The "S" suffix indicates that the plot card has been changed to give predetermined plotting scales and is done so that the curves can be more easily compared. The standard computer run shows a peak in population at about year 2030 and gradual decline thereafter. The population decline is occurring because of the depressing effect of declining natural resources.

It is interesting to note that quality of life reaches its highest point at 1970. Can this be reasonable considering today's strong worldwide feeling of distress and disenchantment? Perhaps so. A sense of well-being may be related more to "progress" and to improvements since the recallable past than to the absolute level of quality of life. A feeling of malaise could therefore occur at the peak of the quality of life curve because little improvement has been observed in the preceding two decades.

In this standard run, pollution peaks in year 2050 at about 4.5 times the pollution intensity of 1970. This is not a high enough value for pollution to enter importantly into the overall dynamic behavior.

P=P, POLR=2, CI=C, FR=F, CR=R, MS=L, QLM=L, QL=Q, CIAF=A, NR=N



WORLD2-STD. S

Pollution Scale 0-8

WORLD2-12S

In this run the natural resource usage normal NRUN1 has been reduced, other things being equal, to 25% of its previous value in the year 1970. This is equivalent to assuming that recycling of waste and new technological advances will reduce the seriousness of declining natural resources. This computer run should be compared with the standard run. We see that declining natural resources no longer depress population through their effect on production. Instead, population and capital investment continue to rise until an environmental crisis arising from pollution asserts itself. Note that the pollution scale has been changed from that in the standard run. Here the scale extends from 0 to 80 rather than 0 to 8.

P=P, POLR=2, CI=C, FR=F, CR=R, MS=L, QI=Q, CIAF=A, NR=N

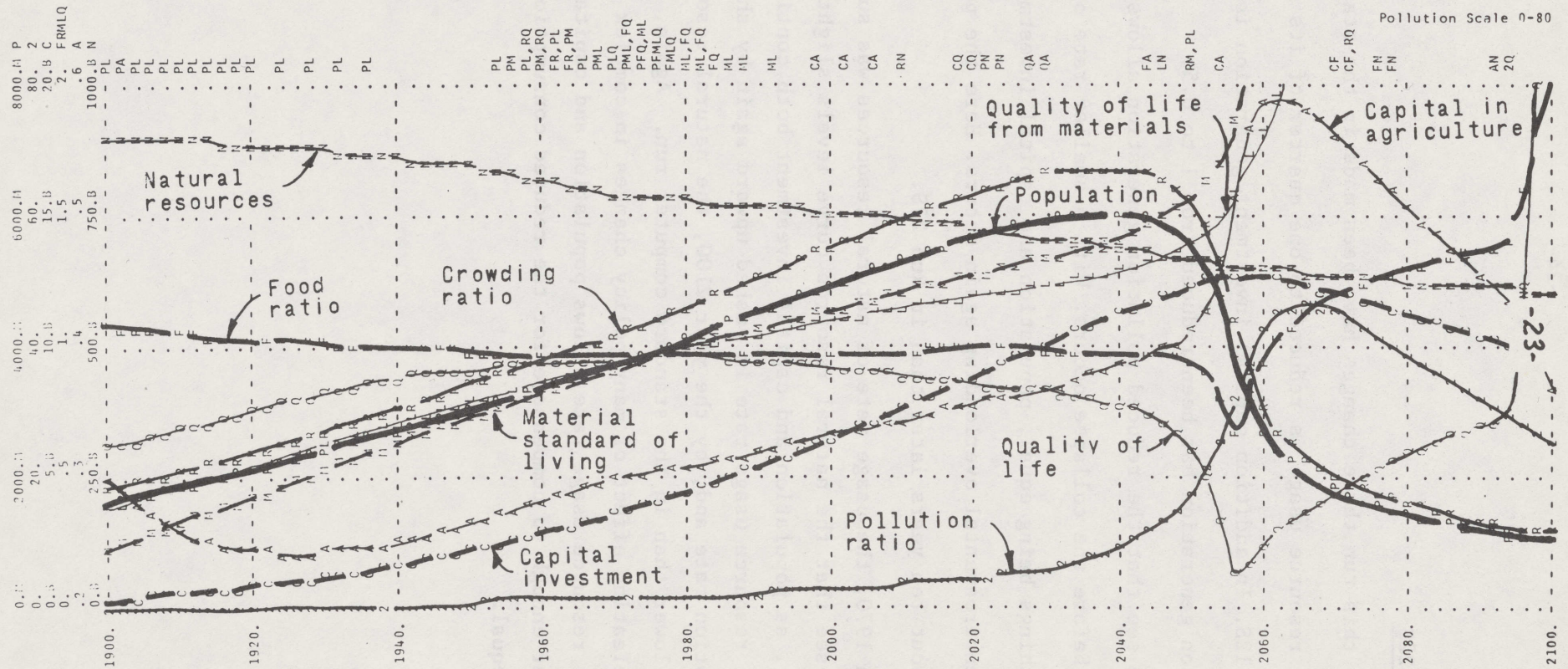
WORLD2-12S WORLD DYNAMICS W2 08/04/70 1621.5

HRUN1  
PRESENT .25  
ORIGINAL 1.

CI C Capital investment (capital units)  
CIAF A Capital-investment-in-agriculture fraction (dimensionless)  
CR R Crowding ratio (dimensionless)  
FR F Food ratio (dimensionless)  
MSL M Material standard of living (dimensionless)  
NR N Natural resources (natural resource units)  
P P Population (people)  
POLR 2 Pollution ratio (dimensionless)  
QL Q Quality of life (satisfaction units)  
QLM L Quality of life from material (dimensionless)

WORLD2-12S

Pollution Scale 0-80



WORLD2-22S

For this run three changes have been made in the standard model. Natural resource usage is reduced to one quarter of its previous rate as in Run 12S. In addition capital investment generation is increased 20% and pollution generation has been reduced from 1 to 0.5.

We see that the reduced pollution generation allows population to rise longer before the collapse occurs. With a smaller rate of pollution generation, other things being equal, population and capital investment continue to rise until environmental overloading again occurs. Here the peak population occurs about ten years later than in Run 27S.

In 1970, the usage rate of natural resources was substantially reduced and we see that the natural resource curve levels slightly at that time. However, as population and capital investment both continue to rise, the natural resource usage rate is pushed upward again by sheer magnitude of consumption rate and, by the year 2100, the natural resource level has fallen lower than in the standard computer run. Again, we see the self-defeating effect of many policy changes in complex systems. A reduced natural resource usage rate allows population and capital investment to rise far enough to compensate for the reduced consumption, other things being equal.

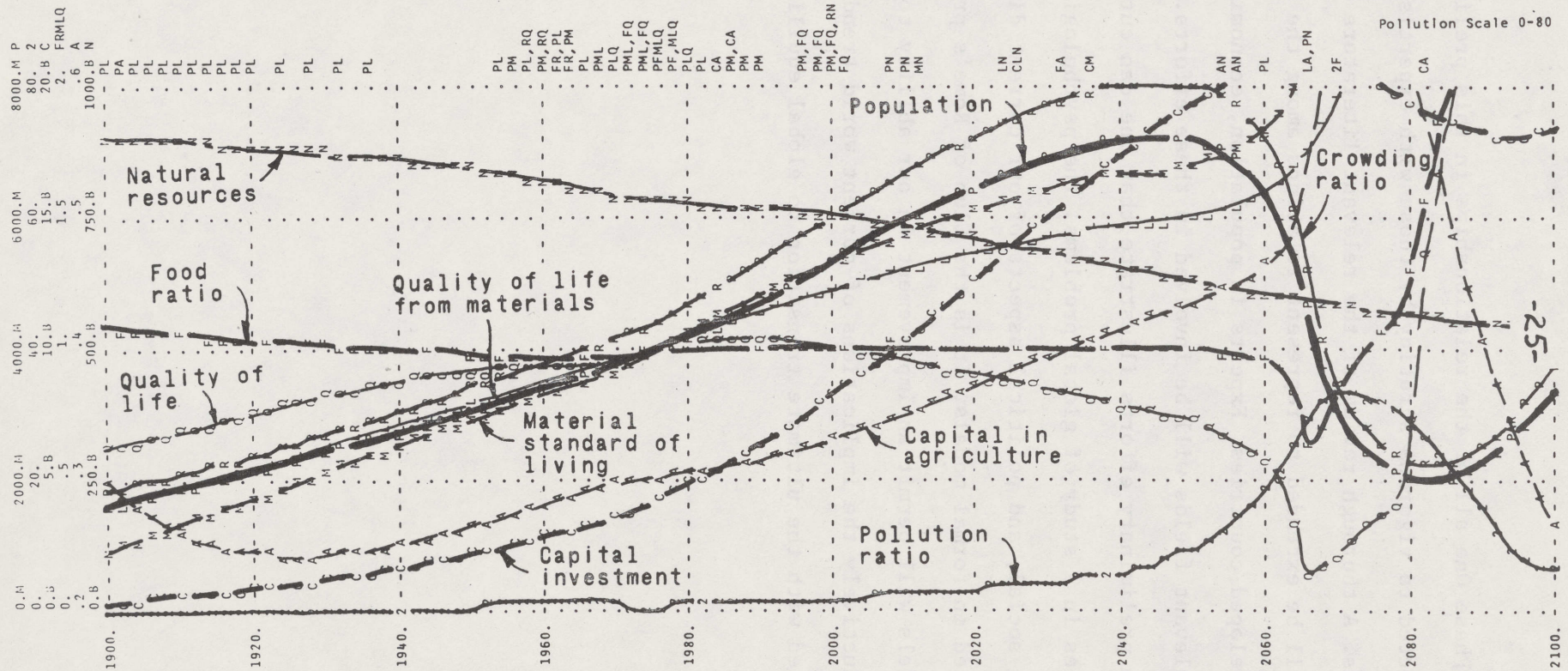
WORLD2-22S WORLD DYNAMICS W2 08/05/70 0848.4

	CIGC1	HRUN1	POLN1
PRESENT	1.2	.25	.5
ORIGINAL	1.	1.	1.

- CI C Capital investment (capital units)
- CIAF A Capital-investment-in-agriculture fraction (dimensionless)
- CR R Crowding ratio (dimensionless)
- FR F Food ratio (dimensionless)
- MSL M Material standard of living (dimensionless)
- NR N Natural resources (natural resource units)
- P P Population (people)
- POLR 2 Pollution ratio (dimensionless)
- QL Q Quality of life (satisfaction units)
- QLM L Quality of life from material (dimensionless)

WORLD2-22S

Pollution Scale 0-80



In Phase One all of the relationships in this preliminary model will be subjected to vigorous scrutiny by those with expertise in the appropriate areas. A thorough review of the relevant literature will be made. The model will be extended to represent relations among the advanced and the less developed countries. Experts in population, economic development, and other relevant fields will be involved in these efforts.

The preliminary efforts illustrate that one can cut across traditional boundaries in a study of global problems. The psychological, economic, biological, social, and political aspects of our current dilemma can be incorporated in formal models. It is the Club of Rome's profound hope that such models will permit an improvement in our ability to consider rationally and productively the implications of current world trends and the options associated with the ultimate transition to global equilibrium.

WORLD 3: THE GLOBAL MODEL

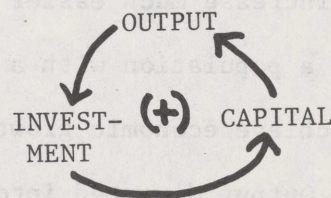
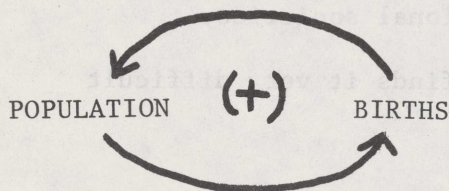
Ultimately--and the sooner the better--there must be a shift in the fundamental concerns of our society from a preoccupation with growth in the quantity of everything around us to a realization that quantity and quality have become irreconcilable enemies of one another.

Dr. Rufus E. Miles, Jr.  
President  
Population Reference Bureau, Inc.

Objectives

The exponential growth of population and capital tempers all global problems--unemployment, starvation, disease, pollution, the threat of warfare, and resource shortages. All are influenced importantly by the interaction of population and capital. No attempt to understand our long-term options can succeed unless it is firmly based on an understanding of the relationships between these two forces and of the ultimate limits to their growth. World 3 explicitly represents the growth forces as a function of the biological, political, economic, physical, and social factors which influence them. It permits analysis of the policy alternatives for natural resources, birth control, food production, economic development, etc. which we must now begin to evaluate.

Population and birth constitute a positive feedback loop. More people produce more births and more births result in more



people. Wherever there is a dominant positive feedback loop of this form, exponential growth will be observed. Wherever exponential growth is observed there must be a positive feedback loop of this type. Capital produces industrial output. Greater output, all else equal, results in a larger investment and thus in more capital. The interactions among population and capital determine the rate at which each of them grows. The interaction takes many forms (Figure 1, p. 34).

#### Basic Structure

As a greater fraction of output is diverted from investment, the growth rate of capital decreases. Output may be diverted to consumption and services, to agriculture, and to military expenditures. As consumption and services increase, health and education improve, average lifetime becomes greater, deaths decrease, and population grows. Similarly, output may be diverted into agricultural capital which results ultimately in greater food and food per capita as well as a higher average lifetime. The primary determinant of the fraction of output reinvested is the output per capita. Where production per capita is low, most of the output must be diverted to consumption, services, and food. Those investments interfere with the accumulation of a large capital base and, at the same time, stimulate the growth of population. Population can increase much easier than capital in traditional societies. Thus a population with a low output per capita finds it very difficult to achieve economic growth.

Output diverted into military expenditures subtracts capital

from the system and does not generate future growth directly. Industrial output also leads to the depletion of natural resources. As natural resources decline, the efficiency of capital decreases and output/capital goes down.

Output per capita is the single positive force acting to slow the population explosion. As output per capita increases, the desired family size declines, the birth rate goes down, and population growth typically decreases. The influence of this is accelerated somewhat by the fact that as death rates decline there is a further decrease in desired family size. A large portion of the world's parents bear children primarily as a source of support in their old age. If there is a high mortality rate, one must bear three or four sons to insure that one will live. Thus as the perceived death rate decreases, birth rates also decline. Output has one additional impact. Output leads to the generation of pollution. Pollution decreases food, and also decreases the average lifetime. Most global problems have important roots in this simple set of interactions.

For example, behind the program to implement the Green Revolution has been the assumption that an exogenous increase in food production capabilities of the less developed countries would permit less output to be invested in agriculture and more to be reinvested in capital, moving the process of capital investment into the phase of self-sustaining growth. A secondary argument has been that the increased food per capita would decrease deaths somewhat and thereby depress the birth rate.

In fact an alternative conclusion might be justified. The increased food from the Green Revolution might as easily increase the food per capita, decrease the death rate, and leave population to grow very rapidly. Should this happen, the increase in population might be very much greater than the increase in capital. Output per capita could remain the same or even decline, thereby drawing a larger percentage of output into consumption and services and maintaining the stagnant economy.

The Green Revolution has been implemented only for three years. Thus the resolution of this issue is still a few years off. However, it is ironic that while billions of dollars were spent in massive modeling efforts to think through every future step of a program to land three men on the moon, no similar effort was made to understand beforehand the possible implications of the Green Revolution for our ability to maintain three and one half billion people on the globe. The global model is a first tentative step in the development of tools necessary for such analyses. The full set of assumptions are represented in the DYNAMO flow diagram (Figure 2, p. 35).

#### Preliminary Conclusions

This model is based on the best available data found and summarized through our six months of effort. It has been evaluated by experts in universities, in national governments, and in various United Nations agencies in the U.S. and abroad. There is little disagreement with the preliminary conclusions.

1. There is no possibility of sufficient technological and cultural progress occurring in the next 100 years to sustain

as many as fourteen billion people on our globe. Since the doubling time of population is currently 32 years and decreasing, this means that sometime within the next 60 years population growth will undergo a profound deceleration.

2. There is no possibility of bringing the vast majority of those living in the developing countries up to the material standard of living enjoyed by the developed nations.
3. There is a strong probability that the western nations will witness a marked decline in their own material standard of living within the next 3 or 4 decades.
4. There is no unique, optimal long-term population level. Rather there is an entire set of tradeoffs between personal freedom, material and social standard of living, and the population level. Given the finite and diminishing stock of resources on this globe, we are inevitably faced with the necessity to recognize that more people implies a lower standard of living.
5. There is, in theory, no fundamental human value which could not be better achieved through a substantial lowering of the global population base.
6. There is a very strong probability that the transition to global equilibrium will involve a traumatic decline in population. It is our conclusion that the overwhelming task for the Club of Rome is to identify and implement that set of policies which will permit us to negotiate an orderly transition to equilibrium. We must bring a transition which, though it will cause drastic changes, will leave us with most of the attributes

which we value in our society and which will preserve options for those who must live on this globe a century and more from now.

No one we have talked with has offered any scientifically based disagreement with the above conclusions. To the contrary, many at high levels of the U.N., the World Bank and similar organizations hold personal opinions much more pessimistic than those of our project staff.

#### Hierarchy of Research

It has become clear that a global model already can provide insights into the general nature of the limiting factors on growth and can provide an overall context for conversations and investigations about specific aspects of global problems. It can point very sharply to the necessary interface conditions which must be met by policies addressed to the problems in any particular problem sector. It aids in identifying the critical areas of effort. World3 has served all these purposes. Its design and its runs will be described during the conference. Its flow diagram is enclosed as Figure 2.

To ensure confidence in the conclusions of World3 it has been necessary to go in detail to each of the five sectors: Capital, Food Production, Pollution, Population and Natural Resources, and to examine certain social and political phenomena not specifically addressed by the global model. We have undertaken a hierarchy of research studies. Each sub-study addresses a critical phenomenon identified in simulating the global model. The results of each sub-study provide insights into the level of aggregation and the important factors which should be included in revisions



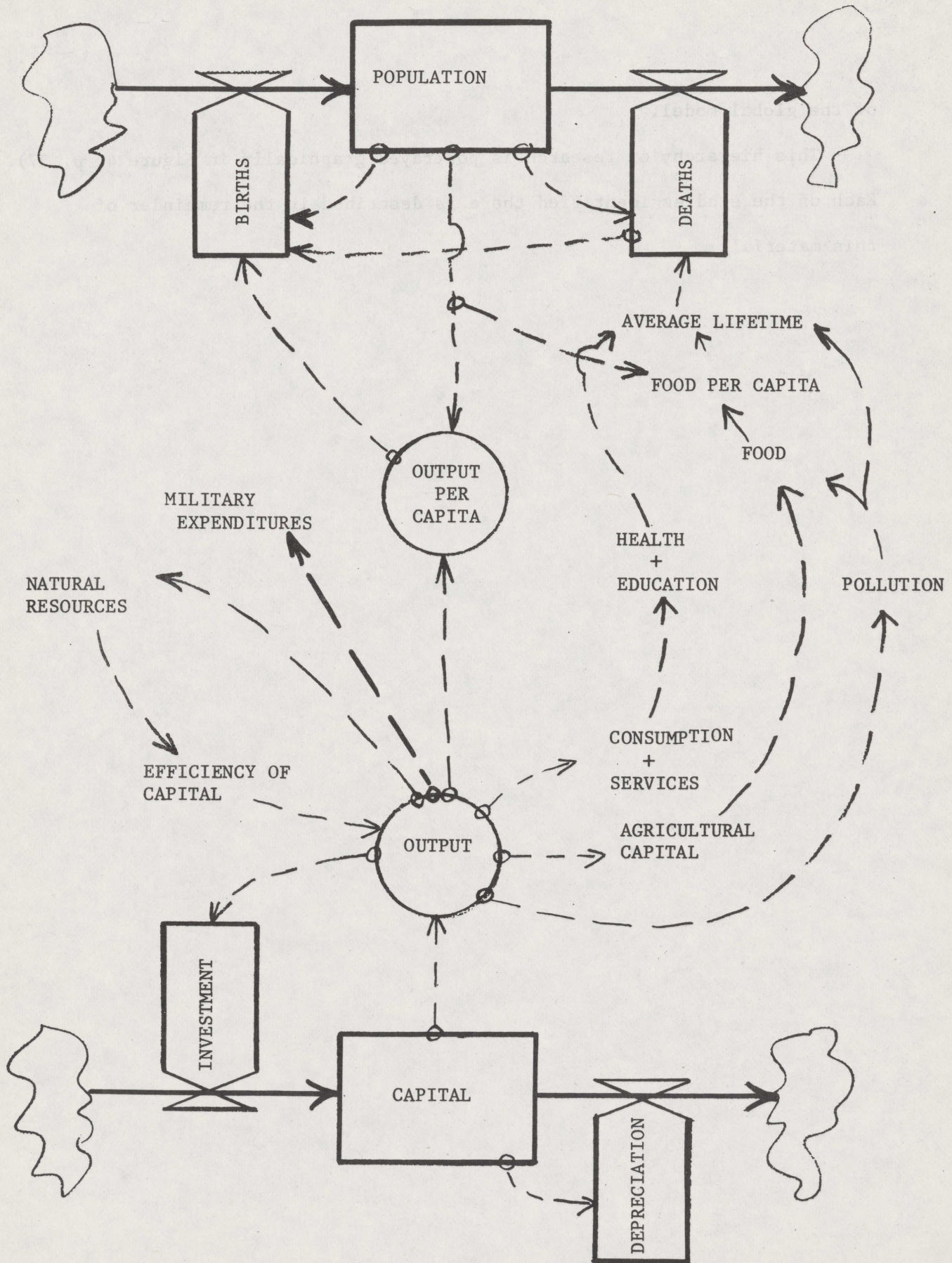
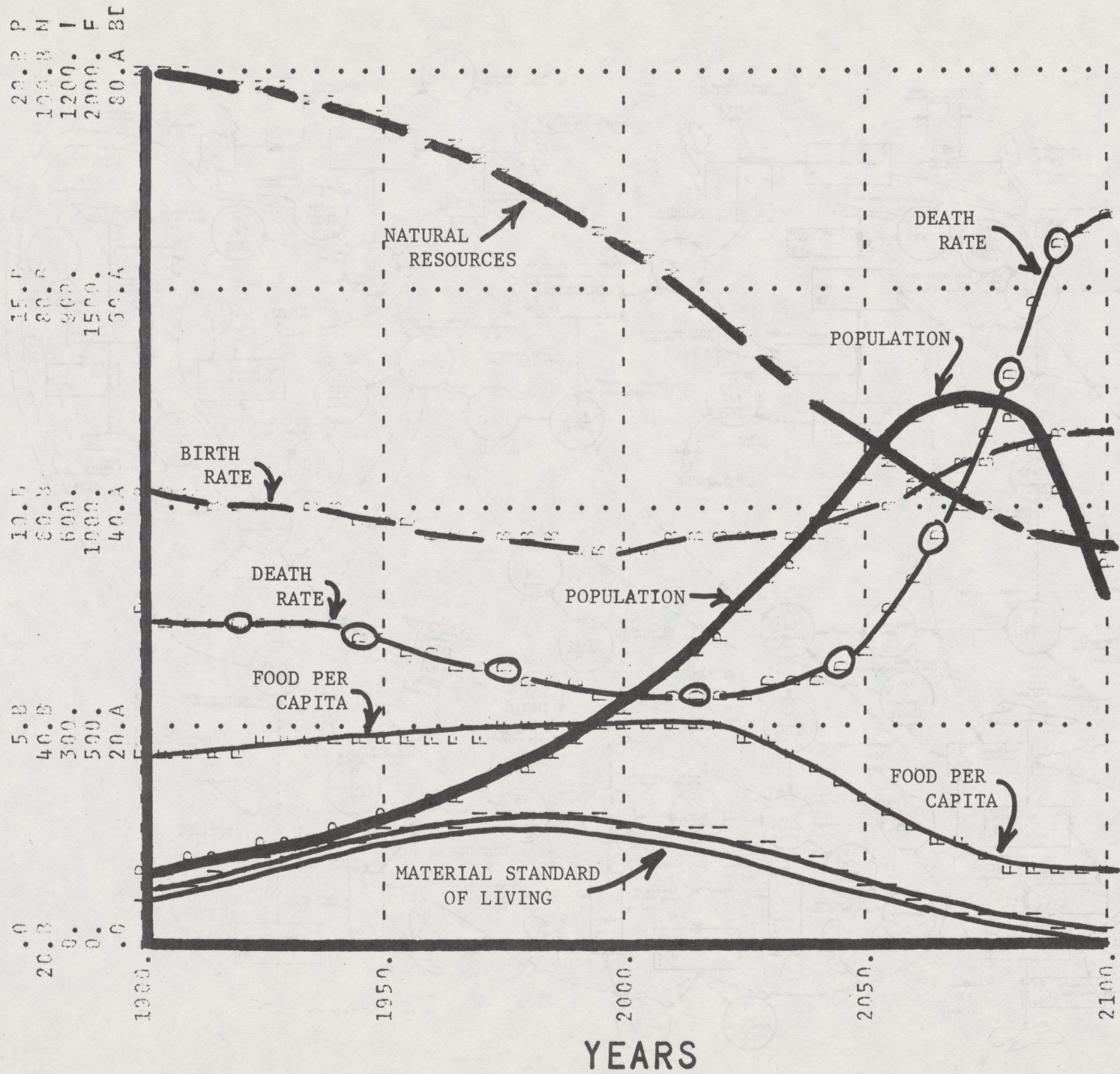


Figure 1: Basic Interactions in the World Model



Figure 3: Sample Simulation of World 3:  
Resource Depletion Halts Growth



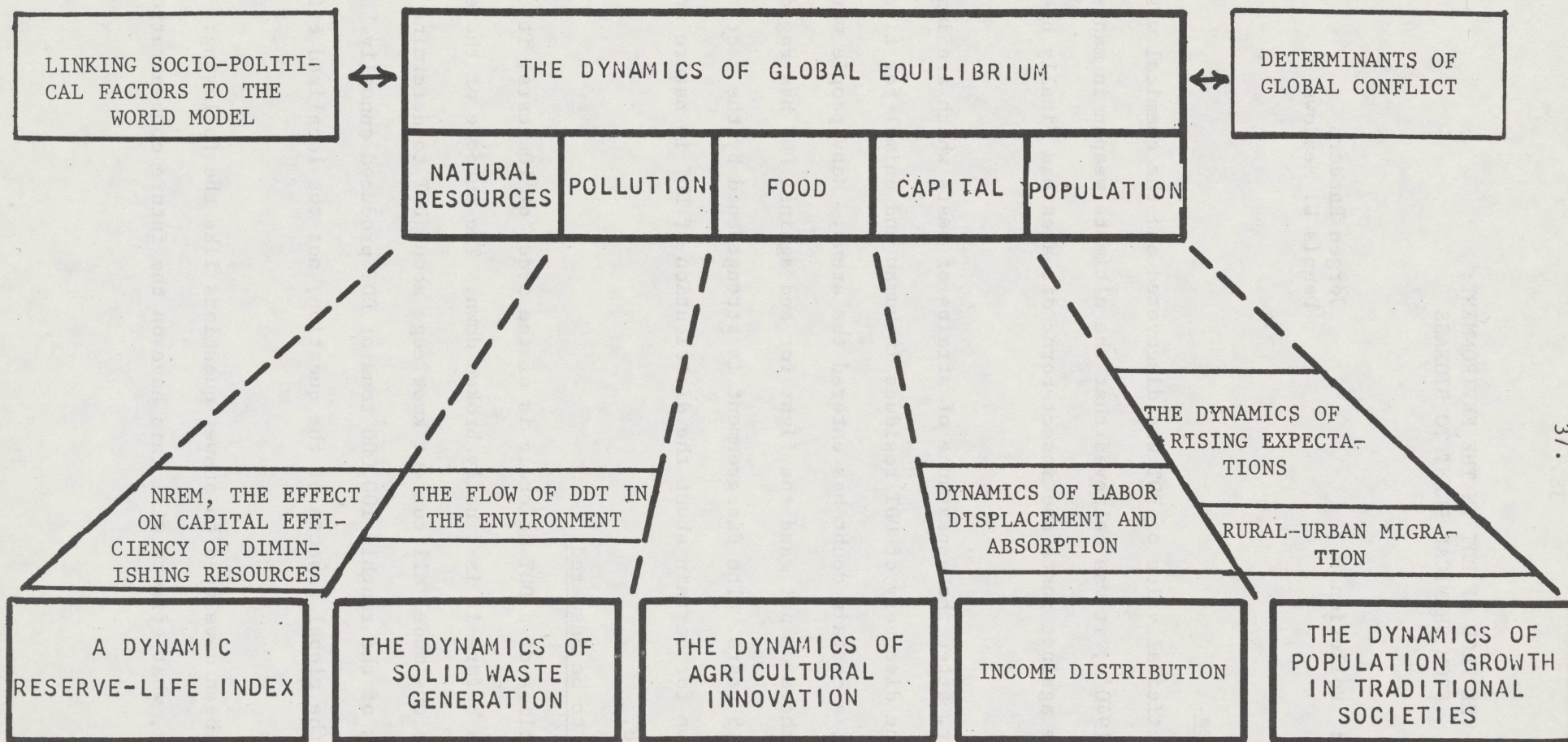


Figure 4: THE HIERARCHY OF RESEARCH IN PHASE ONE OF THE CLUB OF ROME "PROJECT ON THE PREDICAMENT OF MANKIND"

THE FLOW OF DDT IN THE ENVIRONMENT:  
FROM CHEMICAL PLANT TO BIOMASS

World Model Sector: Pollution

Jørgen Randers  
Dennis L. Meadows

General Problem Area.

When the insecticidal value of DDT was discovered and the chemical was put to use in the 1940's, it was believed that the ultimate weapon in man's continuing struggle against pests and insect-borne diseases had finally been found.

Today, however, after the appearance of strains of pests which are immune to DDT and after the discovery of DDT residues in human and animal fat tissue all over the world, a certain doubt has entered the arena. Many people want DDT banned while others do not, and the fight for and against DDT has raged for the last 10 - 15 years. The disagreement is strengthened by the fact that very little is known for certain about the distribution of DDT in nature and its effects on life.

Specific Questions to be Answered.

Since the halflife of a DDT molecule is of the order of 10 years, it can move long distances before it is finally broken down. The purpose of the study is to assemble into one model all current knowledge about DDT to determine the future implications of the roughly 100,000 tons of DDT produced annually. We are interested in the global aspects of the question, not the localized effect in the sprayed area.

The model has been developed to answer questions like the following:  
If we ban DDT today, what effects will this have on the future concentration

of DDT in fish? Will DDT concentrations really start to decrease at once as one tends to expect? Is it necessary to know numerical values for the parameters (e.g. degradation halflives, evaporation rates, concentration factors, excretion halflives) in the system with great accuracy before making meaningful policy decisions regarding DDT? If so, on which parameters should we focus our research effort?

#### The Model.

Our study of the existing literature led us to the conclusion that the important routes followed by DDT in the environment are the ones shown in the field flow diagram in Figure 1.

The more elaborate DYNAMO flow diagram is shown in Figure 2.

#### Model Simulations.

Running the model using the best existing estimates for the parameters in the model resulted in the output shown in Figure 3. The run uses historically correct application data for the time period 1940-1970--following this year, however, we have assumed a gradual decrease in the usage of DDT over the next 25 years. As can be seen from the figure, the DDT concentration in fish does not peak until 11 years after the year of maximum DDT usage (i.e. 1971). Moreover, the concentration of DDT in fish does not fall below the 1971 value until 1996 (i.e. only after 25 years).

To determine whether the above conclusions are very sensitive to the parameters values used, two runs were made (Figures 4 and 5) with respectively extremely pessimistic and extremely optimistic choices of parameters. The result was a delay of, respectively, 20 years and 7 years between maximum application and maximum DDT concentration in fish.

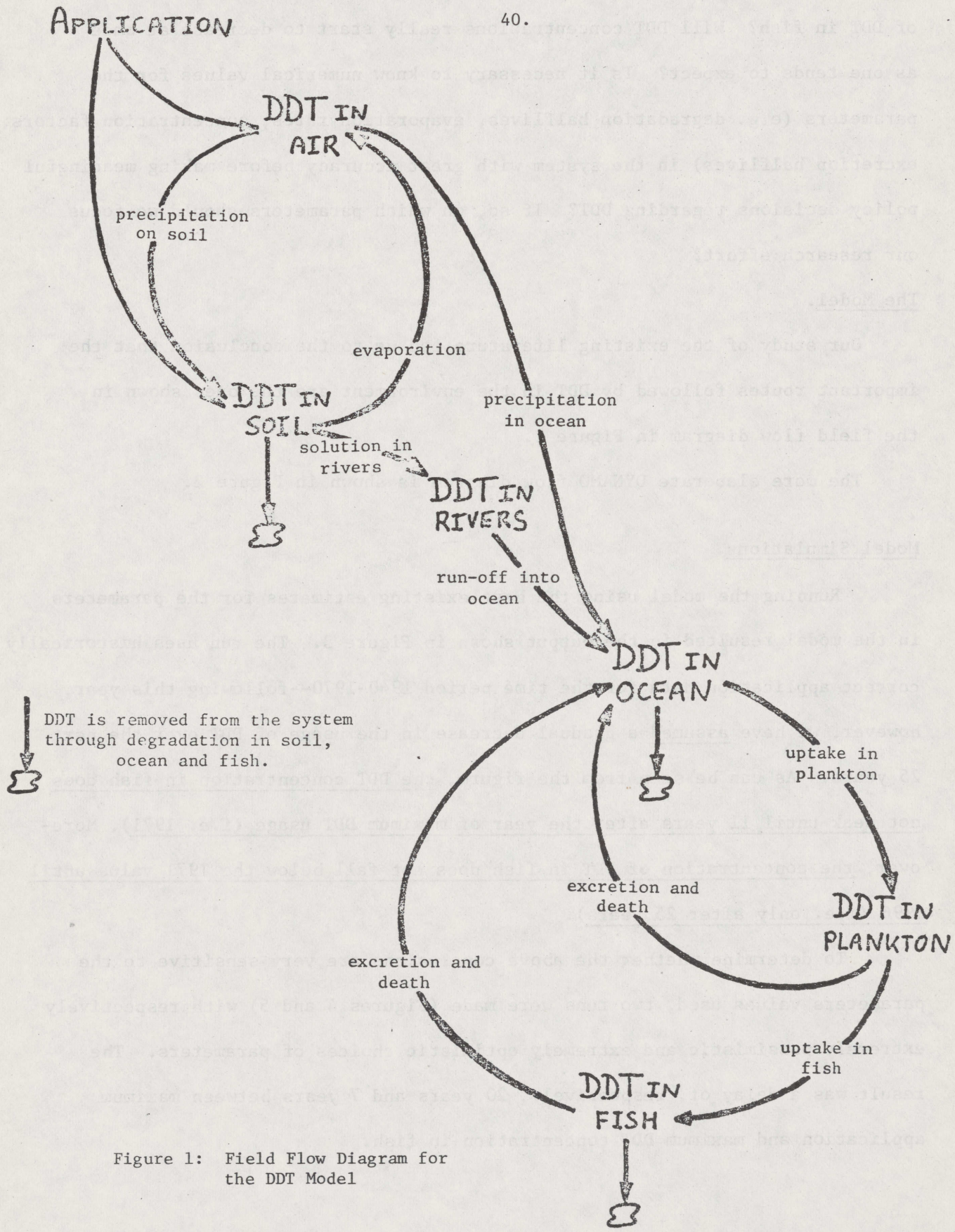


Figure 1: Field Flow Diagram for the DDT Model

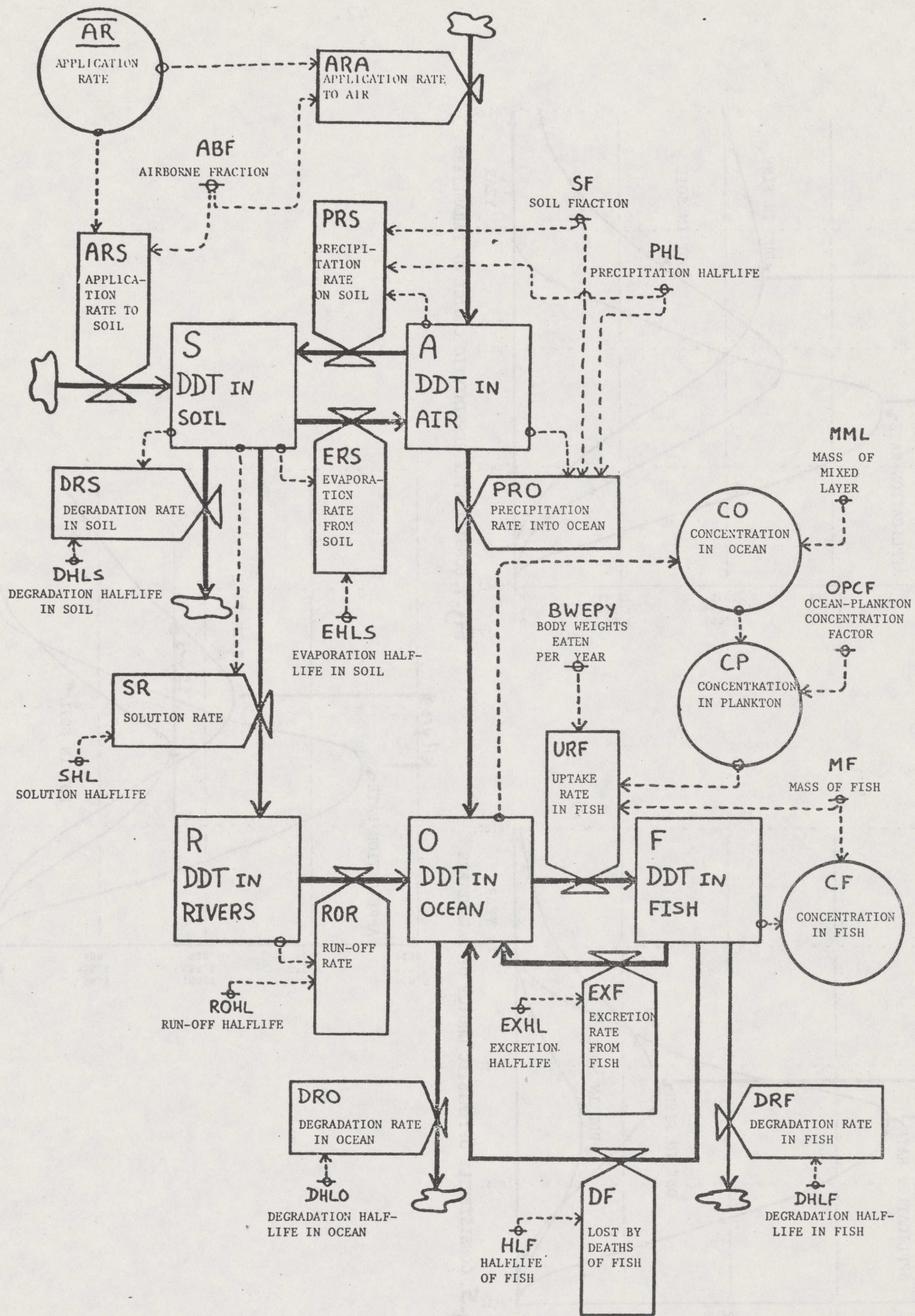


Figure 2: Flow Diagram for the DDT Model

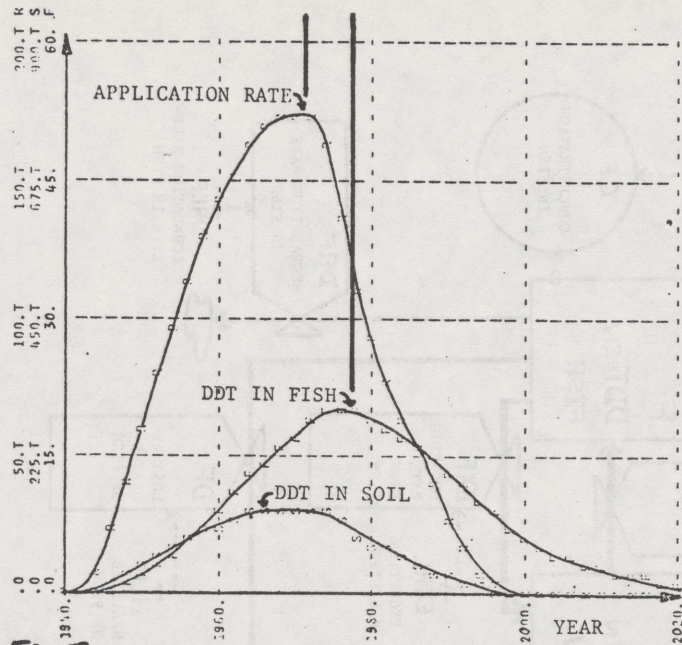


Fig. 5. CONSISTENTLY OPTIMISTIC CHOICE OF PARAMETERS

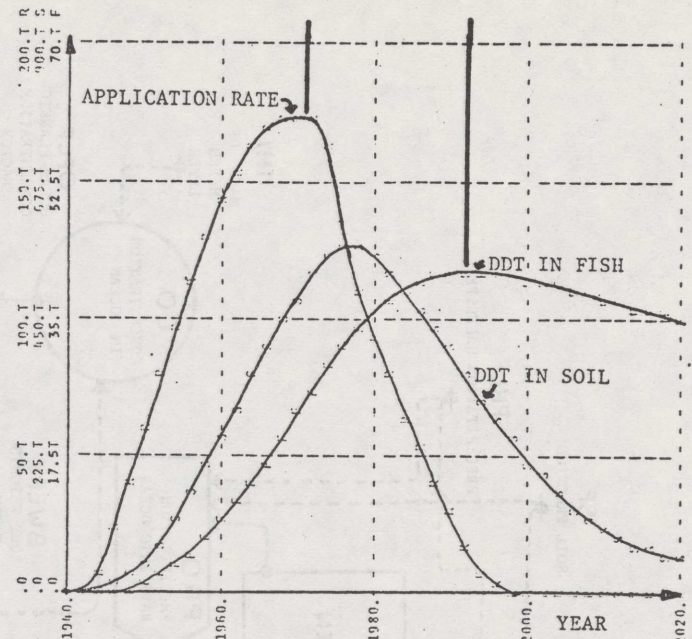


Fig. 4. CONSISTENTLY PESSIMISTIC CHOICE OF PARAMETERS

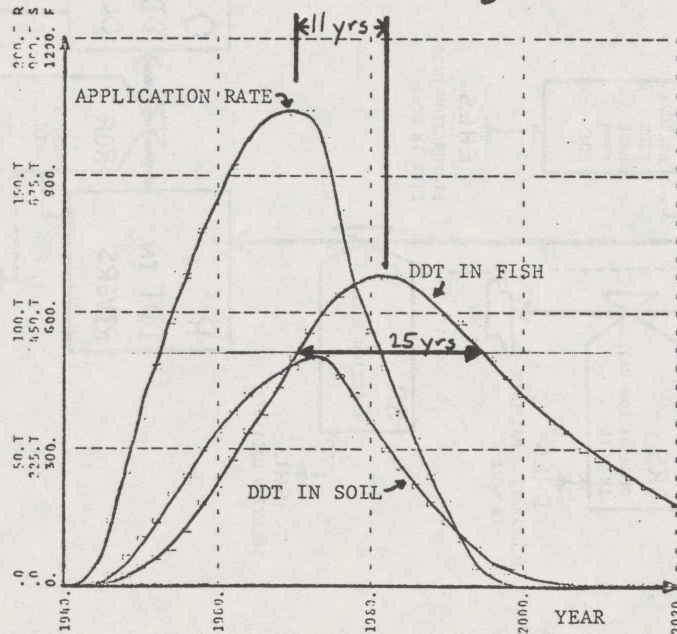


Fig. 3. BEST ESTIMATES USED FOR ALL PARAMETERS

#### Policy Implications.

Keeping in mind that the two last choices of parameters represent extremes which are quite unrealistic, we think that it is safe to say that a "delayed response" of DDT concentration in fish with respect to a decrease in the use of DDT will occur. Further, the length of the delayed response and the levels to which DDT pollution rises even after DDT usage begins to decline both suggest that waiting for damage at environmental levels to be proven before application is decreased is not an adequate policy. Even a total ban on the use of DDT leaves society exposed to high levels of DDT contamination for 30 years. The results of a complete ban are demonstrated in Figure 6. It should be noted that even in this case we will have half the present concentration of DDT in fish in 1990.

#### Contacts and Information Sources.

The study report will be included in the official reference materials for the United Nations Conference on the Environment in Stockholm in 1972.

Thirty-three literature sources have been incorporated in the full report.

#### Future Research.

A draft report on the study is in preparation. This will be submitted to pesticide scientists and ecologists for criticism. A revised version will be submitted for publication in May.

The structure of the DDT model is relevant also to the flow of heavy metals and other long-lived pollutants (e.g. mercury) through our ecosystem. The model and its coefficients will be adapted to model several other potentially important pollutants.

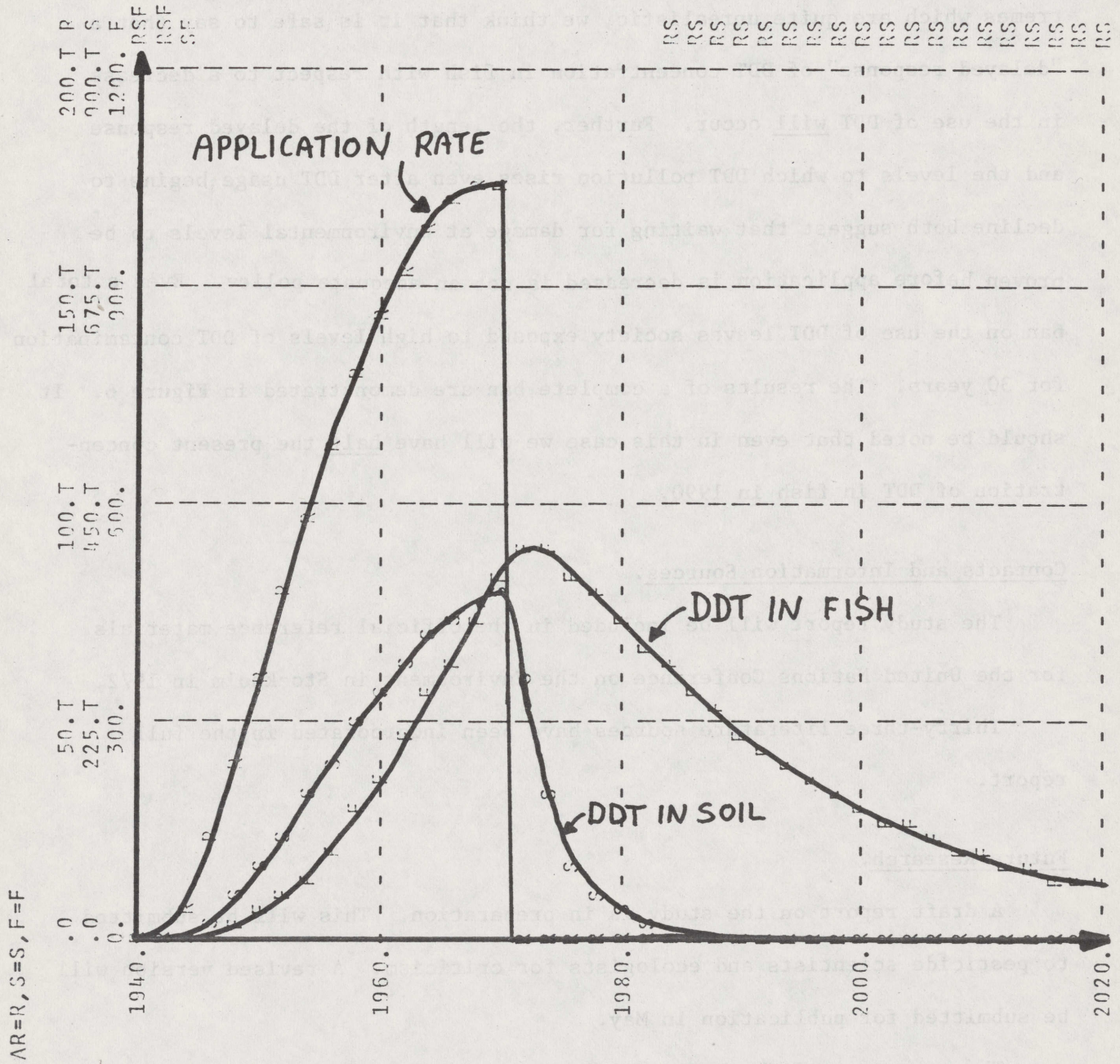


Figure 6: Realistic Projection of the Effects of a Total Ban on the Use of DDT Enacted in 1971

Where to find more.

The final report will be available after May 1, 1971 from

Jørgen Randers  
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U.S.A.

## WORLD MODEL SECTORS: NATURAL RESOURCES AND POLLUTION

## The Dynamics of Solid Waste Generation

Jørgen Randers

General Problem Area: Natural Resources and Solid Waste.

All industrialized countries have an urgent solid waste problem. The problem, which is characterized by an ever-increasing solid waste generation rate, has two aspects: a pressing shortage of waste dumping areas and rising depletion of non-renewable natural resources.

The flow of the earth's natural resources into enormous junkyards of solid waste must be slowed down. If we do not succeed in this, the industrialized world will certainly be unable to maintain its high standard of living while the less developed world never will catch up with our present level.

The Specific Question Studied: How do we reduce the solid waste generation rate?

We want both to slow down the consumption of natural resources and to reduce the environmental degradation caused by the growth of our dumps. The one satisfactory approach is to reduce the flow of materials from natural resources to solid waste. If the standard of living is not to be immediately decreased, this can practically be done only by increasing the products' lifetimes (no planned obsolescence, cheaper repair) or by recycling of the material in the discarded products.

Hence we would like to answer questions like: What determines the size of the material flow from natural resources to solid waste? What determines the percentage of virgin and recycled material in the flow? How can one increase the recycled fraction? What are the effects of using more durable products? What are the relative advantages of different policies (e.g. tax

on extraction, subsidy for recycling) meant to enhance recycling? Can we afford to let naturally occurring price increases stimulate recycling, or should we undertake now to subsidize recycling and sponsor research to develop better recycling technology?

Solid Waste System for a single resource from an international point of view.

In order to study the above mentioned questions, we constructed a System Dynamics model based on the feedback interrelationships shown in Figure 1 (Figure 7 in Solid Waste Paper)\* These feedback loops determine the behavior of the natural resource - solid waste system when the system is viewed from a rather aggregate point of view.

The flow diagram of the computer model itself is shown in Figure 2 (Figure 21 in Solid Waste).

Output from the Model: How does the natural resource - solid waste system respond to policy changes?

The system parameters were chosen so that the model represents the world's copper market, and the resulting run is shown in Figure 3 (Figure 24 in Solid Waste). (The horizontal axis shows the time in years.)

Figure 4 (Figure 26 in Solid Waste) shows the results of introducing a subsidy for recycling while Figure 5 (Figure 31 in Solid Waste) shows the results of making products with longer lifetime.

Policy Implications of the Study.

No one policy can avoid the ultimate depletion of our natural resources; it is, however, possible to postpone its occurrence substantially by a carefully chosen set of policies.

It is also useful to note that some of the more obvious policies have unexpected ("counter-intuitive") effects -- like the fact that a reduction of the raw material per product may in fact increase the solid waste generation

\* "Solid Waste Paper" refers to the study report (see page 50 of this summary).

rate because the "light-weight" products have a very much shorter product lifetime. Also the cost-effectiveness of different policies varies widely. The actual effectiveness can only be determined through simulation analyses.

Work with the model has led us to the following general conclusions:

1. Recycling ought to be supported heavily and immediately by taxing extraction or subsidizing recycling -- for instance by supporting technological advances which make recycling less expensive and by attempting to make products that can be recycled more easily.
2. One should strive towards increased product lifetime -- by making better products and by providing better repair and maintenance service.
3. One should strive towards minimizing the amount of raw material in each product, but, and this is extremely important, only as long as this does not lead to unduly shortened product lifetime.

What we want to minimize is

$$\frac{\text{amount of solid waste per product}}{\text{product lifetime}}$$

which is equal to the solid waste generation rate (in tons/year) for one product. We are not interested in reducing the solid waste per product if that leads to a proportionally shorter product lifetime.

4. Objectives 2 through 3 can be attained by a tax on products which is proportional to the waste in the product divided by the product lifetime.

Such a tax would represent an incentive to industry to reduce the solid waste per product to a minimum (e.g. by making products

easily recyclable or by reducing waste through improved construction) and at the same time to increase product lifetime (e.g. by better construction or better repair and maintenance facilities).

5. It should finally be pointed out that these policies ought to be implemented as fast as possible in order to have maximum effect. If we wait for natural price increases or the first resource shortages to initiate these policies, it will be too late to forestall severe shortages.

#### Outside Groups reporting interest in the Project.

The Massachusetts Commission on Solid Waste Recycling represented by Professor David Wilson, M.I.T., has expressed interest in the present work and requested that its recommendations be presented before the Committee.

United States Senator Thomas Eagleton, who obtained a copy of the preliminary study report, sent it to Mr. William Ruckelshaus, Director of the Environmental Protection Board in Washington with a special recommendation that it be studied for its relevance toward current U.S. resource policy.

A seminar on the early phases of this work was presented before Resources for the Future, Washington, D. C.

Finally, The Royal Norwegian Council for Scientific and Technological Research has requested permission to use the study in an attempt to decide on long run policies regarding pollution and solid waste in Norway.

#### Future Research.

We will revise the preliminary study report to reflect the comments we have received and write up the final draft. Then this model will be combined with the model of technology advance by William Behrens before adapting its

coefficients to represent several specific, critical resources.

Where to Find More on the Subject.

The complete study report, "The Dynamics of Solid Waste Generation" (76 pages with 39 figures) can be obtained from

Jørgen Randers E40-214  
Massachusetts Institute of Technology  
Cambridge, Massachusetts - 02139  
U.S.A.

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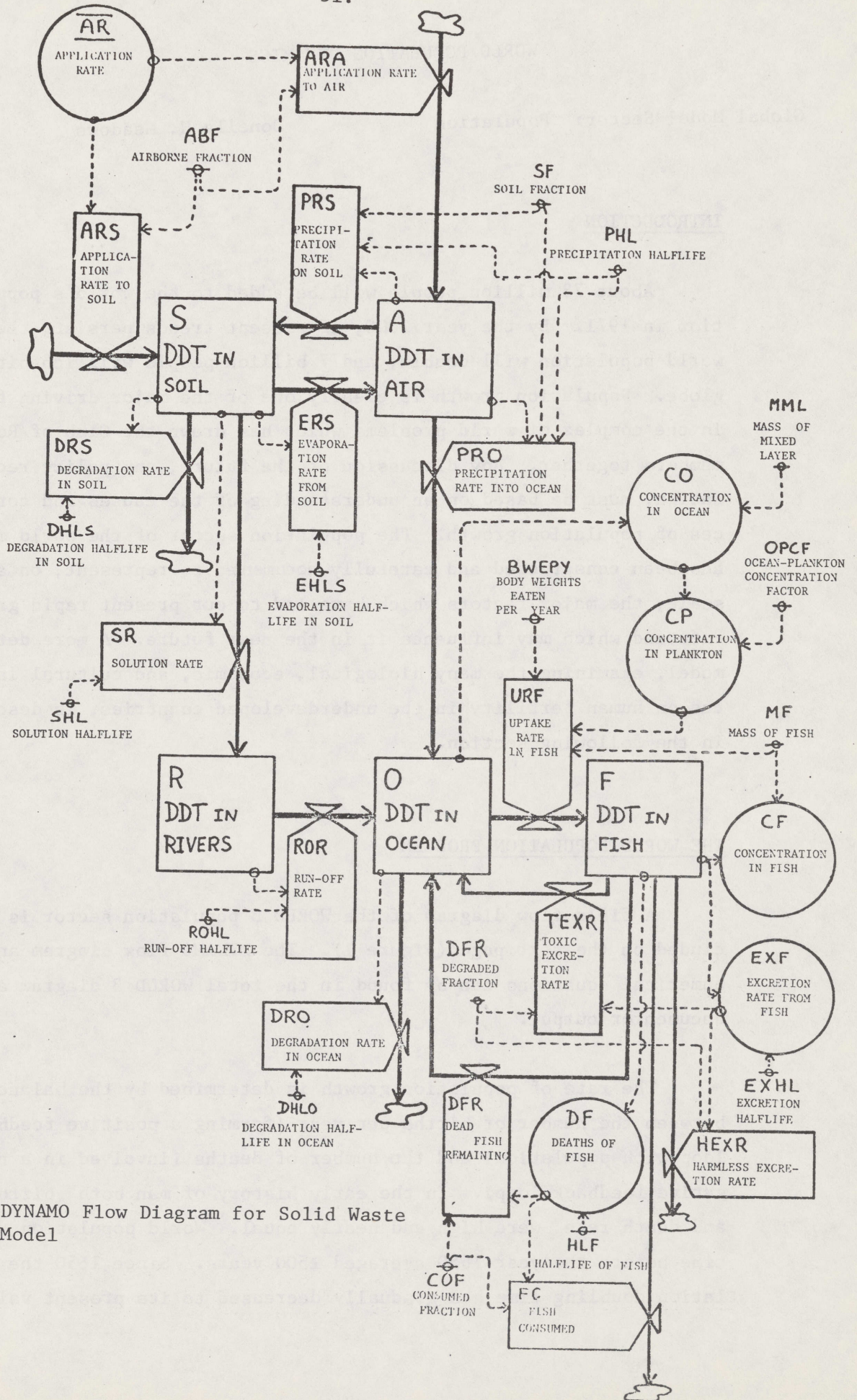


Figure 2: DYNAMO Flow Diagram for Solid Waste Model

## WORLD POPULATION DYNAMICS

Global Model Sector: Population

Donella H. Meadows

INTRODUCTION

About 73 million people will be added to the world's population in 1971. By the year 2000, if present trends persist, the total world population will double, and 7 billion people will inhabit our globe. Population growth is clearly one of the major driving forces in the complex of world problems which has drawn the Club of Rome members together. Any discussion of the future, any policy recommendation, must be based on an understanding of the causes and consequences of population growth. The population sector of the world model has been constructed and carefully documented to represent, on a broad scale, the major factors which have led to our present rapid growth rate and which may influence it in the near future. A more detailed model, examining the many biological, economic, and cultural influences on human fertility in the underdeveloped countries, is described in the following section.

THE WORLD POPULATION PROBLEM

A field-flow diagram of the WORLD 3 population sector is included on the next page (Figure 1). The DYNAMO flow diagram and numerical equations can be found in the total WORLD 3 diagram and documentor output.

The rate of population growth is determined by the balance between the number of births per year (forming a positive feedback loop with population) and the number of deaths (involved in a negative feedback loop). In the early history of man both birth rate and death rate were high and nearly equal. World population doubling time before the year 1650 averaged 1500 years. Since 1650 the population doubling time has gradually decreased to its present value of

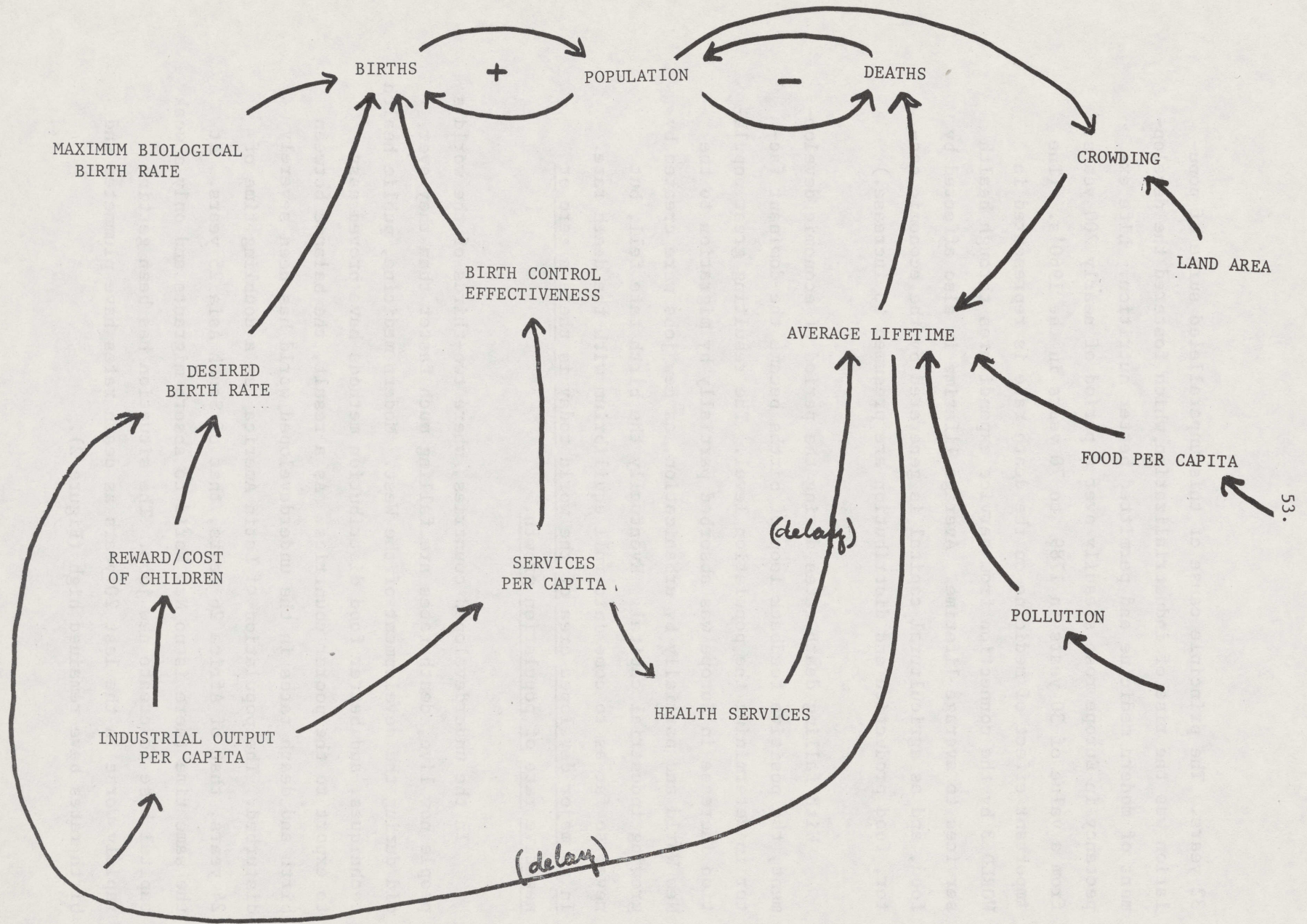


FIGURE 1

WORLD MODEL POPULATION SECTOR

32 years. The principle cause of this unparalleled surge of population was the rise of industrialization, which fostered the development of modern medicine and permitted better nutrition. Life expectancy in Europe rose steadily over a period of nearly 200 years, from a value of 30 years in 1789 to 70 years in the 1960's. (The important effect of medicine on the death rate is represented in WORLD 3 by the connection from service expenditures through health services to average lifetime. Average lifetime is also affected by food, and as agricultural capital is generated by the economic sector, food production and distribution are presumed to increase.)

With falling death rates during the period of economic development, the positive feedback loop of births became the dominant factor in determining the population level. The resulting great population increase in Europe was absorbed partially by migration to the New World and partially by urbanization, as new jobs were created by growing industrial capital. Eventually the birth rate fell, but never so far as to come into full equilibrium with the death rate. In no major developed area of the world today is there a zero or negative rate of population growth.

In the underdeveloped countries, where two-thirds of the world's people now live, death rates are falling much faster than they ever did during the development of the West. Modern medicine, public health techniques, and better food distribution methods have proved easy to export to the poorer countries. As a result, the balance between birth and death rates in the underdeveloped world has been severely disturbed. The population of Latin America has a doubling time of 24 years, that of Africa 26 years, that of South Asia 25 years. At the same time there is no New World to absorb migrants and only a weak capital base to create new jobs. The situation has been getting rapidly worse in the last 20 years as death rates have plummeted and birth rates have remained high (Figure 2).

The global population doubling time in the next decade or two will almost certainly continue to decrease. Death rates have not yet completed their decline. The world average life expectancy in 1969 was 53 years. That of India was 43 years, Peru 55 years, and the African continent 43 years. If birth rates remain at their present level, all present forecasts of future population growth will be too low. The supra-exponential population growth curve will continue until some limiting factor -- food shortage, crowding, pollution, or breakdown of health services -- increases the death rate again to bring a new equilibrium (or very much slower rate of growth) at a higher level of population.

Will the birth rate decrease, as the family planners of the world hope? The WORLD 3 model has assumed three major determinants of birth rate. One is the maximum biological birth rate, the rate at which a population would produce children if there were no voluntary checks on intercourse or fertility. The maximum biological birth rate is essentially constant around the world.<sup>1</sup> The desired birth rate is the rate at which births would occur if all unwanted births were eliminated -- if every family produced exactly its desired number of children. The birth control effectiveness measures the degree to which the population can achieve its desired birth rate. It is, in other words, a moderator between maximum and desired birth rate.

Both desired birth rate and birth control effectiveness are indirect functions of industrialization, or the standard of living of the population. It is empirically well established that a low living standard leads to a desire for a large family. As income is raised, desired family size decreases, until, at very high income levels, there is a weak positive relationship between per capita income and number of

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1. Trends towards improved nutrition actually increase the maximum fertility, but this is a secondary consideration.

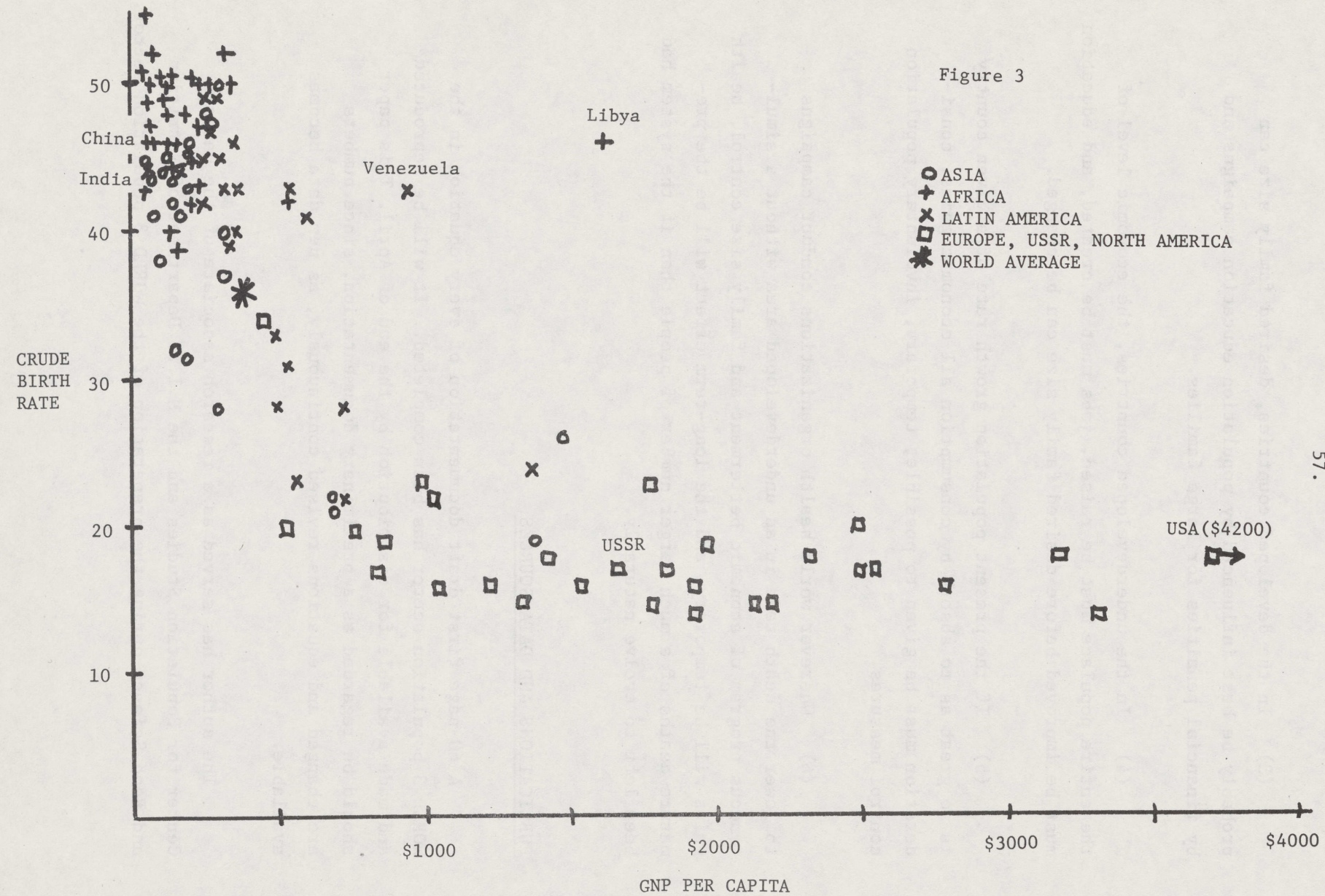
children desired. At the same time, a higher income (and the resulting better education) tend to make birth control effectiveness higher. The following graph of 1969 birth rates of the various countries of the world vs. GNP per capita (Figure 3) illustrates the strong effect of income on birth rate in all the major cultures of the world. The two main exceptions, Venezuela and Libya, are countries where the wealth, in both cases from oil exports, is very unevenly distributed. The actual per capita GNP of the vast majority of the population is far lower than that indicated, and therefore the birth rate remains high.

The most important point to be derived from the WORLD 3 model of fertility is that effective birth control is a necessary, but not a sufficient condition for low birth rates. If the population actually wants a large number of children, family planning programs will have no effect, other than to replace the primitive control methods already used by every population (abstinence, abortion, withdrawal) by more palatable methods. The most effective lever for reducing birth rate is an economic one.

#### CONCLUSIONS FROM THE STUDY

(1) The growth of world population must be checked as soon as possible. There will be a long and unavoidable delay between a drop in individual fertility and a decrease in total population growth, due to the extremely young age distribution of the population. If a voluntary decrease in the world birth rate does not occur soon, there will be an inevitable, uncontrollable increase in the death rate, due to some natural negative check in the system.

(2) Improved contraceptive measures and family-planning programs will continue to have no effect where there is no effort also made to influence the desired family size of the population.



(3) In the developed countries, desired family size can probably be best influenced by population education campaigns and by financial penalties for large families.

(4) In the underdeveloped countries, the economic level of the entire populace must be raised, jobs must be created, and education must be improved before desired family size can be changed.

(5) If the present population growth rate of a given country is so great as to absorb by consumption all economic gains, consideration must be given to possible, temporary, involuntary population control measures.

(6) Wherever world health organizations conduct campaigns to lower the death rate in an underdeveloped area without a simultaneous program of economic betterment and family size control, health gains will be temporary, and the long-term effect will be the premature deaths of a much larger number of people than if the system had been left to evolve naturally.

#### PUBLICATIONS AND DATA SOURCES

A 60-page first draft documentation of every equation in the WORLD 3 population sector has been completed. It will be reproduced and made available for distribution by the end of April. This paper should be regarded as a preliminary documentation, since numbers are changed and equations revised continuously, as new data becomes available.

The author has served as a research associate of the Harvard Center for Population Studies and the M.I.T. Department of Nutrition and Food Science during the preparation of the WORLD 3 population sector.

Members of both institutions have made substantial contributions to the data and concepts incorporated in the model. Among them are:

Dr. John E. Gordon  
Senior Lecturer  
Department of Nutrition, M.I.T.;

Dr. John B. Stanbury  
Professor of Nutrition, M.I.T.;

Dr. David M. Heer  
Professor of Population Sciences  
Harvard University;

Dr. John B. Wyon  
Senior Research Associate and  
Lecturer on Population Studies  
Harvard University;

Dr. Charles Neave  
Assistant Professor of Population Studies  
Harvard University;

Dr. Harold A. Thomas  
Professor of Civil and Sanitary Engineering  
Harvard University.

Other important sources were:

Dr. Carroll L. Wilson  
Professor of Management, M.I.T.;

Dr. Milos Macura  
Director, Population Division  
United Nations, ECOSOC.

And publications of:

The Population Council;

The Population Reference Bureau;

The United States Agency for International Development.

## POPULATION DYNAMICS IN THE TRADITIONAL AGRICULTURAL VILLAGE

Global Model Sector: Population

Donella H. Meadows

Introduction.

Fifty percent of the world's people, seventy-five percent of the people in underdeveloped countries, live in traditional agricultural villages. These villages are characterized by a direct dependence on the output of the village land, a near-subsistence standard of living, a high birth rate and, thanks to the spread of modern public health measures, a rapidly falling death rate.

The people in the villages have found two ways of dealing with the recent increase in their population growth rate. They cultivate the village lands more intensively, and they migrate to the town or city, in hopes of finding a better living there. Migration is an effective release of population pressure for the village, but it creates immense problems for the cities. Jobs, homes, and educational facilities must be found for the influx of unskilled laborers and their families. If the capital base is not sufficient, the result is a ring of squatters' shacks around each city, and, eventually, a high probability of social unrest.

The governments of the underdeveloped countries have instituted numerous policies designed to impact at the village level. Examples of such policies are family planning to decrease the birth rate, the Green Revolution to raise the village productivity and the standard of living, and decentralization of industry to reduce the flow of migrants to the city. The village system has proved extremely resistant to any of these changes. In particular, no birth rate of any traditional society has been changed by any factor other than a sustained rate of economic growth substantially greater than the rate of

population growth. In other terms, there has been no successful family planning effort in any area where per capita income was low and not growing.

Object of the Study.

What factors influence birth, death, and migration rates in an agricultural village? What are the internal regulatory mechanisms already existent in the village? Is there any alternative way to decrease fertility other than vast economic investment? How much and by what mechanisms may present development programs be expected to modify the traditional village society? Could one devise a program which works within the present village structure to aid the acceptance and achievement of national development goals?

We have begun a detailed model of the population dynamics of the traditional agricultural village in an attempt to answer the above questions and to illuminate the underlying dynamic structure of the World3 population sector. The preliminary work on this model has been divided into four sectors. This paper will discuss the determinants of fertility and mortality of the traditional village. The following two papers deal with the causes and consequences of migration and the effect on the system of changing aspirations and contact with the outside world. When these three sectors are completed and interlocked, they will be combined with the agricultural model prepared by Dr. Erich Zahn under the economic sector of World3. Possible policies, such as education, family planning, and agricultural modernization, will be modelled as exogenous influences to test the response of the total village system to outside pressure. A search will be made for a policy or combination of policies which

1. decreases the growth rate of the village population
2. decreases the rate of net out-migration
3. increases the standard of living of the village.

### The Village Fertility-Mortality Model.

The following flow diagram (Figure 1) illustrates the basic relationships assumed for the fertility and mortality sectors of the agricultural village model. Population is indicated as a single level, although it may be necessary to disaggregate it by age, to represent short-term fluctuations in the birth rate and the size of the labor force.

The female reproductive cycle is explicitly represented, so that factors such as long breast-feeding, which is a known anti-fertility measure, can be assessed. Abortions and stillbirths, frequent in many traditional societies, are included, since they may significantly increase the average interval between successful pregnancies. Net births refer to children who survive until age two. Infant mortality is assumed to have a short-term effect on fertility, since there is often an immediate attempt to replace a dead child. Thus the current proposal to decrease fertility by attempting to lower infant mortality can be weighed against the concomitant increase in net births. Adult mortality has a more long-term effect on desired family size. Effectiveness of contraception plays much the same role as it does in the World3 population sector -- it determines how effectively a family can reduce its fertility to the desired level rather than that which would prevail if no contraception were employed.

### Conclusions.

The simulation runs presented in this section must be regarded as preliminary, since they are based on simplified assumptions about migration and social change. A more accurate representation will be possible when the migration and aspiration sectors, described in the following papers, are combined with the fertility model. These runs are included only to demonstrate that the model village displays the same stability as real villages in underdeveloped countries, and



that the model response to external policies is characteristic of real-world results.

Figure 2 shows the natural equilibrium of an agricultural village with no contact with the modern world. Births and deaths are high, food and income are at subsistence levels, and the slight rate of population increase is exactly balanced by a small stream of out-migrants. Total village population is constant.

In Figure 3 a team of public health workers comes to the village at year 50 and gradually establishes public health improvements and medical care facilities. Medical care increases gradually from year 50 to 100 and then stays constant at a high level. Both adult and infant mortality rates decrease and net births increase since fewer babies die. The village population increases from its equilibrium value of 8,000 to about 12,000. As a result food per capita decreases, causing a rise in number of out-migrants and in death rates. Eventually a new equilibrium is reached, in which the village has more people living at a lower standard of living, sending more migrants to the city. In spite of the better medical care, the adult mortality rate has decreased only slightly and the infant mortality rate has actually risen because of poor nutrition.

Figure 4 illustrates a development program similar to those in effect today. In addition to the medical care increase introduced in Figure 3, gradual increases in agricultural output and in birth control efficiency (a family planning program) are imposed, beginning in year 50 and continuing to year 200. There is a sudden drop in death rate and an initial increase in net births (due to greater survival of infants), followed by a gradual decline in the birth rate. Per capita income and food rise at first, but in the long run the increase in population outstrips the increasing land productivity,

POP=P, MORT=D, CRP=B, DES=X, IMORT=I, IC=\*, M=M, DICPC=+, IPC=\$, FDC=F

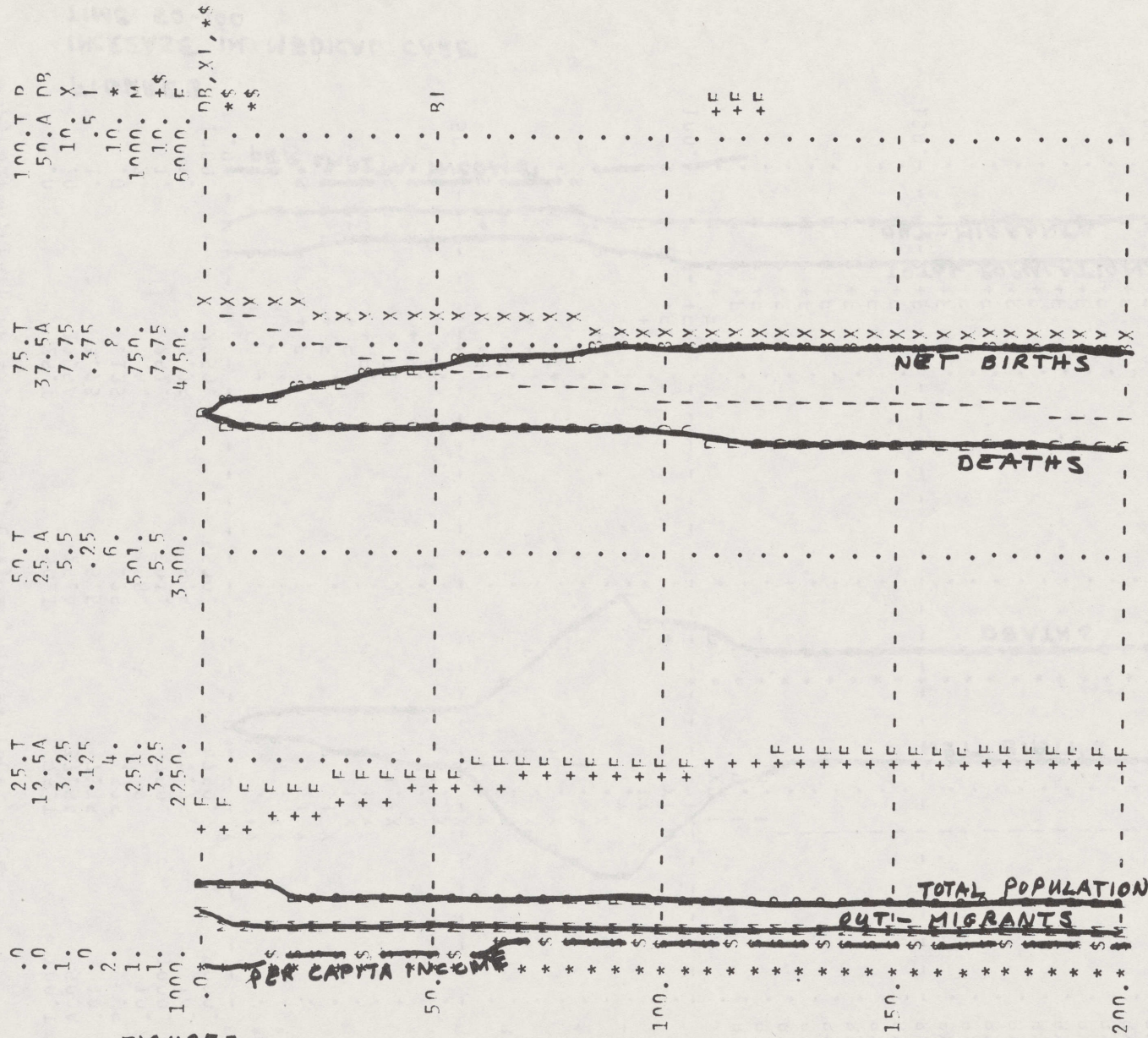


FIGURE 2  
VILLAGE AT EQUILIBRIUM



POP=P, MORT=D, CBR=B, DES=X, IMORT=I, MC=\*, M=M, DIPC=+, IPC=\$, FDC=E

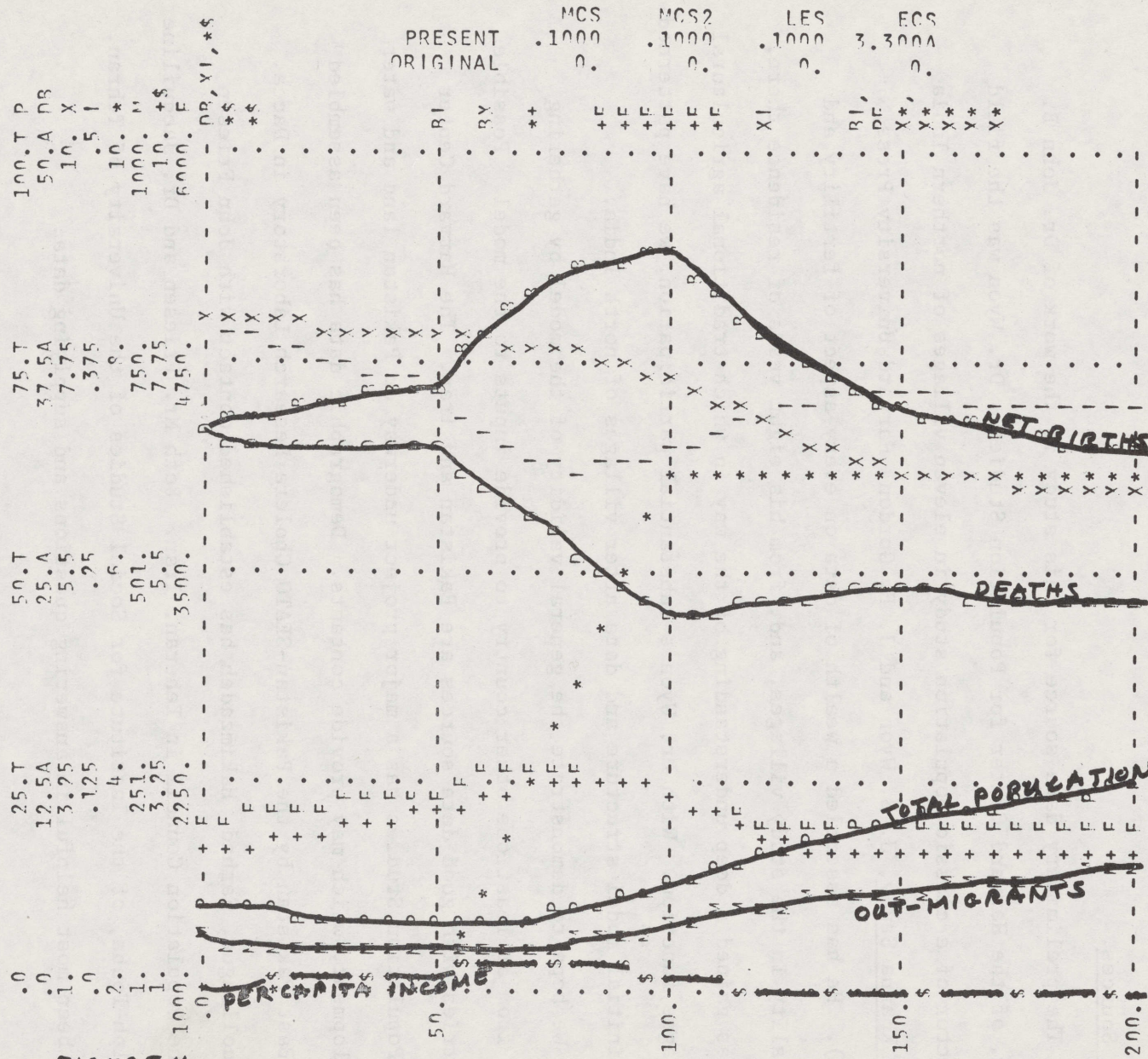


FIGURE 4  
 INCREASE IN MEDICAL CARE  
 LAND EFFICIENCY  
 BIRTH CONTROL EFFECTIVENESS

and both food and income per capita decrease. At the end of the run the village population is over 25,000, and nearly 200 migrants are leaving for the city each year.

#### Data Sources.

The preliminary data source for this study is the work of Dr. John B. Wyon, of the Harvard Center for Population Studies. Dr. Wyon was the field director of a classic population study in eleven villages of northern India (The Khanna Study, J. B. Wyon and J. E. Gordon, Harvard University Press, 1971). He has assembled a wealth of data on every aspect of fertility and mortality in the study villages, and, from his eight years of residence there, he has gained a deep understanding of the way in which traditional agricultural villages function. With Dr. Wyon's substantial participation, we have patterned the initial model structure and data after villages of north India.

We hope to demonstrate the general validity of the model by gathering data from at least one other country to provide inputs to the model. Possible countries with good data sources are Pakistan and Iran. The Harvard Center for Population Studies has a major project underway on Pakistan land and water development, which may provide contacts. Demographic data has been assembled for East Pakistan by the Pakistan-SEATO Cholera Research Laboratory in Dacca. Our colleague, Farhad Hakimzadeh, has established contact with John Friesen of the Population Council in Teheran, Iran. Both Mr. Friesen and Dr. Jacqueline Rudolph-Touba, of the Institute for Social Studies of the University of Tehran, have been most helpful in answering questions and supplying data.

#### Publications.

A detailed proposal outlining the village study has been submitted for one year of funding from the Ford Foundation. If the funding is forthcoming,

interim reports on the progress of the model will be issued throughout the coming year. Copies of the initial proposal and subsequent reports may be obtained from

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## RURAL-URBAN MIGRATION IN DEVELOPING COUNTRIES

Global Model Sector: Population

Michael R. Goodman

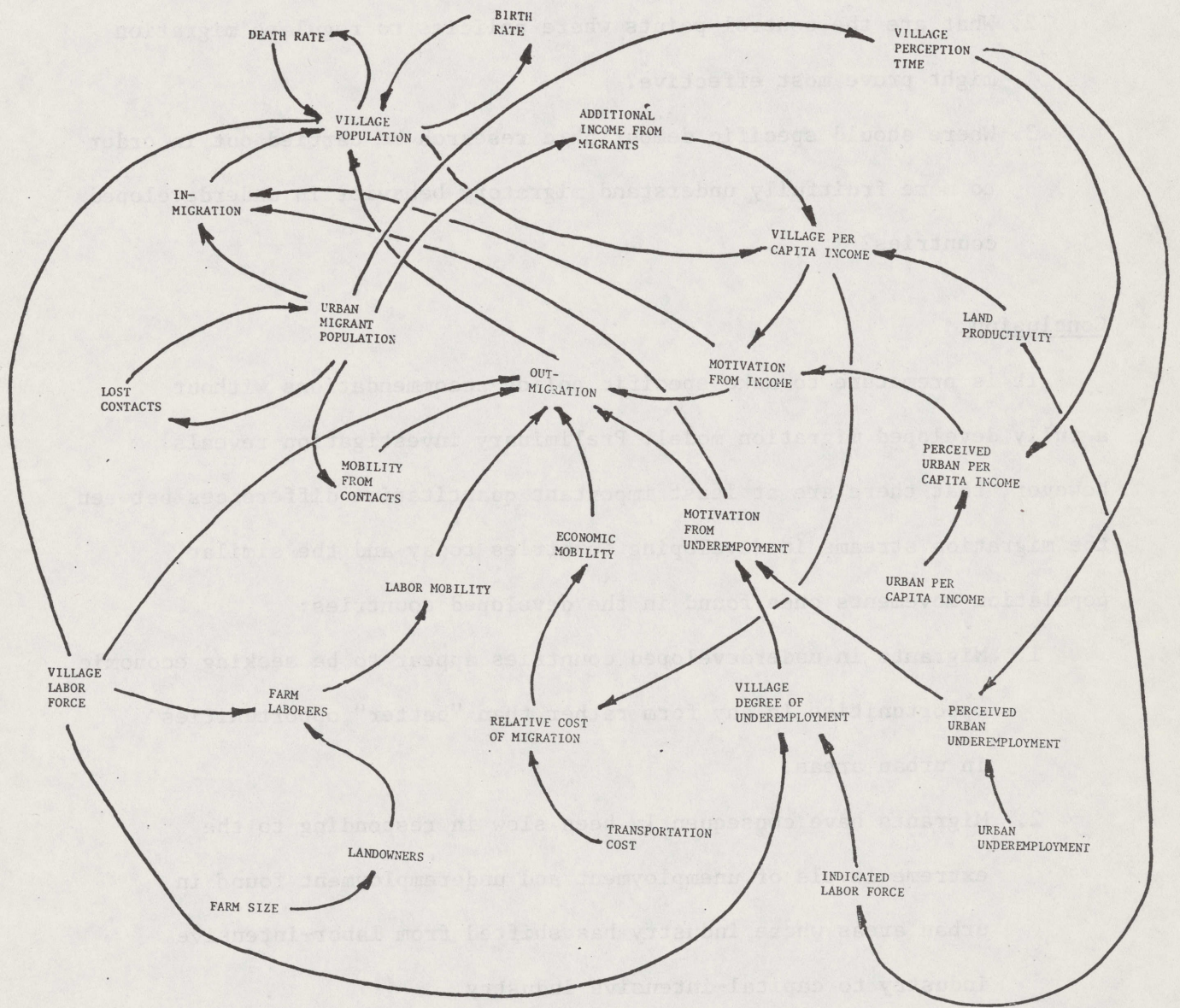
Introduction

Migration into urban areas of developing countries seems to be a natural response to growing "population pressures" in rural areas. Unfortunately, the present flood of migrants in developing countries can not be absorbed fruitfully in the industrial sectors of the urban areas. Thus migration threatens to slow economic growth and to bring social upheaval. Of particular interest to national governments are the specific components of the pressure or inducement to migrate from traditional agrarian villages. A general model of rural to urban migration that focuses on the rural origin of the migrant and considers both social and economic factors causing migration is being developed for eventual use in the Village Population Model. Figure 1 presents the general causal relationships perceived as being the underlying determinants of migration.

Object of Study

The migration model will provide the answers to the following questions:

1. Do rural-urban migration trends being observed in developing countries differ qualitatively from the trends observed during the economic growth of the presently developed countries?



RURAL-URBAN MIGRATION

- a. Are present trends "naturally" part of industrialization?
  - b. What are the specific effects of the Green Revolution?
  - c. What are the misconceptions surrounding rural-urban migration?
2. What are the control points where policies to regulate migration might prove most effective?
  3. Where should specific demographic research be carried out in order to more fruitfully understand migratory behavior in underdeveloped countries?

### Conclusion

It is premature to make specific policy recommendations without a fully developed migration model. Preliminary investigation reveals, however, that there are at least important quantitative differences between the migration streams in developing countries today and the similar population movements once found in the developed countries:

1. Migrants in underdeveloped countries appear to be seeking economic opportunities in any form rather than "better" opportunities in urban areas.
2. Migrants have consequently been slow in responding to the extreme levels of unemployment and underemployment found in urban areas where industry has shifted from labor-intensive industry to capital-intensive industry.
3. The speed of adoption of efficient agricultural methods to meet the demands of an expanding population on limited land resources has adversely affected agricultural labor opportunities on a scale never found in developed countries.

### Contacts and Resources

The basis of the model structure is a summary of relevant material in twenty-one literature sources. An annotated bibliography of these sources is available from Michael R. Goodman, System Dynamics Group, E40-214, M. I. T., Cambridge, Massachusetts 02139. In addition, conversations with Professor B. F. Johnston, Agricultural Economist, Stanford University, have served as a valuable asset in understanding migration phenomena in developing countries.

### Future Work.

Refinement of the basic causal structure as seen in Figure 1 is continuing in order to generate a realistic representation of rural to urban migration. When the model has been validated against actual cases it will be incorporated into the Village Population Model.

## THE DYNAMICS OF RISING ASPIRATIONS

Global Model Sector: Population

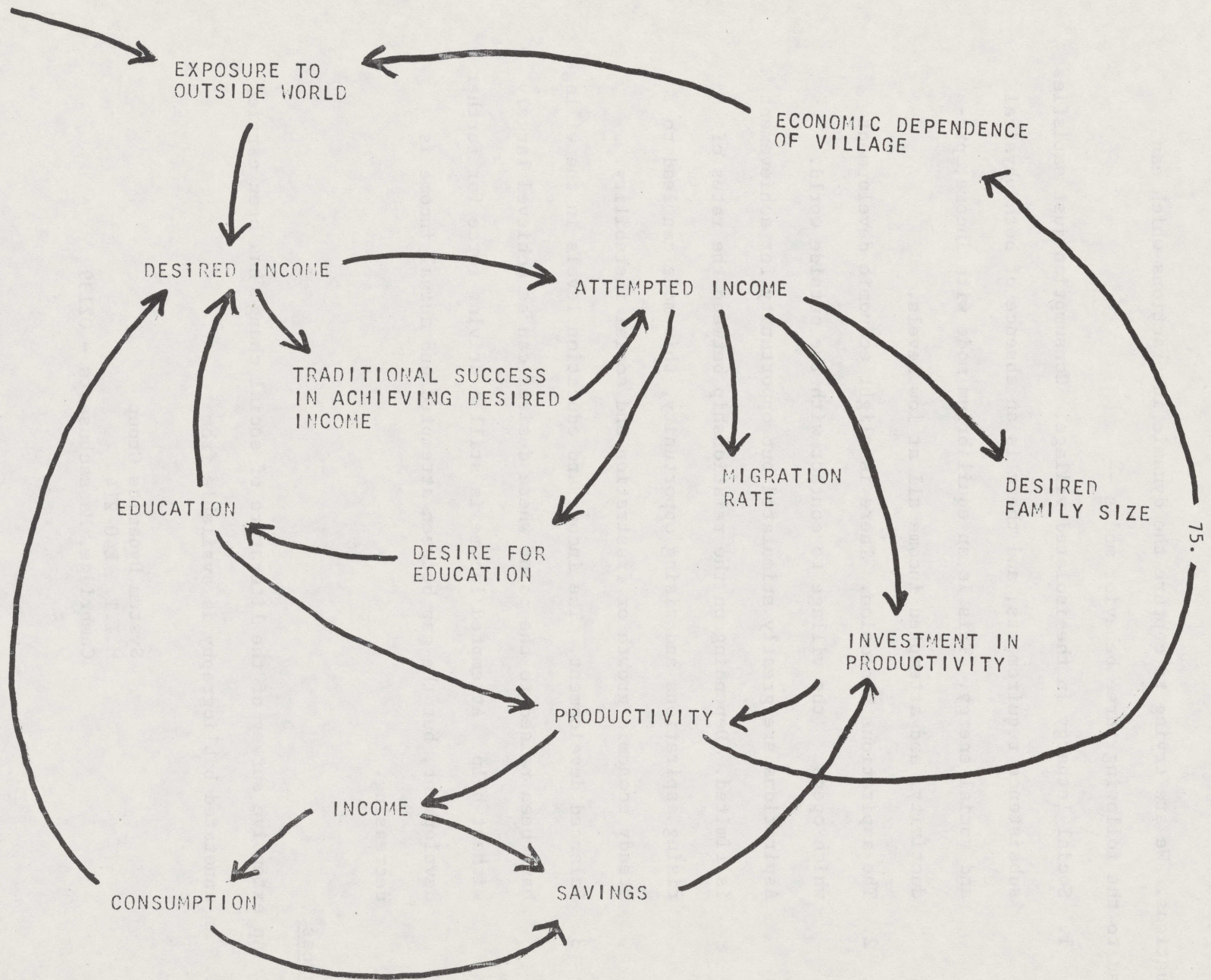
Farhad Hakimzadeh  
Donella H. MeadowsIntroduction.

The decisions people make about saving and investment, about having children, and about where and when to work, are dependent upon their own personal goals and the way they choose to achieve those goals. The phenomenon of "rising aspirations" among the poor people of the world has come about from exposure of traditional societies to the different goals of a modern society. It is a dynamic process with important implications for the success of any planned development policy. In order to express correctly the internal decision structure of the agricultural village, we have begun to model the process of goal creation, or rising aspirations.

Objectives.

This model is designed to interface with the other sectors of the village model. In particular, it should answer the following important questions: How do people form the operational goals that motivate their own attempts to better their lives? How might educational efforts or contact with other societies influence those goals? How will a group of people with a given operational goal choose between the alternatives available to them (such as better land cultivation, fewer children, or migration to the city) to achieve that goal?

The field flow diagram illustrates the relationship among the major variables involved in determining the level of aspirations in a traditional agricultural village. This diagram is currently being translated into DYNAMO



equations. We are trying to capture the dynamic interactions which can lead to the following three behavior modes --

1. Social lethargy in the isolated village. Consumption just satisfies subsistence requirements, and there is an absence of both physical and social energy. This is an equilibrium mode with income, productivity, and attempted income all at low levels.
2. The aspirations explosion. There is slight economic development which opens the village to contact with the outside world. Aspirations are greatly stimulated but opportunity for achievement is limited. Depending on the relationship between the rates of rising aspirations and rising opportunity, this mode can lead to steady economic growth or frustration and social instability.
3. Balanced development. The income and education levels in the village have been raised to the point where desires can be achieved largely without help. Attempted income is still a driving force for further development, but the gap between attempted and actual income is decreasing.

#### Sources.

An extensive survey of the literature of social change has been carried out. An annotated bibliography is available from

System Dynamics Group  
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A PRELIMINARY ANALYSIS OF LABOR DISPLACEMENT  
AND ABSORPTION IN A TWO-SECTOR ECONOMY

Global Model Sector: Agriculture  
Employment

Peter Milling

Introduction.

During the first two-thirds of the last decade the problems of providing enough food for the world population were the focus of international concern. But the implementation of new seed varieties and the more extensive use of fertilizers has given most of the developing countries the potential to grow all the food needed for the nourishment of their population for at least the next decade. Thus, the perspective was changed. Unemployment is now recognized as a global problem and the provision of jobs has become one of the most urgent tasks for the governments of the less developed countries. The problem is aggravated by a rapidly growing labor force, due to the population explosion.

Object of the Study.

A simple analytical two-sector economic model is developed, relating labor productivity in agriculture and in industry to output and the demand for labor. This model allows one -- with certain simplifying assumptions -- to deduce the minimum required growth in non-agricultural output to provide enough jobs to maintain the current relative level of employment, when labor productivity in the agricultural and/or non-agricultural sector change.

The objectives of this study are to emphasize the importance of a rational government policy, preventing the displacement of labor in agriculture by mechanization of farms, economies of scale, technical progress, etc., as long as there is a substantial surplus of labor in these economies.

### Conclusions.

The results are most important for those countries with a substantial fraction of its labor force in agriculture. It shows that economic growth, no matter how achieved, is no sufficient guarantee of high employment. Labor-saving, highly efficient production techniques may, particularly in the agriculture sector, have the effect of increasing the unemployment if the non-agricultural sector is not in a period of vigorous and self-sustained growth.

### Information Sources.

Discussions with Dr. Carl Gotsch, Professor at the Harvard Development Advisory Service, led to insights in the nature and the danger of the employment problem in the developing countries. Further information was obtained through

1. Professor Bruce Johnston  
Food Research Institute  
Stanford University
2. Dr. W. H. Pawley  
Chairman of the P.A.B.  
Advisory Committee  
and Director of the FAO  
Second Indicative World Plan
3. Professor William W. Seifert  
Department of Electrical Engineering  
Massachusetts Institute of Technology

### Future Work.

This model is part of the effort to understand the dynamics of unemployment in underdeveloped countries. Its explanatory value is restricted because of the limiting assumptions, made to keep the mathematical requirements on a relatively low level.

Future extensions of this model are not intended. Future work will be

conducted with a simulation model which incorporates and extends the assumptions of the preliminary model.

Publications.

Copies of the complete paper, "A Preliminary Analysis of Labor Displacement and Absorption in a Two-Sector Economy," are available from

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DETERMINANTS AND IMPLICATIONS OF  
AGRICULTURAL INNOVATION  
IN DEVELOPING COUNTRIES

Global Model Sectors: Capital, Employment and Land

Erich Zahn

INTRODUCTION

Employment is one of the most important factors for economic development in modern as well as in traditional societies. It is a prerequisite for economic, social, and political stability. However, unemployment is usually not the cause from which crises arise, unemployment is more a symptom of an unstable situation, a result which is generated by factors located deep in the structure of our social systems.

This study will primarily focus on the employment problem in the agricultural sector of developing countries, where we observe a rapidly growing employment crisis, indicated by a fast-increasing gap between population growth and the ability to create new jobs. In Latin America, for example, unemployment in many areas is over 35% of the potential labor force. Besides this growing problem there already exists an enormous waste of human resources. A large percentage of the productive labor force is occupying its time in jobs with very small outputs. This situation forces people to migrate from rural traditional agricultural areas to urban industrial areas. Migration occurred also in the more developed countries as they modernized but now it is not associated with economic progress as it was there. In today's developing world we observe a curious phenomenon. Despite the existence of a significant urban unemployment, and because of an increasing efficiency of the agricultural production which has been referred to as the "Green Revolution", migration to the cities accelerates so fast that the increase in employment in industry cannot expand rapidly enough to absorb this additional, urban labor force.

OBJECT OF THE STUDY

In order to gain a better understanding of the dynamics of employment two "System Dynamics" models have been constructed. The two models address specific problems of different levels of aggregation.

The first model deals with the dynamics of farm production, the change in average farm size, and employment per hectare. Here we primarily look at the agricultural input-output relations and the impacts of different factor combinations on labor input and farm productivity. The production of crops is modeled as a complex process depending not only on the levels of resources but also on the ways farmers use their skills and knowledge on their investments and on their reactions to changes in the economic, social, and political environment. The principle feedback relationships of the model are illustrated in Figure 1.

The main questions that are addressed by this model are:

- (1) How does the seed and fertilizer revolution affect the agricultural output and the combination of energy inputs, such as human, animal, and machinery power?
- (2) How does mechanization influence the efficiency of land and how does it change the labor input?
- (3) Does the introduction of new technologies depend on the farm size?
- (4) What are the barriers for the introduction of new technologies?
- (5) What policies at the national level can stop or at least decrease the deleterious effects of new technology on the agricultural labor force?

The model has been analyzed by computer simulation. Figure 2 and Figure 3 show the results of two preliminary runs.

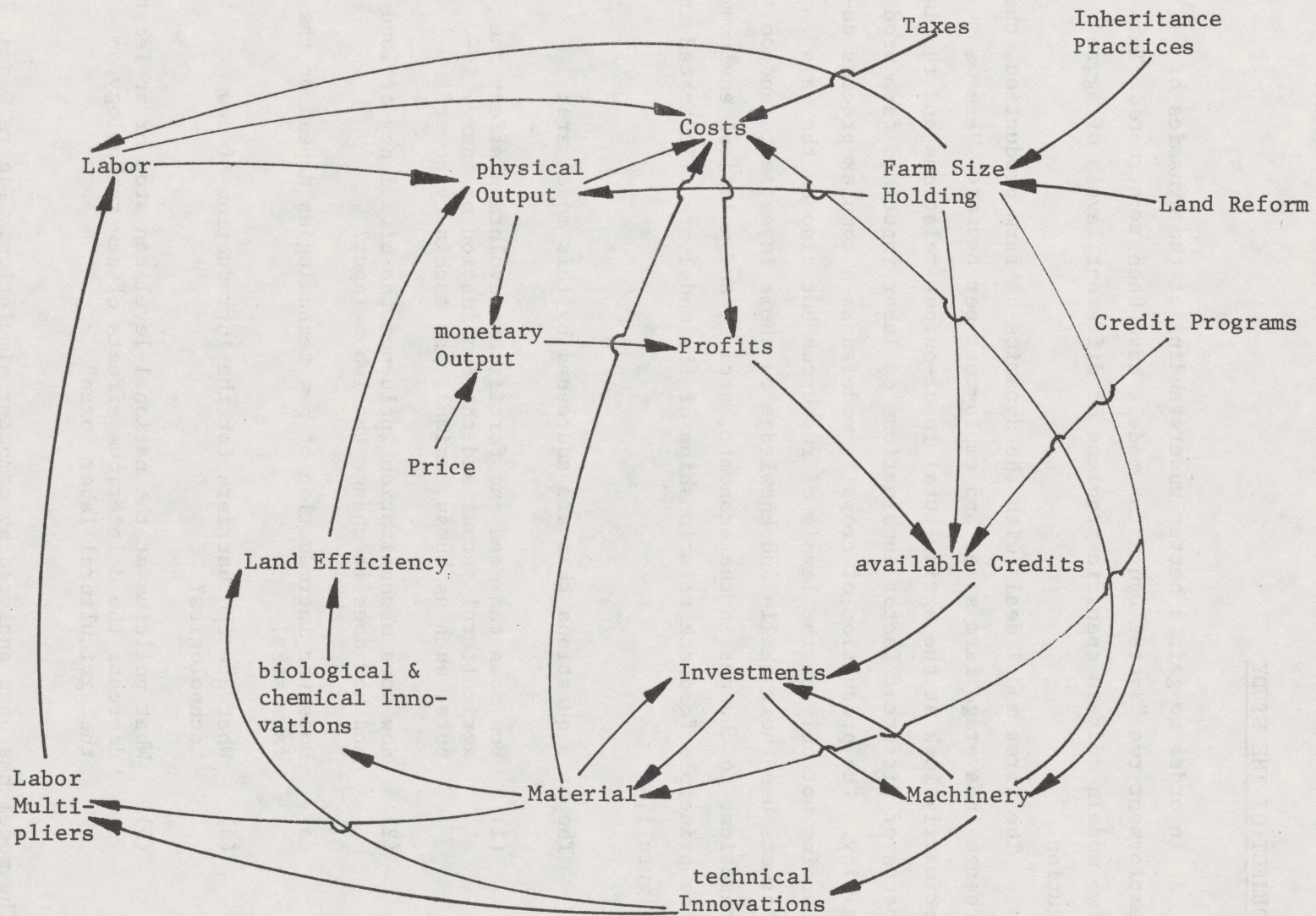


Figure 1: Basic Field Flow Diagram of the Farm Production Model





While the first model examines changes on a specific farm, the second model focuses on the dynamics of agricultural unemployment in the total rural sector. The main relationships of this model are shown in Figure 4. Here we look at the effects of various policies and programs, such as:

- (1) land reforms;
- (2) institutional credit services;
- (3) price supports;
- (4) subsidizing new input factors;
- (5) ceilings on land rentals;
- (6) education and research programs.

The simulation of this model, when its coefficients are set to represent the current global situation, shows an increasing number of unemployed people, who are potential migrants. This run shown in Figure 5 illustrates the behavior of an agricultural sector which is seen as a closed system with no migration. No new technologies are taken into account.

#### CONCLUSIONS

Although both models are not in their final stage we are able to draw some basic conclusions.

If the "Green Revolution" is to be more than a stop gap measure additional efforts have to be made. The tendency of large land holders to combine the introduction of biological and chemical innovations with a process of mechanization has to be reduced if the less developed countries are to move along the path already traced by the more developed countries. Unfortunately, our simulations suggest that the "Green Revolution" will accelerate the trends. In order to encourage the farmers to use more labor-intensive technology national land reform programs and different mechanization strategies are necessary. Whether or not the opportunities presented by the new high yielding varieties are

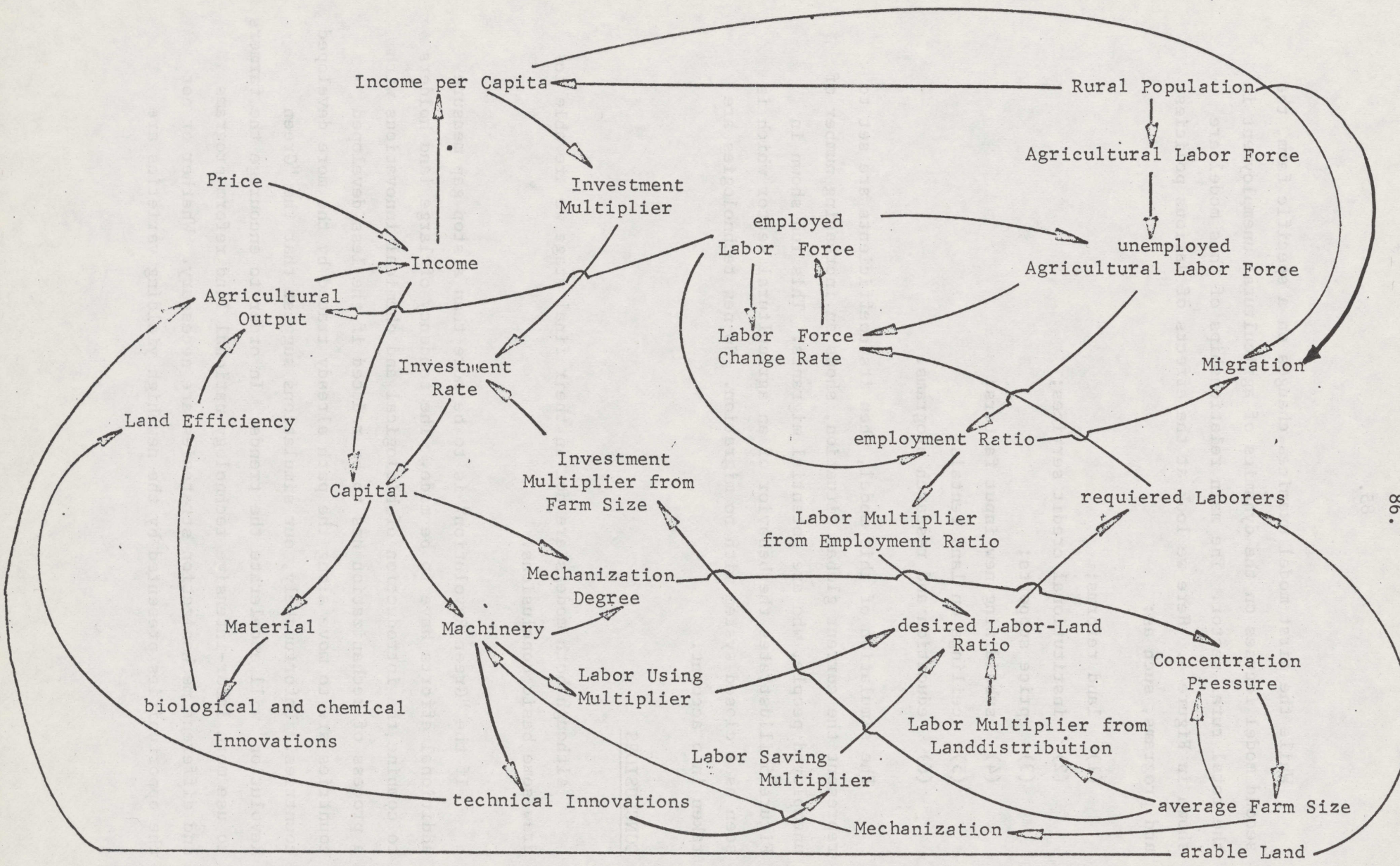
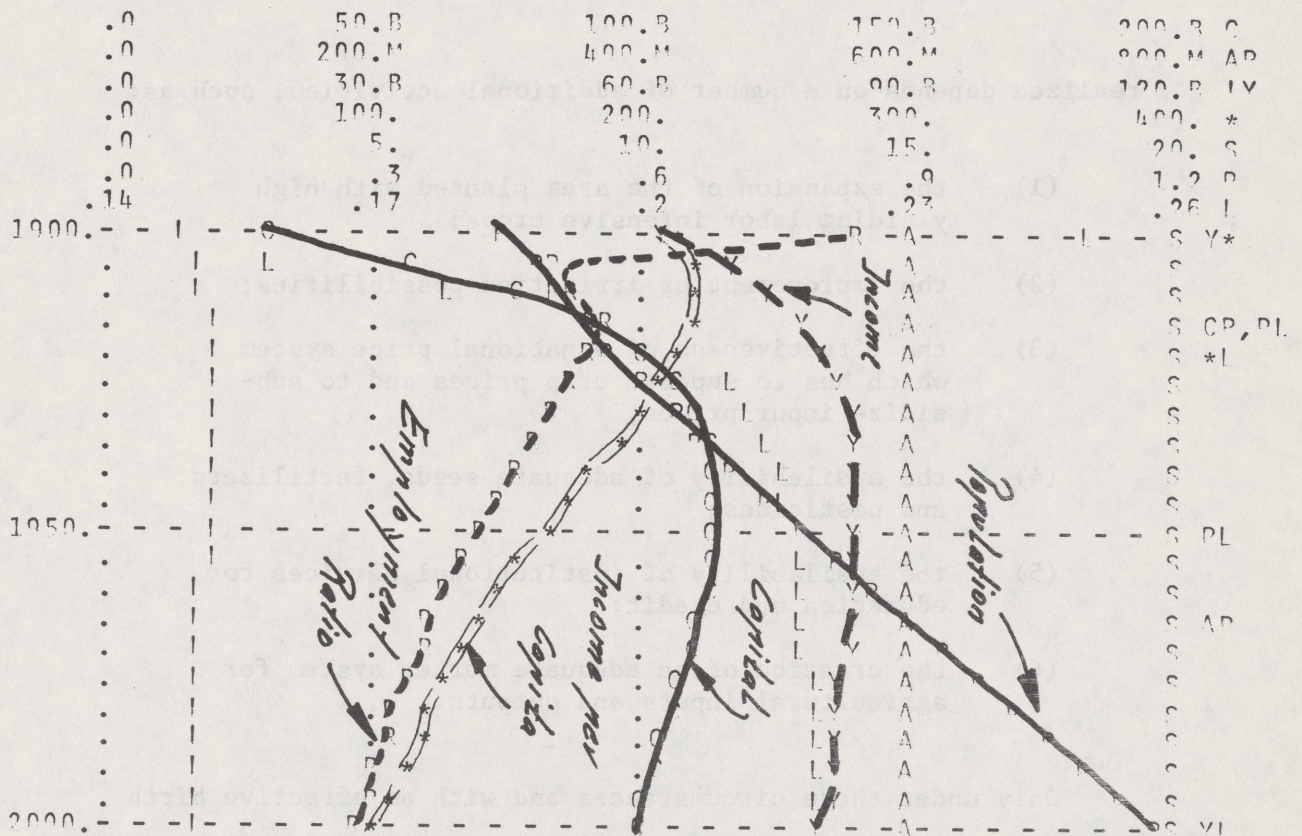


Figure 4: Field Flow Diagram - The Dynamics of agricultural Unemployment

C=C, AL=A, POP=P, IR=I, Y=Y, IPC=\*, ABS=S, ER=P, LLP=L



CLP=C, CLAP=A, ECR=E, ELF=L, ULF=U, PL=P

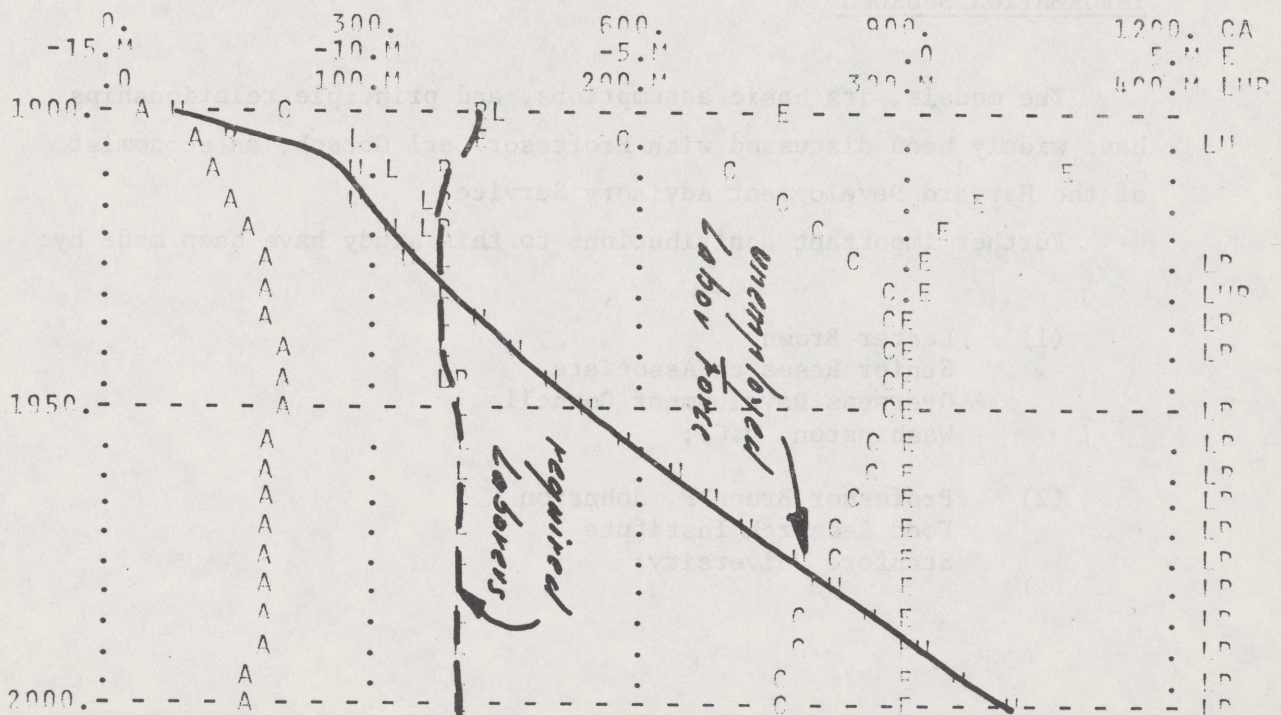


Figure 5

realized depends on a number of additional activities, such as:

- (1) the expansion of the area planted with high yielding labor intensive crops;
- (2) the improvement of irrigation possibilities;
- (3) the effectiveness of a national price system which has to support crop prices and to subsidize input prices;
- (4) the availability of adequate seeds, fertilizers, and pesticides;
- (5) the availability of institutional services for education and credit;
- (6) the creation of an adequate market system for agricultural inputs and outputs.

Only under these circumstances and with an effective birth control, which slows down the population growth the problem of unemployment in developing countries may be solved.

#### INFORMATION SOURCES

The models, its basic assumptions, and principle relationships have widely been discussed with Professor Carl Gotsch, an economist of the Harvard Development Advisory Service.

Further important contributions to this study have been made by:

- (1) Lester Brown  
Senior Research Associate  
Overseas Development Council  
Washington, D.C.;
- (2) Professor Bruce F. Johnston  
Food Research Institute  
Stanford University;

- (3) Dr. W.H. Pawley  
Chairman of the PAB  
Advisory Committee  
and director of the FAO  
Second Indicative World Plan for Agriculture;
- (4) Robert d'A. Shaw  
Associate Fellow of the Overseas Development Council  
Washington, D.C.;
- His book "Jobs and Agricultural Development"  
was one of the principle literature references.
- (5) Professor William W. Seifert  
Department of Electrical Engineering  
M.I.T.

#### FUTURE WORK

The two models described will be completed and then validated by using data from West Pakistan and the Indian Punjab, which have extremely different land holding size distributions. The results will be the base for a comprehensive economic model, including an agricultural, an industrial, and a service sector. This model will be used to study the dynamics of economic growth in underdeveloped countries. Discussions are underway with the World Bank to obtain their support and data resources for application of the comprehensive model to a specific region.

#### PUBLICATION

A 60 page paper "Characteristics and Implications of Agricultural Innovation in Developing Countries" will be available from the System Dynamics Group, Massachusetts Institute of Technology, Alfred P. Sloan School of Management, at the end of April.

## A DYNAMIC RESERVE LIFE INDEX

Global Model Sector: Natural Resources

William W. Behrens

Introduction.

Effective planning for the future availability of natural resources depends on an operational measure of remaining reserves. The static reserve life index, defined as the current level of known reserves divided by the current annual consumption, is the most commonly used measure at present. This measure is poorly suited for long term policy formulation because of the following assumptions implicit in its definition:

1. Population and per capita consumption will remain constant.
2. The grade of extracted resources will not decrease.
3. No major new discoveries will be made.
4. There will be no changes in extraction technology.
5. There will be no changes in substitution technology.
6. Changing costs will not effect consumption patterns.

Object of Study.

A useful measure of reserves must not be restricted by the above assumptions. The object of this study is to provide a dynamic framework within which the interrelated determinants of resource availability can be examined and researched. This structure, as outlined in Figure 1 below, will dictate the boundary within which we can test and evaluate policies designed to reduce the impact of future resource scarcity.

A simulation model has been developed from this structure, so that the behavior of the resource system can be observed over time in response to policy changes. A preliminary computer run of this model is shown in Figure 2.

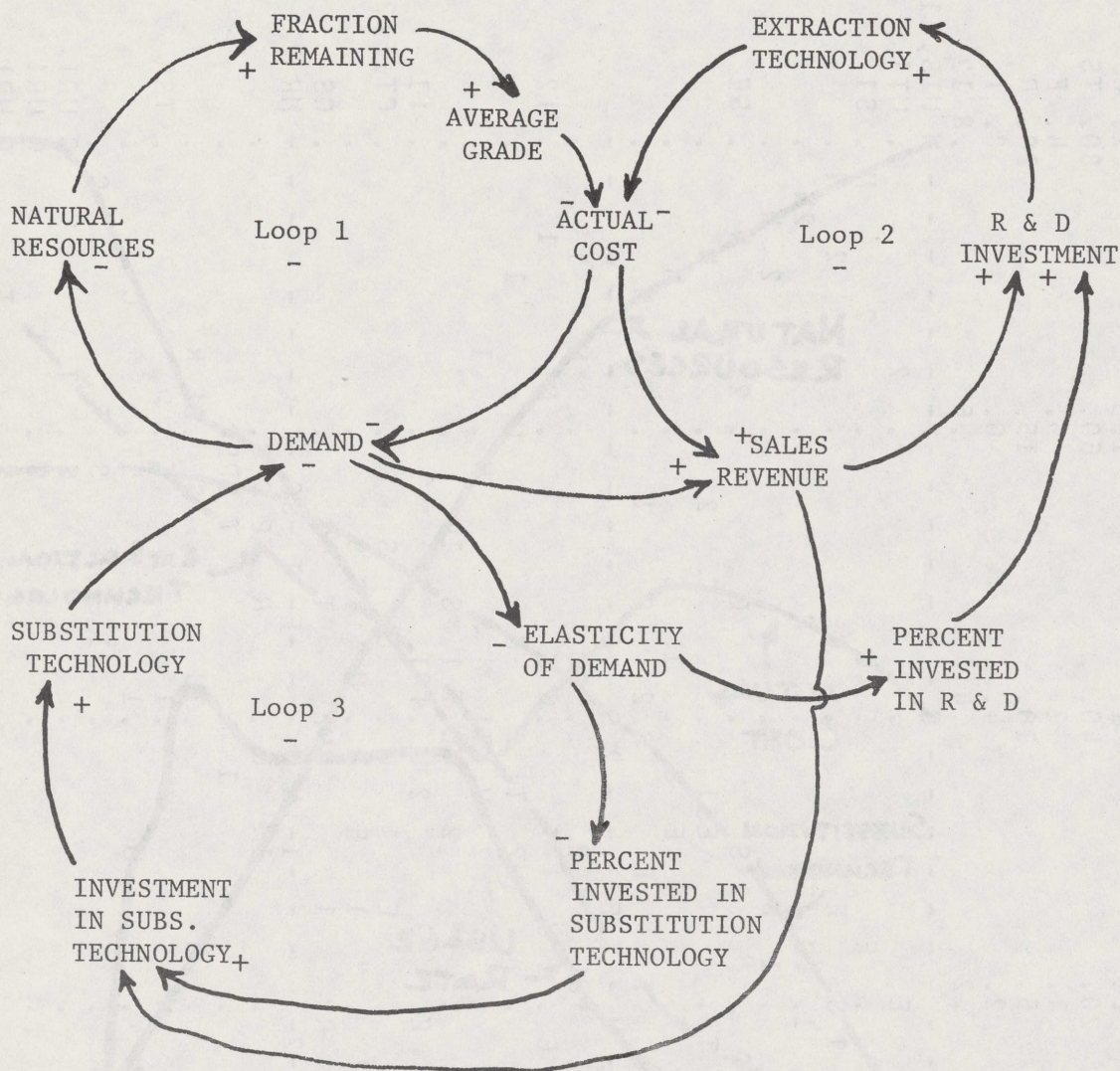


Figure 1: The Structure Governing Resource Availability

This run shows that resources will never be completely extracted, because as costs rise the usage rate will gradually fall to zero before all the resources are depleted. The run also illustrates the endogenous (system induced) advances in extraction and substitution technology, which result in changes in both costs and usage.



### Conclusions.

The study is currently in a preliminary state of development. The model assumes that improvements in technology are initiated by economic pressures; substitution technology, for example, improves when the demand functions of the resource indicate that a profit could be made on a substitute at comparable cost. First results indicate that this purely economic response to increasing scarcity is not sufficient to prevent the economically depressing effect of resource depletion. Its only effect is to postpone price increases, thus decreasing the length of time before complete depletion, when rising prices can induce adaptive behavior. What appears to be needed, in the most general terms, is an effort directed toward averting resource problems before they develop instead of as they develop. This might take the form of using substitutes even before they are economically competitive, or we might consider taxing extraction in order to artificially depress resource usage. The most general conclusion is that the ultimate economic consequences of resource depletion by exponentially growing usage rates simply cannot be averted by the normal, endogenous progress in the technologies of extraction and substitution.

### Contacts and Sources.

The hypotheses underlying this model have been discussed and researched with personnel from M.I.T. and Resources for the Future, Inc.

### Future Work.

Much of the work in this study is yet to be done. Validation of the structure must precede any extensive testing of policy alternatives. A copy of the preliminary report has been left with the natural resource division

of the United Nations' Economic and Social Council with a request for cooperation in applying the model to specific resources.

Publication.

Information concerning this study and other areas of interest in the Natural Resource Sector can be obtained from

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One paper, "The Dynamics of Resource Utilization," presents the structure in Figure 1, p. 91, in more detail and analyzes its long-term behavior. It is available at the address above.

NATURAL RESOURCE EXTRACTION MULTIPLIER

Global Model Sector: Natural Resources

William B. Behrens

Introduction.

The World model developed in the Club of Rome project on the Predicament of Mankind exhibits several distinct behavior patterns. Each pattern results as one specific pressure increases sufficiently to retard economic and population growth. Pollution, crowding, starvation, and natural resource depletion are all represented in the model. The collapse of growth through natural resource depletion is brought about by one table function, the Natural Resource Extraction Multiplier. Its place in the system structure is shown in Figure 1.

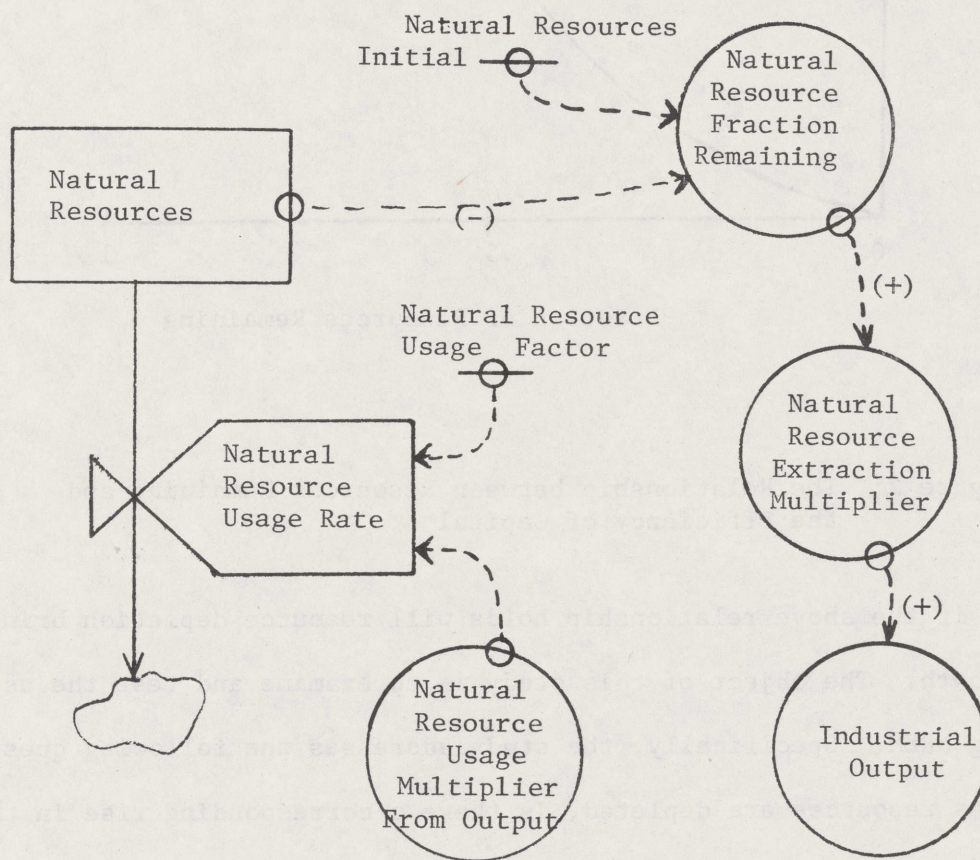


Figure 1: The Natural Resource Sector and its effect on Industrial Output through NREM

NREM assumes that resource depletion reduces the efficiency of the capital used in the productive process, depressing the Industrial Output. The general form of the Natural Resource Extraction Multiplier Table is shown in Figure 2.

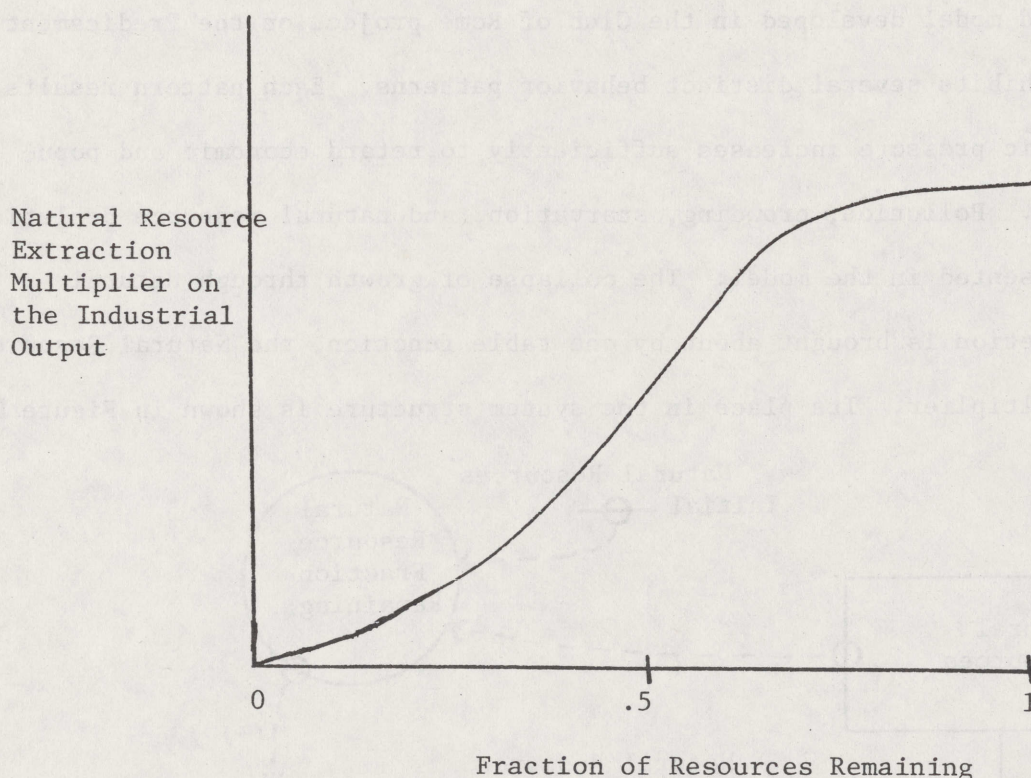


Figure 2: The Relationship between Resources Remaining and the Efficiency of Capital

Only if the above relationship holds will resource depletion bring an end to growth. The object of this study is to examine and test the assumptions underlying NREM. Specifically, the study addresses the following questions:

1. As resources are depleted, is there a corresponding rise in the costs of extracting, processing, and distributing resources?
2. If so, can the progress of technology be a sufficient force in the

- long run to counteract the rising costs?
3. How accurate must we be in our estimate of the level of resources remaining in order to answer questions 1 and 2?
  4. How does the possibility of substitution for materials already in short supply alter the answers to the questions above?
  5. How would essentially free energy alter the characteristics of the NREM?

The study addresses these questions in the case of a generalized mineral resource and demonstrates the validity of the NREM assumption. The study then focuses on two specific resources, mercury and lead, which are currently approaching exhaustion, to evaluate the NREM for each.

#### Conclusions.

The economic structure of our global society and the geology of resource location and grade lead inevitably to the relationship, NREM. NREM dictates that the depletion of resources is a sufficient pressure in itself to cause growth to cease. The progress of technology in resource extraction and usage, while necessary to preserve the short-term economies of our society, in the long run leads to an even more precipitous collapse of the economic structure. Technological advance thus serves to decrease radically the time our global society will ultimately have to adjust to much lower resource availability.

The implications of NREM for policy changes are varied. We must realize that continued exponential growth in our dependence on natural resources will ultimately lead to our own collapse. Efforts directed at increasing the known supply of resources without attempting to slow down the growth will prove to be fruitless in the long run; exponential growth drastically diminishes the

effectiveness of any increase in a mineral's reserve index.<sup>1</sup> Instead, we must look toward a policy of "zero economic growth," maximizing both the lifetime and the efficiency of use of our natural resources.

#### References and Contacts.

The study is based on a theoretical framework taken from a number of literature sources, notably Barnett and Morse, Scarcity and Growth (Johns Hopkins Press, 1963); Resources and Man, a study by the National Academy of Sciences (W. H. Freeman and Co., 1969); P. T. Flawn, Mineral Resources (Rand McNally and Co., 1966); and P. R. Ehrlich, Population, Resources, Environment (W. H. Freeman and Co., 1970). Reference is also made to several sources of statistics, including the U.S. Bureau of Mines Minerals Yearbook. Of great importance were discussions with Charles J. Cicchetti and others of Resources for the Future, Inc., Washington, D. C.

#### Future Work.

This study is intended to serve as a basis for future studies on the dynamics of resource scarcity and their interactions with the economic structure of society.

#### Publication.

The full report on this study and additional information regarding other areas of concern in the Natural Resource sector can be obtained from

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<sup>1</sup> For example, at an annual growth in use of only 3 percent, a reserve index of 400 years yields 85 years of consumption; a reserve index of 4000 years yields only 160 years of consumption.

## LINKING SOCIO-POLITICAL FACTORS TO THE WORLD MODEL

Steffen C. Harbordt

Scope and Objectives of the Study

The Club of Rome Project on the Predicament of Mankind has begun with a study of ecological trends important at the global level. The model in its present form, World 3E, expresses mainly physical relationships among pollution, population, land, natural resources, and capital. However, the real-world interactions among these variables are mediated by social, economic, and political factors. Not to include these factors explicitly in the model would implicitly mean basing predictions and policy decisions derived from it on the ceteris paribus assumption of unchanging social and political circumstances. This assumption is obviously highly unrealistic if one intends to cover a time span of even 100 years.

On the other hand, it would require greater resources than are available in the current phase of the project to develop a second, entirely social and political approach to the subject. An important future goal is the insertion of relevant socio-political variables into the existing model or the construction of an entirely new and expanded model. For the moment, however, a much more modest approach is required to examine the influences of social and political factors on the behavior of the existing model (consideration of ecological influences on the social factors being postponed for now). This paper outlines selected global factors which may be important and shows how they are interrelated. It provides an impact matrix to relate these trends to the elements of the present model and shows how they could be linked to the model as exogenous variations in some of its functions. The worth of this paper lies mainly in provoking criticisms which should lead to continuous improvements. It may also serve as an example of how professionals in other fields -- economics, demography, meteorology, etc. -- can relate their knowledge directly to the structure of the model.

An extensive survey of the literature in socio-political trends with global impact leads to the selection of seven factors for inclusion in this study:

- (1) naturalization;
- (2) social mobilization;
  - a. urbanization
  - b. mass communication
  - c. literacy
- (3) political participation;
- (4) nation building;
- (5) modernization;
- (6) self regulation - self transformation;
  - a. control capacity
  - b. consensus-formation capacity
- (7) increasing governmental activity.

These trends are operationally defined and related to each other and to the World 3 elements they influence (Figure 1).

A new conceptual technique for displaying the impact of exogenous trends on a System Dynamics model's elements, an impact matrix, is developed and presented. After summarizing the magnitude, direction, and delay in the impact of each socio-political trend, simulation runs are made to test the model's sensitivity. Areas of sensitivity point to the most important future areas of research on the global model.

### CONCLUSIONS

The trends towards literacy and rational (as opposed to superstitious) behavior are identified as having the most widespread impact on the World 3 model assumptions. Future extensions of the

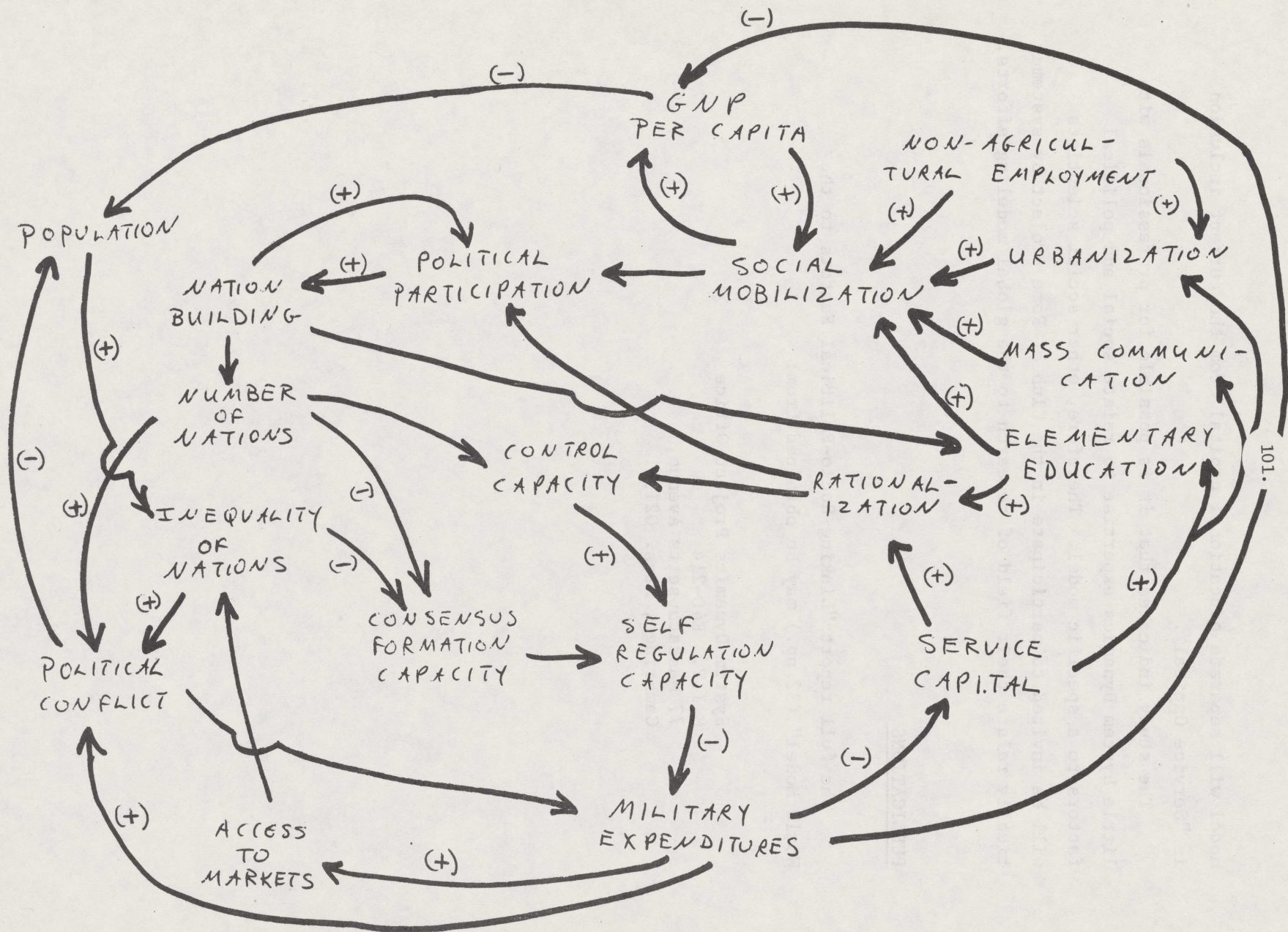


Figure 1: Relations Among Socio-Political Factors and World3 model Elements

model will separate educational capital from the current inclusion in "Service Capital".

The study indicates that it is possible for professionals with little System Dynamics expertise to relate social and political factors to a specific model. Therefore, other social scientists will be invited to participate in the Club of Rome project by systematically relate their field of research to the global modeling efforts.

PUBLICATIONS

The full report "Linking Socio-Political Factors to the World Model" (32 pp.) may be obtained from:

System Dynamics Project Office  
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## DETERMINANTS OF INTERNATIONAL CONFLICT

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Introduction.

One characteristic of any global simulation effort is that interactions among nations or regions are below the level of aggregation in the model. Many results of the continuous exchange of people, resources, and information among countries can be included in a global model. But the implications of conflict are difficult to include at this level of detail. International warfare has important implications for pollution generation, for the average lifetime of population, for resource depletion, and the rate at which productive capital is accumulated. It is thus important to understand the determinants of international conflict. This sub-study has, therefore, been initiated to summarize current political science knowledge about this point, to construct an appropriate System Dynamics model of international conflict, and to use its results for modifying policy recommendations derived from the global model.

The Theoretical Basis.

There have been many theories of international conflict. An important branch of research on this problem is that conducted by Professor Nazli Choucri of M.I.T.'s Department of Political Science, in collaboration with Professor Robert North of Stanford University's Political Science Department. Together they have accumulated empirical evidence on nearly 100 international conflicts. They have data on the demographic, the economic, the political characteristics of each participant. With this information, it appears possible to understand

international conflict as a function of population pressure, resource shortages, and expanding technological capability.

Neither Choucri nor North has the system modeling capability needed to relate this data to their theory in a meaningful way. Thus they have begun cooperation with our group, with the intention of developing a System Dynamics model which relates the variables above to observed conflict outbreaks.

This work is particularly relevant to the Club of Rome effort because it relates the propensity to engage in war to parameters included in the global model. While the global simulation model will not exhibit warfare as an endogenous behavior mode, it appears perfectly feasible to construct a tension index analogous to the quality of life index in earlier model versions, which stands at the side of each run and indicates, during all phases of model evolution, the potential danger of international conflict.

Separate funding has been found to support this aspect of the total project, and a preliminary report will be available at the end of the summer.

#### Publication.

A summary of current conflict theory and a verbal statement relating population, resources, and technology to the likelihood of war has been published:

Choucri, Nazli. "Alternative Dynamics of International Conflict: Population, Resources, Technology and Some Implications for Policy." In: World Politics Special Issue on Theory and Policy in International Relations. (1971). Forthcoming.

Reprints are available from

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