COUNTERINTUITIVE BEHAVIOR OF SOCIAL SYSTEMS[1]

by

JAY W. FORRESTER[2]

ABSTRACT

This paper addresses several social concerns: population trends; quality of urban life; policies for urban growth; and the unexpected, ineffective, or detrimental results often generated by government programs.

Society becomes frustrated as repeated attacks on deficiencies in social systems lead only to worse symptoms. Legislation is debated and passed with great hope, but many programs prove to be ineffective. Results are often far short of expectations. Because dynamic behavior of social systems is not understood, government programs often cause exactly the reverse of desired results.

The field of system dynamics now can explain how such contrary results happen. Fundamental reasons cause people to misjudge behavior of social systems. Orderly processes in creating human judgment and intuition lead people to wrong decisions when faced with complex and highly interacting systems. Until we reach a much better public understanding of social systems, attempts to develop corrective programs for social troubles will continue to be disappointing.

This paper cautions against continuing to depend on the same past approaches that have led to present feelings of frustration. New methods developed over the last 30 years will lead to a better understanding of social systems and thereby to more effective policies for guiding the future.

---

[1] This paper was first copyrighted © 1971 by Jay W. Forrester. It is based on testimony for the Subcommittee on Urban Growth of the Committee on Banking and Currency, U.S. House of Representatives, on October 7, 1970. The original text appeared in the January, 1971, issue of the *Technology Review* published by the Alumni Association of the Massachusetts Institute of Technology. All figures are taken from *World Dynamics* by Jay W. Forrester, Pegasus Communications, Waltham MA. Updated March, 1995

[2] Professor, Massachusetts Institute of Technology, Cambridge, MA, USA

I. A NEW APPROACH TO SOCIAL SYSTEMS

The human mind is not adapted to interpreting how social systems behave. Social systems belong to the class called multi-loop nonlinear feedback systems. In the long history of evolution it has not been necessary until very recent historical times for people to understand complex feedback systems. Evolutionary processes have not given us the mental ability to interpret properly the dynamic behavior of those complex systems in which we are now imbedded.

The social sciences, which should be dealing with the great challenges of society, have instead retreated into small corners of research. Various mistaken practices compound our natural mental shortcomings. Computers are often being used for what computers do poorly and the human mind does well. At the same time the human mind is used for what the human mind does poorly and computers do well. Furthermore, impossible tasks are attempted while achievable and important goals are ignored.

Until recently, no way to estimate the behavior of social systems existed except by contemplation, discussion, argument, and guesswork. As a way out of the present dilemma, I will sketch here an approach that combines the strength of the human mind and the strength of today's computers. The approach grows out of developments over the last 60 years, in which much of the pioneering research occurred at the Massachusetts Institute of Technology. Concepts of feedback system behavior apply sweepingly from physical systems through social systems. Feedback system ideas were first developed and applied to engineering systems. Understanding closed-loop (feedback) systems has now reached practical usefulness in social systems.

I am speaking of the professional field of *system dynamics*. Applications of system dynamics have been made to corporate policy, behavior of diabetes as a medical system, growth and stagnation of urban areas, and to world forces representing the interactions of population, pollution, industrialization, natural resources, and food.

Development of system dynamics began at M.I.T. in 1956. Continuing development of system dynamics has now spread to many countries. The international System Dynamics Society, and its journal the System Dynamics Review, unify work in the profession. Dozens of books and thousands of papers now exist on system dynamics and its applications.[3]

---

[3]. A bibliography with over 3000 entries on computer disks is available from the System Dynamics Society, Milne 300, Rockefeller College, University at Albany, SUNY, Albany, NY 1222, USA

II. COMPUTER MODELS OF SOCIAL SYSTEMS

People would never send a space ship to the moon without first testing prototype models and making computer simulations of anticipated trajectories. No company would put a new household appliance or airplane into production without first making laboratory tests. Such models and laboratory tests do not guarantee against failure, but they do identify many weaknesses which can be corrected before they cause full-scale disasters.

Social systems are far more complex and harder to understand than technological systems. Why then do we not use the same approach of making models of social systems and conducting laboratory experiments before adopting new laws and government programs? The customary answer assumes that our knowledge of social systems is not sufficient for constructing useful models.

But what justification can there be for assuming that we do not know enough to construct models of social systems but believe we do know enough to directly redesign social systems by passing laws and starting new programs? I suggest that we now do know enough to make useful models of social systems. Conversely, we do not know enough to design the most effective social policies directly without first going through a model-building experimental phase. Substantial supporting evidence is accumulating that proper use of models of social systems can lead to far better systems, laws, and programs.

Realistic laboratory models of social systems can now be constructed. Such models are simplifications of actual systems, but computer models can be far more comprehensive than the mental models that would otherwise be used.

Before going further, please realize that there is nothing new in the use of models to represent social systems. Each of us uses models constantly. Every person in private life and in business instinctively uses models for decision making. The mental images in one's head about one's surroundings are models. One's head does not contain real families, businesses, cities, governments, or countries. One uses selected concepts and relationships to represent real systems. A mental image is a model. All decisions are taken on the basis of models. All laws are passed on the basis of models. All executive actions are taken on the basis of models. The question is not to use or ignore models. The question is only a choice among alternative models.

Mental models are fuzzy, incomplete, and imprecisely stated. Furthermore, within a single individual, mental models change with time, even during the flow of a single conversation. The human mind assembles a few relationships to fit the context of a discussion. As debate shifts, so do the mental models. Even when only a single topic is being discussed, each participant in a conversation employs a different mental model to interpret the subject. Fundamental assumptions differ but are never brought into the open. Goals are different but left unstated.

It is little wonder that compromise takes so long. And even when consensus is reached, the underlying assumptions may be fallacies that lead to laws and programs that fail. The human mind is not adapted to understanding correctly the consequences implied by a mental model. A mental model may be correct in structure and assumptions but, even so, the human mind--either individually or as a group consensus--is apt to draw the wrong implications for the future.

Inability of the human mind to use its own mental models becomes clear when a computer model is constructed to reproduce the assumptions contained in a person’s mental model. The computer model is refined until it fully agrees with the perceptions of a particular person or group. Then, usually, the system that has been described does not act the way the people anticipated. There are internal contradictions in mental models between assumed structure and assumed future consequences. Ordinarily assumptions about structure and internal governing policies are more nearly correct than are the assumptions about implied behavior.

By contrast to mental models, system dynamics simulation models are explicit about assumptions and how they interrelate. Any concept that can be clearly described in words can be incorporated in a computer model. Constructing a computer model forces clarification of ideas. Unclear and hidden assumptions are exposed so they may be examined and debated.

The primary advantage of a computer simulation model over a mental model lies in the way a computer model can reliably determine the future dynamic consequences of how the assumptions within the model interact with one another. There need be no doubt about a digital computer accurately simulating the actions that result from statements about the structure and policies in a model.

In some ways, computer models are strikingly similar to mental models. Computer models are derived from the same sources; they may be discussed in the same terms. But computer models differ from mental models in important ways. Computer models are stated explicitly. The “mathematical” notation used for describing the computer models is unambiguous. Computer simulation language is clearer, simpler, and more precise than spoken languages. Computer instructions have clarity of meaning and simplicity of language syntax. Language of a computer model can be understood by almost anyone, regardless of educational background. Furthermore, any concept that can be clearly stated in ordinary language can be translated into computer-model language.

There are many approaches to computer models. Some are naive. Some are conceptually inconsistent with the nature of actual systems. Some are based on methodologies for obtaining input data that commit the models to omitting major relationships in the psychological and human areas that we all know to be crucial. With so much activity in computer models and with the same terminology having different meanings in the different approaches, the situation is confusing to a casual observer. The key to success is not in having a computer; the important thing is how the computer is used. With respect to models, the key is not to computerize a model, but, instead, to have a model structure and decision-making policies that properly represent the system under consideration.

I am speaking here of system dynamics models—the kind of computer models that are only now becoming widely used in the social sciences. System dynamics models are not derived statistically from time-series data. Instead, they are statements about system structure and the policies that guide decisions. Models contain the assumptions being made about a system. A model is only as good as the expertise which lies behind its formulation. A good computer model is distinguished from a poor one by the degree to which it captures the essence of a system that it represents. Many other kinds of mathematical models are limited because they will not accept the multiple-feedback-loop and nonlinear nature of real systems.

On the other hand, system dynamics computer models can reflect the behavior of actual systems. System dynamics models show how difficulties with actual social systems arise, and demonstrate why so many efforts to improve social systems have failed. Models can be constructed that are far superior to the intuitive models in people's heads on which national social programs are now based.

System dynamics differs in two important ways from common practice in the social sciences and government. Other approaches assume that the major difficulty in understanding systems lies in shortage of information and data. Once data is collected, people have felt confident in interpreting the implications. I differ on both of these attitudes. The problem is not shortage of data but rather inability to perceive the consequences of information we already possess. The system dynamics approach starts with concepts and information on which people are already acting. Generally, available information about system structure and decision-making policies is sufficient. Available information is assembled into a computer model that can show behavioral consequences of well-known parts of a system. Generally, behavior is different from what people have assumed.

III. COUNTERINTUITIVE NATURE OF SOCIAL SYSTEMS

Our first insights into complex social systems came from corporate work. Time after time we went into corporations that were having severe and well-known difficulties. The difficulties would be obvious, such as falling market share, low profitability, or instability of employment. Such difficulties were known throughout the company and were discussed in the business press.

One can enter a troubled company and discuss what people see as the causes and solutions to their problems. One finds that people perceive reasonably correctly their immediate environments. They know what they are trying to accomplish. They know the crises which will force certain actions. They are sensitive to the power structure of the organization, to traditions, and to their own personal goals and welfare. When interviewing circumstances are conducive to frank disclosure, people state what they are doing and can give rational reasons for their actions. In a troubled company, people are usually trying in good conscience and to the best of their abilities to help solve the major difficulties. Policies are being followed that they believe will alleviate the difficulties. One can combine the stated policies into a computer model to show the consequences of how the policies interact with one another. In many instances it emerges that the known policies describe a system which actually causes the observed troubles. In other words, the known and intended practices of the organization are sufficient to create the difficulties being experienced. Usually, problems are blamed on outside forces, but a dynamic analysis often shows how internal policies are causing the troubles. In fact, a downward spiral can develop in which the presumed solutions make the difficulties worse and thereby cause greater incentives to redouble the very actions that are the causes of trouble.

The same downward spiral frequently develops in government. Judgment and debate lead to a program that appears to be sound. Commitment increases to the apparent solution. If the presumed solution actually makes matters worse, the process by which degradation happens is not evident. So, when the troubles increase, the efforts are intensified that are actually worsening the situation.

IV. DYNAMICS OF URBAN SYSTEMS

Our first major excursion outside of corporate policy began in February, 1968, when John F. Collins, former mayor of Boston, became Professor of Urban Affairs at M.I.T. He and I discussed my work in system dynamics and his experience with urban difficulties. A close collaboration led to applying to cities the same methods that had been created for understanding corporations. The resulting model structure represented fundamental urban processes. The computer-model structure showed how industry, housing, and people interact with each other as a city grows and decays. The results are described in my book *Urban Dynamics* (Forrester, 1969).

I had not previously been involved with urban behavior, but the story emerging from the urban model was strikingly similar to what we had seen in corporations. Actions believed to alleviate the difficulties of a city can actually make matters worse. We examined four common programs for improving the depressed nature of central cities. One program was creation of jobs by busing the unemployed to suburban jobs or through governmental jobs as employer of last resort. Second was a training program to increase skills of the lowest-income group. Third was financial aid to depressed cities from federal subsidies. Fourth was construction of low-cost housing. All of these were shown to lie between neutral and highly detrimental regardless of the criteria used for judgment. The four programs range from ineffective to harmful judged either by their effect on the economic health of a city or by their long-range effect on the low-income population. The results both confirm and explain much of what has been happening over the last several decades in cities.

The investigation showed how depressed areas in cities arise from *excess* low-income housing rather than from a commonly presumed housing shortage. The legal and tax structures have combined to give incentives for keeping old buildings in place. As industrial buildings age, employment opportunities decline. As residential buildings age, they are used by lower-income groups who are forced to use them at higher population densities. Therefore, aging buildings cause jobs to decline and population to rise. Housing, at the higher population densities, accommodates more low-income urban population than can find jobs. A social trap is created where excess low-cost housing beckons low-income people inward because of the available housing. Unemployed people continue coming to a city until their numbers sufficiently exceed the available jobs that the standard of living declines far enough to stop further inflow. Income to the area is then too low to maintain all of the housing. Excess housing falls into disrepair and is abandoned. Extreme crowding can exist in those buildings that are occupied, while other buildings become excess and are abandoned because the economy of the area cannot support all of the residential structures. Excess residential buildings threaten an area in two ways—they occupy land so it cannot be used for job-creating buildings, and they attract a population that needs jobs.

Any change, which would otherwise raise the standard of living, only takes off the economic pressure momentarily and causes population to rise enough that the standard of living again falls to the barely tolerable level. A self-regulating system is thereby at work which drives the condition of the depressed area down far enough to stop the inflow of people.

At any time, a near-equilibrium exists affecting population mobility between different areas of a country. To the extent that there is disequilibrium, it means that some area is slightly more attractive than others and population begins to move in the direction of the more attractive area. Movement continues until rising population drives the more attractive area down in attractiveness to again be in equilibrium with its surroundings. Other things being equal, an increase in population of a city crowds housing, overloads job opportunities, causes congestion, increases pollution, encourages crime, and reduces every component of the quality of life.

A powerful dynamic force establishes equilibrium between all areas in total attractiveness. Any proposed social program should take into account the eventual shifts that will occur in the many components of attractiveness. As used here, attractiveness is the composite effect of all factors that cause population movement toward or away from an area. Most areas in a country have nearly equal attractiveness most of the time, with only sufficient disequilibrium in attractiveness to account for the shifts in population. But areas can have the same composite attractiveness with very different mixes in the components of attractiveness. In one area component A could be high and B low, while the reverse could be true in another area that nevertheless had the same total composite attractiveness. If a program makes some aspect of an area more attractive than its neighbor's, and thereby makes total attractiveness higher momentarily, population of that area rises until other components of attractiveness are driven down far enough to again establish an equilibrium. Efforts to improve some condition of a city will result primarily in increasing population until other conditions deteriorate to reestablish an equilibrium. The overall condition of urban life, for any particular economic class of population, cannot be appreciably better or worse than that of the remainder of the country to and from which people may come. Programs aimed at improving a city can succeed only if they result in eventually raising the average quality of life for the country as a whole.

V. ON RAISING THE QUALITY OF LIFE

There is substantial doubt that urban programs have been contributing to the national quality of life. Concentrating population in urban locations, undermining the cohesiveness of communities, and making government bureaucracy so big that individuals feels powerless, all reduce the quality of life.

Any proposed program should deal with both the quality of life and the factors affecting population. "Raising the quality of life" means releasing stress from crowding, reducing pollution, alleviating hunger, and treating ill health. But these pressures are the influences that control population movement. If one pressure is relaxed, population will then move in until other pressures rise to stop the inflow. To raise one component of quality of life without intentionally creating compensating counter pressures to prevent a rise in population will be self-defeating.

Consider the meaning of interacting attractiveness components as they affect a depressed ghetto area of a city. First, we must understand the way population density is already being controlled. A set of forces exist that determine why population density is not far higher or lower than it is. There are many possible combinations of forces that an urban area can exert. The particular combination will determine the population mix and the economic health of a city. The depressed areas of most American cities are created by a combination of forces in which there is a job shortage and a housing excess. The availability of housing draws the lowest-income group until they so far exceed the economic opportunities of the area that the low standard of living, the frustration, and the crime rate counterbalance the housing availability. Until the pool of excess housing is reduced, little can be done to improve the economic condition of an inner city. A low-cost housing program alone moves exactly in the wrong direction. It draws more low-income people. It makes the area differentially more attractive to the poor who need jobs and less attractive to those who create jobs. In the new population equilibrium that develops, some characteristics of the social system must counterbalance the additional attractiveness created by the low-cost housing. That counterbalance is a further decline of the economic condition of the area. Unfortunately, as the area becomes more destitute, pressures rise for still more low-cost housing. The consequence is a downward spiral that draws in the low-income population, depresses their economic condition, prevents escape, and reduces hope. All of this is done with the best of intentions.

My paper, "Systems Analysis as a Tool or Urban Planning" (Forrester, 1969), from a symposium in October, 1969, at the National Academy of Engineering, suggests a reversal of present practice by simultaneously reducing the aging housing in decaying cities and allocating land to income-earning opportunities. The land shifted to industry permits the "balance of trade" of an area to be corrected by allowing labor to create and export products to generate income streams with which to buy the necessities of modern life from the outside. The concurrent reduction of excess housing is absolutely essential. It supplies the land for new job-creating structures. Equally important, the resulting housing shortage creates the population-stabilizing pressure that allows economic revival to proceed without being inundated by rising population. Revival of an urban area can be done without driving the present low-income residents out of an area. Revival policies should create upward economic mobility to convert the low-income population to a self-supporting basis.

Many people, at first, believe these revival policies of less low-cost housing and conditions to favor business to create jobs will not be accepted by elected officials or residents of depressed urban areas. However, some of the strongest support has come from within those groups that are closest to the symptoms, who have lived through the failures of the past, and who must endure present conditions until lasting solutions are found.

The country has slipped into short-term policies for managing cities that have become part of the system that is generating even greater troubles. If we were malicious and wanted to create urban slums, trap low-income people in ghetto areas, and increase the number of people on welfare, we could do little better than follow present policies. The trend toward stressing income and sales taxes and away from the real estate tax encourages old buildings to remain in place and block self-renewal. The concessions in the income tax laws to encourage low-income housing do, in the long run, actually increase the total low-income population. Highway expenditures and government loans for suburban housing have made it easier for higher-income groups to abandon urban areas than to revive them. Expanding the areas incorporated into urban government, in an effort to increase revenue base, has been more than offset by lowered administrative efficiency, more citizen frustration, and the accelerated decline that is triggered in the annexed areas. The belief that more money will solve urban problems has taken attention away from correcting the underlying causes and has instead allowed the problems to grow to the limit of available money.

VI. CHARACTERISTICS OF SOCIAL SYSTEMS

Many characteristics of social systems mislead people. Behavior that people do not anticipate appears in corporate and urban systems and in world-wide pressures now enveloping the planet. Three counterintuitive behaviors of social systems are especially dangerous.

First, social systems are inherently insensitive to most policy changes that people choose in an effort to alter the behavior of systems. In fact, social systems draw attention to the very points at which an attempt to intervene will fail. Human intuition develops from exposure to simple systems. In simple systems, the cause of a trouble is close in both time and space to symptoms of the trouble. If one touches a hot stove, the burn occurs here and now; the cause is obvious. However, in complex dynamic systems, causes are often far removed in both time and space from the symptoms. True causes may lie far back in time and arise from an entirely different part of the system from when and where the symptoms occur. However, the complex system can mislead in devious ways by presenting an apparent cause that meets the expectations derived from simple systems. A person will observe what appear to be causes that lie close to the symptoms in both time and space—shortly before in time and close to the symptoms. However, the apparent causes are usually coincident occurrences that, like the trouble symptom itself, are being produced by the feedback-loop dynamics of a larger system. For example, human suffering in cities is accompanied (some think caused) by inadequate housing. As a result, housing is increased and population rises to defeat the effort. More people are trapped in the depressed urban system. As another example, symptoms of excess population are beginning to overshadow all countries. Symptoms appear as urban crowding and social pressure. Rather than face the rising population problem squarely, governments try to relieve the immediate pressures by more policemen, financial aid, busing to suburban schools, and subsidized health facilities. As a consequence, increasing population reduces the quality of life for everyone.

Second, social systems seem to have a few sensitive influence points through which behavior can be changed. These high-influence points are not where most people expect. Furthermore, when a high-influence policy is identified, the chances are great that a person guided by intuition and judgment will alter the system in the wrong direction. For example, in an urban system, housing is a sensitive control point but, if one wishes to make the city a better place for low-income as well as other people, it appears that low-income housing should be reduced rather than increased. Another example lies in the world-wide problem of rising population and the disparity between the standards of living in the developed and the underdeveloped countries. System dynamics models suggest sensitive control points for increasing the world-wide quality of life exist in the rate of generation of capital investment and in food production, but that expansion of industrialization and food output are the counter productive directions, both should be restrained. The common answer to world distress has been to increase industrialization and food production, but hope for long-term improvements probably lies in reducing emphasis on both. Contrary to intuitive expectations, the opposite of present practice may actually raise the quality of life and contribute to stabilizing population.

Third, social systems exhibit a conflict between short-term and long-term consequences of a policy change. A policy that produces improvement in the short run is usually one that degrades a system in the long run. Likewise, policies that produce long-run improvement may initially depress behavior of a system. This is especially treacherous. The short run is more visible and more compelling. Short-run pressures speak loudly for immediate attention. However, sequences of actions all aimed at short-run improvement can eventually burden a system with long-run depressants so severe that even heroic short-run measures no longer suffice. Many problems being faced today are the cumulative result of short-run measures taken in prior decades.

VII. A GLOBAL PERSPECTIVE

After discussing social organizations in corporations and cities, the following discussion turns to an even larger world-wide system.

In July, 1970, we held at MIT a two-week international conference on world dynamics. A meeting was organized for the Club of Rome, a private group of about 100 individuals drawn from many countries who had joined together to attempt a better understanding of world problems. Their concern lay in the interactions of population, resources, industrialization, pollution, and world-wide disparities of standard of living. The July agenda included the theory and behavior of complex systems and talks on specific social systems ranging through corporations, commodity markets, biological systems, drug addiction, and growth and decline of cities. A dynamics model, especially prepared for the conference, showed interactions among world population, industrialization depletion of natural resources, agriculture, and pollution. A detailed discussion of the world model appears in *World Dynamics* (Forrester, 1971). That model was refined in the "Project on the Predicament of Mankind" sponsored by the Club of Rome at MIT (Donella Meadows, et al, 1972; Dennis Meadows, et al, 1973 and 1974).

The model of world interactions showed different alternative futures depending on whether social policies are adopted to limit population growth while a high standard of living is still possible or whether the future is ignored until population is suppressed by pollution, crowding, disease, water and resource shortage, social strife, hunger. Malthus dealt only with the latter, but it is possible for civilization to encounter other controlling pressures before a food shortage occurs.

It is certain that resource shortage, pollution, crowding, disease, food failure, war, or some other equally powerful force will limit population and industrialization if persuasion and psychological factors do not. Exponential growth cannot continue forever. At present population growth rates, there would remain only one square yard per person in less than 400 years. Our greatest challenge is to guide the transition from growth to equilibrium. There are many possible mechanisms for limiting growth. That current growth rates of population and industrialization will stop is inevitable. Unless we choose favorable processes to limit growth, the social and environmental systems by their internal processes will choose for us. The natural mechanisms for terminating exponential growth appear the least desirable. Unless the world understands and begins to act soon, civilization will be overwhelmed by forces we have created but can no longer control.

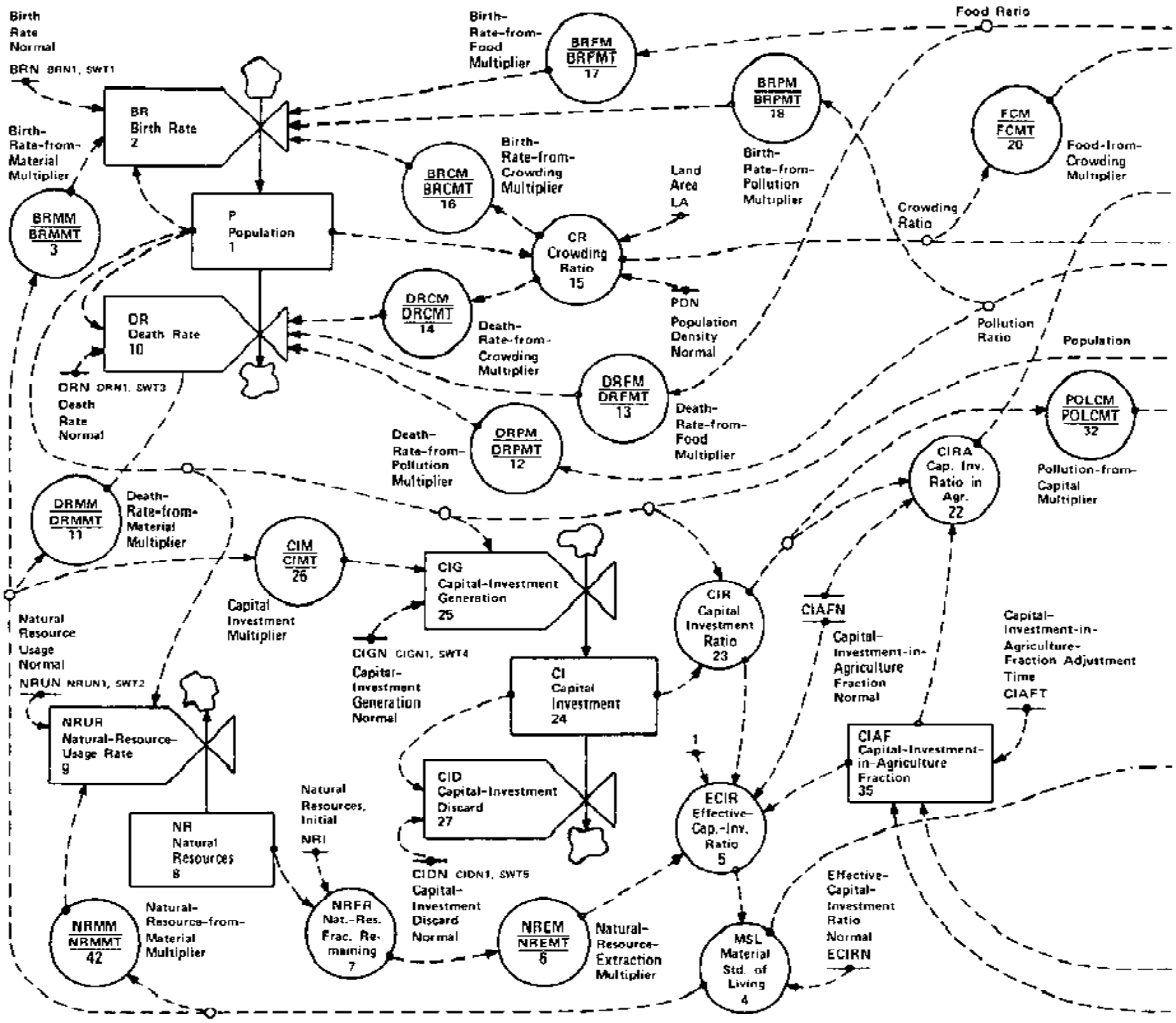
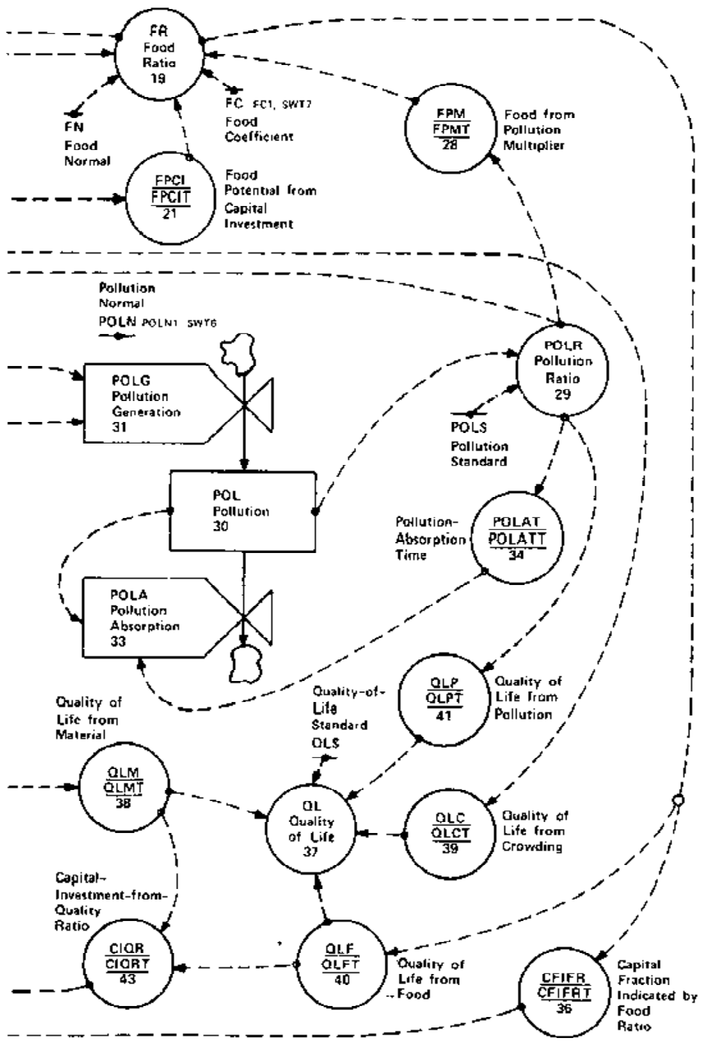


Fig. 1 This world model is a beginning basis for analyzing the effect of changing population and economic growth over the next 50 years. The model includes interrelationships of population, capital investment, natural resources, pollution, and agriculture.

Figure 1 (from Forrester, 1971) interrelates the mutual effects of population, capital investment, natural resources, pollution, and agriculture as the five system “levels” shown by the rectangles. Each level is caused to change by the rates of flow in and out, such as the birth rate and death rate that increase and decrease population. The dotted lines, through intermediate concepts shown at the circles, control the rates of flow. For example, death rate at Symbol 10 depends on population P and the “normal” lifetime as stated by death rate normal (DRN). But death rate also depends on conditions in other parts of the system. From Circle 12



comes the influence of pollution that here assumes death rate will double if pollution becomes 20 times as severe as in 1970; and, progressively, that death rate would increase by a factor of 10 if pollution became 60 times as much. Likewise from Circle 13 the effect of food per capita increases death rate as food becomes less available. The detailed definition of the model states how each rate of flow is assumed to depend on the levels of population, natural resources, capital investment, capital devoted to agriculture, and pollution.

Individually the assumptions in the models are plausible, create little disagreement, and reflect common discussions and assertions about the world system. Each assumption is explicit and can be subjected to scrutiny. From one viewpoint, the system of Figure 1 is very simplified. It focuses on a few major factors and omits most of the substructure of world social and economic activity. But from another viewpoint, Figure 1 is comprehensive and complex. The system is far more complete and the theory described by the accompanying computer model is much more explicit than the mental models that are being used as a basis for world and governmental planning. The model incorporates many nonlinear relationships. The world system shown here exhibits provocative and even frightening possibilities.

Using a system dynamics model, a computer can show how a system, as described for each of its parts, would behave. Given a set of beginning conditions, the computer can calculate and plot the results that unfold through time. The world today is entering a condition in which pressures are rising simultaneously from every one of the influences that can suppress growth—depleted resources (especially water and energy), pollution, crowding, and insufficient food. It is still unclear which counter force from the environment will dominate if mankind continues along the present path.

Figure 2 shows the mode of behavior of this model system if industrialization is suppressed by falling natural resources. The model system starts with estimates of conditions in 1900. Adjustments were made so that the generated paths pass through the estimated conditions of 1970.

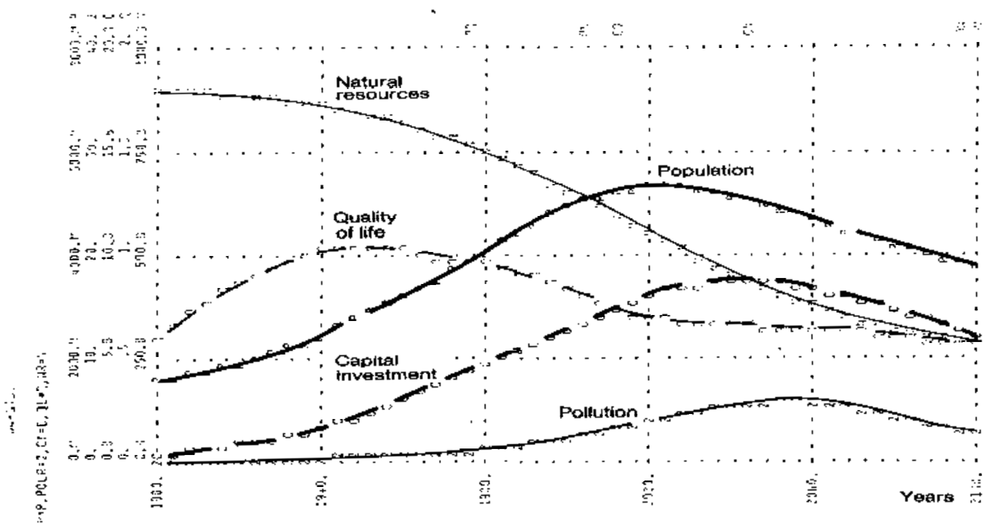


Fig. 2. Basic world model behavior showing the mode in which industrialization and population are suppressed by falling natural resources.

In Figure 2, the quality of life peaks in the 1950s and by 2020 has fallen far enough to halt further rise in population. Declining resources and the consequent fall in capital investment exert further pressure to gradually reduce world population.

VIII. ATTRACTIVE POLICIES CAN CREATE DISASTERS

We may not be fortunate enough to run gradually out of natural resources. Science and technology may very well find ways to use the more plentiful metals and atomic energy so that resource depletion does not intervene. If so, the way then remains open for another growth-resisting pressure to arise. Figure 3 shows what happens if the resource shortage is avoided. Here the only change from Figure 2 is in usage rate of natural resources after year 1970. In Figure 3, resources are used after 1970 at a rate 75 per cent less than assumed in Figure 2. In other words, the standard of living is sustained with a lower drain on the expendable and irreplaceable resources. But the picture is even less attractive! By not running out of resources, population and capital investment are allowed to rise until a pollution crisis is created. Pollution then acts directly to reduce birth rate, increase death rate, and depress food production. Population, which according to this simple model peaks at the year 2030, has fallen to one-sixth of the peak population within an interval of 20 years—a world-wide catastrophe of a magnitude never before experienced. Should it occur, one can speculate on which sectors of the world population will suffer most. It is quite possible that the more industrialized countries (which are the ones that would have caused such a disaster) would be the least able to survive such a disruption to environment and food supply. Industrialized countries might take the brunt of the collapse.

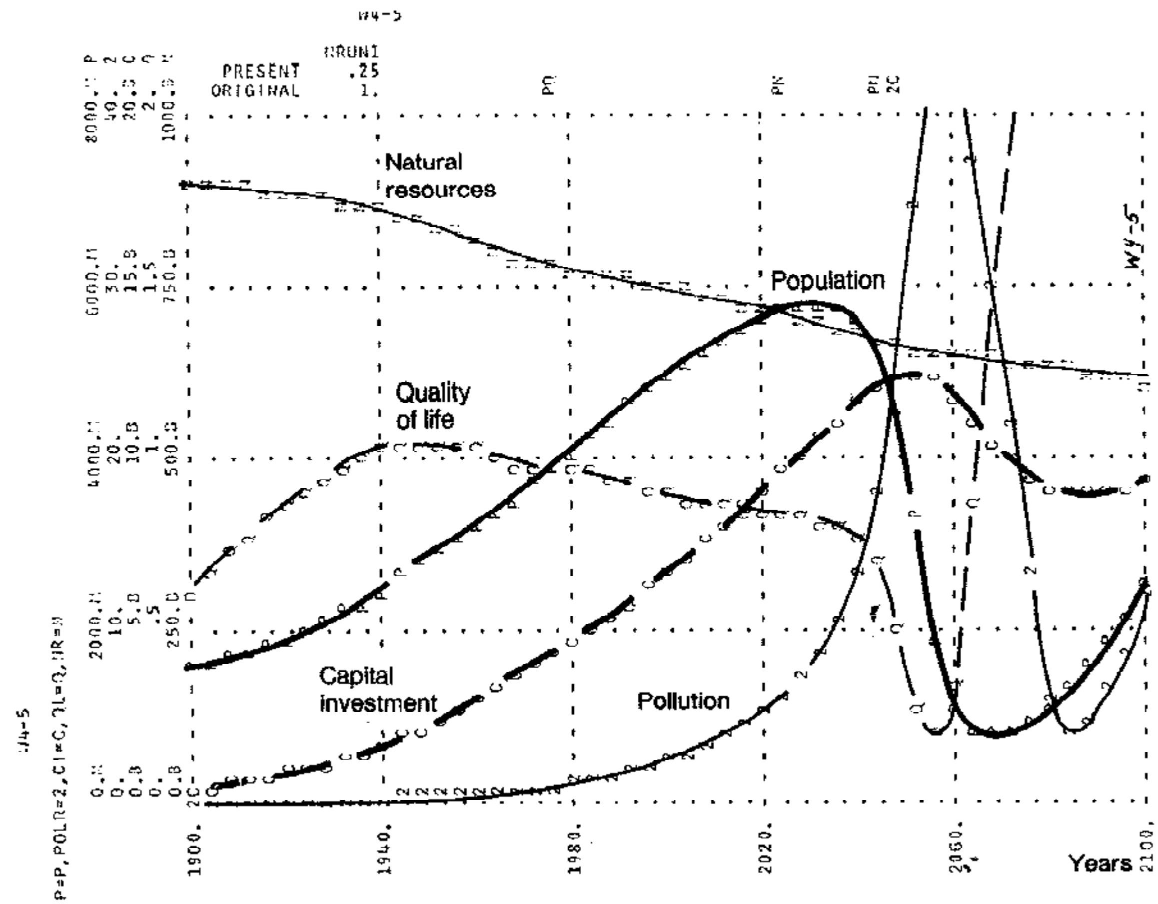


Fig. 3. A pollution crisis is precipitated by lower usage of natural resources. In 1970, natural resource usage is reduced 75 per cent by more effective technology without affecting material standard of living.

Figure 3 shows how a technological success (reducing our dependence on natural resources) can merely save us from one fate only to fall victim to something worse (a pollution catastrophe). Throughout the world an undercurrent of doubt is developing about technology as a savior from social and environmental ills. There is a basis for such doubt. The source of doubt lies not in technology itself but in management of the entire technological-human-political-economic-natural complex.

Figure 3 is a dramatic example of the general process discussed earlier wherein a program aimed at one trouble system results in creating a new set of troubles in some other part of the system. Here, success in alleviating a natural resource shortage throws the system over into a pollution crisis that stops and reverses population expansion. The way in which a solution to one trouble creates a new problem has defeated many past governmental programs and will continue to do so until more effort is devoted to understanding the dynamic behavior of social systems.

Suppose in the basic world system of Figures 1 and 2 we ask how to sustain the quality of life which is beginning to decline after 1950. One attempt, which is popular, might be to increase the rate of industrialization by raising the rate of capital investment. A dynamics model can shed light on such hypothetical questions in a few minutes and at negligible cost. Figure 4 shows what happens if the "normal" rate of capital accumulation is increased by 20 per cent in 1970. Again, the pollution crisis appears. This time the cause is not more efficient use of natural resources but an upsurge of industrialization that overtaxes the environment before resource depletion has a chance to depress industrialization. Again, an "obvious" desirable policy has caused troubles worse than the ones that were originally being corrected.

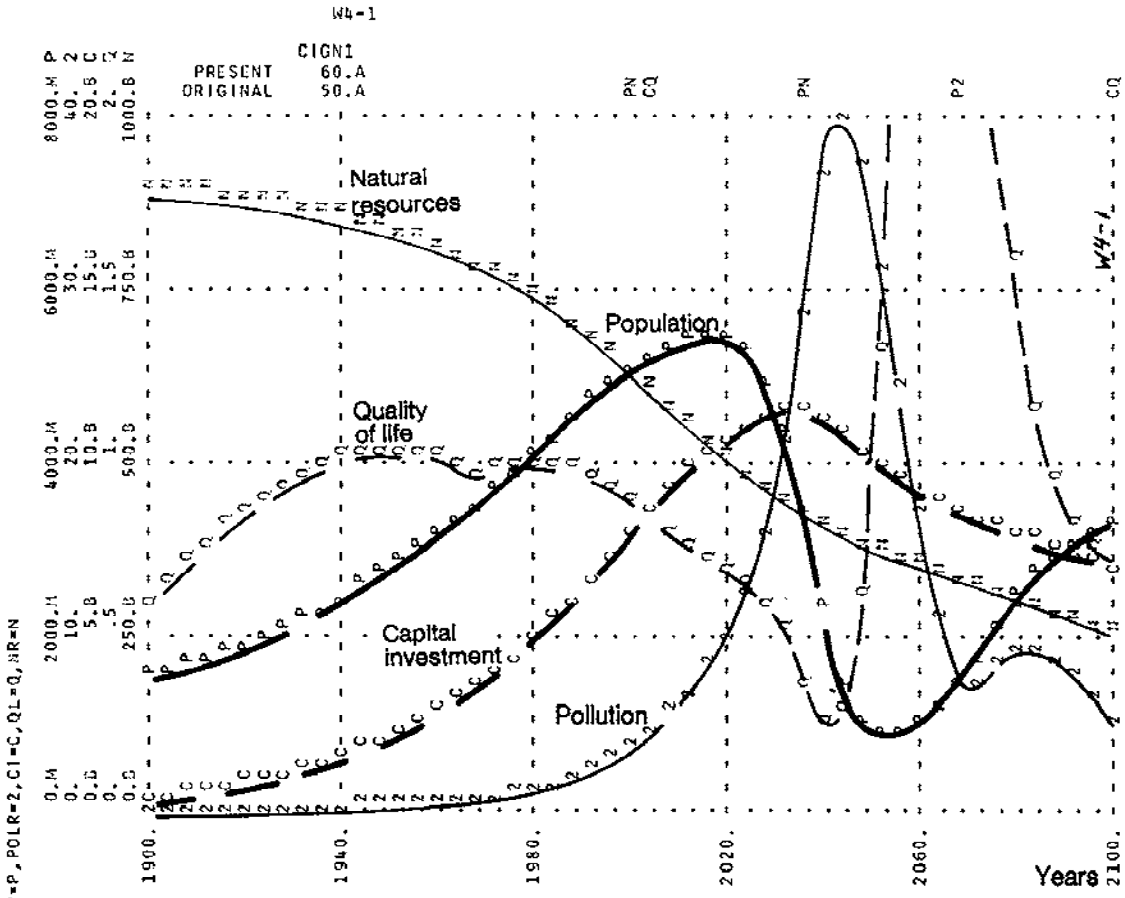


Fig. 4. In 1970, the rate of capital accumulation is increased 20 per cent in an effort to reverse the decline in quality of life. The pollution crisis occurs before natural resources are depleted.

This triggering of a pollution crisis is important, not only for its own message, but because it demonstrates how an apparently desirable change in a social system can have unexpected and even disastrous results.

Figure 4 should make us cautious about rushing into programs on the basis of short-term humanitarian impulses. The eventual result can be anti-humanitarian. Emotionally inspired efforts often fall into one of three traps set for us by the nature of social systems: (1) The programs are apt to address symptoms rather than causes and attempt to operate through points in the system that have little leverage for change; (2) the characteristic of systems whereby a policy change has the opposite effect in the short run from the effect in the long run can eventually cause deepening difficulties after a sequence of short-term actions; and (3) the effect of a program can be along an entirely different direction than was originally expected, so that suppressing one symptom only causes trouble to burst forth at another point.

IX. COMBINATIONS OF "OBVIOUS" POLICIES

Figure 5 retains the 20 per cent additional capital investment rate after 1970 from Figure 4 and in addition explores birth rate reduction as a hope of avoiding crisis. Here the normal birth rate has been cut in half in 1970. (Changes in normal rates refer to coefficients which have the specified effect if all other things remain the same. But other things in the system change and also exert their effects on the actual rates.) The result shows interesting behavior. Quality of life surges upward for 30 years for the reasons that are customarily expected. Although not shown in the figure, food-per-capita grows, material standard of living rises, and crowding does not become as great. But the more affluent world population continues to use natural resources and to accumulate capital plant at about the same rate as in Figure 4. Load on the environment is more closely related to industrialization than to population so the pollution crisis occurs at about the same time as in Figure 4.

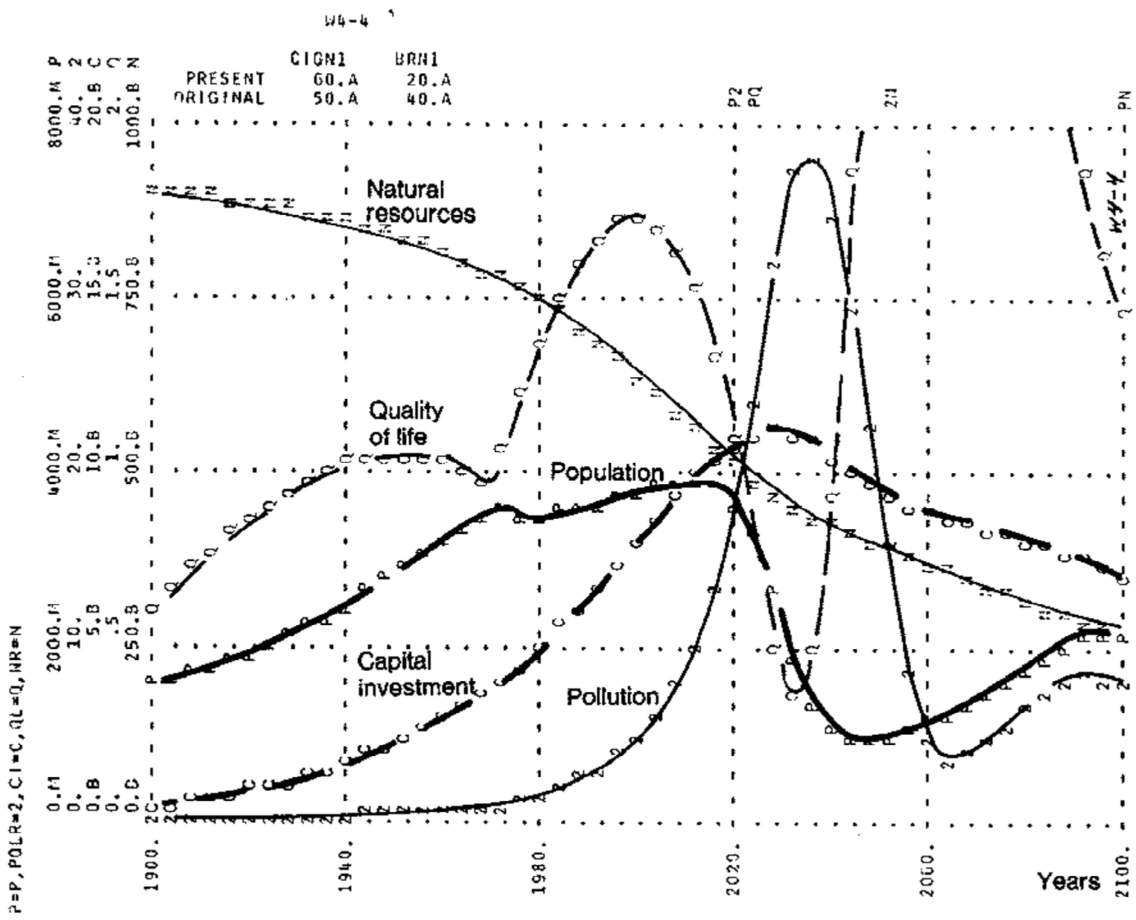


Fig. 5. In 1970 the 20 per cent increase in capital accumulation of Figure 4 is retained and "normal" birth rate is reduced 50 per cent. Capital investment continues to grow until a pollution crisis develops. After an initial decline, population is again pushed up by the rapid rise in quality of life that precedes the collapse.

Figure 5 shows that the 50 per cent reduction in normal birth rate in 1970 was sufficient to start a decline in total population. But the rising quality of life and the reduction of pressures act to start the population curve upward again. Serious questions are raised about the effectiveness of birth control as a means of controlling population when birth rate reduction is the only policy. Secondary consequences of a birth control program will increase influences that raise birth rate and reduce the apparent pressures that require population control. A birth control program which would be effective, all other things being equal, may largely fail because other things will not remain equal. Early success can set in motion forces that eventually defeat the program.

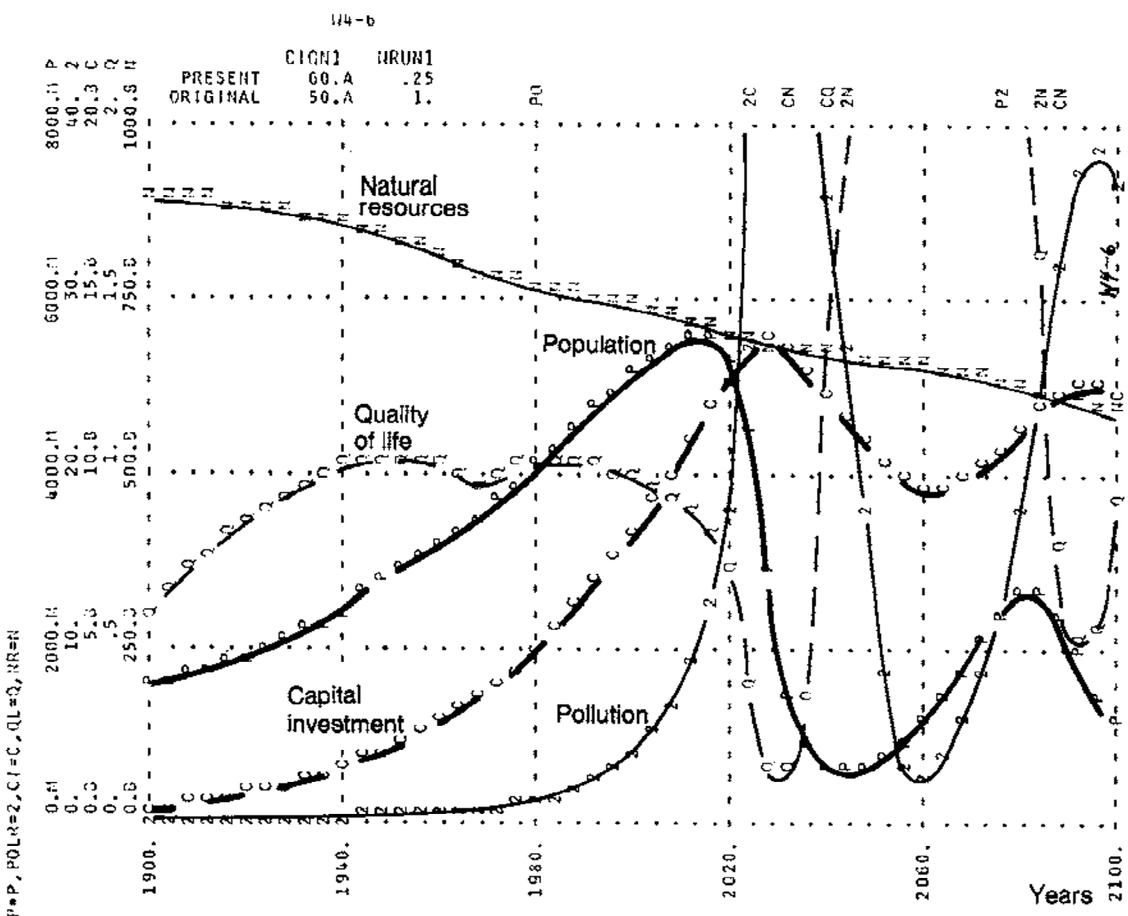


Fig. 6. The 20 per cent increase of capital investment from Figure 4 and the 75 per cent reduction of natural resource usage from Figure 3 are combined.

Figure 6 combines the reduced resource usage rate and increased capital investment rate of Figures 3 and 4. As a result, population collapse occurs slightly sooner and more severely based on the modified system of Figure 6.

Figure 7 examines the result if technology finds ways to reduce pollution generated by industrialization. Pollution rate, other things being the same, is reduced by 50 per cent from that in Figure 6. The result is to postpone the day of reckoning by 20 years and to allow population to grow 25 per cent greater before population collapse occurs. The "solution" of reduced pollution has, in effect, caused more people to suffer the eventual consequences. Figure 7 again reveals the dangers of partial solutions. Actions at one point in a system to relieve one kind of distress produce an unexpected result in some other part of the system. If the interactions are not sufficiently understood, the consequences can be bad as or worse than those that led to the initial action.

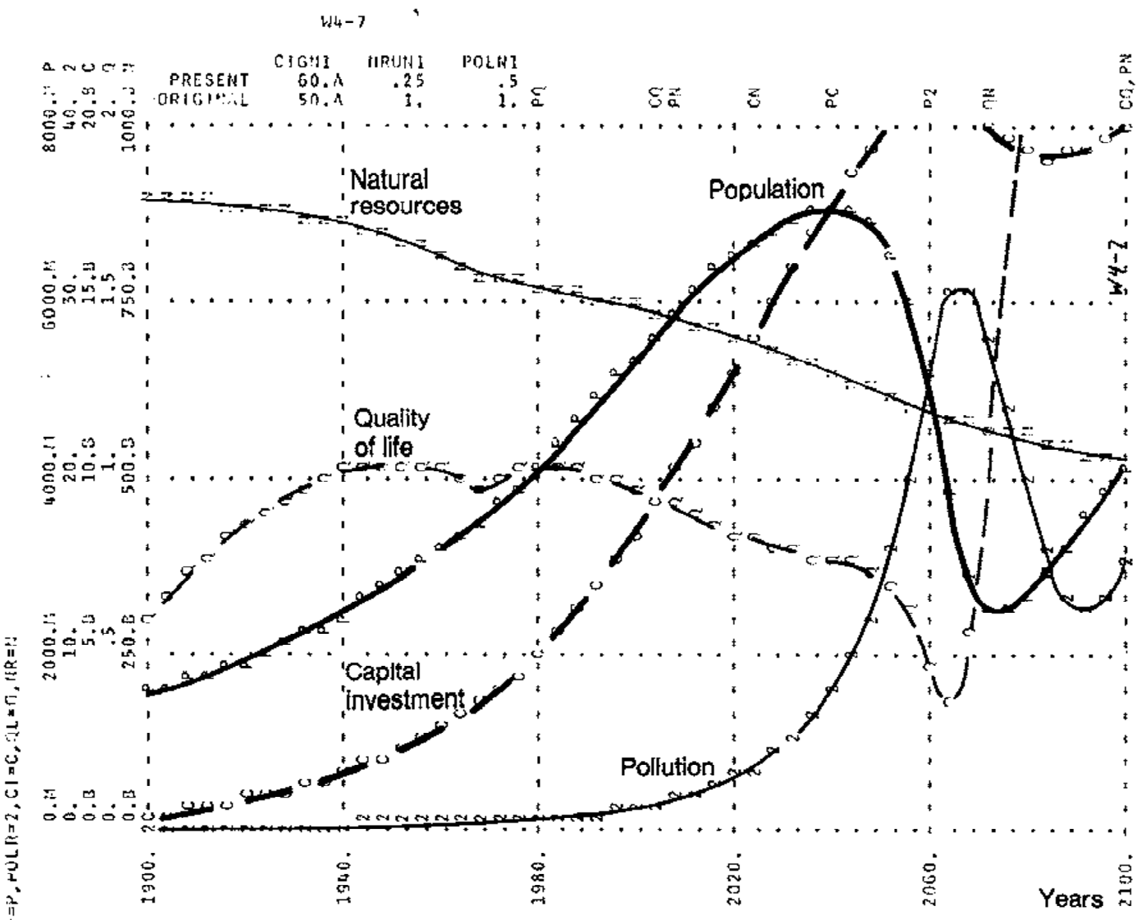


Fig. 7. Increased capital investment rate and reduced natural resource usage from Figure 6 are retained. In addition in 1970 the normal rate of pollution generation is reduced 50 per cent. The effect of pollution control is to allow population to grow 25 per cent further and to delay the pollution crisis by 20 years.

X. AN ALTERNATIVE TO CATASTROPHE

There are no utopias in social systems. There appear to be no sustainable modes of behavior that are free of pressures and stresses. But many modes of behavior are possible and some are more desirable than others. The more attractive behaviors in social systems seem possible only if we act on a good understanding of the dynamic behavior of systems and are willing to endure the self-discipline and short-term pressures that will accompany the route to a desirable future. The world system of Figure 1 can exhibit modes that are more hopeful than the crises of Figure 2 through 7. The more promising modes may require a degree of restraint and dedication to a long-range future that people are not capable of sustaining.

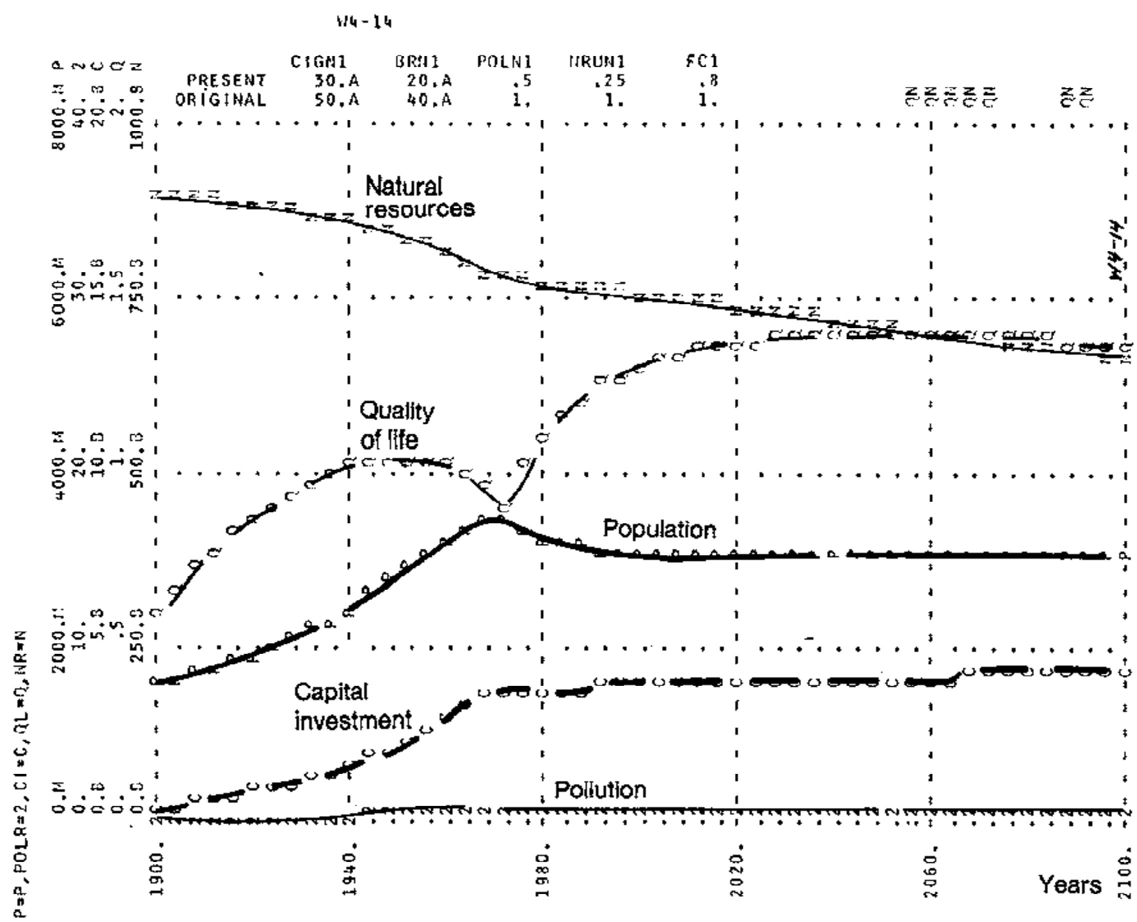


Fig. 8. One set of conditions that establishes a world equilibrium at a high quality of life. In 1970 normal capital investment rate is reduced 40 per cent, normal birth rate is reduced 50 per cent, normal pollution generation is reduced 50 per cent, normal natural resource usage rate is reduced 75 per cent, and normal food production reduced 20 per cent.

Figure 8 shows the world system if several policy changes are adopted together in the year 1970. Population is stabilized. Quality of life rises about 50 per cent. Pollution remains at about the 1970 level. Would such a world be accepted? It implies an end to population and economic growth.

In Figure 8 the normal rate of capital accumulation is reduced 40 per cent from its previous value. The normal birth rate is reduced 50 per cent from its earlier value. The normal pollution generation is reduced 50 per cent from the value before 1970. The normal rate of food production is reduced 20 per cent from its previous value. (These changes in "normal" values are the changes for a specific set of system conditions. Actual system rates continue to be affected by the varying conditions of the system.) However, reduction in investment rate and reduction in emphasis on agriculture are counterintuitive and not likely to be accepted without extensive system studies and years of argument—perhaps more years than are available. The changes in pollution generation and natural resource usage may be easier to understand and to achieve. The severe reduction in world-wide birth rate is the most doubtful. Even if technical and biological methods existed, the improved condition of the world might remove the incentive for sustaining the birthrate reduction.

XI. FUTURE POLICY ISSUES

Changes in the world as a whole bear directly on the future of the United States. American urbanization and industrialization are a major part of the world scene. The United States is setting a pattern that other countries are emulating. However, the example set by the United States is not sustainable. Our foreign policy and our overseas commercial activity are running contrary to changes that should occur in the world system.

The following issues are raised by preliminary studies. Implications for action must be examined more deeply and confirmed by more research into the assumptions about structure and detail of the world system.

(a) Industrialization may be a more fundamentally disturbing force in world ecology than is population. In fact, the population explosion is perhaps best viewed as a result of technology and industrialization. I include medicine and public health improvements as a part of the industrialization that has led to rising population.

(b) Within the next century, the world will be facing a four-pronged dilemma—suppression of modern industrial society by a natural resource shortage, collapse of world population from changes wrought by pollution, population limitation by food shortage, or population control by war, disease, and social stresses caused by physical and psychological crowding.

(c) We may now be living in a “golden age” where, in spite of the world-wide feeling of malaise, the quality of life is, on the average, higher than ever before in history and higher now than the future offers.

(d) Efforts for direct population control may be inherently self-defeating. If population control results, as hoped, in high per capita food supply and material standard of living, these very improvements can generate forces to trigger a resurgence of population growth.

(e) The high standard of living of modern industrial societies results from a production of food and material goods that has been able to outrun rising population. But, as agriculture reaches a space limit, and as both reach a pollution limit, population tends to catch up. Population will then grow until the “quality of life” falls far enough to generate sufficiently large pressures to stabilize population.

(f) There may be no realistic hope for the present underdeveloped countries reaching the standard of living demonstrated by the present industrialized nations. The pollution and natural resource load placed on the world environmental system by each person in an advanced country is probably 10 to 20 times greater than the load now generated by a person in an underdeveloped country. With four times as much population in underdeveloped countries as in the present developed countries, their rising to the economic level of the United States could mean an increase of 40 times the present natural resource and pollution load on the world environment. Noting the destruction that has already occurred on land, in the air, and especially in the oceans, no capability exists for handling such a rise in standard of living for the present total population of the world.

(g) A society with a high level of industrialization may be nonsustainable. Present societies may be self-extinguishing if they exhaust the natural environments on which they depend. Or, if unending substitution for declining natural resources is possible, the international strife over pollution and environmental rights may pull the average world-wide standard of living back to the level of a century ago.

(h) From the long view of a hundred years hence, the present efforts of underdeveloped countries to industrialize along Western patterns may be unwise. They may now be closer to the ultimate equilibrium with the environment than are the industrialized nations. The present underdeveloped countries may be in a better condition for surviving the forthcoming worldwide environmental and economic pressures than are the advanced countries. When one of the several potential forces materializes that is strong enough to cause a collapse in world population, the advanced countries may suffer far more than their share of the decline.

XII. A NEW FRONTIER

It is now possible to take hypotheses about separate parts of a social system, combine them in a computer model, and learn the consequences. The hypotheses may at first be no more correct than the ones we are using in our intuitive thinking. But the process of computer modeling and model testing requires these hypotheses to be stated explicitly. The model comes out of the hazy realm of mental models into unambiguous model statements to which all have access. Assumptions can then be checked against all available information and can be rapidly improved. The great uncertainty with mental models arises from inability to anticipate the consequences of interactions between parts of a system. This uncertainty about future dynamic implications of assumptions in a model is totally eliminated in computer models. Given a stated set of assumptions, the computer traces the resulting consequences without doubt or error. Computer simulation is a powerful procedure for clarifying issues. It is not easy. Results will not be immediate.

We are on the threshold of a great new era in human pioneering. In the past there have been periods characterized by geographical exploration. Other periods have dealt with the formation of national governments. At other times the focus was on the creation of great literature. Most recently we have been through the pioneering frontier of science and technology. But science and technology are now a routine part of life. Science is no longer a frontier. The process of scientific discovery is orderly and organized.

The next frontier for human endeavor is to pioneer a better understanding of environmental, economic, and social systems. The means are available. The task will be no easier than past development of science and technology. For the next 50 years we can expect rapid advance in understanding the complex dynamics of social systems. To do so will require research, development of teaching methods and materials, and creation of appropriate educational programs. The research results of today will find their way into secondary schools just as concepts of basic physics moved from research laboratories to general education over the last century.

What we do today affects our future many decades hence. If we follow intuition and the fallacies embedded in mental models, the trends of the past will continue into deepening difficulty. If we set appropriate research and education programs, which are now possible, we can expect a far sounder basis for future action.

XIII. THE NATION'S ALTERNATIVES

The record to date implies that people accept future growth of United States population as preordained, beyond the purview and influence of legislative action, and as a ground rule which imposes on the nation a task of finding cities in which a rising future population can live. However, I have described the circular processes in social systems where there is no unidirectional cause and effect. Instead, a ring of actions and consequences close back on themselves. One could say, incompletely, that population will grow and that cities, space, and food must be provided. But one can likewise say, also incompletely, that the provision of cities, space and food will cause population to grow. Population generates pressure for urban growth, but urban pressures help to limit population.

Population grows until stresses rise far enough, which is to say that the quality of life falls far enough, to stop further increase. Everything we do to reduce those pressures causes the population to rise farther and faster and hastens the day when expediencies will no longer suffice. The United States is in the position of a wild animal running from pursuers. We still have some space, natural resources, and agricultural land left within which to maneuver. We can avoid the question of rising population as long as we can flee into this bountiful reservoir that nature provided. But it is obvious that the reservoirs are limited. A wild animal flees until it is cornered, until it has no more space. Then it turns to fight, but it no longer has room to maneuver. The animal is less able to forestall disaster than if it had fought in the open while there was still room to yield and to dodge. The United States is running away from its long-term threats by trying to relieve social pressures as they arise. But if we persist in treating only symptoms and not causes, the result will increase the ultimate threat and reduce our choices for response.

What does this mean? Instead of automatically accepting the need for new towns and the desirability of locating industry in rural areas, we should consider confining our cities. If it were possible to prohibit the encroachment by housing and industry onto even a single additional acre of farm and forest, the resulting social pressure would hasten the day when we would stabilize population. Some European countries are closer to curtailing urban growth than are we.

As I understand it, farmland surrounding Copenhagen cannot be used for either residence or industry until the severest of pressures forces the government to rezone small additional parcels. When land is rezoned, the corresponding rise in land price is fully taxed to remove the incentive for land speculation. The waiting time for an empty apartment in Copenhagen may be years. Such pressures certainly cause the Danes to face the population problem more squarely than do we.

Our greatest challenge now is handling the transition from growth to equilibrium. For a thousand years, tradition has encouraged and rewarded growth. Folklore and success stories praise growth and expansion. But growth is not the path for an unlimited future. Many present stresses in society arise from pressures that accompany the transition from growth into equilibrium. However, the pressures thus far in cities are minor compared to those which are approaching. Population pressures and economic forces in a city that was reaching equilibrium have in the past been able to escape to new land areas.

Escape is becoming less possible. Until now we have had, in effect, an inexhaustible supply of farm land and food-growing potential, but now we are reaching a critical point where, all at the same time, population is overrunning productive land, agricultural land is almost fully employed for the first time, the rise in population is putting more demand on food supplies, and urbanization is pushing agriculture out of the fertile areas into marginal lands. For the first time demand is rising into a condition where supply will begin to fall while need increases. The crossover from plenty to shortage can occur abruptly.

The fiscal and monetary policies of a country form a complex dynamic system of the kind I have been discussing. It is clear that the United States has no established policies to guide interactions between government, growth, unemployment, and inflation. The need to develop long-term policies becomes ever more urgent as the country moves for the first time from a history of growth into the turbulent pressures accompanying the transition from growth to one of the many possible kinds of equilibrium. We need to choose and work toward a desirable kind of equilibrium before we arrive at a point where the system imposes its own choice of regrettable consequences.

In a hierarchy of systems, a conflict exists between goals of a subsystem and welfare of the broader system. The conflict is seen in an urban system. The goal of a city is to expand and to try to raise its quality of life. But growth policies increase population, industrialization, pollution, and demands on food supply. The broader social systems of a country and the world require that goals of urban areas be curtailed and that pressures from such curtailment become high enough to keep urban areas and population within bounds that are satisfactory to the larger system of which cities are a part. If this nation continues to pursue traditional urban goals, the result will deepen distress of the country as a whole and eventually deepen the crisis in cities themselves. We may be at a point where higher pressures in the present are necessary if insurmountable pressures are to be avoided in the future.

I have given a glimpse of the nature of multi-loop feedback systems, a class to which social system belong. I have shown how these complex systems mislead people because intuition has been formed by experienced from simple systems from which we expect behavior very different from that actually possessed by complex systems. The United States is still pursuing programs that will be even more frustrating and futile than many of the past.

But there is hope. It is now possible to gain a better understanding of dynamic behavior in social systems. Progress will be slow. There are many cross-currents in the social sciences which will cause confusion and delay. The system dynamics approach that I have been describing is very different from the emphasis on data gathering and statistical analysis that occupies much of social research. But there have been breakthroughs in several areas. If we proceed expeditiously but thoughtfully, there is a basis for optimism.

BIBLIOGRAPHY

Alfeld, Louis Edward, and Alan K. Graham, 1976. *Introduction to Urban Dynamics,* Pegasus Communications, Waltham MA. 333 pp.

Forrester, Jay W., 1961. *Industrial Dynamics*, Pegasus Communications, Waltham MA. 464 pp.

Forrester, Jay W., 1968. *Principles of Systems*, (2nd ed.). Pegasus Communications, Waltham MA. 391 pp.

Forrester, Jay W., 1968. *Principles of Systems*, (2nd ed.). Pegasus Communications, Waltham MA. 391 pp.

Forrester, Jay W., 1969. *Urban Dynamics*, Pegasus Communications, Waltham MA. 285 pp.

Forrester, Jay W. 1969a. "Systems Analysis as a Tool for Urban Planning." In Martin Goland (ed.), *The Engineer and the City*, pp. 44-53. Washington, D.C.: National Academy of Engineering. Reprinted in several places, including Chapter 2 in *Readings in Urban Dynamics: Volume 1*, 1974, N. J. Mass, ed, and as Chapter 11, pp. 175-189, in the author's *Collected Papers,* 1975, both from Pegasus Communications, Waltham MA; and in *Industrialized Building Systems for Housing*, Albert G. H. Dietz and Laurence S. Cutler, eds., MIT Press, Cambridge, MA, 1971.

Forrester, Jay W., 1971. *World Dynamics*, (1973 second ed.). Pegasus Communications, Waltham MA. 144 pp. Second edition has an added chapter on physical vs. social limits.

Forrester, Jay W., 1975. *Collected Papers of Jay W. Forrester* Pegasus Communications, Waltham MA. 284 pp.

Goodman, Michael R., 1974. *Study Notes in System Dynamics*, Pegasus Communications, Waltham MA. 388 pp.

Mass, Nathaniel J., ed., 1974. *Readings in Urban Dynamics: Volume I*, Pegasus Communications, Waltham MA, 303 pp.

Meadows, Dennis L., and Donella H. Meadows, ed., 1973. *Toward Global Equilibrium: Collected Papers*, Pegasus Communications, Waltham MA, 358 pp.

Meadows, Dennis L., William W. Behrens, III, Donella H. Meadows, Roger F. Naill, Jørgen Randers, and Erich K. O. Zahn, 1974. *Dynamics of Growth in a Finite World*, Pegasus Communications, Waltham MA. 637 pp.

Meadows, Donella H., Dennis L. Meadows, Jørgen Randers, and William W. Behrens, III, 1972. *The Limits to Growth*, New York: Universe Books. 205 pp.

Schroeder, Walter W., III, Robert E. Sweeney, and Louis Edward Alfeld, ed., 1975. *Readings in Urban Dynamics: Volume 2*, Pegasus Communications, Waltham MA, 305 pp.