World Dynamics in the 21st Century

by

David E. Brown

Submitted to the Department of Civil and Environmental Engineering in partial fulfillment of the requirements for the degree of

Master of Science in Civil and Environmental Engineering

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

May 6, 1997

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Abstract

The original *World Dynamics* world model by Jay Forrester was published in the early 1970s, and represented one of the first detailed computer models of world processes. Incorporating then current values for population, pollution, and other factors, the model suggested that if growth trends continued, physical limits would be reached and bring a halt to growth. Furthermore, many policies aimed at averting such limits were predicted by the model as being ineffective and even damaging in the long-term. Now, almost thirty years later, society is beginning to recognize the importance of long-term sustainability of the world. This research explores the effects that thirty years of continued growth, with little change in society's values, has on the world system.

The world model as used in *World Dynamics* is implemented on current simulation software, and the behavior of the world system is explored given thirty years of relative inaction on the part of policymakers to curb growth. Policies which, in the original model, were implemented in 1970 are now delayed until the year 2000. Model runs are performed for many of the sets of policies used in the original book, and the outcomes are compared. Additionally, several policies are run using the assumption of unlimited natural resources, which was a major criticism of the original world model.

Model runs using the year 2000 policies suggest that the longer society delays action, the less time will be available and the harder it will be to achieve desirable results. In several instances the delay produced a significantly lower quality of life. Other runs imply a "point of no return", after which date the policies are incapable of affecting the growth and collapse behavior of the system. Unlimited resources are found to promote growth and instability in the system, rather than solve its problems. The results strongly suggest the need for a society which understands the principles and behavior of complex systems.

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Chapter 1

Background and Introduction

1.1 A summary of global concerns

Predicting the future has been an ongoing interest of mankind from the earliest times. Whether by crystal ball or Doppler radar, the knowledge of what is in store for us in the days to come has at times been paramount. As modernization spread throughout the world, several major areas of concern, such as population growth and the environment, have emerged and kept our attention. Along with these have come questions which are not only highly complex, but likely to be unanswerable. Problems such as, "What is the best environmental policy for the United States? Is this also the best policy for the world? What will happen to world population in the next century, and what effects will it have," have found their way into nightly news broadcasts and public discussions with increasing frequency. The public has become aware of the so-called "pressing" issues of the day, thanks in large part to the extensive, sometimes overzealous media coverage, but for the most part society has no understanding of either the magnitude of the crises, or how their solution or alleviation might spawn new, even more urgent problems.

1.2 System dynamics and the world model

There is, however, a field of study which is well suited to analysis of these kinds of complex systems. Developed at MIT by Jay Forrester in the 1950s, System Dynamics uses computers to simulate the response of complex systems to a set of inputs. To set up a computer model of a system, one first creates a "mental model" of how the various components interact, and then explicitly enters these relationships into the computer, which calculates and displays the system's responses over time. What makes System Dynamics so useful is its ability to be applied to both technical and non-technical areas, including social and environmental systems. Forrester pioneered the use of System Dynamics in these areas, publishing books on the dynamics of industry [1], urban areas [2], and finally the world [3].

In his book appropriately titled *World Dynamics*, Forrester presents us with the world model, a system composed of five levels (variables which describe the state of the system at any time): Population, Pollution, Capital Investment, Natural Resources, and Capital Investment in Agriculture Fraction, along with numerous other variables which are used to calculate and transmit various pieces of information (such as Quality of Life, Birth Rate, etc.) The model was run with data from 1970 (the current year at the time) on population growth, industrialization, and other known quantities. The output from the original run of the model is shown below as a graph depicting world population, natural resources, capital investment, quality of life, and pollution.

In addition to the base case run of the world model, Forrester went on to capture the effects of various global policy decisions such as increased capital investment, birth control, and pollution restrictions. *World Dynamics* contains over 20 runs of the world model, each one portraying a different scenario and policy decisions. Based on these runs, Forrester was able to identify key leverage points in the world model -- variables which could profoundly affect the behavior of the system. From these he developed a set of recommended policies aimed at achieving global equilibrium while increasing humankind's quality of life.

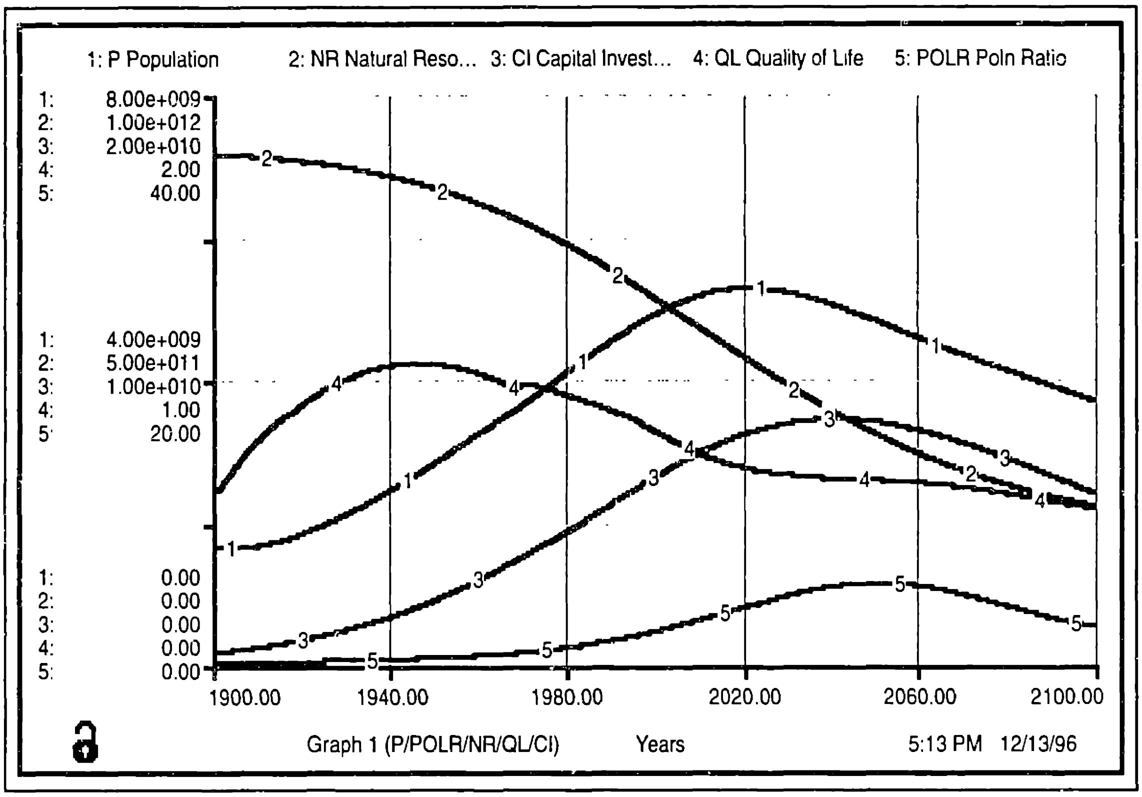

Figure 1.1: Original run of the world model

World Dynamics and the world model surged in popularity as well as controversy. Reviews showed up in every sector of print media, from *Fortune* and *The Wall Street Journal*, to *Playboy* and *The Christian Science Monitor* [4]. Many people took the results of the various computer runs to mean that society was doomed to collapse, while others asserted the model was flawed. Though the debates have for the most part died down, there are some important basic insights which the world model provides.

1.3 What the world model tells us

The world model is valuable because it allows us to see the behavior of the world system in response to a set of conditions. By behavior is meant the overall shape of the curves on the graph, as well as the "behavior modes" of the system (discussed in Chapter 2). Important also are the relative changes in output from one simulation run to the next, since these give clues to the various mechanisms operating within the system, and how to control them. The model can not, however, be used as a tool to predict the dates of future occurrences. One cannot say based on world model simulations that in the year 2020, a pollution crisis will occur if current trends continue. Again, it must be emphasized that the *qualities* of the graphs (the overall shape and behavior of the curves, and their relation to one another) are of significance, and not their *quantities*.

Using basic physics, we can state certain facts about world issues such as population and natural resources. For example, world population cannot continue growing at its present rate forever -- there simply will not be enough space left on Earth after a certain time. Thus, population **must** eventually level off or decline. The natural question to ask now is how will it do this. With similar questions arising for other global issues such as pollution and natural resources, we use the world model to show a possible outcome of the system.

By far the most important thing the world model can tell us is the reaction of the system to various control policies. Forrester demonstrated that not only do standard socio-economic policies not work in preventing undesirable outcomes in the system, but the majority of them tend to drive the system into such outcomes sooner than they would have otherwise occurred! A now classic example from *World Dynamics* explains how policies (or technologies) which lower the natural resource usage rate can lead to a pollution crisis due to rapid and expansive industry growth based on abundance of natural resources. Given the sensitive nature of the world system and the issues involved, it quickly becomes clear that policymakers, and the general public, need to not only be aware of the world system, but to understand how systems function in general. Ironically, the world has been moving in directions opposite to those prescribed by Forrester and the world model for a transition to a global equilibrium. Speeches by political candidates, especially those in the United States, promote (and boast of) rapid growth and industrial expansion along with increased capital investment -- exactly the policies which cause collapse in the world model. As Forrester has stated, "Time is short. We must move quickly if we are to keep future options open." [5]

1.4 The importance and validity of the world model

The impact on society of *World Dynamics* (and its successor *Limits to Growth* [6]) has been enormous. However, before embarking on further study of the world model, it is necessary to establish its importance and validity in the face of numerous criticisms.

1.4.1 Criticisms by the economists

Within a few months of their first printings, *World Dynamics* and *Limits to Growth* were being discussed around the globe. Criticism came largely from mainstream economists, whose background and training is founded on the merits of economic growth. Kenneth Boulding, former president of the American Economic Association, had this to say in his review of *World Dynamics*:

> The very best that could be hoped for is a slow decline into a stationary state with levels of living and quality of life considerably below what they are now. Even this, the most optimistic outcome, seems to be rather unlikely. The most probable outcome seems to be some sort of overshooting of the final equilibrium in population, pollution, capital stocks, and so on, with consequent declines which may easily be catastrophic. With a wide range of reasonable assumptions, doomsday arrives somewhere in the middle of the twenty-first century, either in terms of starvation, overcrowding with its implied disorder, or pollution. [7]

Boulding's interpretation of the book is typical of the economists' misunderstanding of the model outcomes. He regards the model as predicting the future of humanity in a quantitative way, whereas it shows qualitative results *if current trends were to continue*. In fact, the very purpose of the book was to encourage a reconsideration of current trends in order to avoid outcomes such as pollution crises and crowding. Boulding also fabricates the idea of a "most probable" outcome, even though the book never favors one outcome over another, but instead examines a wide range of possible outcomes under differing sets of policy decisions.

One of the most vehemently opposed to *World Dynamics* has been William Nordhaus, Professor of Economics at Yale. His arguments embody the main line of criticism centered at the world model by the economists. Nordhaus outlined three "serious problems" in the model, which were: 1) net birth rate in the model does not fall with rising gross national product, a trend that has been observed in the real world; 2) technology is not modeled according to standard economic production functions, which allow for resource renewability and substitution; 3) there is no price mechanism in the model [8].

Forrester has instructively shown each "serious problem" to be the result of Nordhaus's lack of understanding of the model, and when properly analyzed, the model agrees with Nordhaus's claims of real world behavior [9]. If one plots net birth rate versus GNP directly as it comes from the model runs, the relation in fact matches the real world trend. Nordhaus had apparently held all other model variables fixed when he compared net birth rate to GNP, erroneously eliminating any feedback effects from population, pollution, and capital investment. The second error cited by Nordhaus resulted from a misreading of the definition of model variables. Capital investment in the model is defined as including technology, while natural resources is defined to be the entire world supply (both discovered and discoverable). Using these definitions, Forrester shows that the model does not violate any of Nordhaus's stated economic principles. Finally, Forrester counters the criticism of the lack of a price mechanism with the idea that prices are a short-term phenomenon which result in the same outcome as assumed in the model. For example, if natural resources fall, the price of extraction would rise, meaning a greater effort would be needed to produce a given product. The world model captures the price mechanism dynamics by relating the "resource extraction multiplier" (measuring the ease of extraction of resources which affects capital investment) directly to the remaining level of resources. A price mechanism is not necessary because the model deals with long term dynamics of the world system.

1.4.2 Criticisms from the non-academic side

The popular press was quick to label *World Dynamics* and *Limits to Growth* as "doomsday books", again following the misconception that the models were forecasting the demise of civilization. Among the major criticisms were the world model's high degree of aggregation, its apparent lack of accounting for technological improvements, and its use of an electronic computer to model social systems.

Forrester has shown that these issues arise from the public's misreading of *World Dynamics*, and their failure to comprehend complex systems as a whole. [10] For example, technology is incorporated into the world model as part of capital, since they have similar abilities to regenerate and increase. *World Dynamics* itself clearly states on page 53 that, "Capital includes buildings, roads, and factories. It also includes education and the results of scientific research, for the latter are not represented elsewhere in the model system and the investment in them decays at about the same rate as for physical capital."

The use of a computers during the 1970s was almost exclusively reserved for the academic and governmental sectors. As with any novel invention, people are at first cautious and skeptical, especially when their conception and values of the future is at stake. However, the computer's use is merely as a tool to perform the model calculations. It neither adds to nor takes away from the model's assumptions, and only serves to demonstrate the behavior of the model in a quick and efficient way. Today, with the public's widespread use and familiarity with personal computers, much of the criticism arising from the use of a computer model has vanished.

1.4.3 The importance and impact of *World Dynamics* and *Limits to Growth*

The publishing and circulation of *World Dynamics* and *Limits to Growth* in the early 1970s fueled the fire of public concern for the future of humanity. The two books marked the beginning of a series of important works on global awareness, both in the public press and through academic research, which came to a head with *The Global 2000 Report to the President*, commissioned by President Carter. The table below presents a chronology of the important works of the 1970s and early 1980s.

Table 1.1: Milestones in global awareness

Year	Event / Work	Description
1970	Jay Forrester gives testimony to US House of Representatives.[a]	Forrester outlines the need for a national growth policy -- one which allows for a transition from growth to equilibrium.
1971	*World Dynamics* [ref. 3] published.	First book to use a computer model of the world to simulate possible outcomes.
1972	*Limits to Growth* [ref. 6] published.	Successor to *World Dynamics*. Model produced same basic outcomes.
1972	Report on *Limits to Growth* published by the World Bank.	Analyzed resources, population, pollution aspects.
1972 - 79	UN world conferences throughout the 1970s.	Conference topics: 1972: Human Environment, 1974: Population, Food, 1976: Human Settlements, 1977: Water, Desertification, 1979: Science and Technology for Development.
1974, 75	*On Growth* [ref. 11] vol. I, II published.	Interviews with world figures on the prospects of mankind.
1980	*The Global 2000 Report to the President* [ref. 27] published.	Enforced the message of *World Dynamics* that if current trends continued, population and environmental issues will worsen.
1984	*The Resourceful Earth* [ref. 18] published.	Response to *The Global 2000 Report.* Argued resources, population and pollution will not cause societal depression.
1985	Cassandra Conference held at Texas A&M University.	Discussion of issues dealing with "Resources and the Human Predicament".

a. U.S., Ad Hoc Subcommittee on Urban Growth of The Committee on Banking and Currency, House of Representatives, Ninety-First Congress, Second Session on Industrial Location Policy, October 7, 1970, "Testimony by Jay W. Forrester".

The message of *World Dynamics* and *Limits to Growth* infused itself into every tier of society, from the general public to world leaders. Support for the conclusions of the books came from as many areas, including academics in the "hard" sciences, ecologists, and politicians. Following are a few selected quotes exemplifying the diverse support of the *Limits to Growth* ideas:

> *from an interview with B.F. Skinner*:
>
> The [Club of Rome's] model of the planet's future is a very important step, Skinner said. 'Any clarification of the future is a step in the right direction.' [11]

> *Carl Kaysen* (director of Institute for Advanced Study, Princeton University):
>
> Very few things in the political world happen because the logical arguments show that they would be good things to do. I don't want to underprize the role of reason, in which I believe ultimately; sometimes it takes a very long time for the arguments of reason to prevail. [12]

> *Maurice Strong* (secretary-general of United Nations Conference on the Human Environment):
>
> *Limits to Growth* has made its major contribution by the very fact that it has made men and particularly leaders address themselves to the fundamental problem of how man is going to manage the world's first high-technology civilization and the proliferation of complex interdependencies that technology has produced. It has made us realize in very simple terms that this physical system of interdependencies upon which man depends is in fact global and that it has to be seen as global, that it has to be dealt with and managed as a global unit. [13]

> *Linus Pauling*:
>
> I think we should level off the GNP, even decrease it, and decrease likewise the population. [14]

Hugh Montefiore (Bishop of Kingston-on-Thames):

> Yes, man is knocking against the limits of the world. He is only knocking. He hasn't actually reached the limits of the world yet. But obviously if he continues to increase the number of his species, if he continues to increase the rate at which he uses raw materials and consequently increases the rates of waste, pollution and environmental deterioration, then we will -- quite soon -- reach the limits of the world. I hope it won't happen. My interest is in stopping it. [15]

1.4.4 *World Dynamics* and *Limits to Growth* today

With such a tremendous volume of activity during the 1970s and 80s, what can be said about the world models today? The general public's sense of the models is that they have been discredited. The tidal wave of media coverage (consisting almost exclusively of the negative criticisms, as is typical) and constant focus on the misunderstood "doomsday" predictions are primarily responsible for this discrediting. Yet, there remains almost no study or fact which clearly disproves the results obtained in either model. The issues of population and pollution are still being hotly debated, and no definitive answer has been reached. Speaking at the Cassandra Conference, Donella Meadows, principle author of *Limits to Growth,* said, "none of the subsequent models [by other researchers] has disproved the basic conclusions of *Limits* ... most of the reactions to *Limits* were not careful or rational; they were emotional." [16]

The pollution sector of the world model received surprisingly little attention. The pollution formulation in the model carries the assumption that as pollution levels rise beyond a certain limit, removal processes begin to fail as the pollution "chokes up" the cleaning mechanisms. Obviously this implies that pollution can overrun the abatement processes, and indeed it does in several of the model runs. The pollution formulation may be analogous to waste removal by ocean life: If pollutants rise too high, beneficial life forms could be killed, and thereby slow down the pollution removal process. Whether the model's pollution assumptions are true has still not been thoroughly investigated. One of the few assessments to look at the pollution assumption was the World Bank's study of *The Limits to Growth*, whose pollution sector is essentially equivalent to that of *World Dynamics*. The study found, "it is probably true that the world's ability to assimilate persistent pollutants behaves roughly as the *Limits* authors suggest. This suggests the important conclusion that pollution controls imposed early in a country's industrial development will be more effective than pollution controls imposed later -- when pollution absorption by the local environment may have begun to decline." [17]

The resource issue is the only area which has garnered enough research and evidence to contradict the world models. Several studies and criticisms have demonstrated that the world's resource base could be much larger than originally formulated in the models [18, 19, 20]. Forrester as well concedes that resources were overemphasized in *Limits*. The consequences of an unlimited resource base are examined in chapter 3 of this thesis.

The fact that there has not been any definitive, significant improvements on the world model (or on the issues of pollution and population), make it suitable for study as we approach the year 2000.

1.5 The dual purpose of this thesis

Almost thirty years have elapsed since *World Dynamics* was first published. World population has continued to increase, politicians continue to talk of growing the economy, and industry continues its expansion into developing nations around the globe. How will the world system react, now that thirty years have gone by with little change in mankind's values or advancement trends? Do we still have time to control our destiny if we decide to do so? Such questions form the basis for the first purpose of this thesis: to examine the outcomes of the world model and how they are affected by the timing of policy interventions, given thirty years of continued growth.

More importantly, though, is the second purpose: to call attention to the need for an understanding of systems, such as the world model, among the population at large. The world system will control itself one way or another -- that much is guaranteed. If we are to choose the least traumatic pathway, it will certainly involve fundamental shifts in humankind's global attitude and values. Achieving value changes means politicians and policymakers must adopt the new values, which in turn means for the most part the general public itself must adopt them. Adoption of new values takes time. Edward Goldsmith, editor of the British journal *Ecologist*, has said of the future, "Change must occur on all fronts and must be orchestrated nationally and internationally. However, political action is unlikely to be taken unless the changes proposed are 'politically feasible,' which simply means that they can be implemented by politicians without their losing votes. In other words, it is public opinion that must first be changed. The changes required are so radical that they involve just about all the basic values that we in our industrial society cherish most dearly. Needless to say, this cannot be done overnight." [21]

It is unfortunate but true that humans are not born with an innate understanding of systems. Only the simplest of systems, such as a bathtub filling with water, can be easily understood and predicted by inspection alone. Larger, more complex systems require integration of many interdependent variables, and often produce results which are contrary to the intended outcome. To decipher these systems mentally is a task that is next to impossible; one must have the aid of a computer. Such highly complex social systems operate in our world, and determine our future.

1.6 Organization and presentation of data

The following three chapters present the outcomes of the world model using the year 2000 as the "switch time" when policy interventions take effect (the original world model used 1970 as the switch time.) The figures (graphs) from the model are presented in the same order as found in *World Dynamics*, with the number in parenthesis referring to the corresponding original in the book. Below is an example output graph with the various components labeled. At the end of each chapter is a table which summarizes the important comparisons to be made between the models. Since the only change between the two models is the time of policy implementation, all differences can be attributed to this.

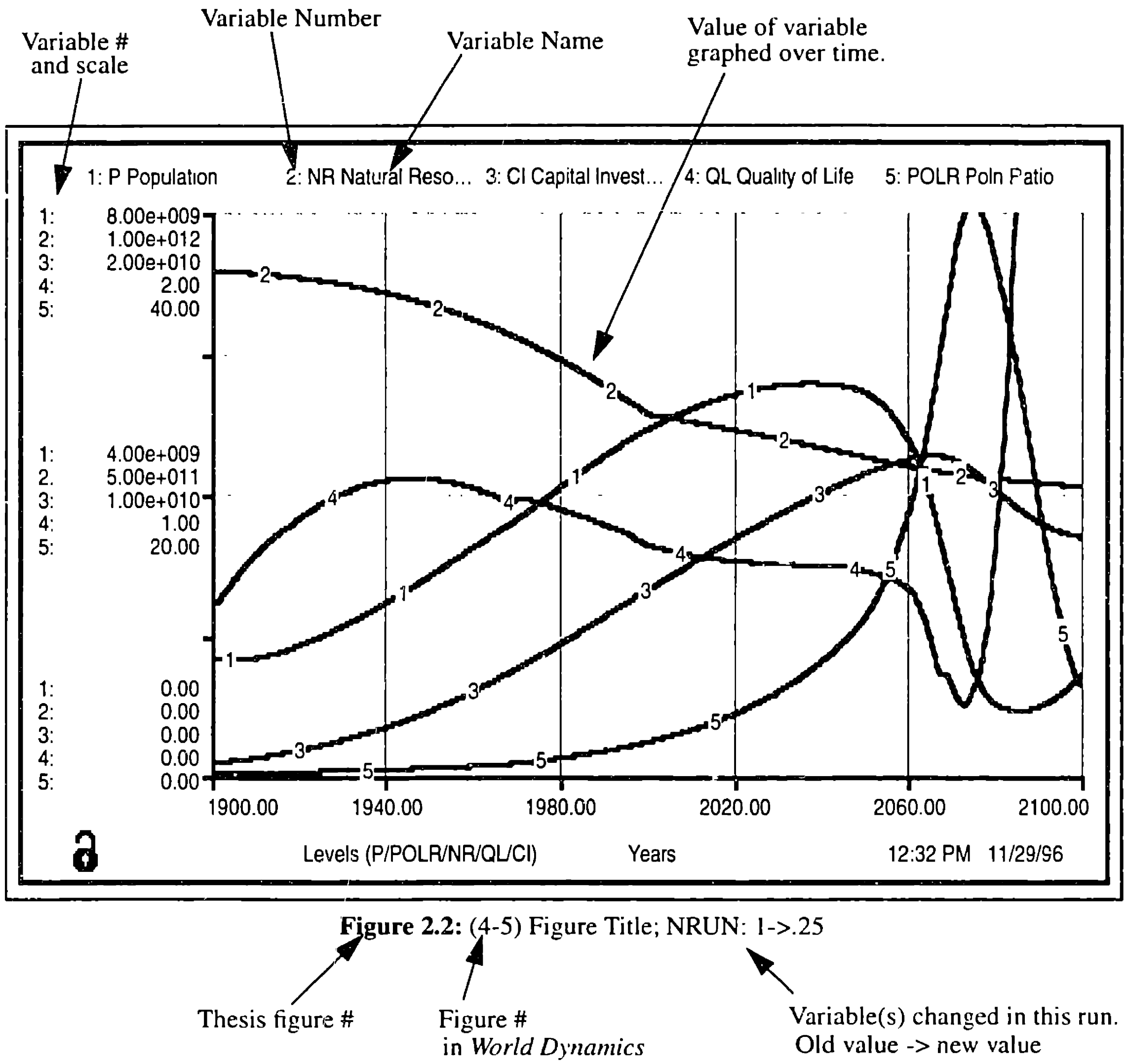

Figure 1.2: Example world model figure

The reader may note that not every figure in the original *World Dynamics* is presented in the chapters. This is due to either redundancy or a lack of significant differences. However, all the figures and their differences (or lack thereof) are summarized in the tables at the end of the chapters.

Chapter 2

Thirty years of inaction

2.1 How to read the following chapters

The reader is urged to have a copy of *World Dynamics* close by when reading the following chapters. Alternatively, Appendix A contains a listing of the *World Dynamics* figures referenced in this thesis. Each graph presented here has a corresponding graph in the book (or Appendix A), the difference being the "switch time" for policy implementations used in the model. To see the differences between the 1970 results (those in the book / appendix) with the year 2000 results (those presented in the body of the thesis), the reader should turn to the corresponding graph in *World Dynamics*. Following each graph is a discussion of the important differences.

2.2 The four behavior modes of the world model

The world model was shown to exhibit four distinct modes of behavior based on different policy choices: natural resource depletion, pollution crisis, crowding, and food shortage. These behavior modes are now reexamined with the year 2000 as the time policies activate.

2.2.1 Natural resource depletion

Resource depletion is the default behavior mode of the world model when no policy intervention is in place. As time passes, population continues to grow and industrialize, which leads to increased use of resources. As these resources become depleted, they become harder to extract, which dampens the growth of population. Society begins to stagnate as fewer and fewer resources limit growth. The model output is shown below. It is the same as the original model run in *World Dynamics*, since there are no policy changes, and is provided as a reference.

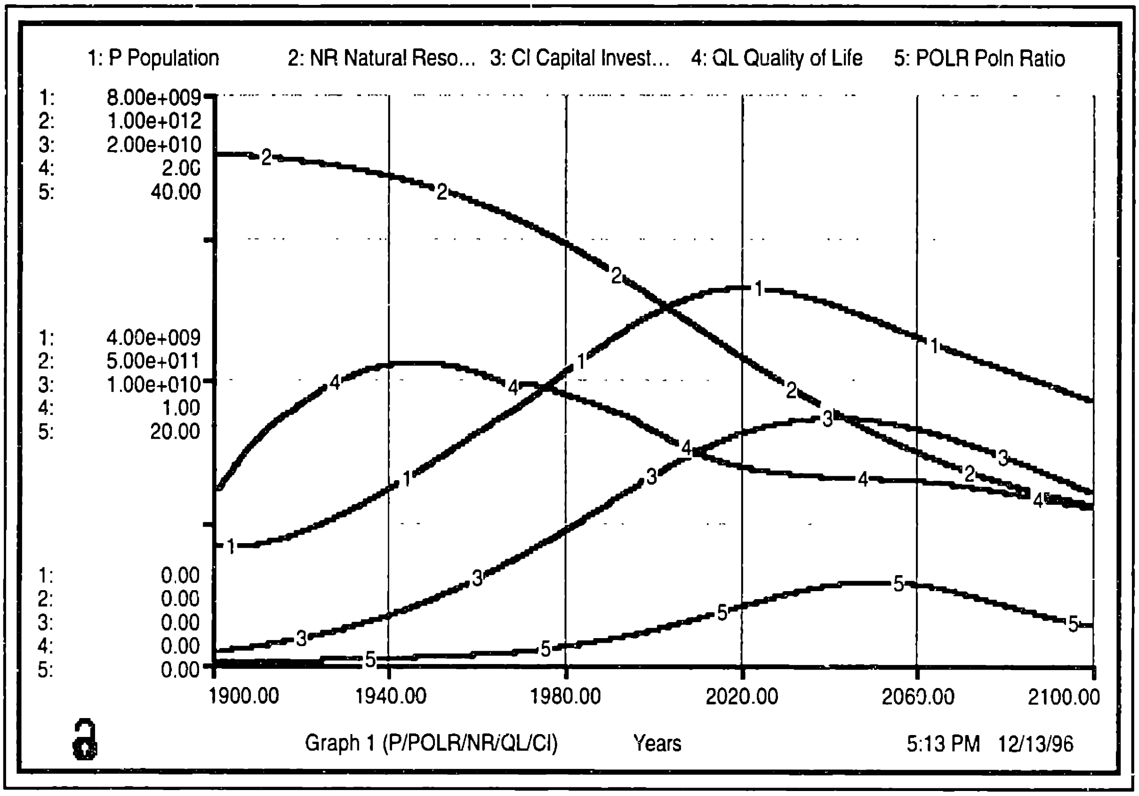

Figure 2.1: (4-1) Natural re[illegible]e depletion mode.

2.2.2 Pollution crisis mode

The second, more dramatic behavior mode of the world model is the pollution crisis. One way to achieve this is by cutting the natural resource usage rate. The original run of the model cut the usage rate to 25% of its initial value beginning in 1970. Shown below is the year 2000 result.

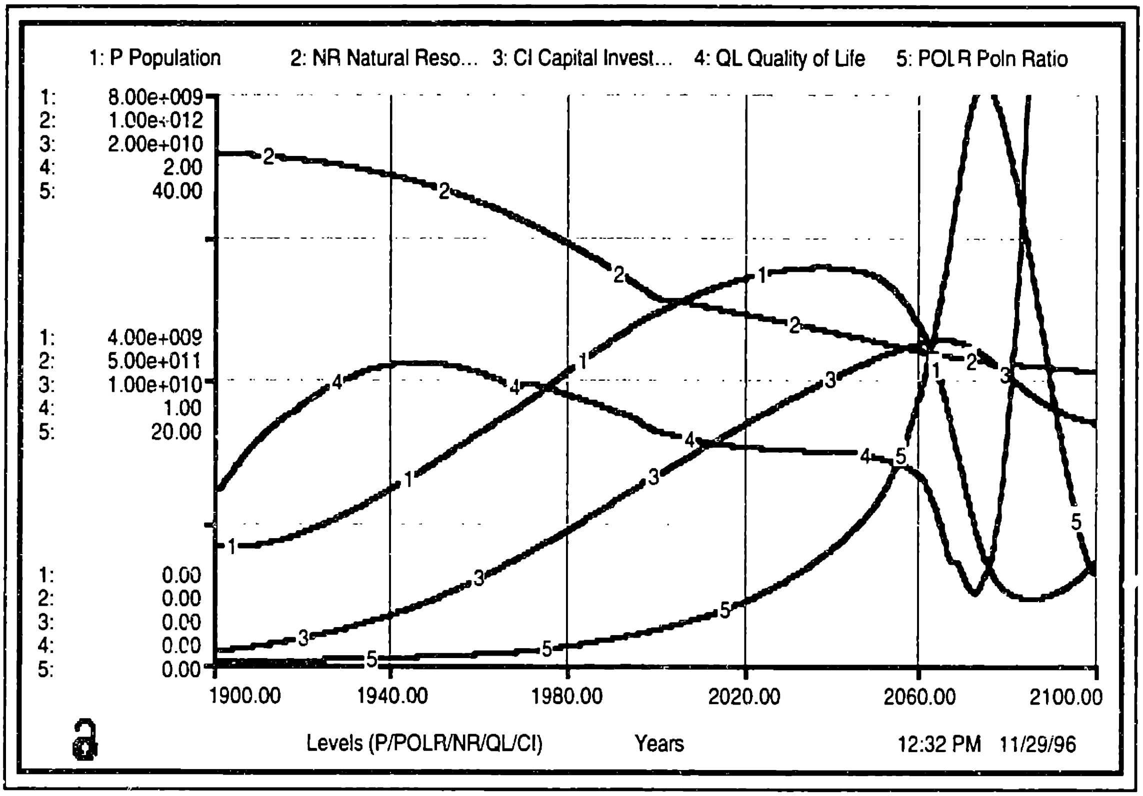

Figure 2.2: (4-5) Pollution crisis mode; NRUN: 1->.25

Between 1970 and 2000, the system continues in the resource depletion mode, and we see quality of life declining. At 2000, natural resources no longer influence the system as strongly as before, and pollution takes over as the dominant variable. By 2040, population and capital investment have reached a maximum (their growth halted due to increasing pollution), but that is just the beginning of the crisis. With so much population and capital in existence, pollution surges until it has literally choked population down to significantly low levels.

The maximum pollution level achieved in both runs is approximately 80 years following the reduction in natural resources. This indicates a relative insensitivity of the system to this policy; shifting the switch time from 1970 to 2000 merely delays the crisis date by

30 years. If the switch time is extended further, the system will eventually remain in the natural resource depletion mode, with population and capital depressed so as unable to utilize the lower rate of resource usage.

2.2.3 Crowding mode

Crowding, the third behavior mode, comes into effect when resource depletion and pollution have been averted. The original model achieved this by setting the resource usage rate to 0, and making pollution 10% of what it would have otherwise been.

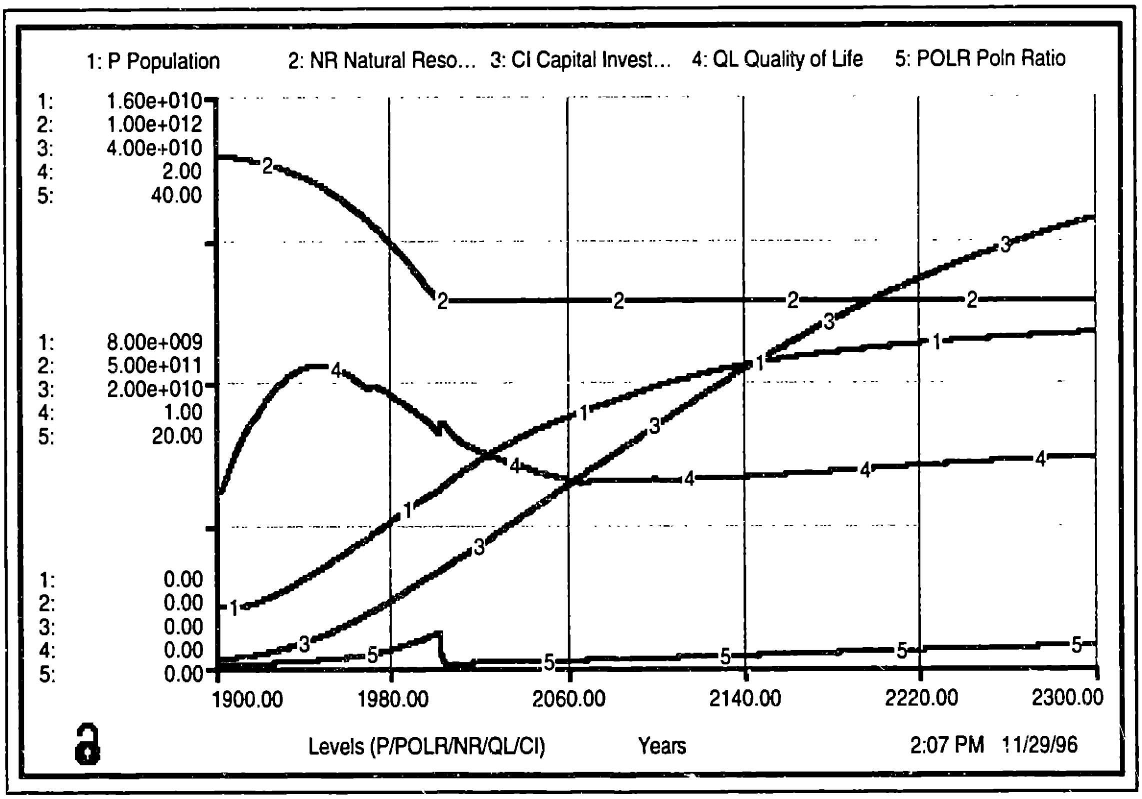

Figure 2.3: (4-9) Crowding mode; NRUN: 1-> 0, POLN: 1->.1

The crowding mode exhibits little variation from its 1970 counterpart. Because the dynamics of the crowding mode are performed on a longer time scale (notice the model is run to 2300 in order for the variables to settle), a shift of 30 years is negligible when compared to the 300 year time span of the process.

2.2.4 Food shortage mode

The final barrier to growth in the world model is food. When the previous three modes have been eliminated, food remains as the limiting factor to population growth.

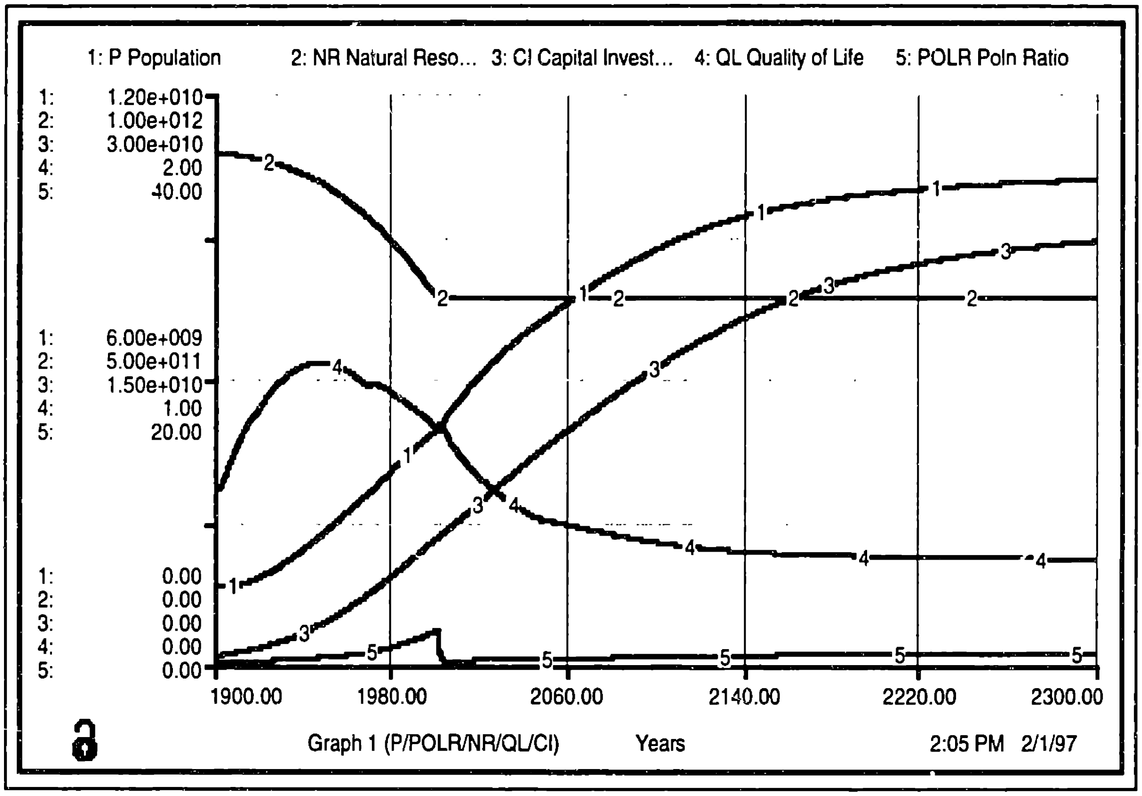

Figure 2.4: (4-11) Food shortage; NRUN: 1->0, POLN: 1->.1, BRCM/DRCM altered

As with the crowding mode, the dynamics of the food shortage play out over 300 years, which makes the initial 30 year discrepancy insignificant in the long run.

2.2.5 Conclusion

The four behavior modes of the world system arise from various policies and restrictions placed on society. It is important to realize both the probability and the feasibility of these restrictions, in order to assess the most probable pathway for the system. The first two modes, resource depletion and pollution crisis, arise from little or no adjustments to the world system, and seem to be likely courses for the actual system to follow. Not surprisingly, the issues of dwindling natural resources and increasing pollution have been hotly debated and researched since the 1970s. The latter two modes, crowding and food shortage, require conditions which are both improbable and difficult to achieve -- namely a sudden, drastic reduction in the amount of pollution, along with virtually no depletion of resources. Forrester experimented with various policies that might be implemented by society to achieve a higher standard of living. The following sections reexamine the behavior of the world model with these policies in the year 2000.

2.3 "Obvious response" policies

Large scale crises, especially those involving human lives, have typically elicited swift actions from society aimed at a rescue. For example, the waves of famine which sweep over Africa each decade have spawned numerous organizations which deliver and donate food to the area. Similarly, poverty stricken countries are aided externally by several charitable groups that focus on needy children. We have also mentioned the typical politician's answer to a declining economy as being increased capital investment. All of these actions seem on the surface to be the logical solution to the problem, and certainly the most humane. However, in many systems including the world model, such "obvious responses", as Forrester has deemed them, turn out to be not only ineffective in alleviating the problem, but also serve to fuel the crisis even more. Complex social systems such as the world system have four qualities which tend to render usual policy responses ineffective [22]:

1. Solving one problem usually creates another in its place.
2. Short-term and long-term effects of policies are usually opposite.
3. The goals of a subsystem tend to conflict with those of the larger system.
4. Social systems are inherently insensitive to "obvious response" policy changes.

The following sections illustrate these points with the world model.

2.3.1 Capital investment

In an attempt to increase the quality of life, suppose capital investment is increased by 20%.

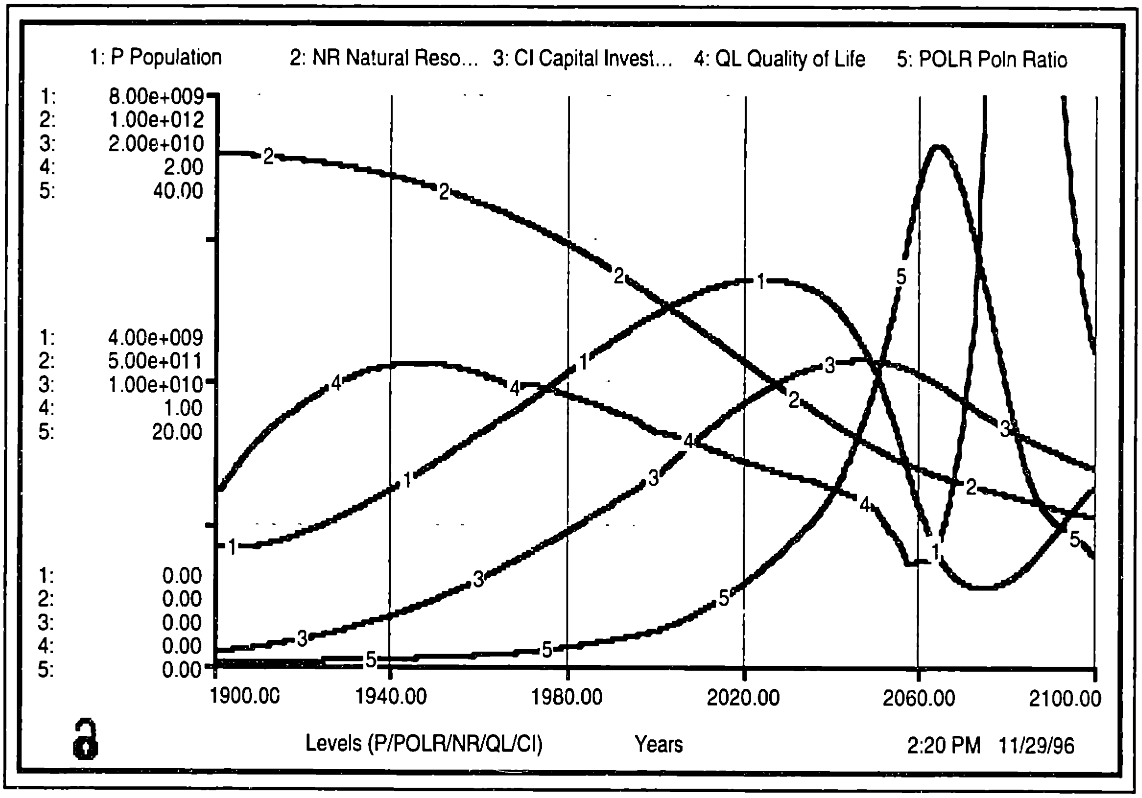

Figure 2.5: (5-1) Capital investment increased; CIGN: .05->.06

Just as in the original model run of 1970, increasing capital investment generation has caused the pollution crisis to appear. The crisis created by acting 30 years later is not quite the same as its 1970 counterpart. Here, the collapse of the system is drawn out over 50 years (from the peak of population at 2030 to the trough at 2080), compared with the shorter span of about 30 years in the original. The difference is due to the 30 year gap in which resources are further used up in the year 2000 run, meaning industry lacks the fuel to grow as rapidly as it did in the 1970 run. Which crisis is worse is a matter of judgement and definition; the original is more violent, having a larger population and higher peak pollution levels, whereas the year 2000 run lasts almost twice as long.

2.3.2 Birth rate

A popular social policy in many countries has been control of the birth rate through education and restrictions on family size. The rationale behind these policies is that less people means a higher quality of life. The long-term effect, however, is minimal.

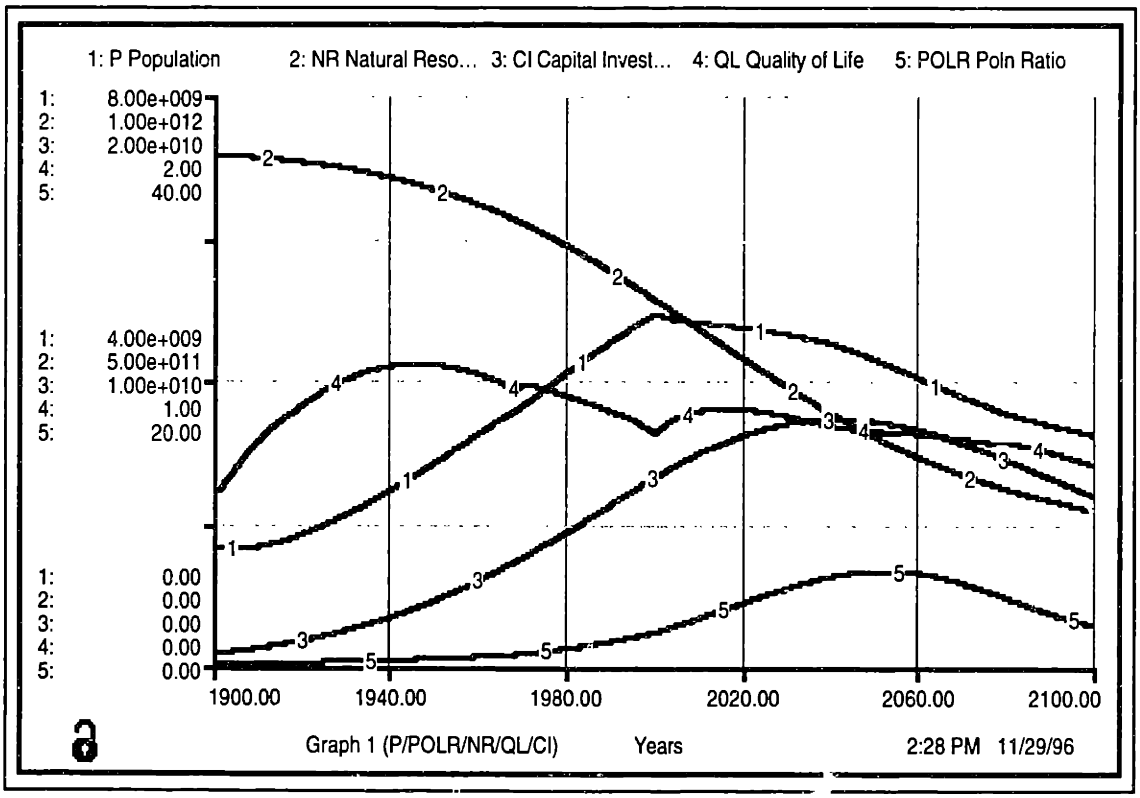

Figure 2.6: (5-2) Birth rate reduction; BRN: .04->.028

When birth rate is lowered in the year 2000, the system has already become depressed from falling natural resources. Quality of life, which in the 1970 run rose to new highs for 30 years, does not even reach its 1940 value in the year 2000 run. Looking at other variables in the system shown below, we see a similar fate for the material standard of living.

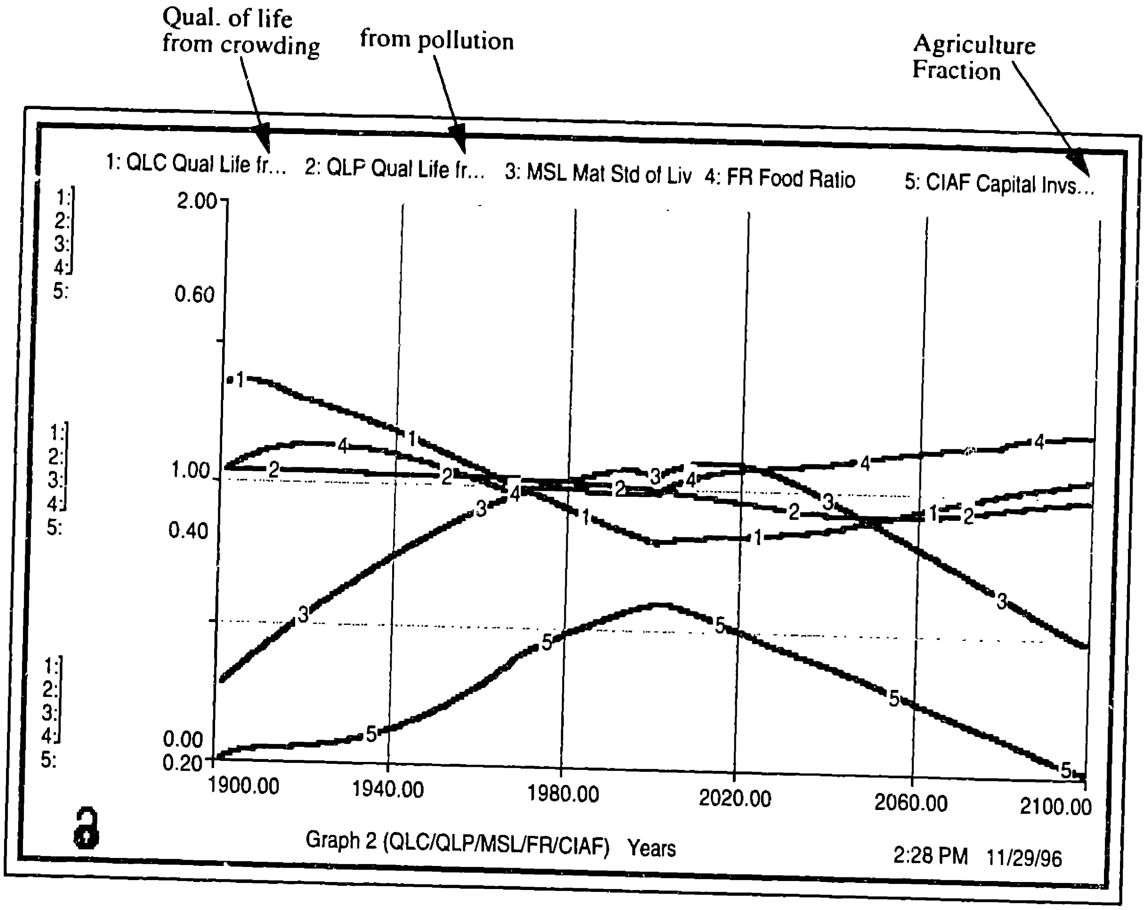

Figure 2.7: (5-3) Ratios for birth rate figure; BRN: .04->.028

2.3.3 Combination policies

Even when used in combination, the "obvious response" policies fail to make a long-term difference. Drastic, best-case policies such as no usage of natural resources, 90% pollution reduction, and a 50% birth rate reduction are ineffective in stopping the exponential growth power of population, as seen in the figure below.

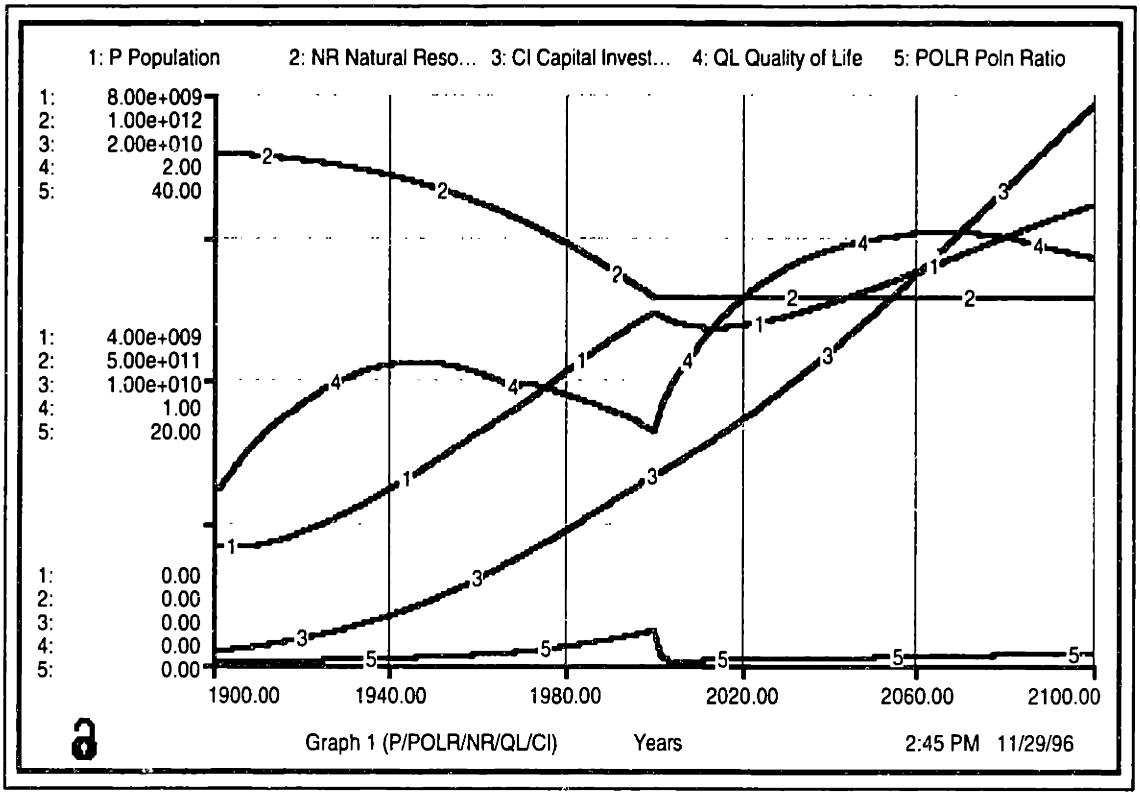

Figure 2.8: (5-6) Combination policies; NRUN: 1-> 0, POLN: 1->.1, BRN: .04->.02

The dynamics play out as they did in the 1970 run, with population resuming growth after a 20 year delay. The birth control program has proved unable to control population in the long run. Once resources and pollution are no longer keeping population down (as in the previous figure 2.7), birth control by itself does little to halt growth. In fact, lowering the birth rate allows for a larger per capita accumulation of capital, which ultimately translates into higher pollution and resource usage.

A key feature to note in each of the figures presented so far is the lower overall quality of life compared to the 1970 model. Allowing the system to continue for 30 more years in the resource mode has dampened the dynamics of the corresponding 1970 run, and quality of life is lower in every instance than its 1970 counterpart. The more society delays in implementing policies, the lower the resulting quality of life in the world system.

2.3.4 Behavior modes affected by policy delays

Though most "obvious response" policies have the same effect on the year 2000 system as they did in 1970, there are some that result in different behavior modes. In these cases, the 30 year delay is enough to keep the system in the resource depletion mode.

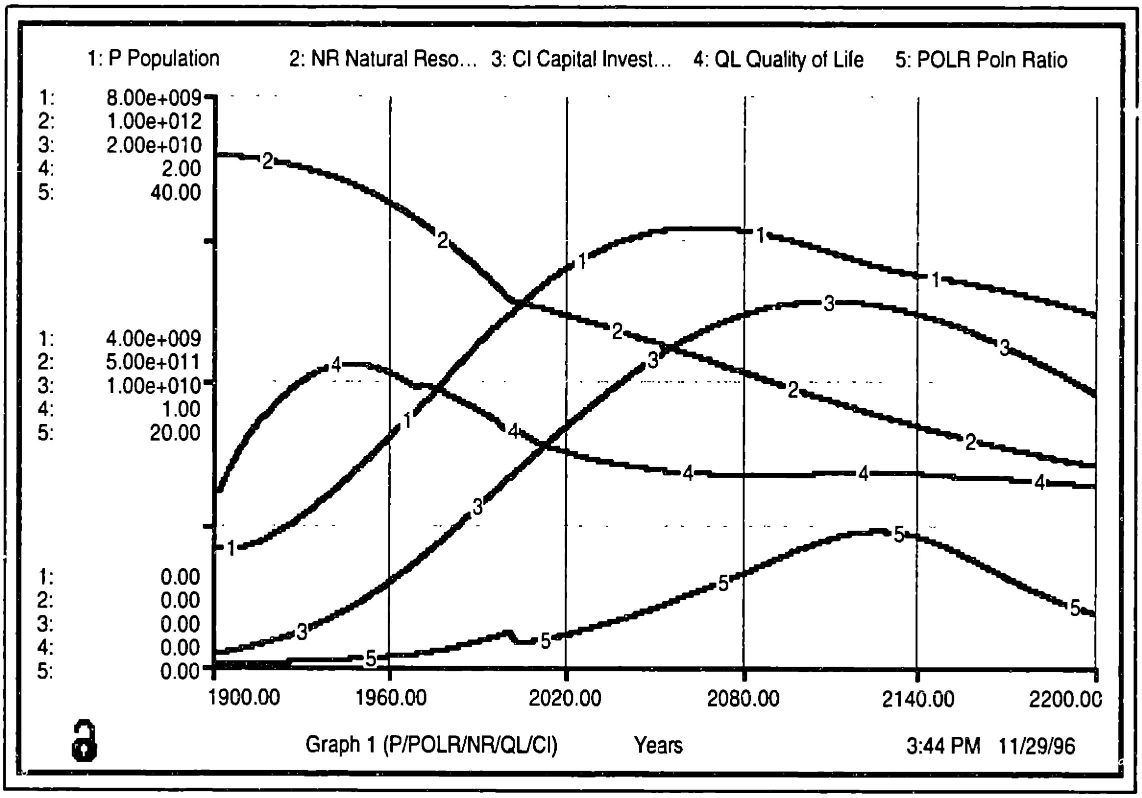

Figure 2.9: (5-8) Behavior mode switch; NRUN: 1-> .25; POLN: 1->.7;

Above, the system employs a 75% reduction in natural resource usage and a 30% reduction in pollution. The 1970 model resulted in a pollution crisis under this set of policies. The year 2000 run begins to show rising pollution levels, but growth is depressed enough by falling resources so that the system remains in the resource depletion mode.

Another set of policies which produces a different outcome in the year 2000 model is shown below. Here resource usage is reduced 75%, along with a 60% pollution reduction, increased capital investment (+20%), and increased food production (+25%). This set of policies strongly favors a pollution crisis, since all of its components are growth promoters. Yet, the system fails to shift out of the resource depletion mode when these policies are implemented in the year 2000.

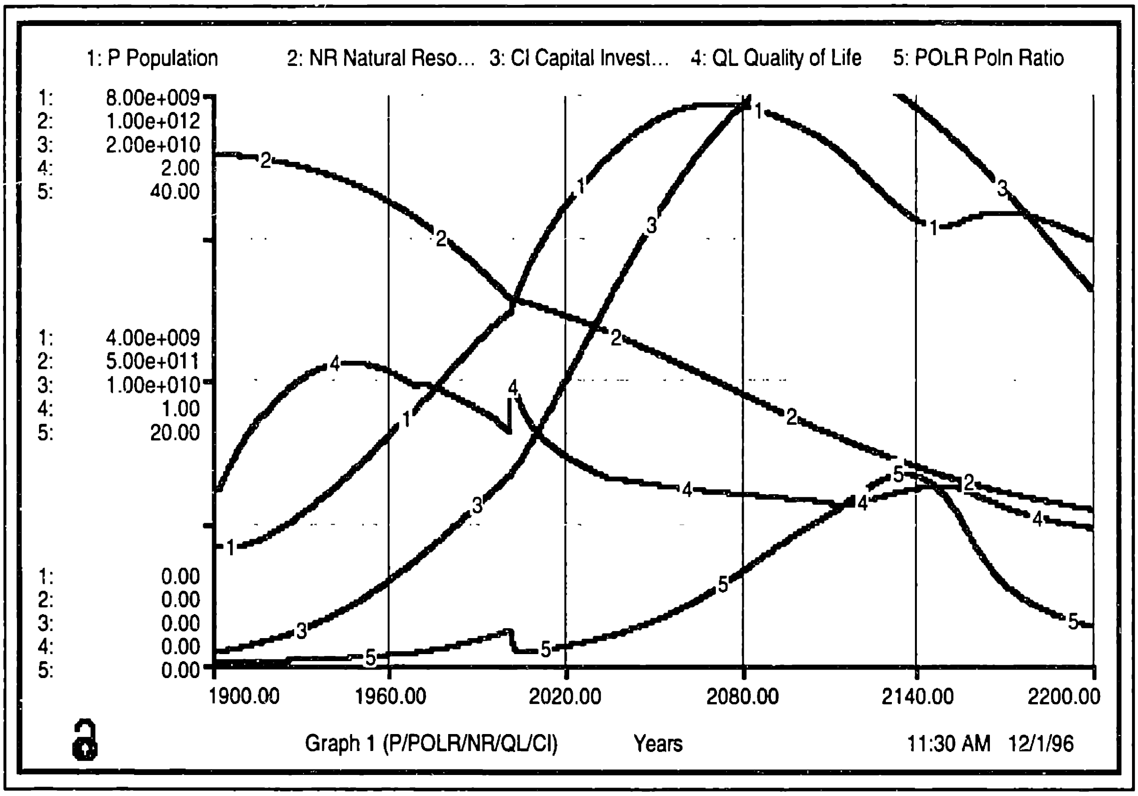

Figure 2.10: (5-13) Behavior mode switch; NRUN: 1->.25, POLN: 1->.4; CIGN: .05->.06, FC: 1->1.25

A troubling aspect of the last two figures is the implication of a "point of no return" for the world system -- a date beyond which a set of policies will be unable to prevent a particular outcome. The timing of policy intervention, then, takes on as important a role as the set of policies which are used. Not only must society draft policies which are effective, but it must also put them in place before the world is locked onto a fixed course from falling resources or rising population.

The real world implications of a "point of no return" are alarming. Unlike the model, the real world cannot implement policies immediately. Even if the correct set of policies is known, the physical and social changes which need to take place in order for policies to be put into place take years to achieve. As each year goes by, the system will be pushed further towards its limits, resulting in a less attractive world to live in.

2.3.5 Conclusion and summary of results

The data presented from the year 2000 run of the world model suggests that the waiting period of thirty years results in a world that is worse off than its 1970 counterpart. The majority of model runs behaved in the same fashion as their corresponding original runs in *World Dynamics*, the major difference being a 30 year shift of the time axis. However, in each scenario, quality of life ended at a value lower than it was in the 1970 runs. Continued use of resources and growth of population over the thirty year period causes the system to be more depressed from the onset of the policy intervention to the final calculated year. The model output enforces the general idea that in the world system, time is of the essence. The longer the waiting period before action is taken against mounting world pressures, the lower the quality of life in the resulting world outcome.

Two of the model runs were significantly affected by the thirty year delay. Both implemented growth-promoting policies such as pollution reduction and reduced resource usage, but remained in the resource depletion mode while their corresponding 1970 runs reached the pollution crisis. Obviously there is some point in time, between 1970 and

2000, beyond which the policy intervention in these models is rendered useless. This "point of no return" is a dangerous trap in the world system, and one which cannot be detected.

The response of the world system to the thirty year delay suggests another, more devious aspect to our real world. The fact that the system usually behaved in much the same way that it did in 1970 implies that society could be unaware of the "point of no return" phenomenon until it is too late. If conditions seem to be relatively stable, with only slight incremental changes year by year, society tends to either overlook or ignore them. Thus, detection of world pressures (such as high pollution or low resource levels) usually occurs only decades after the pressures have manifested themselves and grown in size to a point where they are an obvious threat. This is all the more reason to act quickly.

The table below presents a summary of all the "obvious response" policies tested in the 1970 world model, and their behavior in the year 2000 model.

Table 2.1: Policies and outcomes of the world model

Thesis figure #	*World Dynamics* figure #	Behavior Mode (1970 run)	Behavior Mode (2000 run)	Phase shift[a] (yrs)	Observations
2.5	5-1	Pollution	Pollution	+20	
2.6 / 2.7	5-2 / 5-3	Resources	Resources	-10	Lower qual. of life / mat std of living.
(not shown)	5-4	Pollution	Pollution	+20	
(not shown)	5-5	Crowding	Crowding	+30	Lower qual. of life.
2.8	5-6	Crowding	Crowding	+30	Lower qual. of life.
2.9	5-8	Pollution	Resources	-	System unable to shift to pollution mode. Feasible policies used.
(not shown)	5-9	Resources	Resources	0	Pollution crisis abated due to resource usage.
(not shown)	5-11	Pollution	Pollution	+70	1970 run has more violent crash.
(not shown)	5-12	Pollution	Pollution	+30	"
2.10	5-13	Pollution	Resources	-	
(not shown)	5-14	Pollution	Pollution	+30	Lower qual. of life.

a. Difference between the crisis year (or significant year) in the year 2000 model and the corresponding year in the 1970 model. This is the number of years the 2000 model dynamics have been shifted due to the initial 30 year time delay. A '-' indicates different behavior modes.

2.4 Policies for global equilibrium

No one wants to live in a world system that goes through a behavior mode such as the pollution crisis, or resource depletion. Attaining a better state means humankind will have to understand and adjust to the world system in which we live and operate. To reach an equilibrium in which everyone is better off may mean a sacrifice of current values, a change of outlook, and a strong will. Many of the policies needed to bring the world system into equilibrium go counter to society's first line of thinking. Many require changes of attitude. However, we have seen that many obvious, seemingly rational responses achieve only short-term solutions, and can in the long term push the world system into a deeper quandary. It is time now to look at what happens in the year 2000 to policies which, in the original run, were able to bring the world model to an equilibrium with a gain in the quality of life.

The first set of policies which Forrester used to bring the world model to equilibrium was a cut in resource usage of 75%, and a pollution reduction of 50%.

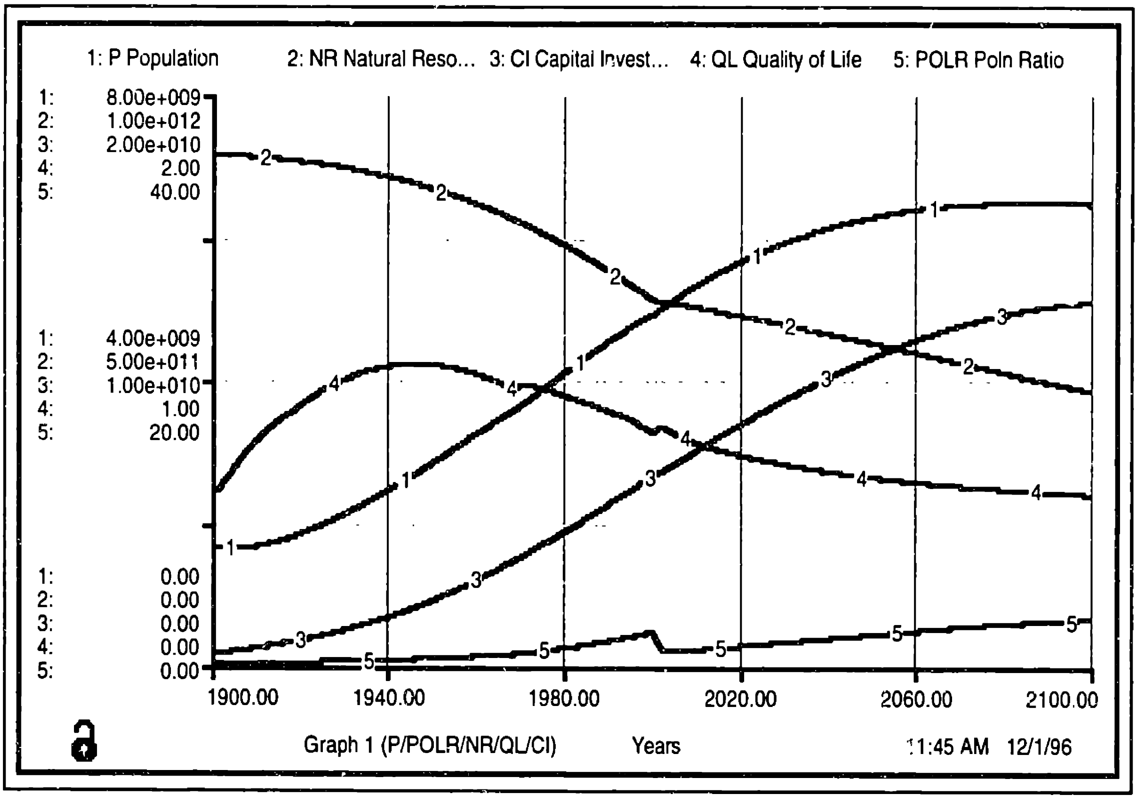

Figure 2.11: (6-1) Equilibrium 1; NRUN: 1->.25, POLN: 1->.5

Comparison with the original run reveals a lower level of capital investment as well as quality of life. Again, keeping the system in the resource depletion mode for an extra 30 years has taken its toll by creating a more depressed society. Also as with the original, the resource depletion mode is still active, and must be curbed while maintaining strict controls on pollution in order for society to remain at this equilibrium.

2.4.1 Reduced capital investment

Implementing a reduction in capital investment maintained an equilibrium for the 1970 model. For the year 2000 run, it came too late.

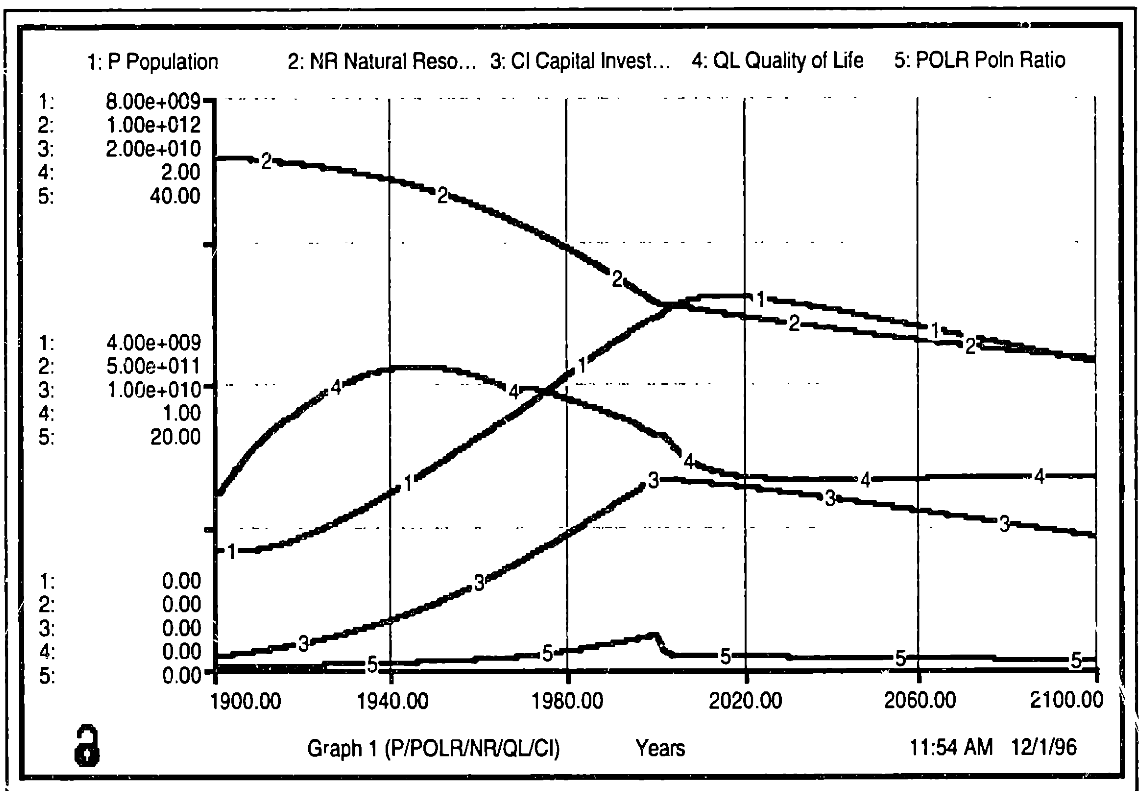

Figure 2.12: (6-3) Equilibrium 2; NRUN: 1->.25, POLN: 1->.5, CIGN: .05->.03

We see that resource depletion has depressed the system enough to cause a continuing decline in population with a lower quality of life. The implications of this are alarming.

Future policies which are designed to take advantage of system principles may already be too late. There may only be a "window of opportunity" in which these policies, or any policies, can be effective. In this instance, the window was less than 30 years.

2.4.2 The prescription for equilibrium

The final set of graphs in *World Dynamics* present a combination of policies which achieves a global equilibrium and high quality of life. The year 2000 run of this scenario, however, continues to suffer from the initial effects of resource depletion.

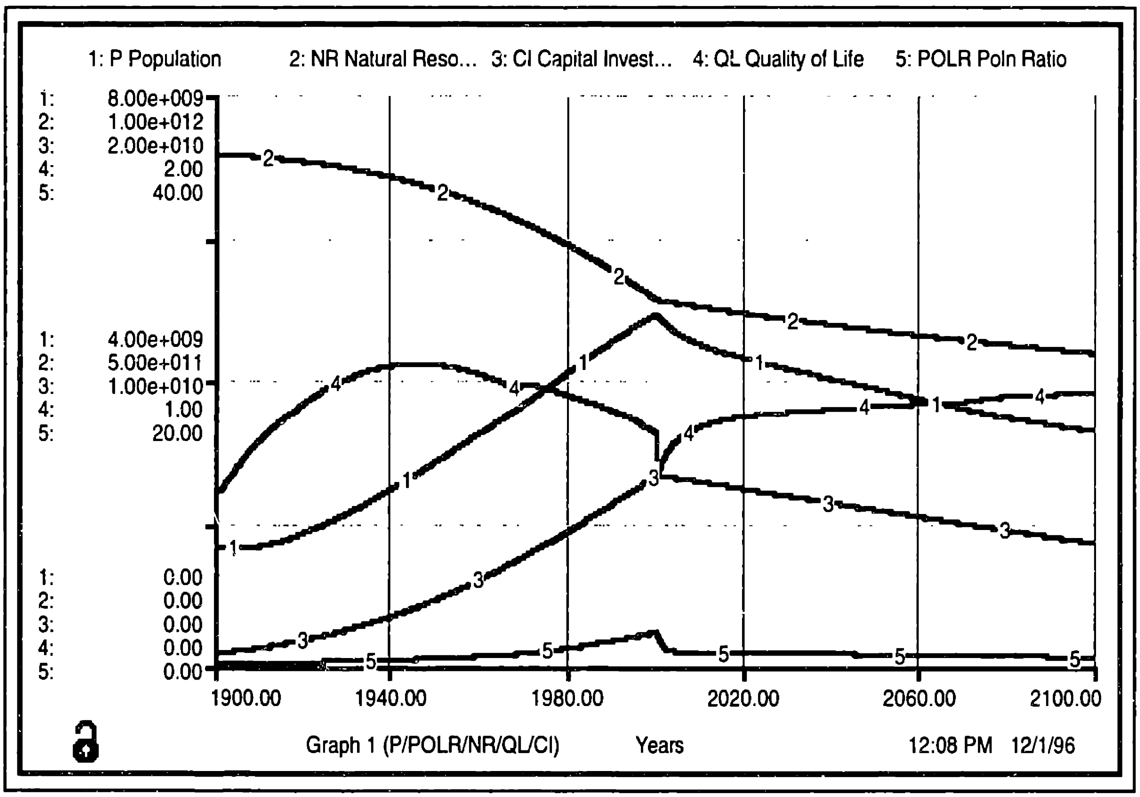

Figure 2.13: (6-7) Final equilibrium; NRUN: 1->.25, POLN: 1->.5, CIGN: .05->.03, FC: 1->.8, BRN: .04->.028

2.4.3 Conclusion and summary of results

The following table presents comparative data on the equilibrium policies of the world model from the 1970 and year 2000 runs.

Table 2.2: Equilibrium runs of the world model

Thesis figure #	World Dynamics figure #	Behavior Mode (1970 run)	Behavior Mode (2000 run)	Phase shift[a]	Notes and other observations
2.11	6-1	Equilib. / Resources	Equilib. / Resources	+30	Lower qual. of life.
2.12	6-3	Equilib.	Resources	0	Declining population in year 2000 run, steady in 1970 run.
(not shown)	6-5	Equilib.	Resources	+30	"
2.13	6-7	Equilib.	Resources	+30	"

a. Year of maximum population in 2000 model - corresponding year in 1970 model.

The transition to a global equilibrium is undoubtedly one of the greatest hurdles humankind has ever faced. If we are to clear it, policies must be designed to work with the complex system in which we live, and they must be in place before their window of opportunity closes. We can not say with certainty when that window will close, or if it already is closed, but what we can say for certain is that continuing the current growth of population will close it for us. The equilibrium runs of the year 2000 model suggest the window may be only 30 years wide, and that we could be on the tail end of it already.

Chapter 3

Unlimited Natural Resources

3.1 The role of resources

The natural resource subsystem in the world model plays an important role in determining the outcome of a model run. The basic behavior mode of the world model is resource depletion, which dampens growth. Resources provide the fuel for the world system's industry, which feeds back to increase population. A lack of resources depresses the system, stunting economic growth and quality of life. Thirty extra years of resource depletion prevented the year 2000 world model from achieving equilibrium as it had in the 1970 runs.

3.2 The resource supply and the world system

Since so much of the world model depends on the level of resources, it is important to be accurate in estimating the total supply. Numerous criticisms of the world model (and its successor in *The Limits To Growth*) focused on the availability of natural resources, claiming that the amount of resources initially allocated in the world model was far below the true amount in the Earth, and that the resource supply is for all practical purposes inexhaustible [23, 24]. Many of the arguments point out that current estimates of supply are low simply because it is unprofitable to prospect for further reserves at this time. Additionally, most resources such as minerals and metals are renewable because they can be used, recovered, purified, and used again. Though there is a cost to this process, it still does not change the basic conservation of mass laws which govern the world.

Resources in the world system are modeled as non-renewable, meaning once a resource unit is taken from the initial pool of resources, it cannot be replaced. To alter the model to reflect the unlimited supply of resources, we have to set the usage rate of resources to be 0 in 1970. The year 1970 is chosen instead of the beginning of the model run due to the calibration of the model. Forrester, in designing the world model, chose initial values for the variables in such a way that, when run, the values of the variables in 1970 correspond to their value in real life. If the resource usage rate had been set to 0 at the beginning of the model run, the value of the variables in 1970 would not correspond to the real world conditions. Note also that setting resources to 0 in the year 2000 would be incorrect, since if resources are assumed to be unlimited, they must start out and remain that way, and not suddenly become unlimited.

3.3 Effects of unlimited resources on the world model

The year 2000 runs of the world model have also been performed with the assumption of unlimited resources, in order to observe the effects of the various policies, and to gain insight into the possible outcomes of current world trends under this assumption. What follows are the results of the year 2000 model runs in a fashion similar to that of Chapter 2. For each graph, the usage rate of natural resources has been set to 0 in the year 1970, while all other policies come into effect in the year 2000 as before.

3.3.1 The pollution crisis mode

When resources are no longer an obstacle to growth, the pollution crisis becomes the dominant mode of behavior for the world system. The graph below shows the basic pollution crisis mode. Note how, even in the absence of any growth-promoting policies, the crisis appears approximately 10 years *earlier* than the original run of the model, and 20 years *earlier* than the corresponding year 2000 run.

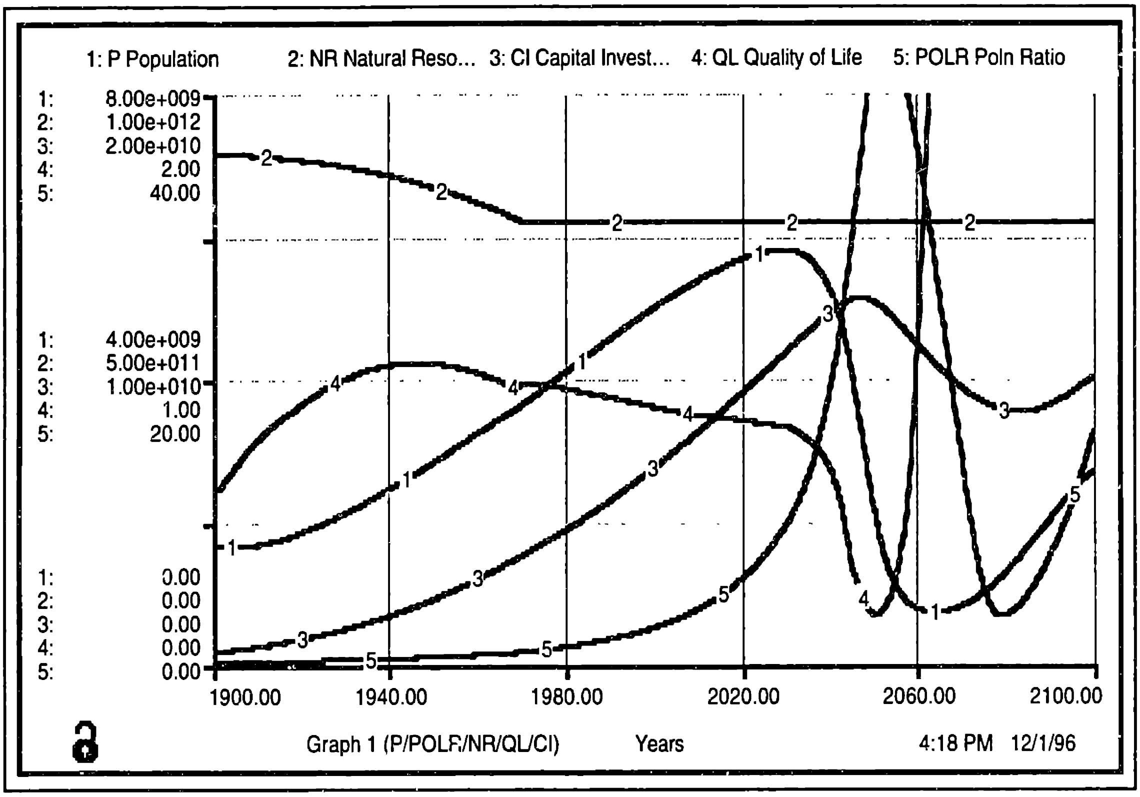

Figure 3.1: (4-5) Basic pollution crisis;

3.3.2 Increased capital investment

Capital investment is a strong growth-promoter in the world system. As natural resources have become unlimited, increases in capital investment serve as sparks that ignite a growth fireball.

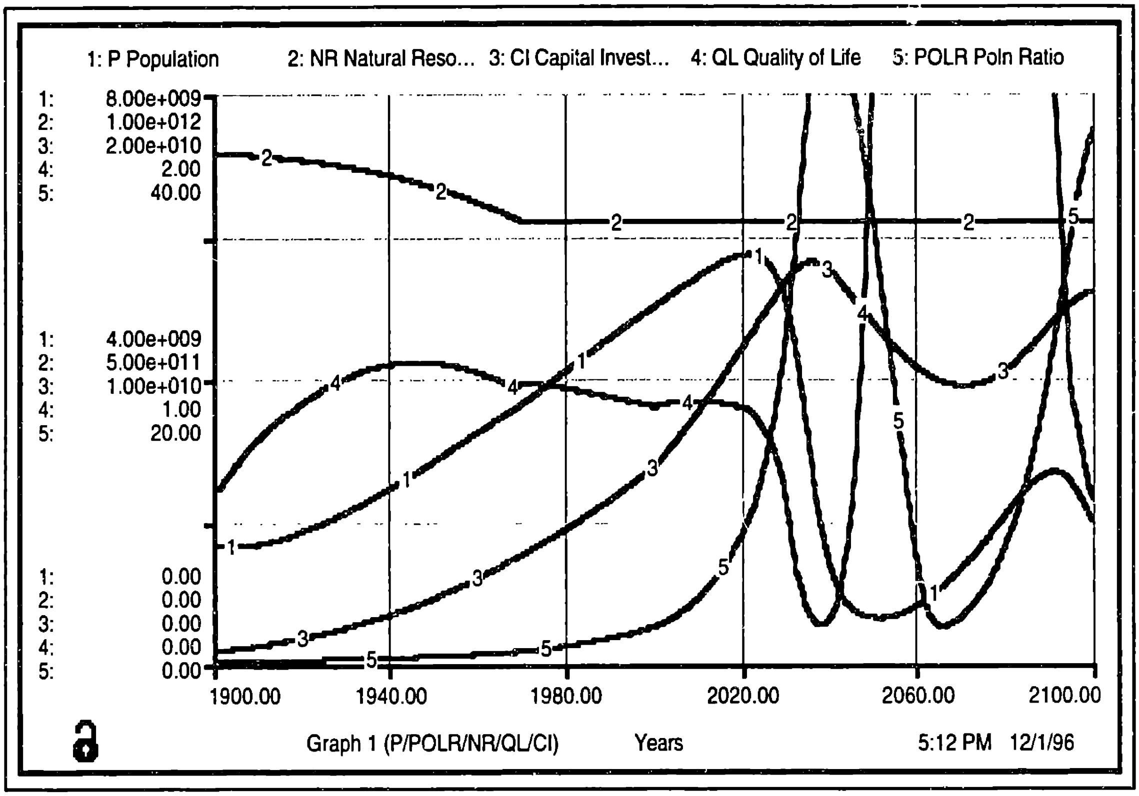

Figure 3.2: (5-1) Increased capital investment; CIGN: .05->.06

Here the world system has become highly unstable. The pollution crisis arrives much more violently than either the original or year 2000 model runs, as demonstrated by the near vertical drop in population. The abundance of resources has allowed population and industry to grow unhindered until they can no longer support themselves. Pollution output exceeds the removal rate and skyrockets, causing population and quality of life to plummet dramatically. On top of this, the crisis again appears sooner than the other model runs, arriving 10 years earlier than the original and 25 years earlier than the year 2000 run.

Another troubling feature is shown in the figure. Instability is so great that as population is recovering from the first pollution crisis, it is hit with a second, slightly smaller crisis around the year 2100. In fact, the system shows what is called oscillatory behavior, and will continue to go through growth and collapse phases unless a new policy is put in place to stop it. One would hope that after such a catastrophe as the first pollution crisis, the world will have learned to better control its future.

3.3.3 Birth rate

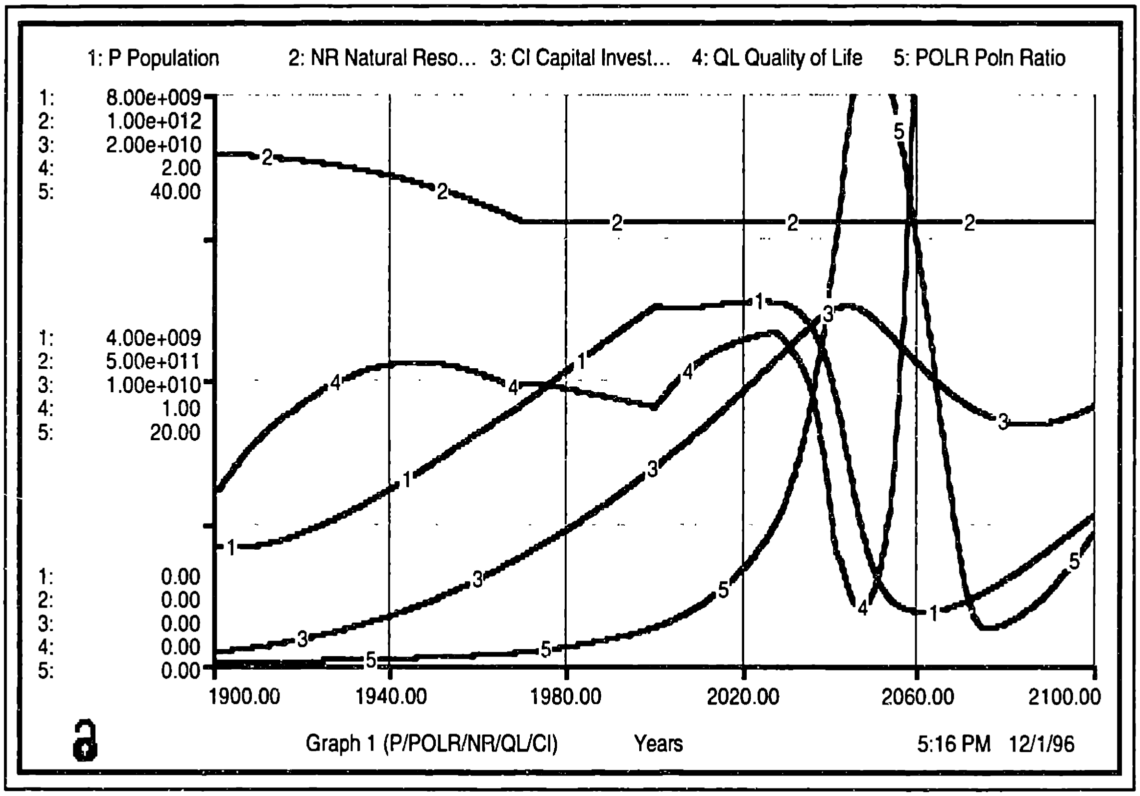

Figure 3.3: (5-2) Reduced birth rate; BRN: .04->.028

Birth control programs by themselves have failed to significantly affect the world system. Here it is no different, and even though population plateaus once the program is put into effect in the year 2000, capital investment and pollution continue to rise; the pollution crisis strikes soon after. Once again we see that instead of being beneficial to the system, unlimited natural resources have greatly contributed to its demise.

3.3.4 Behavior modes altered by unlimited resources

Many policies which avoided the pollution crisis in the original and year 2000 runs of the world model revert back to this mode when resources become unlimited. Some significant ones are discussed in this section.

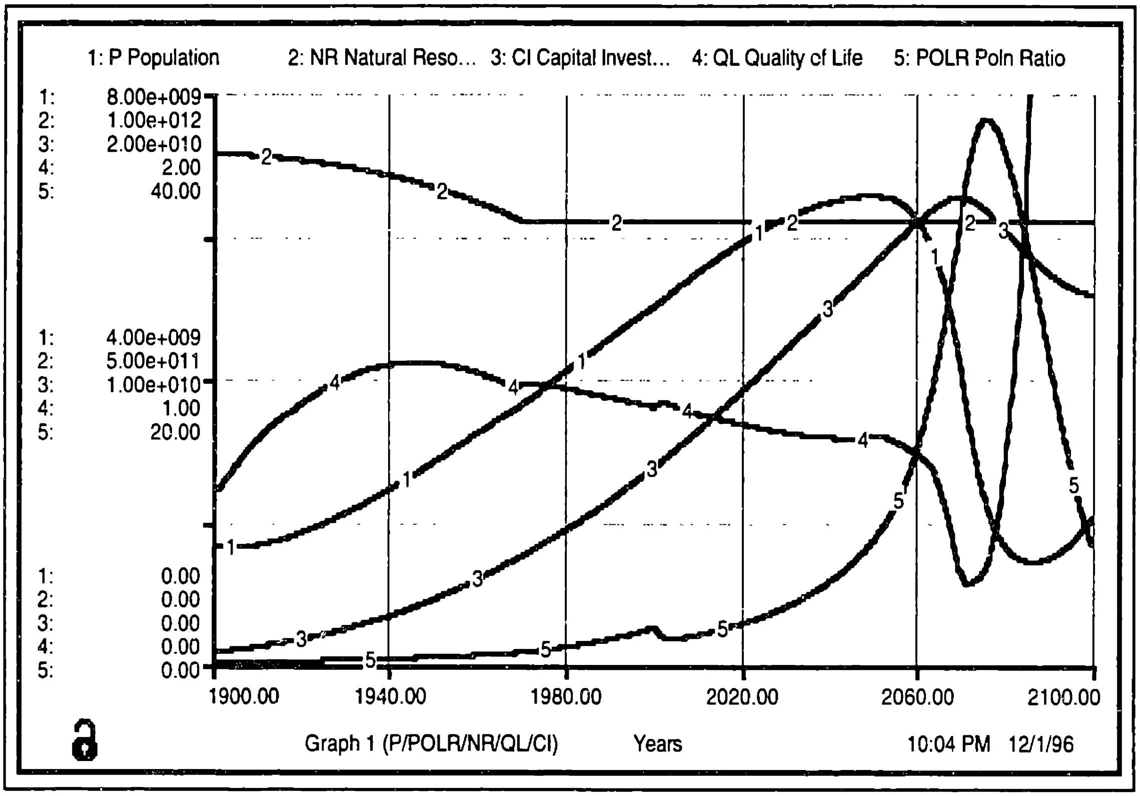

Figure 3.4: (5-8) Pollution controls; POLN: 1->.07

The initial graph is shown above, where pollution has been reduced 30% in the year 2000. This is the first scenario that embodies feasible, achievable policies. It is also a prime example of how ineffective such policies may be. The reduction has afforded the system 20 years until the exponential pollution growth surpasses its year 2000 value. Without a declining resource pool to dampen the system as in the year 2000 run, the pollution crisis mode dominates, appearing at around the same time as in the original model (which activated the pollution control measures 30 years earlier).

Under an infinite resource assumption, increases in the food supply become even more detrimental to the system, causing increased population.

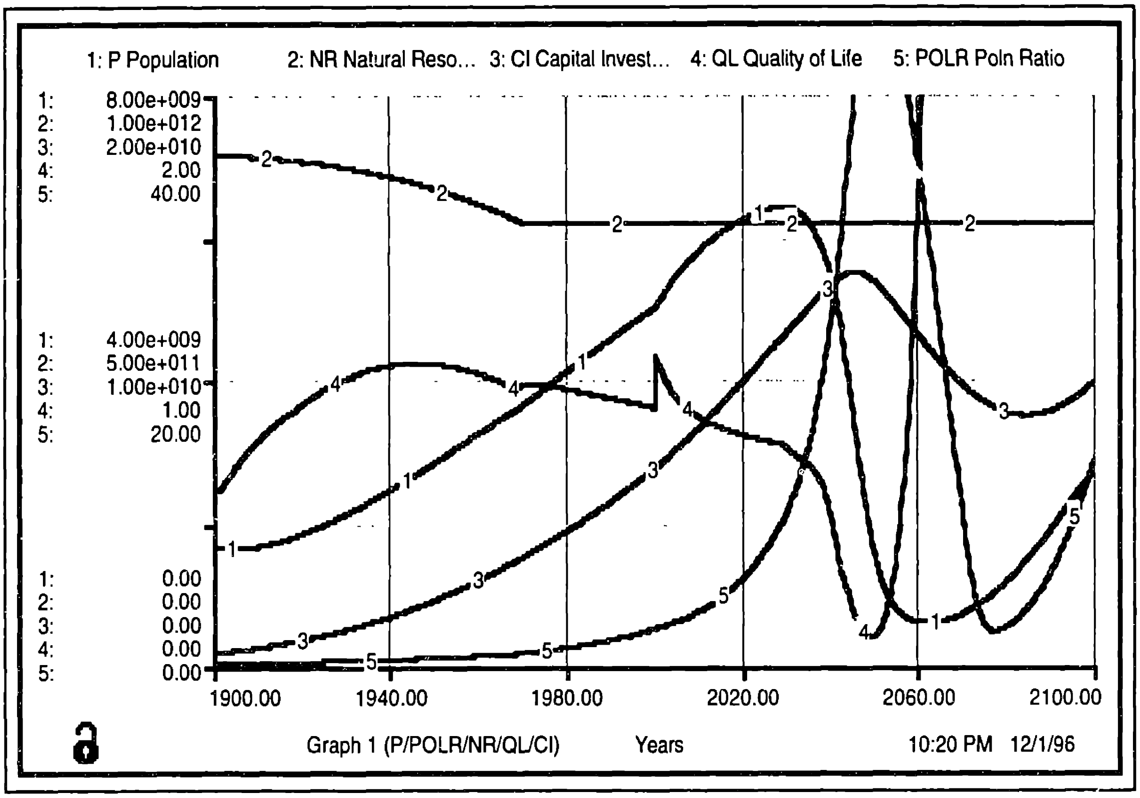

Figure 3.5: (5-9) Increased food production; FC: 1->1.25

The original and year 2000 runs of the model avoided the pollution crisis via the resource depletion mode, even accounting for the increased population. In fact, the original model depicted the start of a pollution explosion around 2020, but it was abated by 2060 due to depressed conditions. Now that same pollution surge is allowed to show itself, and it comes at exactly the same time.

A final example combines three of the most "obvious" and current policy trends today: increased capital investment, pollution control, and increased food production.

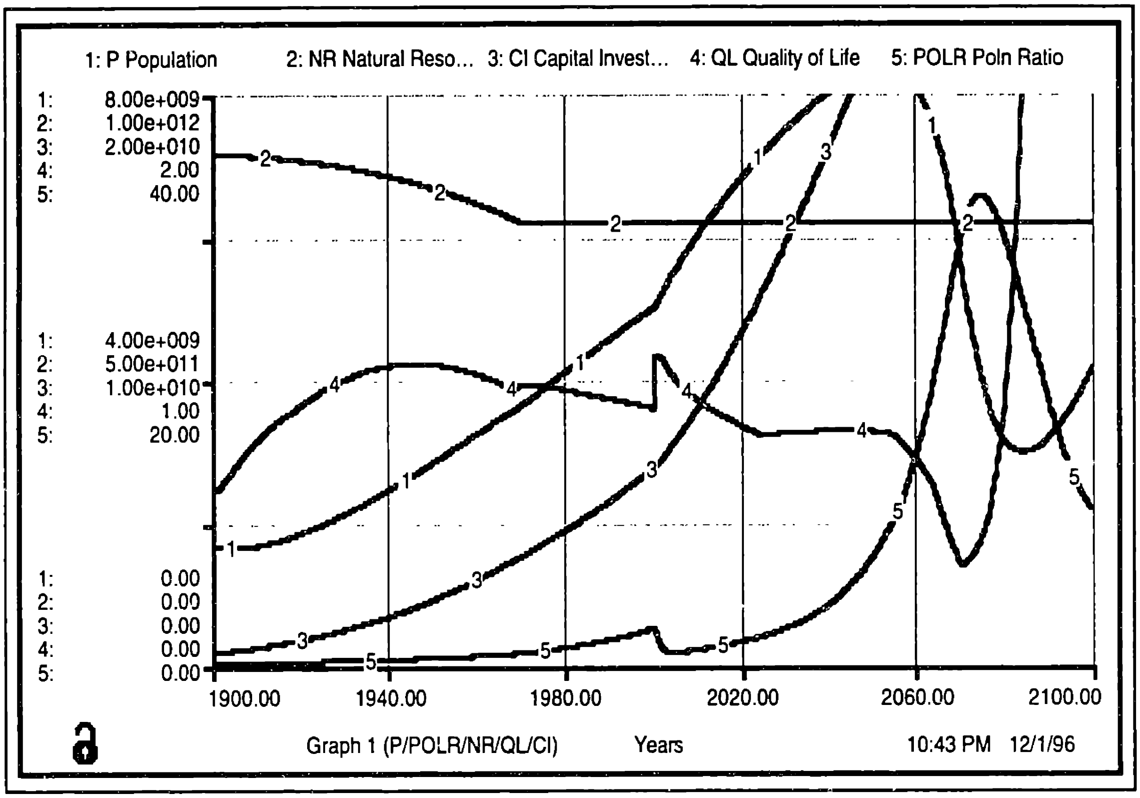

Figure 3.6: (5-13) Combination policies; CIGN: .05->.06, POLN: 1->.4, FC: 1->1.25

Compared to the year 2000 run from chapter 2 which followed the resource depletion mode, this run tells a much different story. Note the minuscule effect that pollution reduction has on the growth of pollution in the year 2000. In fact, any benefits which the pollution reduction afforded have been negated by the increased capital investment and food production combined with the fuel of unlimited resources. The pollution collapse occurs at the same time as the 1970 model, but additionally is more powerful. The drop in population is steeper, and the peak pollution level surpasses that of the 1970 run.

3.3.5 Conclusion and summary of results

The following table summarizes the significant differences between the year 2000 runs with unlimited resources and the other two runs.

Table 3.1: Differences from unlimited resources

Thesis figure #	*World Dynamics* figure #	Behavior Mode (1970 run)	Behavior Mode (2000 run)	Behavior Mode (2000 w/ inf. resrcs)	Phase shift[a]	Observations[b]
3.2	5-1	Pollution	Pollution	Pollution	-5	
3.3	5-2 / 5-3	Resources	Resources	Pollution	-	No population growth after 2000. Crisis appears regardless.
3.4	5-8	Pollution	Resources	Pollution	-10	
3.5	5-9	Resources	Resources	Pollution	-	Population reaches higher maximum, then crashes.
(not shown)	5-11	Pollution	Pollution	Pollution	-5	
(not shown)	5-12	Pollution	Pollution	Pollution	+10	More violent collapse.
3.6	5-13	Pollution	Resources	Pollution	0	Higher peak pollution level.
(not shown)	5-14	Pollution	Pollution	Pollution	+10	More violent collapse.

a. Difference between the year of maximum pollution in 2000 model with unlimited resources and the corresponding year in the 1970 model. A '-' indicates different behavior modes.
b. Observations refer to original 1970 run and year 2000 run with unlimited resources.

The data presented in these subsections clearly show the negative effects an unlimited supply of resources has on the "obvious" policy responses in the world model. Every run of the model showed amplification of the effects of policy levers, and resulted in outcomes equal to or worse than any of the previous runs of the model under the same policies but with finite resources. What does this mean for the real world? It means that if resources are indeed much greater than initially assumed, perhaps even effectively infinite, as many of the proponents of growth claim they are, then our global policy decisions will have to be made with even more intense study and scrutiny than ever. One may imagine a scenario where just one policy out of several turns out to be a) widely accepted (as are many of the "obvious response" policies above), b) highly influential, and c) a cause of negative trends in the world system. Such chances undoubtedly exist. The larger our pool of resources, the higher the probability of a crisis situation.

3.4 Equilibrium with unlimited resources

The original 1970 runs of the world model demonstrated that equilibrium was possible in the world system. Almost all of the policy choices used to achieve this were opposite of the "obvious responses". When put into effect in the year 2000, it was too late to achieve the same standards of 30 years earlier, resources having taken their toll on the system. What then can we expect of the year 2000 model with unlimited resources? Will the increased volatility of the system prevent an equilibrium from being reached, or will the absence of the resource depletion mode create a pathway to stability? These questions are explored as output from the year 2000 model with unlimited resources is presented below.

3.4.1 Pollution control

A reduction in pollution levels by 50% combined with a 75% cut in resource usage was enough to stabilize population in both the 1970 and year 2000 runs of the model. This is not the case when resources are unlimited.

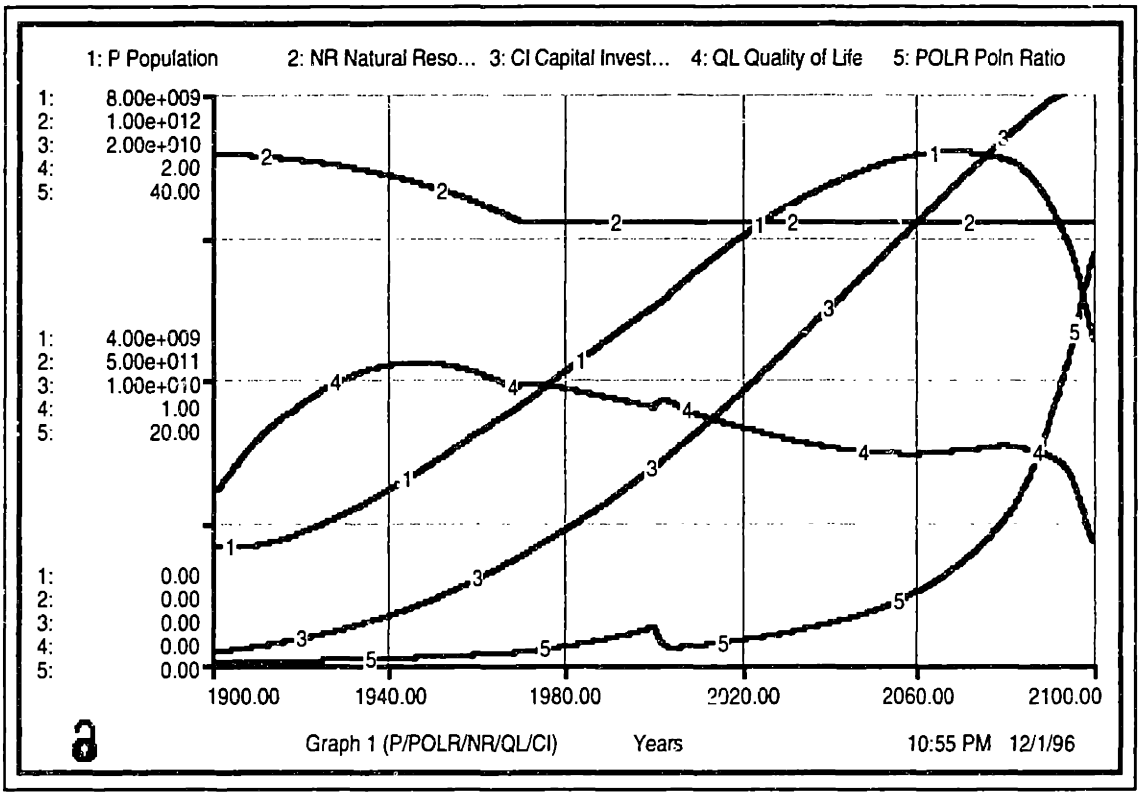

Figure 3.7: (6-1) Equilibrium becomes pollution crisis; POLN: 1->.5

Capital investment, now unchecked by resource depletion, grows freely along with population until their combined strength pushes pollution levels past controllable limits. The pollution crisis appears at the same time the other two model runs had reached equilibrium. The only difference between the policies of this run and the original 1970 run is a further decrease in resource usage, from .25 to 0. Note how the system is sensitive to the resource usage rate: the normal mode of behavior is resource depletion (even with pollution reduced by 50%); cutting resource usage to .25 from 1.0 results in equilibrium; setting resource usage to 0 causes the pollution crisis.

3.4.2 Reduced capital investment

A reduced rate of capital investment in addition to the policies of the previous run is enough to achieve equilibrium.

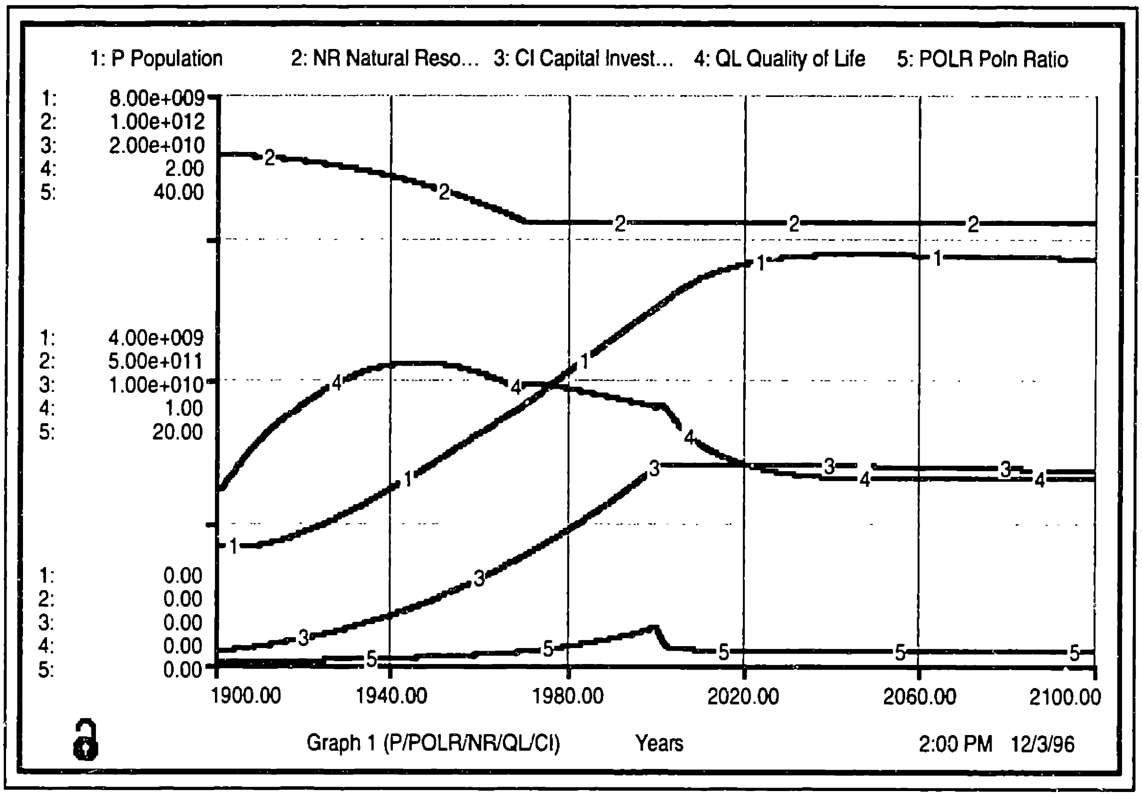

Figure 3.8: (6-3) Reduced capital investment; POLN: 1->.5, CIGN: .05->.03

Unlike the year 2000 run of chapter 2, whose population declined due to resource depletion, the availability of resources is able to sustain the system's equilibrium. Comparison to the original model run reveals that this run has almost 2 billion more people -- a result of the faster growth from unlimited resources. The cost to society is manifested in the lowered quality of life.

3.4.3 The prescription for equilibrium

The set of policies which brought the original world system into equilibrium from 1970, and were unable to sustain it in the year 2000 model, turn out to be almost as effective as the original run when resources are unlimited.

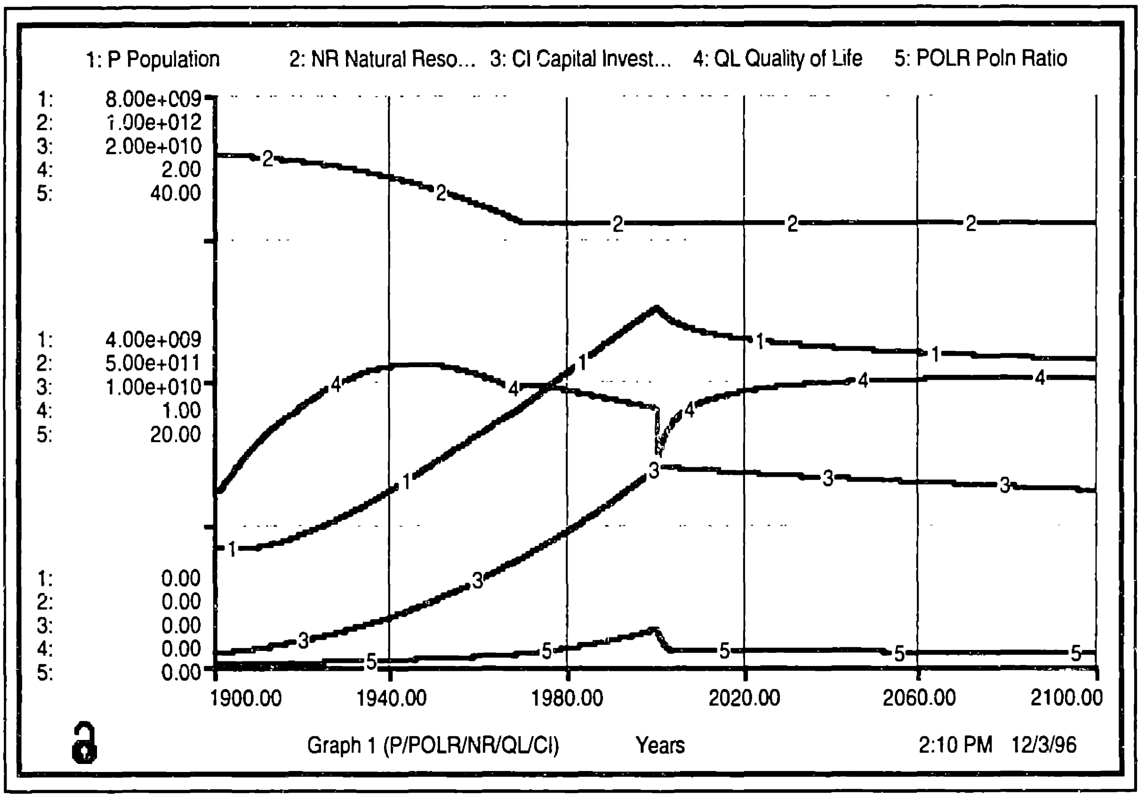

Figure 3.9: (6-7) Prescription for equilibrium; POLN: 1->.5, CIGN: .05->.03, FC: 1->.8, BRN: .04->.028

The critical 30 years of resource depletion, which crippled the year 2000 run under these policies, has now been excluded as a possibility. A population of just over 4 billion has resulted by the year 2100, with a quality of life that has been improving since the policies entered into effect in 2000.

3.4.4 Summary of results

The table below summarizes the data from the equilibrium runs of the world model under the assumption of unlimited resources. Note the trend in population size and quality of life as more counterintuitive, growth-suppressing policies are introduced.

Table 3.2: Summary of equilibrium runs with unlimited resources

Thesis figure #	*World Dynamics* figure #	1970 run Eq. Popln	2000 run w/ unlim. resources Eq. Popln.	1970 run Change in Qual. of Life[a]	2000 run w/ unlim. resources Change in Qual. of Life[a]	Notes
3.7	6-1	6.4 B	-	-30%	-	Pollution crisis in year 2000 run.
3.8	6-3	4.2 B	5.9 B	-25%	-40%	
(not shown)	6-5	3.8 B	5.0 B	-15%	-25%	
3.9	6-7	3.8 B	4.2 B	+5%	0%	

a. Change from 1970 value to equilibrium value.

3.5 Conclusions on unlimited resources

The assumption of unlimited resources has both positive and negative effects on the world system and its ability to achieve equilibrium. On the positive side, the resource depletion pathway is no longer open, which allows the system to attain an equilibrium that was impossible in the year 2000 runs with limited resources. If the resource assumption is true, it could mean we may yet have time to put a well thought out set of policies in place for our future.

The negative effects of the resource assumption are several, and affect both "obvious" policies and equilibrium attainment. The most prominent effect is the increased volatility of the system. That is, the system reacts faster and more strongly to policy levers. In the absence of resources to dampen the growth of industry and population, these factors exponentially increase. In the case of an "obvious response" policy, they cause crises to appear sooner than they otherwise would have. The system also becomes harder to control, since policies will now need to be stricter and possibly applied for longer periods of time, if not indefinitely. To do so would require even more effort from technology, politicians, and society.

Unlimited resources are by no means a savior. Policies which might have been beneficial to the system had resources been limited are now punishing sentences on the world. As seen in the first equilibrium run, the system that had attained stability in 1970 was now shifted into the pollution crisis mode. Secondly, the initial growth the world system produces due to unlimited resources results in higher population levels in all cases (on average, about 30% higher). Correspondingly, quality of life is lower in all instances compared to the 1970 runs. What we see is that as the time interval of *inaction* increases (that time span before policies are implemented), the more time population, capital, and pollution have to grow, and the lower the resulting quality of life will be. If too much time is wasted initially, the system is bound to enter the pollution crisis mode. There thus exists a critical time before which the system can be rescued into equilibrium, and after which it will plummet into the pollution crisis. This issue will be discussed at length in the next chapter.

As time goes by and we do not take steps to alter our present trends, it will become more undesirable to do so in the future. If the world does decide to act on the non-obvious policies depicted in the model, it means many luxuries and benefits of a high-growth society will have to be abandoned. The equilibrium runs call for lowered investment, lowered food production, and tolerance of a [short-term] drop in quality of life. All these become larger and larger pills to swallow as we continue to live with higher pollution levels and more crowding. If our situation worsens, society will undoubtedly resist giving up even more in order to attain a long-term benefit. The inability of the public to think in the long term must be addressed if we are to attempt a solution to this problem.

Chapter 4

Timing of Policy Intervention

4.1 The effects of time on the world system

Throughout this thesis we have seen that time spent in inaction can have disastrous consequences. In many instances the 30 years which have elapsed since the original model runs have been enough to push the system beyond its limits and into a crisis. In others, it became too late to switch the system into an acceptable equilibrium. Our control of the world system lies in the realm of policy intervention, and to use it correctly means we must have a knowledge of its effects at various times in the system's life, for what may work in the beginning may very well not work past a certain turning point.

An examination of the world model outcomes was performed for various policy implementation times. Specifically, the equilibrium policies (since these should be of most interest and importance to society) were put in effect at various times in the course of the world model with the assumption of unlimited natural resources beginning in 1970. Four times were chosen as the standard policy implementation times: 1970, 1985, 2000, 2020. They represent, respectively, 2 outcomes that "could have been", and 2 outcomes that "could be", depending on when and if society acts. Additionally, to ascertain an approximate "point of no return", beyond which policy implementation was unable to rescue the system, some runs of the model were carried out with later policy implementation times. What follows are the results of this examination.

4.2 Equilibrium runs and policy implementation times

The model runs presented use the same policies as their corresponding runs of chapter 3. As in that chapter, all runs assume unlimited natural resources in 1970 and beyond. The variations in these runs focus on the policy implementation times.

4.2.1 Pollution control and capital investment

We first look at the equilibrium originally attained through pollution controls and decreased capital investment, and implemented in 1970 (note that this differs from the original run due to zero natural resource usage).

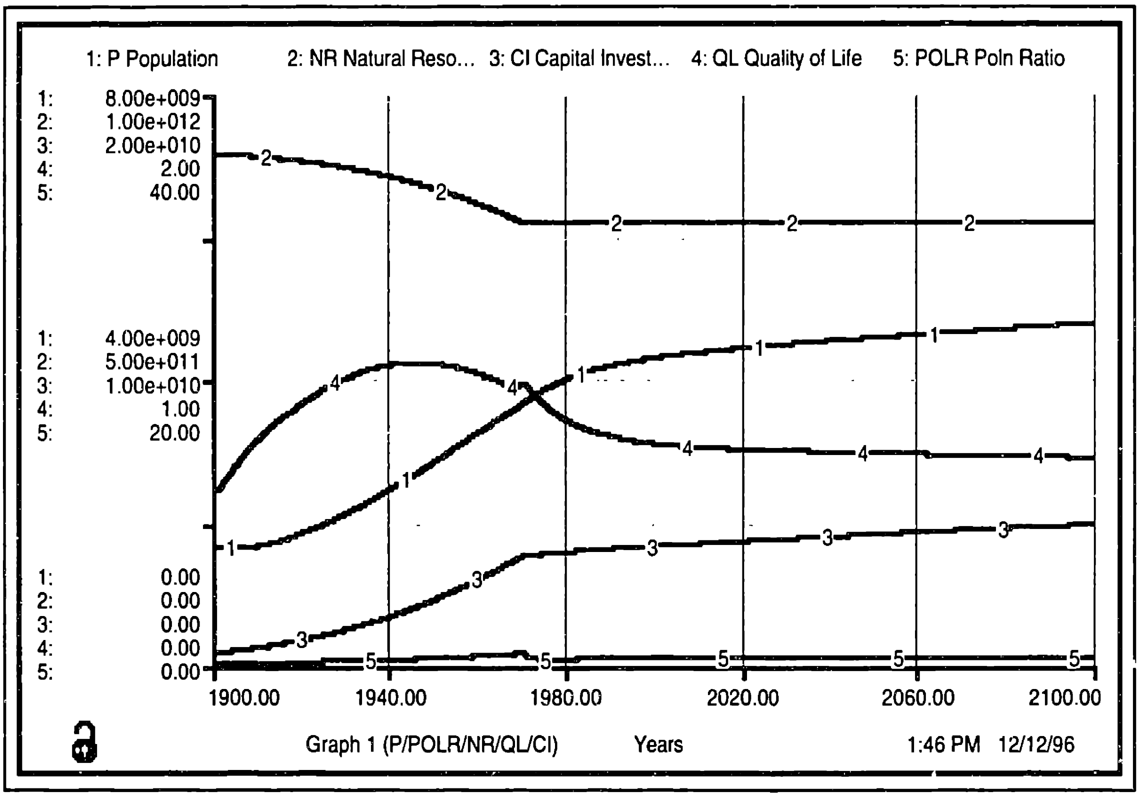

Figure 4.1: (6-3) Equilibrium - 1970; POLN: 1->.5, CIGN: .05->.03

This run is very similar to the original world model run under the same policies. Though quality of life remains low, the system has stabilized. Now compare this to the same policies put into effect beginning in 2020:

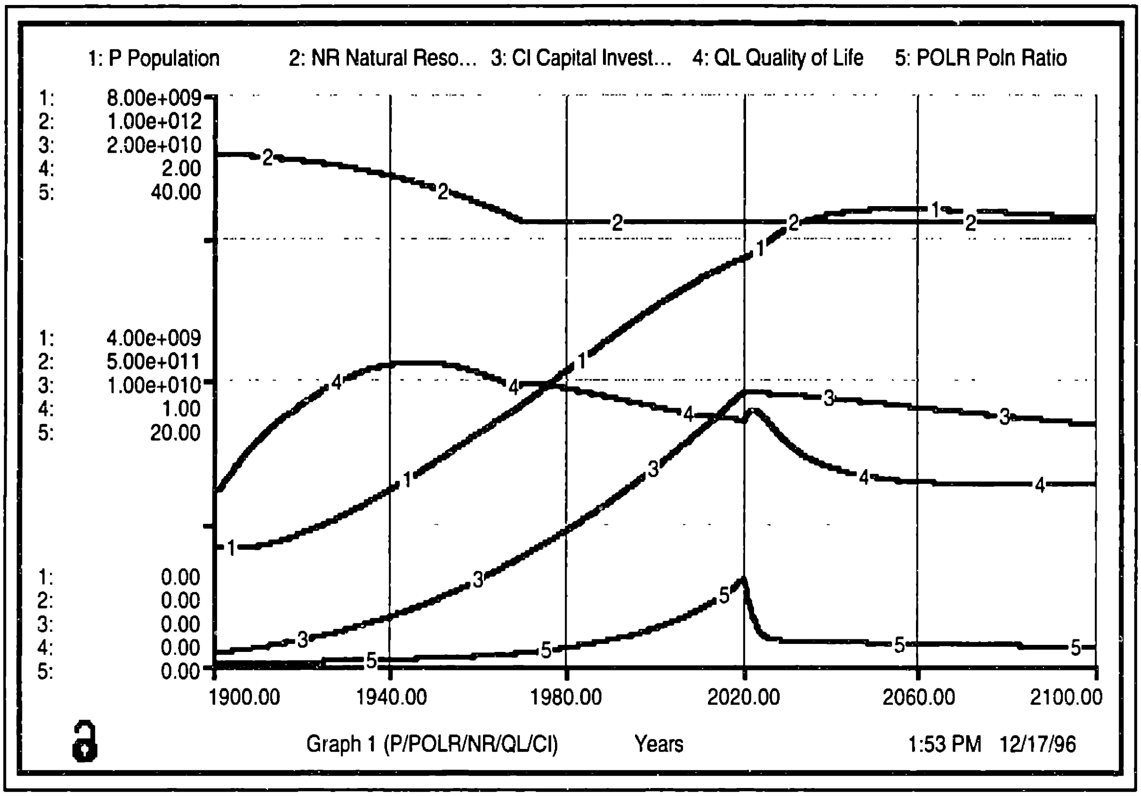

Figure 4.2: (6-3) Equilibrium - 2020; POLN: 1->.5, CIGN: .05->.03

Note the dramatically increased population accompanied by decreased quality of life. How long can the system be allowed to grow before we put policy controls in place? We know that if left on its own, the system will reach the pollution crisis. Already by the year 2020 we see pollution was on its exponential course upwards. Because of this exponential growth, pollution doesn't become a problem until all of a sudden it surges out of control -- such is the nature of exponential growth. Usually by the time it is noticed, it is too late to control. The next set of figures depict the point of no return for this set of policies.

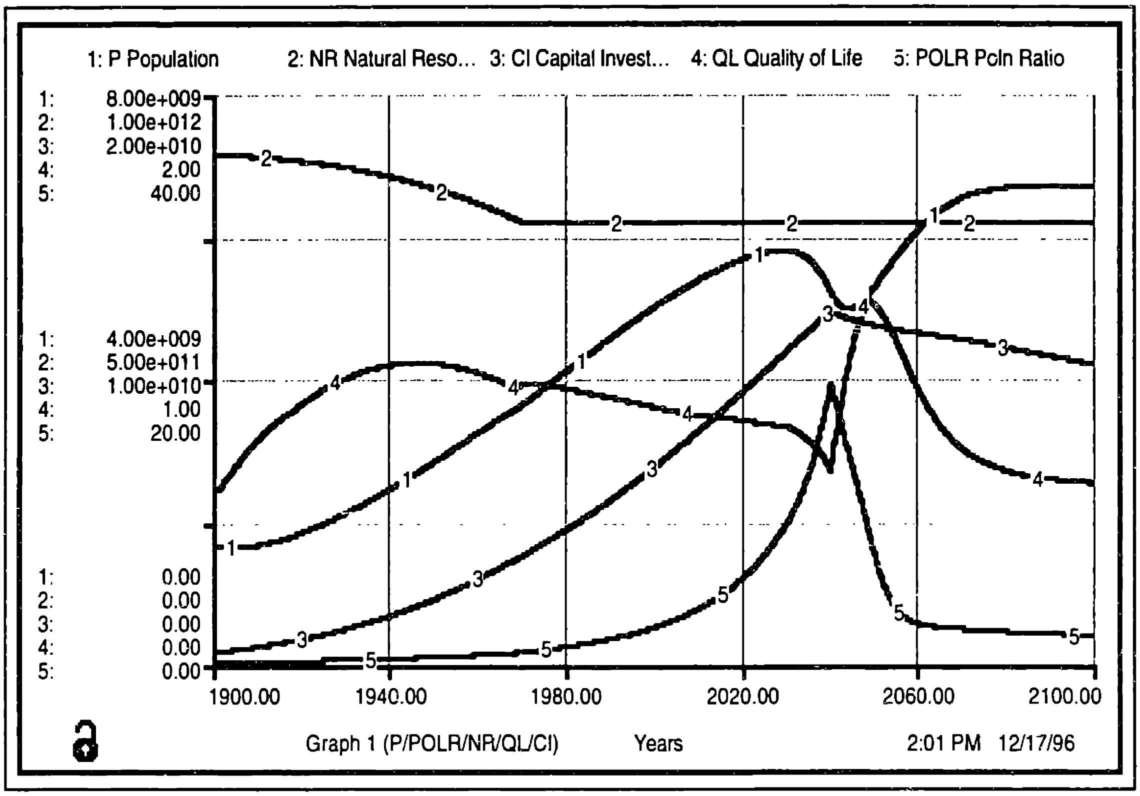

Figure 4.3: (6-3) Equilibrium - 2040; POLN: 1->.5, CIGN: .05->.03

This is the run for the year 2040, apparently just in time to avoid a major pollution crisis. Population recovers and remains at its highest value yet, accompanied by lowered quality of life and a falling level of capital investment. Now we present the same run, with policies implemented *just five years later*:

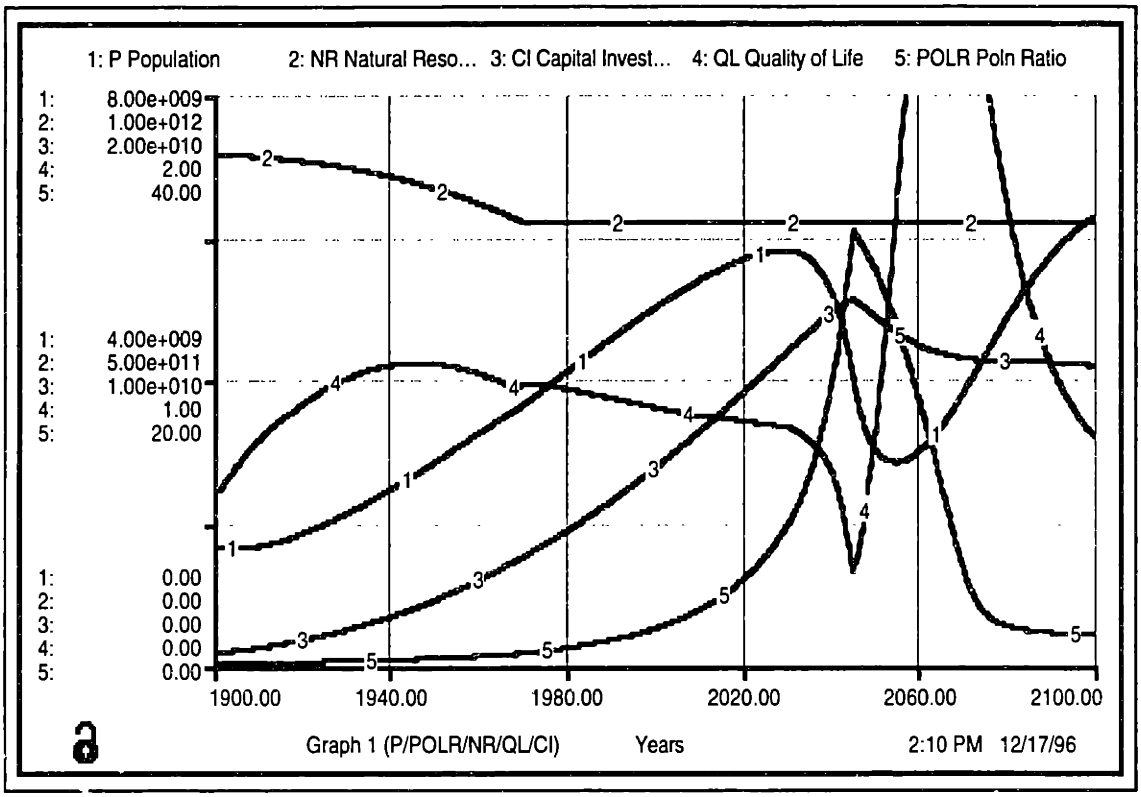

Figure 4.4: (6-3) Equilibrium - 2045; POLN: 1->.5, CIGN: .05->.03

Only five years separates a minor depression in population from a major pollution crisis. Within a span of about 20 years, population is reduced by over 2 billion people as exponentially increasing pollution doubles.

Understanding exponential growth is imperative if we are to be able to design and implement successful global policies. This type of growth is devious because it can initially remain unnoticed for years, only to spring up out of nowhere with just a few doublings. The world model paints a detailed, if not alarming, picture of this. Beginning with the year 1970, the equilibrium policies work fine for 70 years. Society could have achieved stability at any time during this window from 1970 to 2040. Once 2040 is reached, society has less than 5 years to react before being overrun by pollution. Though we cannot know the specific dates of this window, the model exemplifies and supports its existence.

Besides being a dangerous gamble, waiting to act in the world system causes overall quality of life to decline and population to rise. We summarize the effects of policy implementation times for this set of policies in the table below.

Table 4.1: Effects of policy timing on the world model with pollution control and reduced capital investment

Thesis figure #	Policy implementation time	Qual. of life when policies implemented	Equilib. Population	Equilib. Qual. of life	Notes
4.1	1970	1.00	4.8 B	0.73	
(not shown)	1985	0.95	5.3 B	0.69	Graph not shown above.
(not shown)	2000	0.90	5.7 B	0.65	
4.2	2020	0.86	6.3 B	0.63	
4.3	2040	0.75	6.4 B	0.62	Pop., qual. of life affected by minor pollution crisis.
4.4	2045	0.38	6.1 B	0.80	Pollution crisis greatly affects pop. and qual of life.

4.2.2 Food controls

The additional policy of food supply reduction can be used to curb the growth of population. This type of policy lever becomes most effective at high levels of population, since the food supply is critical at this time. The graph below shows the world model outcome using the policies of the previous graph, plus a 20% reduction in the food supply, implemented in the year 2000.

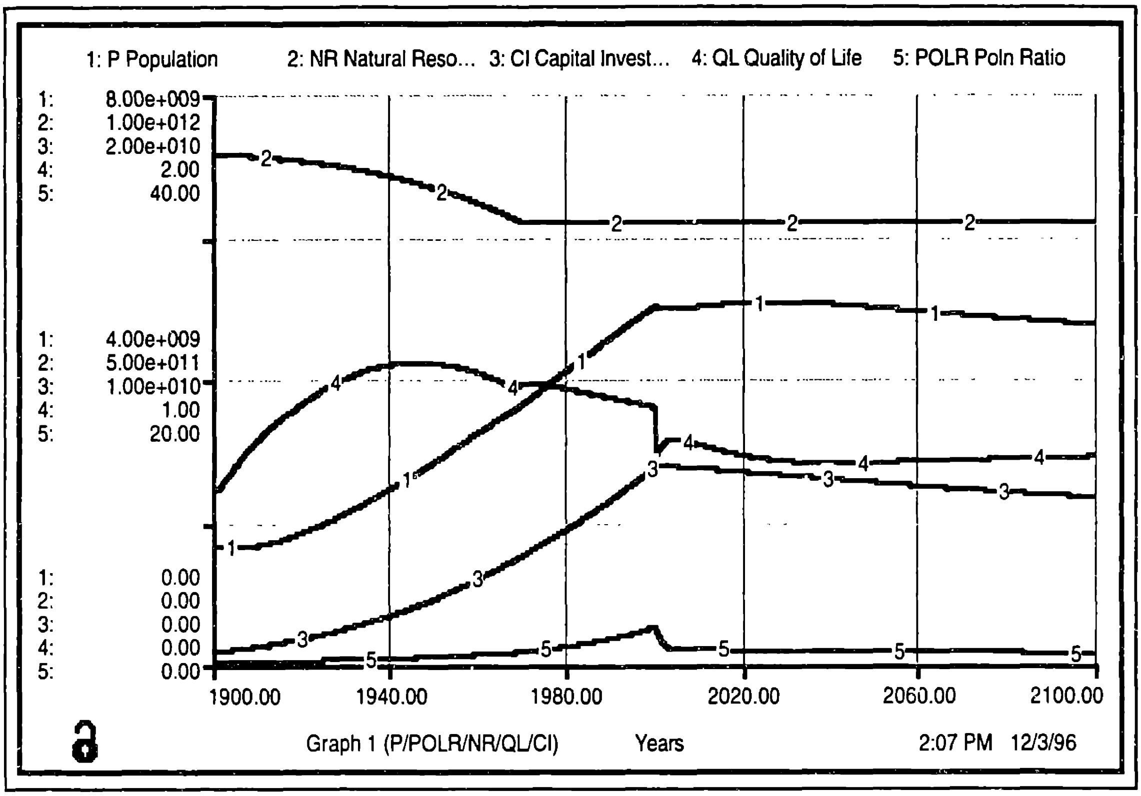

Figure 4.5: (6-5) Food controls added; POLN: 1->.5, CIGN: .05->.03, FC: 1->.8

Once the policies are put into place, population growth comes to a halt, and begins a slight descent to a lower equilibrium level. After a short-term adjustment period, quality of life begins to rise. The population and quality of life statistics for this set of policies are better in each year of implementation than the same policies without food controls (shown in the previous section). The table below presents these results.

Table 4.2: Effects of policy timing on the world model with pollution control, reduced capital investment, and food control

Thesis figure #	Policy implementation time	Qual. of life when policies implemented	Equilib. Population	Equilib. Qual. of life	Notes
(not shown)	1970	1.00	3.8 B	0.81	
(not shown)	1985	0.95	4.3 B	0.77	
4.5	2000	0.72	4.8 B	0.73	Pop. declining, qual. of life rising slightly.
(not shown)	2020	0.69	5.4 B	0.68	"

4.2.3 Birth control

The last addition to the set of policies that yield the best equilibrium conditions is birth control measures. However, even with the full set of four growth-suppressing policies, the world system cannot be rescued once the pollution crisis gets underway around 2045. Though birth control does provide additional improvements to quality of life and population levels, it shows no significant deterring effects on the time or severity of the pollution crisis. The system takes only 5 years, to go from being salvageable to unstoppable. The outcomes from the 2040 and 2045 runs are presented consecutively below.

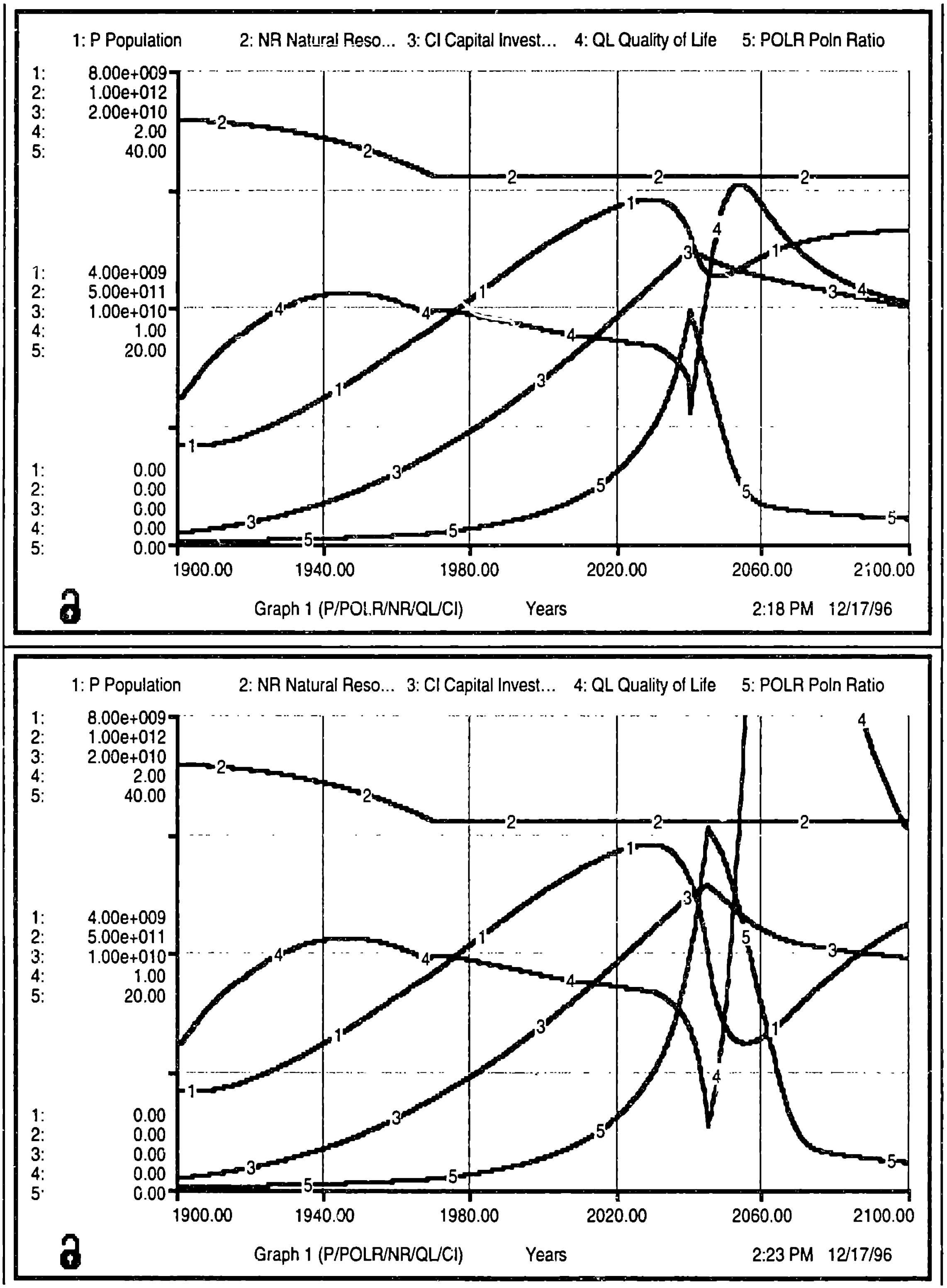

Figure 4.6: (6-7) Five years separate equilibrium and collapse; POLN: 1->.5, CIGN: .03->.05, FC: 1->.8, BRN: .04->.028

The table below summarizes the runs for this set of policies.

Table 4.3: Effects of policy timing on the world model with pollution control, reduced capital investment, food control, and birth control

Thesis figure #	Policy implementation time	Qual. of life when policies implemented	Equilib. Population	Equilib. Qual. of life	Notes
(not shown)	1970	1.00	3.5 B	1.03	
(not shown)	1985	0.95	3.8 B	1.04	
(not shown)	2000	0.90	4.3 B	1.02	
(not shown)	2020	0.83	4.9 B	0.99	
4.6 (top)	2040	0.55	5.8 B	1.07	Pop., qual. of life affected by minor pollution crisis.
4.6 (bottom)	2045	0.30	4.3 B	-	Pollution crisis greatly affects pop., qual. of life.

4.3 Conclusions and implications from the effects of policy implementation times

The data from the world model clearly indicates a declining trend in overall quality of life as we wait longer and longer to implement world-saving policies. There is also an upper bound to the time at which such policies can be enacted. Once this time limit is passed, the policies are rendered ineffective in preventing world catastrophe.

What are the implications to society? For one, we must acknowledge the existence of the "point of no return". Population and pollution can not continue growing forever, so this date must exist. Determining a rough estimate for it is a daunting, if not impossible, task. However, the nature of exponential growth processes, such as population, means that the turning point may be close by, even though present conditions would make it seem quite far away.

Chapter 5

Conclusions on the world model and the world in the 21st century

5.1 A world pushed further to capacity

Society has advanced considerably since the first world model was introduced thirty years ago in *World Dynamics*. The Berlin Wall fell, the Soviet Union dissolved; more and more countries have begun to modernize and industrialize. This advancement, or perhaps more correctly called growth, continues to push our world system closer to its capacities.

Evidence of this exists everywhere. We have seen the environment become a major political (and even global) issue, covering rain forest destruction, recycling of plastics and wood products, greenhouse emissions, and wildlife conservation. Pollution problems have risen: smog, asthma, groundwater contamination, hazardous waste dumping, landfills. Crowding as well has been a cause: crime in cities, war in the Middle East and Eastern Europe. Food crises continue to plague third world countries in Africa and South America. All of these topics have increased in volatility and public awareness in the past thirty years as a direct result of our tremendous growth. Yet, our long-term survival rarely surfaces as an issue of discussion.

The 21st century may well be the most crucial 100 years in our history. The emergence of developing nations, as well as the continued growth of industrialized countries will undoubtedly put greater stresses on the world system. If current growth trends continue, and no efforts are made to control them, the world system will intervene naturally through one or more of the behavior modes of resource depletion, pollution crisis, crowding, and food shortage. Our mission for the 21st century will be to avoid these outcomes, and attain a global equilibrium.

5.2 Policy choices

The course of the world system lies in the choice of policy intervention which society will deem appropriate. We have shown that pitfalls lurk at every step of the way in designing correct policies, as most of the "obvious" responses to problems provide a short-term benefit but a long-term hazard to the world. For an equilibrium to be reached in the world system, the set of policies used goes counter to the usual short-term solution. Will society accept such controls? If society refuses to change, then as time progresses and the world system continues its growth, declining conditions will make acceptance harder. A 20% pay cut means many more consequences for someone in poverty than for a wealthy family.

Most likely it will take the effects of the world system itself to finally spur an acceptance. Once it becomes clear that current policies have caused harm instead of good, will it be possible to reverse the effects? This depends on many factors, including which choice of policies is in effect. The year 2000 model runs in chapter 4 tell us that *if the problems are recognized early*, there is time yet to correct them. The exponential growth character of the world system is both beneficial and harmful: we have up until the last doubling to alleviate and avoid a crisis, but this last doubling arrives suddenly.

Recognition time also poses a significant threat to crisis avoidance. Changes in the world system happen over the long term, which means day to day and in most cases year to year circumstances may not vary noticeably. Humans, as most animals, tend to become accustomed to their surroundings and can not detect such changes. Forrester has called this the "boiled frog syndrome"†. For society to recognize the effect of long-term incre-

†. This term derives from the rather grotesque rumor that a frog placed into boiling water will jump out, but when placed in cold water which is slowly heated to boiling, will allow himself to be cooked alive.

mental changes, it must be notified by a source that has tracked such changes. Though such sources exist as various scientific and public service organizations, their reports of increased deforestation, pollution, and crowding have for the most part been ignored or mired in a sea of controversy. We may just now be starting to recognize the mounting problems facing the world system.

5.3 Resources

Model runs with unlimited natural resources proved to be more unstable and reactive to harmful policies than their corresponding runs with limits on resources. The pollution crisis became the dominant mode of behavior for the world model, appearing where resource depletion had previously been the outcome, and arriving earlier than the pollution crisis in the model with limited resources.

The impact on society of this result may be profound. If resources are indeed unlimited, then any policy which tends to increase industry growth will have its effects magnified, creating pollution and population expansion much greater than would have otherwise been possible if resources were being depleted. The heightened sensitivity of the world system means extra care must be taken to draft policies that affect areas of industry and capital investment. Furthermore, we will never be able to know if resources are effectively unlimited, since by definition it would take forever to find out. As Kahn and Brown have suggested, current resource availability will always appear limited simply because the marginal profitability of prospecting for more resources has reached the marginal cost [25]. For example, if there is enough iron to supply the world for an estimated 100 years, then scouting for more iron ore is a waste of money. If society does not assume unlimited resources when creating policies, it may have unknowingly decided on a course wrought with disaster, for as resources seem to be nearing an end, more will be found and growth will continue. To stop such a vicious cycle would be highly undesirable for society; a much better solution is to avoid it in the first place.

5.4 Equilibrium

Global equilibrium is attainable in the year 2000 model as long as two basic criterion are met: the right combination of policies is used, and they are implemented soon enough. Policies which make equilibrium possible are the same as those of the original model, and mean society must tolerate a short-term drop in quality of life in order to gain an overall increase. It is unclear if this will be possible to carry out.

As each year passes us by with no significant changes in global policy, timing becomes more and more important if we are to head to equilibrium. The runs of the year 2000 model have shown that a "time window" of opportunity exists in the world system. If equilibrium policies are put into effect within this window, the system can achieve stability. However, beyond the boundaries of the window the system continues to a crisis. A rescue attempt at this point would mean severe policies implemented within a short time span. Again, it is unclear if such a feat would be feasible or acceptable to society. Waiting to act also means we are shortening the implementation time of rescue policies. Acceptability of policies which lower short-term standards could be increased by gradually changing current policies over a period of time. By acting early, society could have equilibrium policies completely in effect within the time window while achieving a higher acceptance rate among society.

5.5 Systems thinking and society

Unlike the world model, we cannot try out different policies on the real world and observe their effects. There is only one "run" of the real world system in which we live, and mistakes cannot be corrected simply by starting over. If present trends continue, our chance for equilibrium or crisis will approach quickly, and we must meet the challenge equipped with the knowledge of complex systems. The counterintuitive nature of the world system is not unique -- it appears in many other, varied social systems [26]. For both policymakers and the general public which elects them, an understanding of this behavior is necessary to achieve desirable outcomes. Such an understanding can allow us to control complex systems, and has been called “systems thinking”.

The benefits of systems thinking to society are both numerous and needed. It provides an understanding and respect for the short-term versus long-term behavior of complex systems. Currently, the vast majority of society acts with respect to the short-term; that is, their actions are geared to produce results in the short-term, with little or no concern of long-term consequences. Such behavior has produced the societal dilemmas of today. If we are to make the transition to equilibrium, not only must the correct policies be drafted, but most importantly they must be accepted. And because these policies can produce short-term drops in our current standards of living, a long-term view must be held by society if they are to be put into effect.

The systems thinking viewpoint can also aid in the initial phases of global problem resolution. Before we can craft policies to solve our problems, we must first recognize that they exist. Historically this has proved to be a great barrier. The general public often views the scientists and researchers who speak of long-term consequences with an eye of skepticism, and consequently many smaller, localized crises have had to actually occur before credibility was granted. This disbelief arises chiefly from the public’s lack of understanding of long-term behavior, and will take many years to remedy. If society were composed of systems thinkers, researchers would find a wider and faster acceptance of their results, which, in the world system, could mean the difference between equilibrium and crisis.

5.6 A call to action

Society is at a crossroads in the world system, and must choose its path soon, else it will be chosen for us. We can give ourselves the information needed to chose the correct pathway by incorporating systems thinking into our society. How can we do this? One answer is to start with the younger generation, whose minds are easily adaptable to the systems approach [27]. Another may be to introduce the systems approach through religion [28]. With careful planning and some luck, we may be able to beat the clock and make the transition to equilibrium.

This thesis has shown that thirty years of inaction in the world system will make our task of achieving equilibrium an even harder one. If there is one thing which must be done. it is action by society for our own good. We must begin the processes of recognition of our world system -- how it works, what works, what doesn't work, and what we can do to make it work. Waiting will only give us less time when we do decide to act. Though our values may need to change in order for us to succeed, our goal should be the same as it is today: a better world for tomorrow.

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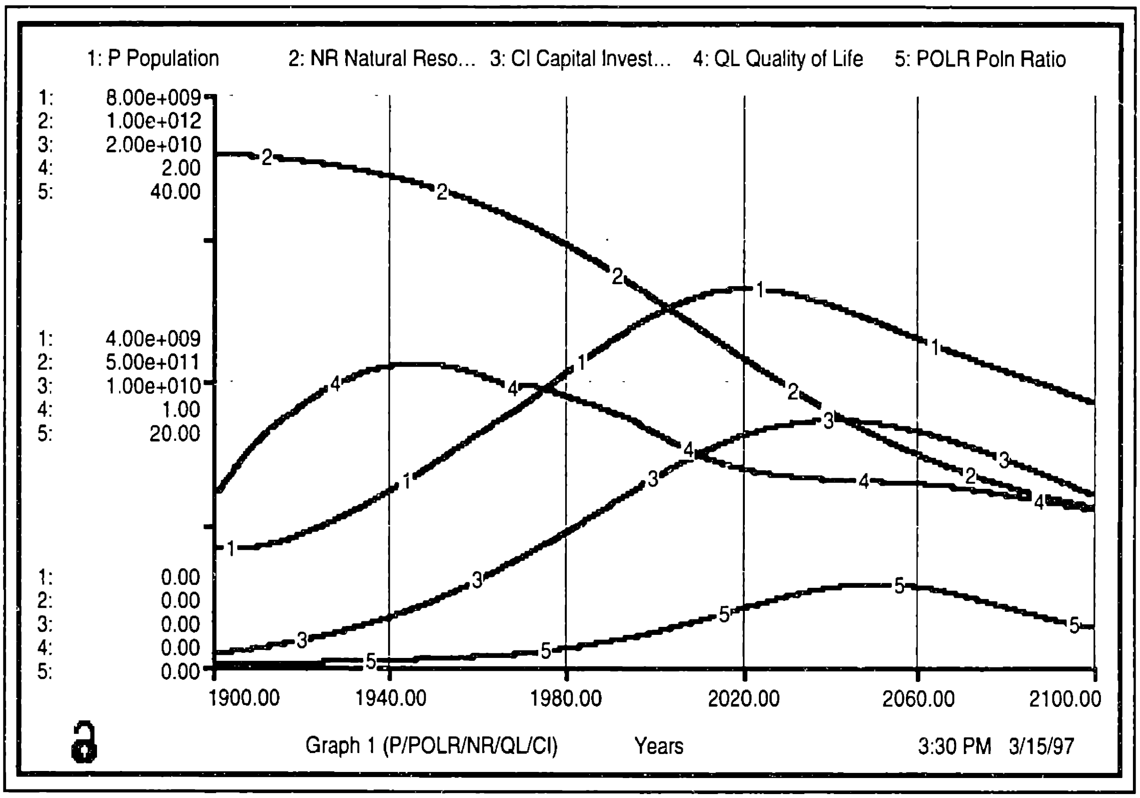
Appendix A

Figures of original *World Dynamics* model

(Figure numbers are from *World Dynamics*, not thesis)

Figure 4-1:



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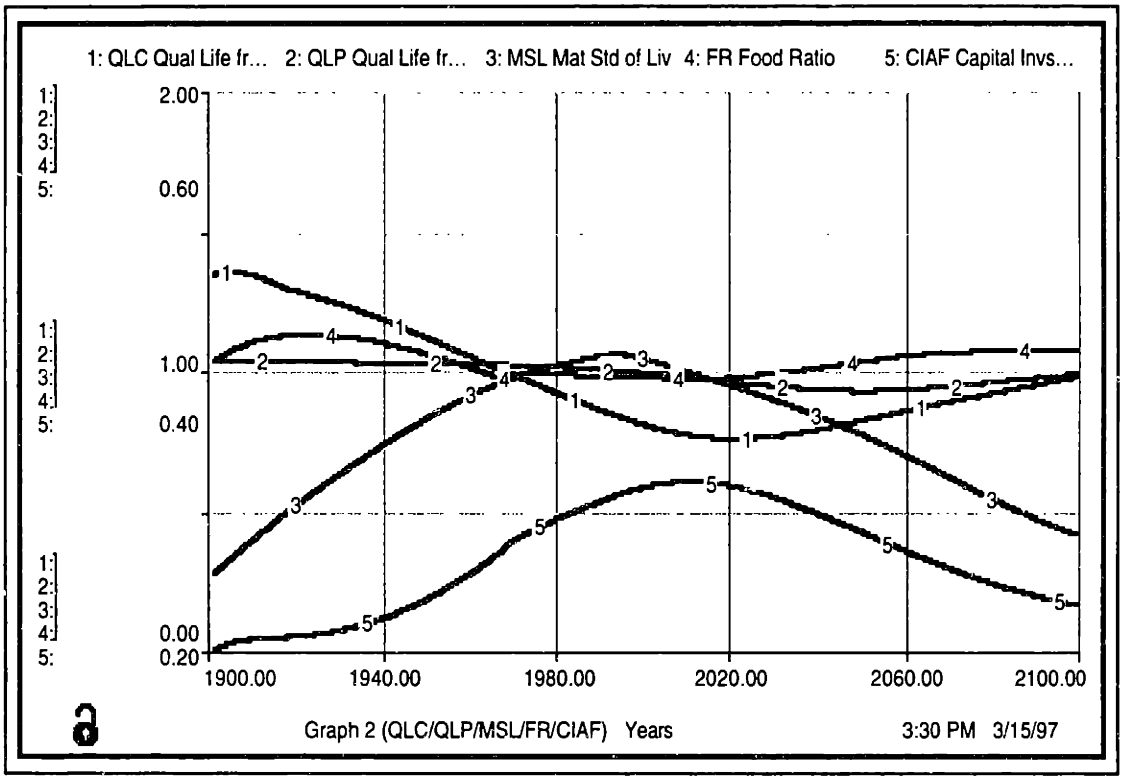
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2: QLP Qual Life fr...
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4: FR Food Ratio
5: CIAF Capital Invs...
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1: 2: 3: 4: 1.00
5: 0.40
1: 2: 3: 4: 0.00
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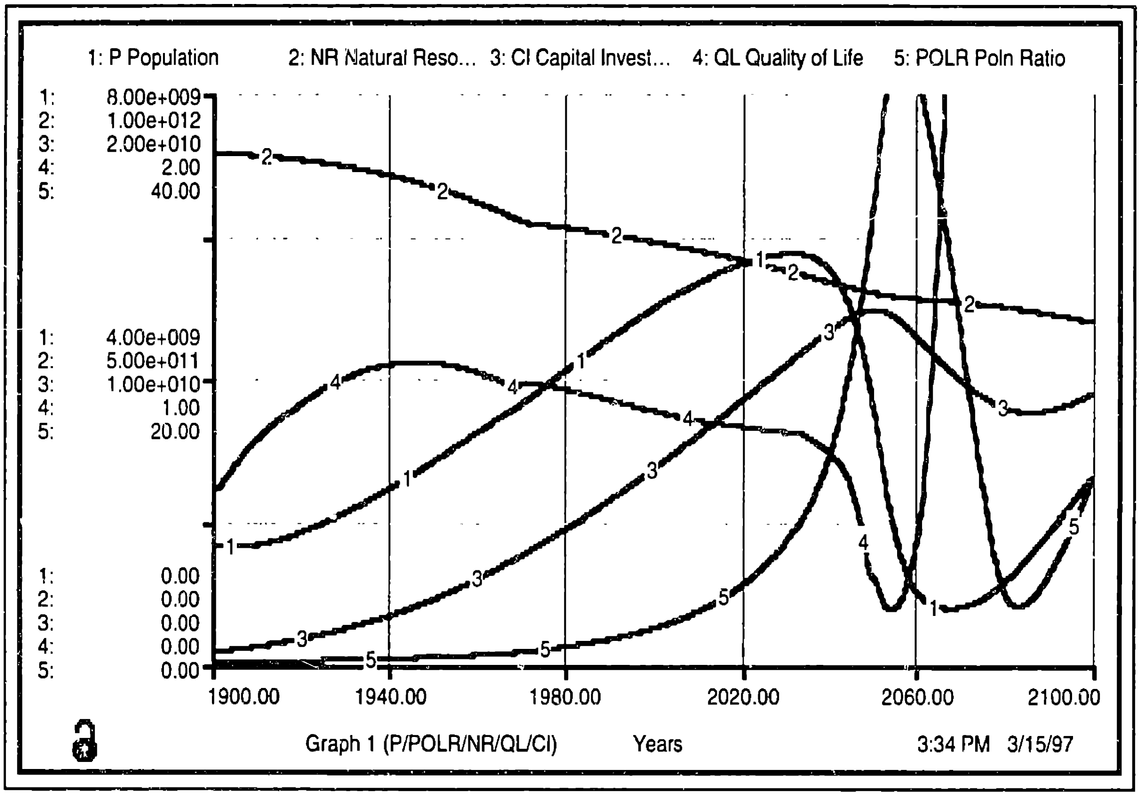
Figure 4-5:



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3: 1.00e+010
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5: 20.00
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3: 0.00
4: 0.00
5: 0.00
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Graph 1 (P/POLR/NR/QL/CI)
Years
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Figure 4-6:

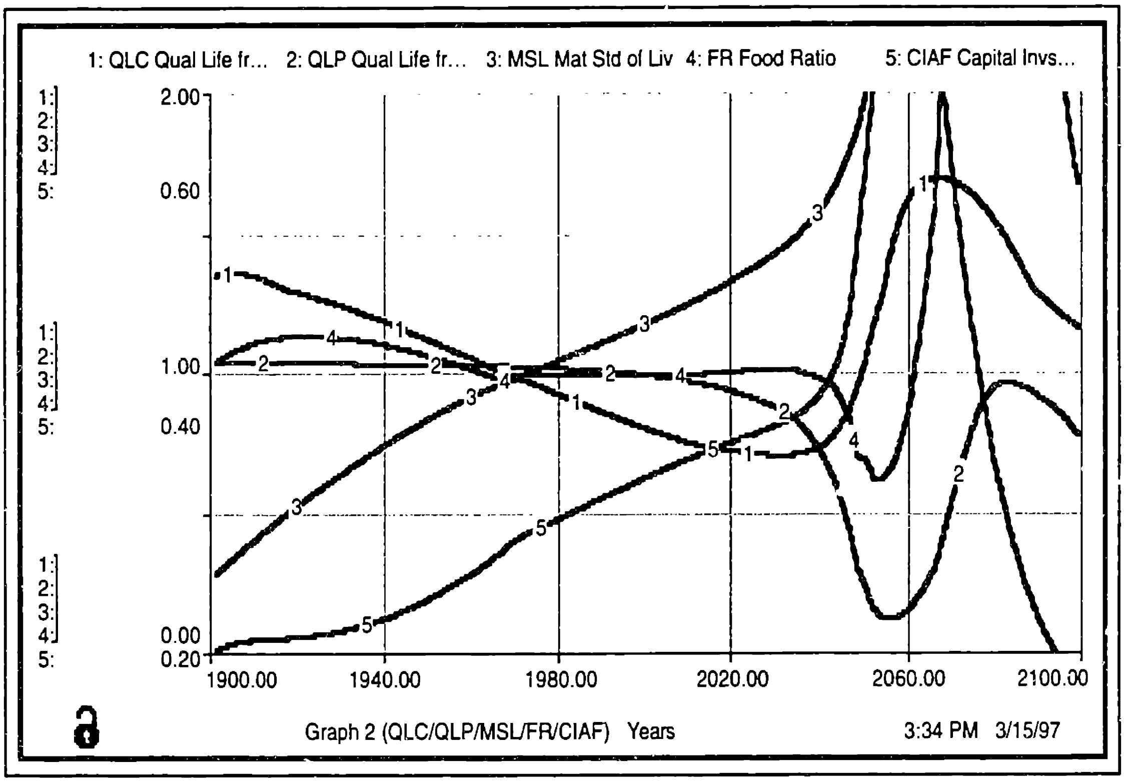

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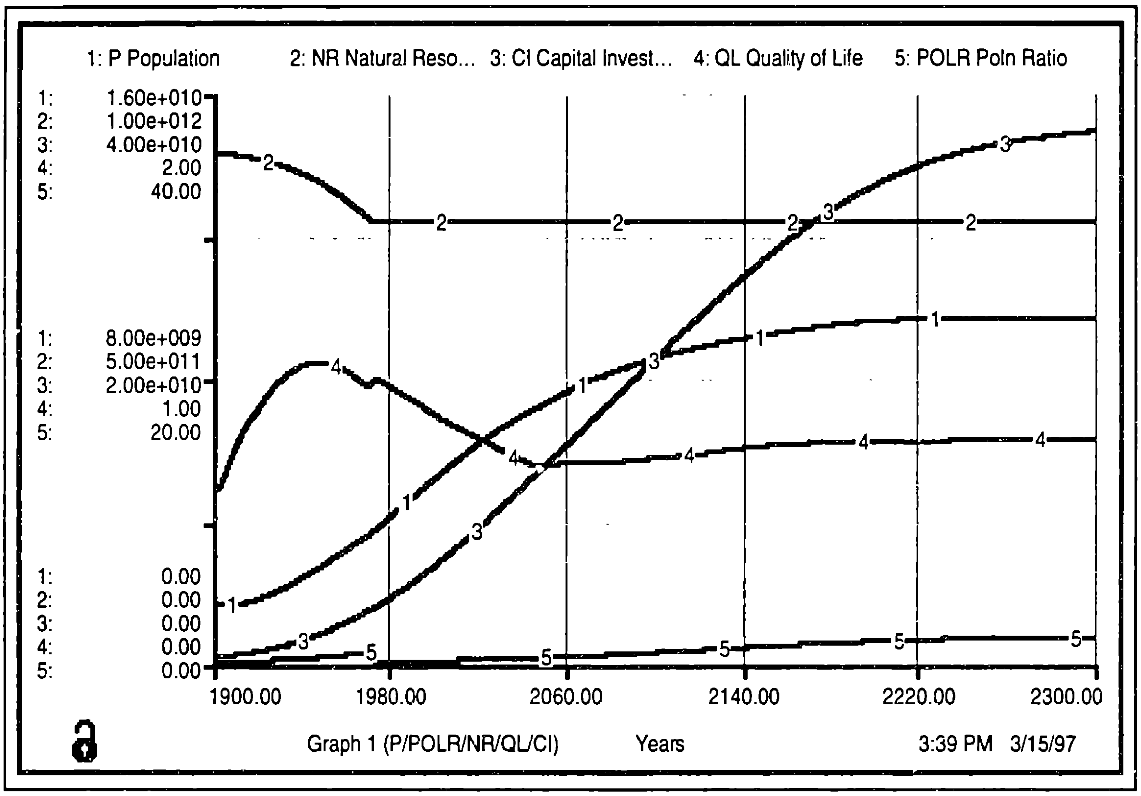
Figure 4-9:



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5: 20.00
1: 0.00
2: 0.00
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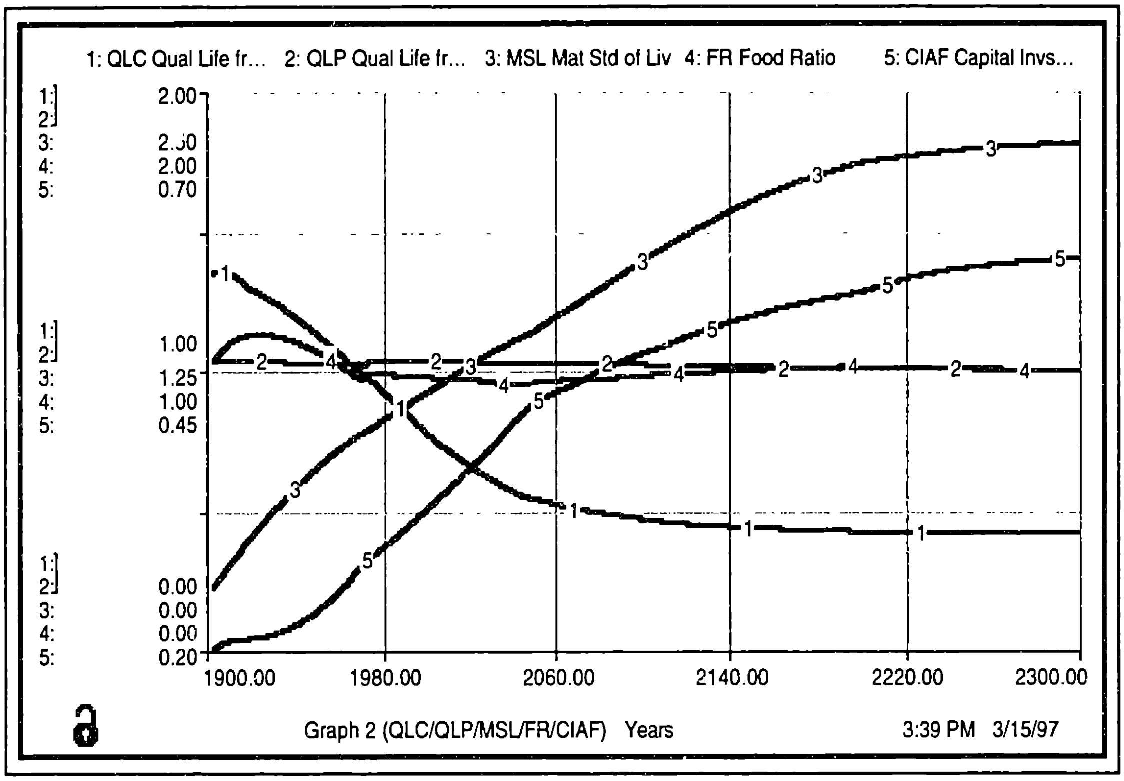
Figure 4-10:



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4: 1.00
5: 0.45
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5: 0.20
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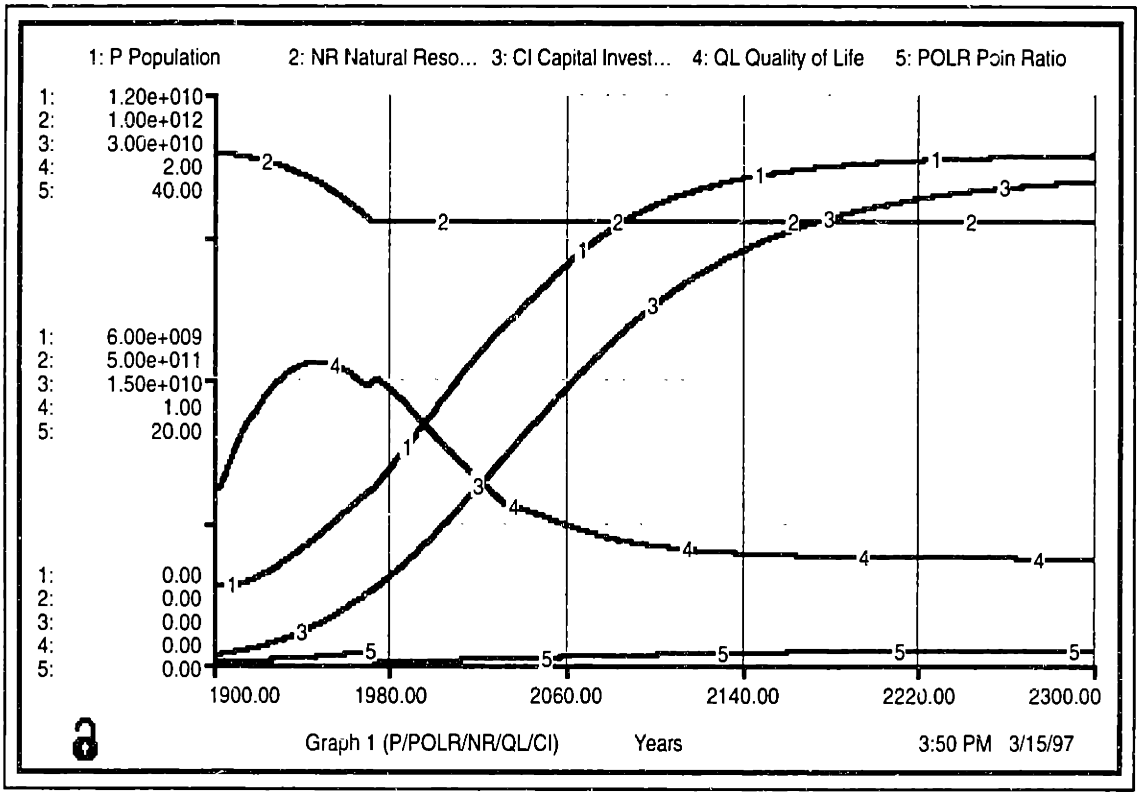
Figure 4-11: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2: NR Natural Reso...
3: CI Capital Invest...
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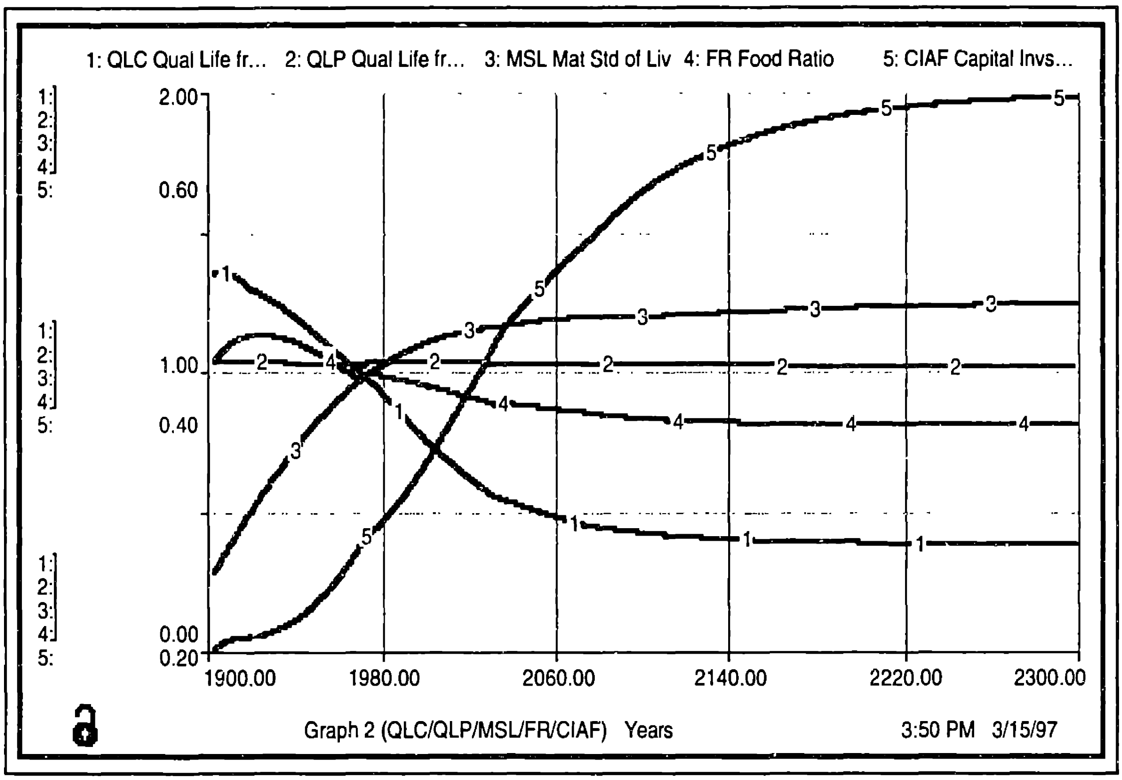
Figure 4-12: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Graph 2 (QLC/QLP/MSL/FR/CIAF) Years
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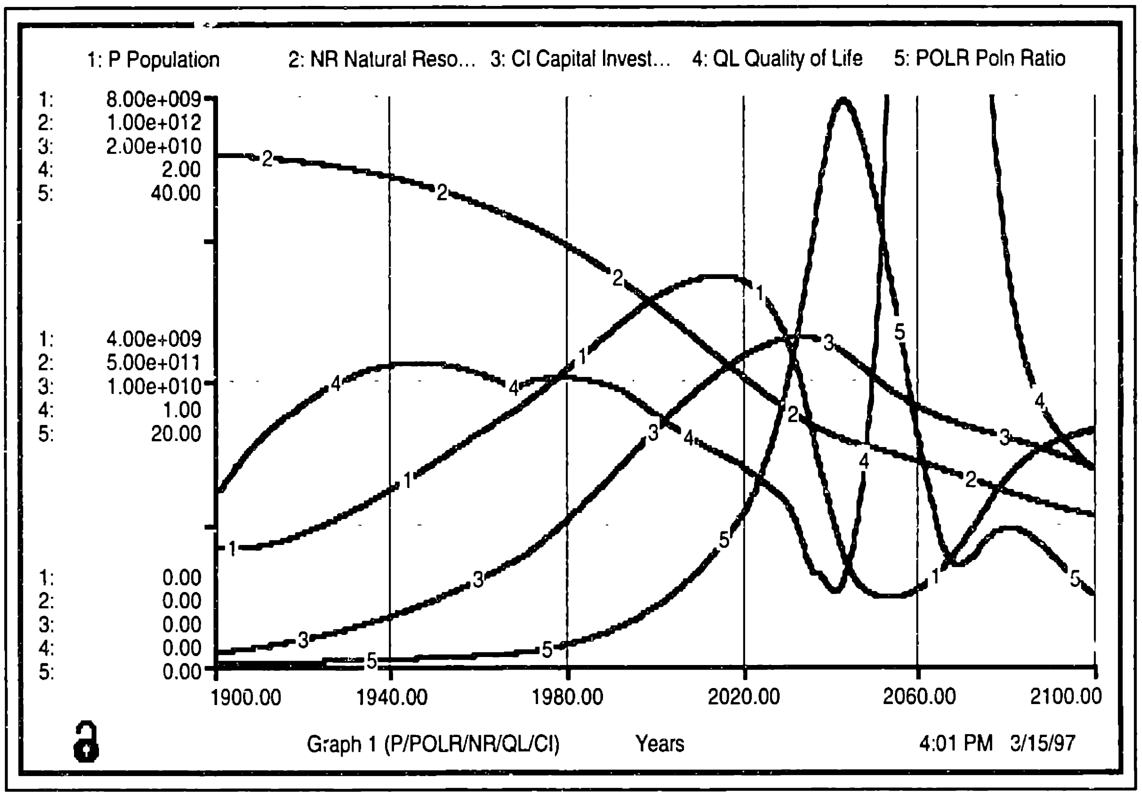
Figure 5-1:



1: P Population
2: NR Natural Reso...
3: CI Capital Invest...
4: QL Quality of Life
5: POLR Poln Ratio
1: 8.00e+009
2: 1.00e+012
3: 2.00e+010
4: 2.00
5: 40.00
1: 4.00e+009
2: 5.00e+011
3: 1.00e+010
4: 1.00
5: 20.00
1: 0.00
2: 0.00
3: 0.00
4: 0.00
5: 0.00
1900.00
1940.00
1980.00
2020.00
2060.00
2100.00
Graph 1 (P/POLR/NR/QL/CI)
Years
4:01 PM 3/15/97

Figure 5-2:

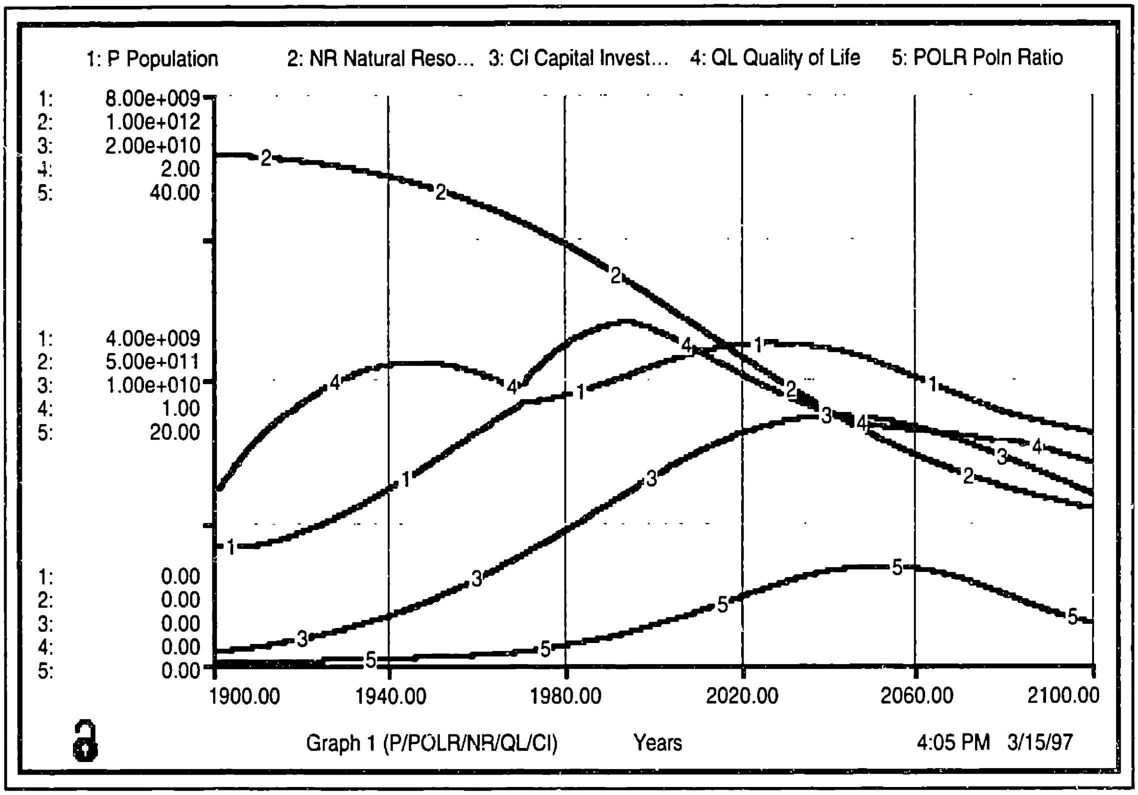
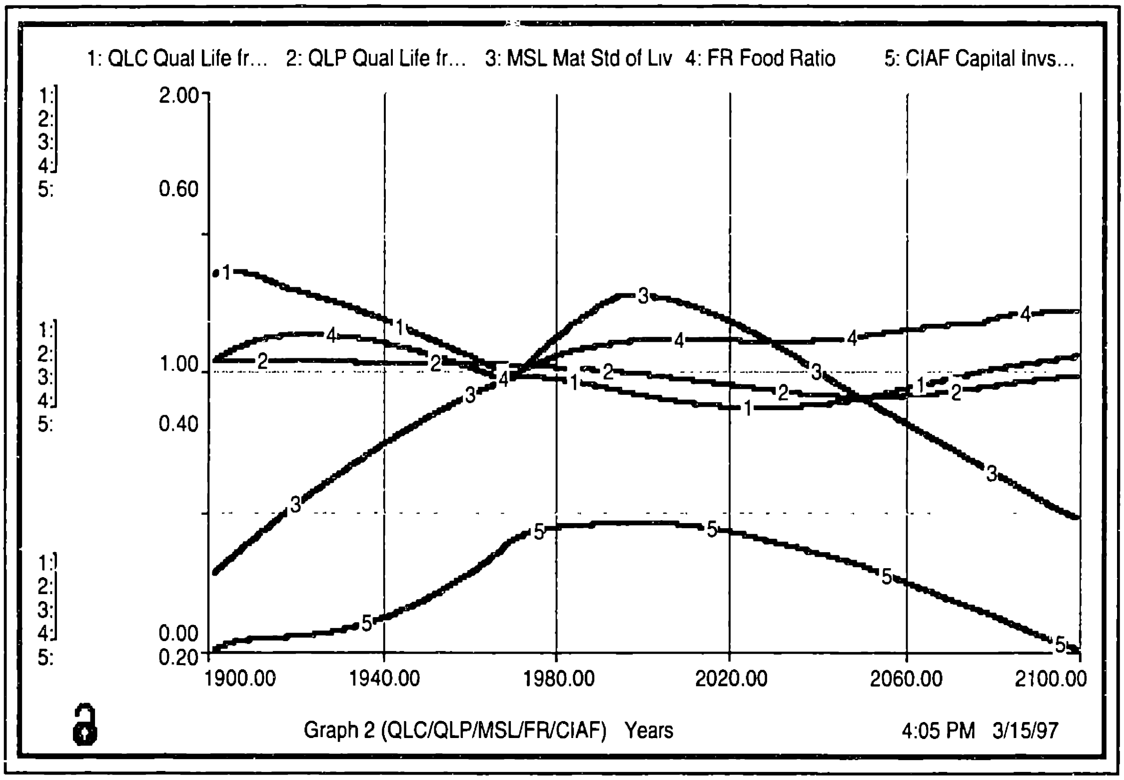

1: P Population
2: NR Natural Reso...
3: CI Capital Invest...
4: QL Quality of Life
5: POLR Poln Ratio
1: 8.00e+009
2: 1.00e+012
3: 2.00e+010
4: 2.00
5: 40.00
1: 4.00e+009
2: 5.00e+011
3: 1.00e+010
4: 1.00
5: 20.00
1: 0.00
2: 0.00
3: 0.00
4: 0.00
5: 0.00
1900.00
1940.00
1980.00
2020.00
2060.00
2100.00
Graph 1 (P/POLR/NR/QL/CI)
Years
4:05 PM 3/15/97

Figure 5-3:



1: QLC Qual Life fr... 2: QLP Qual Life fr... 3: MSL Mat Std of Liv 4: FR Food Ratio 5: CIAF Capital Invs...
1:
2:
3:
4:
5:
2.00
0.60
1.00
0.40
0.00
0.20
1900.00
1940.00
1980.00
2020.00
2060.00
2100.00
Graph 2 (QLC/QLP/MSL/FR/CIAF) Years
4:05 PM 3/15/97

Figure 5-4:

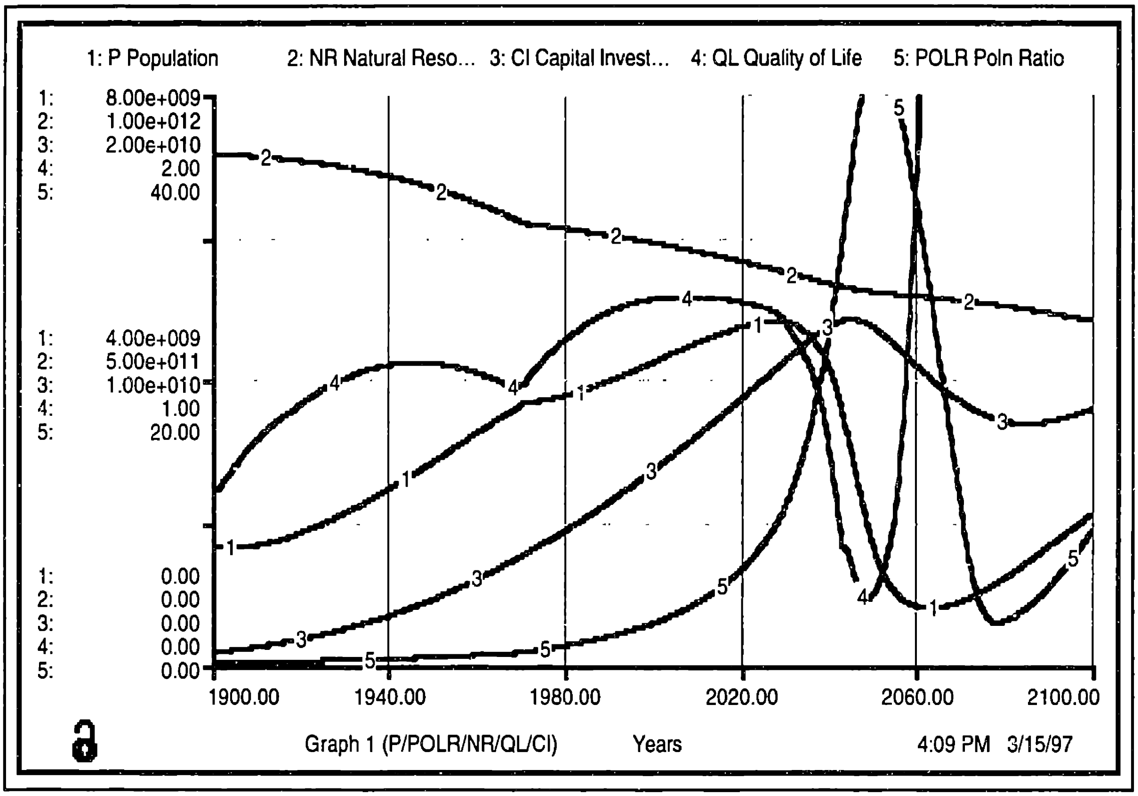

1: P Population
2: NR Natural Reso...
3: CI Capital Invest...
4: QL Quality of Life
5: POLR Poln Ratio
1: 8.00e+009
2: 1.00e+012
3: 2.00e+010
4: 2.00
5: 40.00
1: 4.00e+009
2: 5.00e+011
3: 1.00e+010
4: 1.00
5: 20.00
1: 0.00
2: 0.00
3: 0.00
4: 0.00
5: 0.00
1900.00
1940.00
1980.00
2020.00
2060.00
2100.00
Graph 1 (P/POLR/NR/QL/CI)
Years
4:09 PM 3/15/97

Figure 5-5:

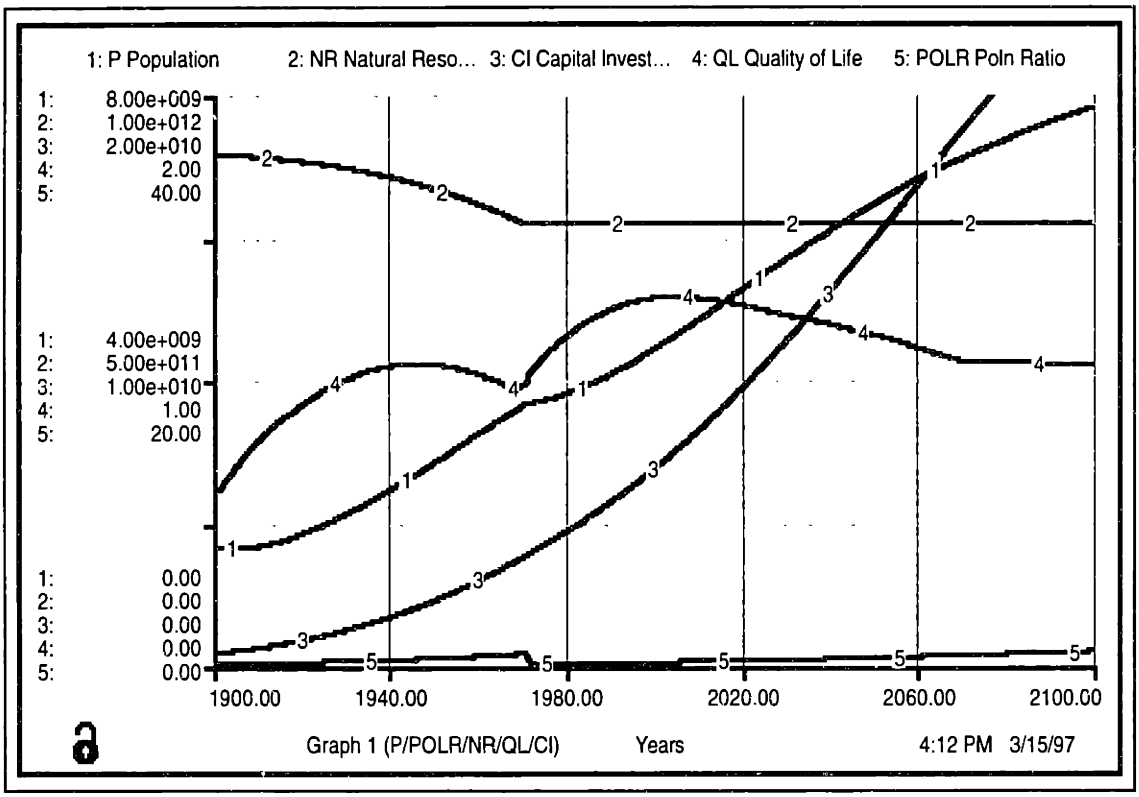
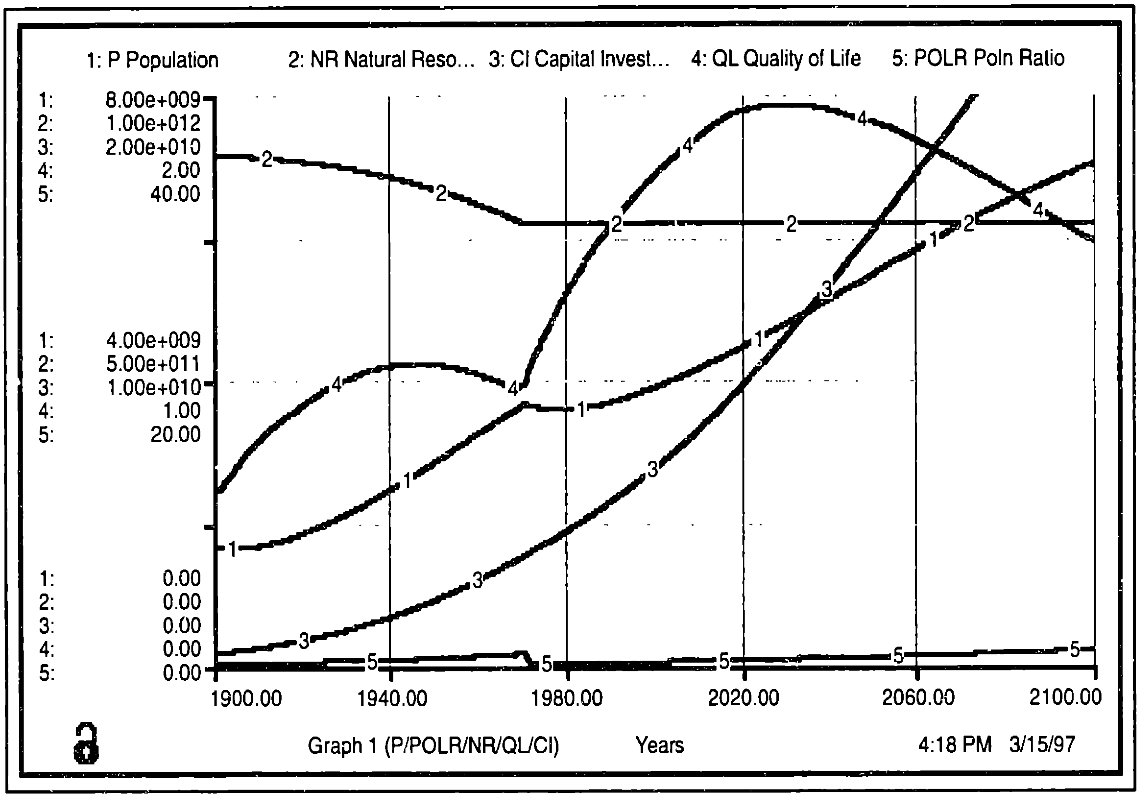
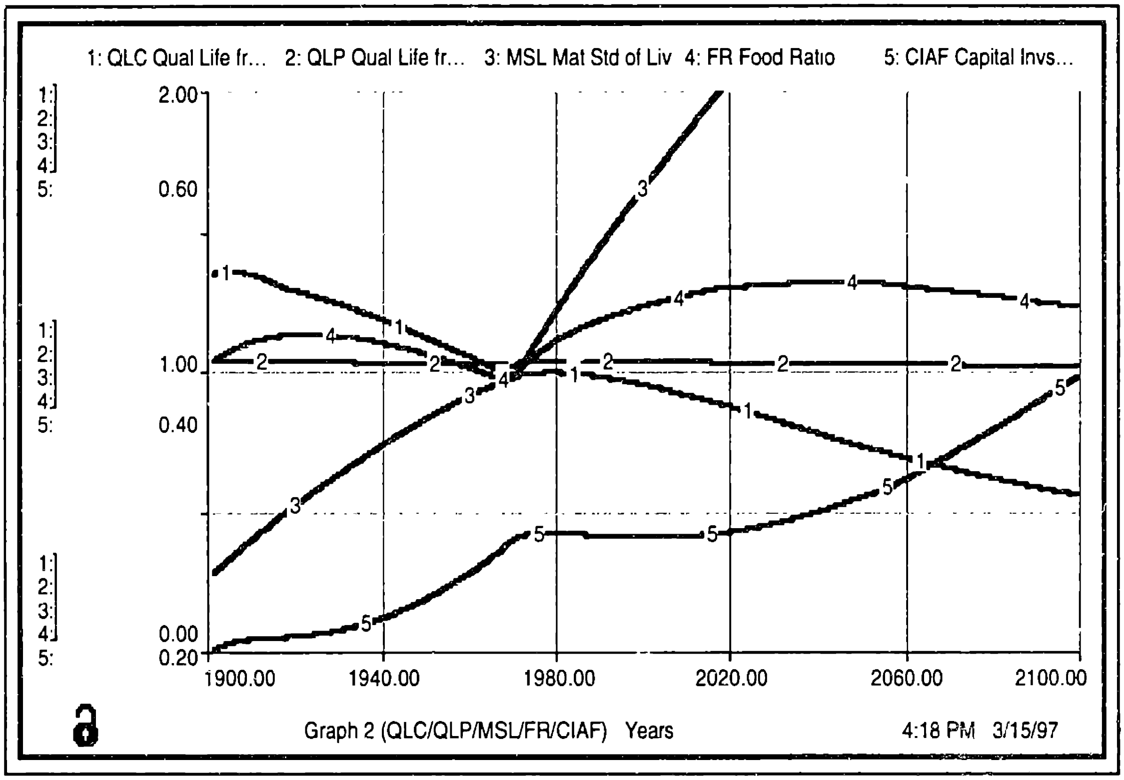

1: P Population
2: NR Natural Reso...
3: CI Capital Invest...
4: QL Quality of Life
5: POLR Poln Ratio
1: 8.00e+009
2: 1.00e+012
3: 2.00e+010
4: 2.00
5: 40.00
1: 4.00e+009
2: 5.00e+011
3: 1.00e+010
4: 1.00
5: 20.00
1: 0.00
2: 0.00
3: 0.00
4: 0.00
5: 0.00
1900.00
1940.00
1980.00
2020.00
2060.00
2100.00
Graph 1 (P/POLR/NR/QL/CI)
Years
4:12 PM 3/15/97

Figure 5-6:



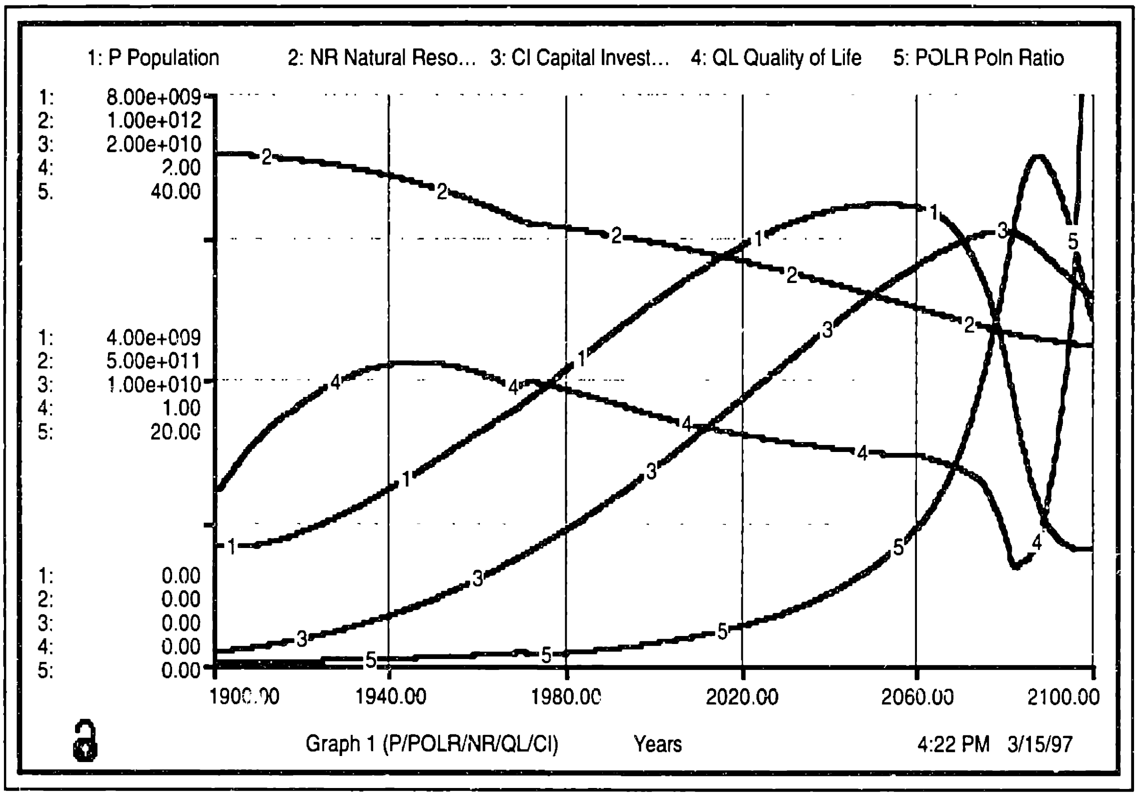
1: P Population
2: NR Natural Reso...
3: CI Capital Invest...
4: QL Quality of Life
5: POLR Poln Ratio
1: 8.00e+009
2: 1.00e+012
3: 2.00e+010
4: 2.00
5: 40.00
1: 4.00e+009
2: 5.00e+011
3: 1.00e+010
4: 1.00
5: 20.00
1: 0.00
2: 0.00
3: 0.00
4: 0.00
5: 0.00
1900.00
1940.00
1980.00
2020.00
2060.00
2100.00
Graph 1 (P/POLR/NR/QL/CI)
Years
4:18 PM 3/15/97

Figure 5-7:



1: QLC Qual Life fr... 2: QLP Qual Life fr... 3: MSL Mat Std of Liv 4: FR Food Ratio 5: CIAF Capital Invs...
2.00
0.60
1.00
0.40
0.00
0.20
1900.00
1940.00
1980.00
2020.00
2060.00
2100.00
Graph 2 (QLC/QLP/MSL/FR/CIAF) Years
4:18 PM 3/15/97

Figure 5-8:



1: P Population
2: NR Natural Reso...
3: CI Capital Invest...
4: QL Quality of Life
5: POLR Poln Ratio
1: 8.00e+009
2: 1.00e+012
3: 2.00e+010
4: 2.00
5: 40.00
1: 4.00e+009
2: 5.00e+011
3: 1.00e+010
4: 1.00
5: 20.00
1: 0.00
2: 0.00
3: 0.00
4: 0.00
5: 0.00
1900.00
1940.00
1980.00
2020.00
2060.00
2100.00
Graph 1 (P/POLR/NR/QL/CI)
Years
4:22 PM 3/15/97

Figure 5-9:

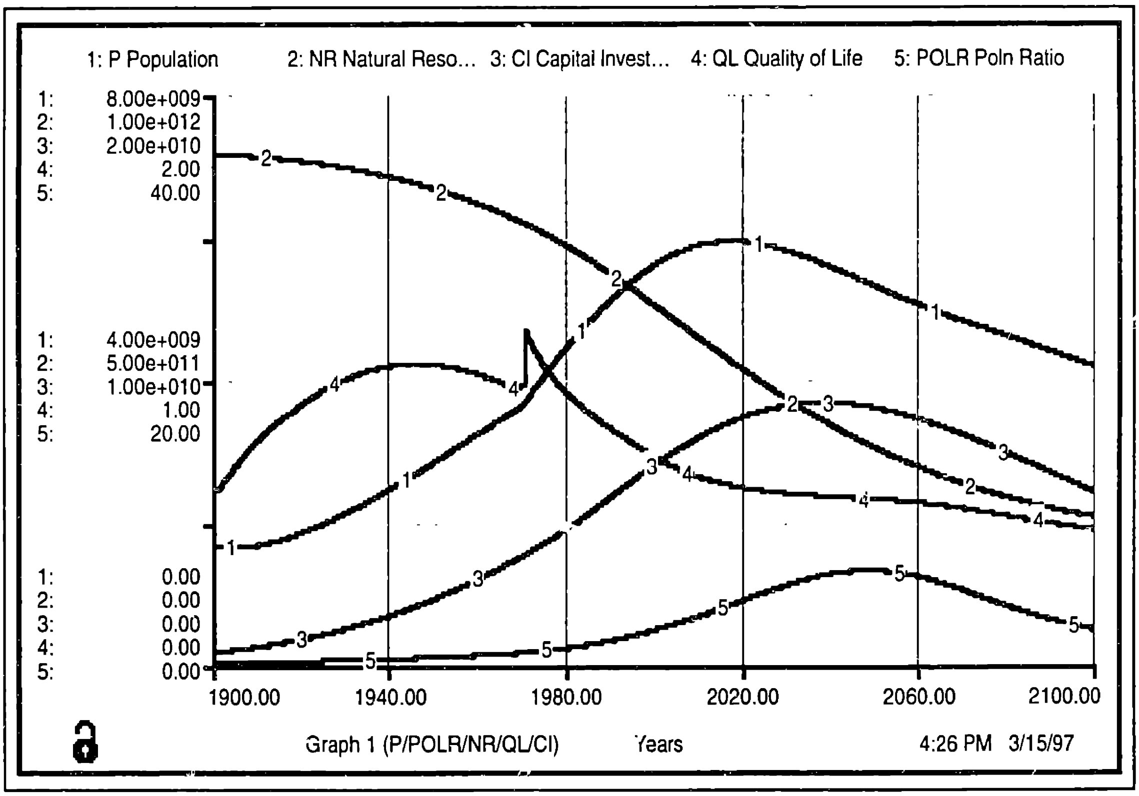
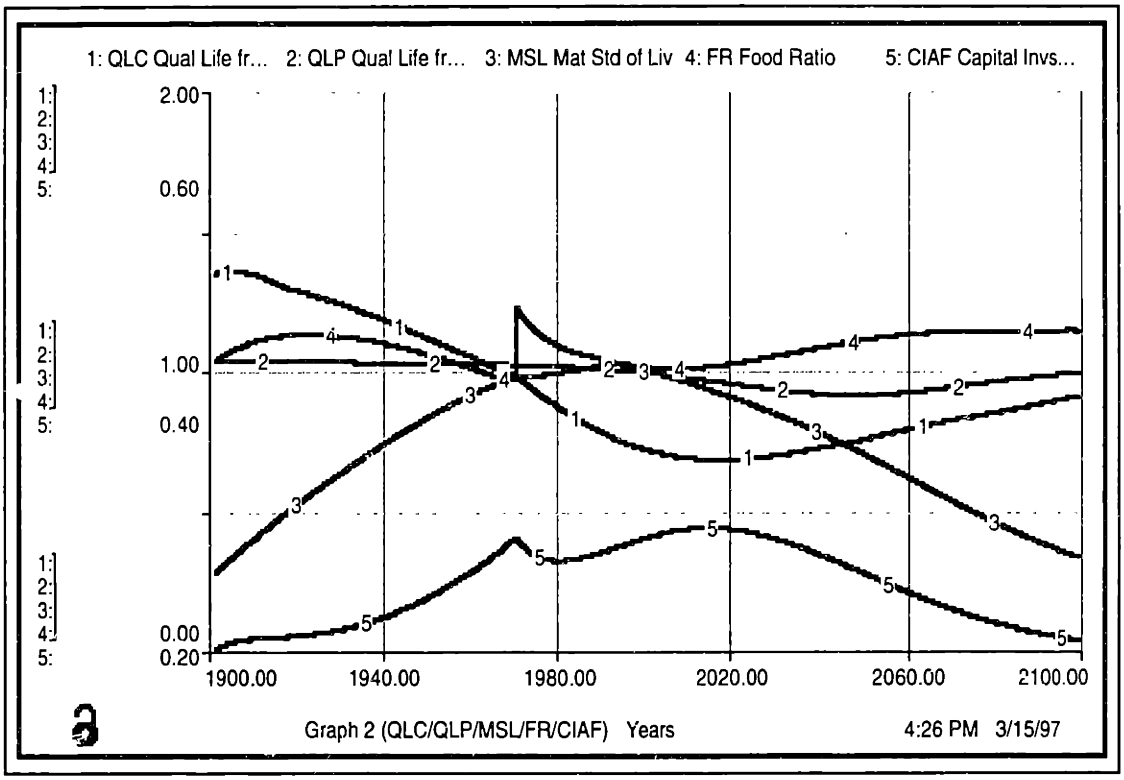
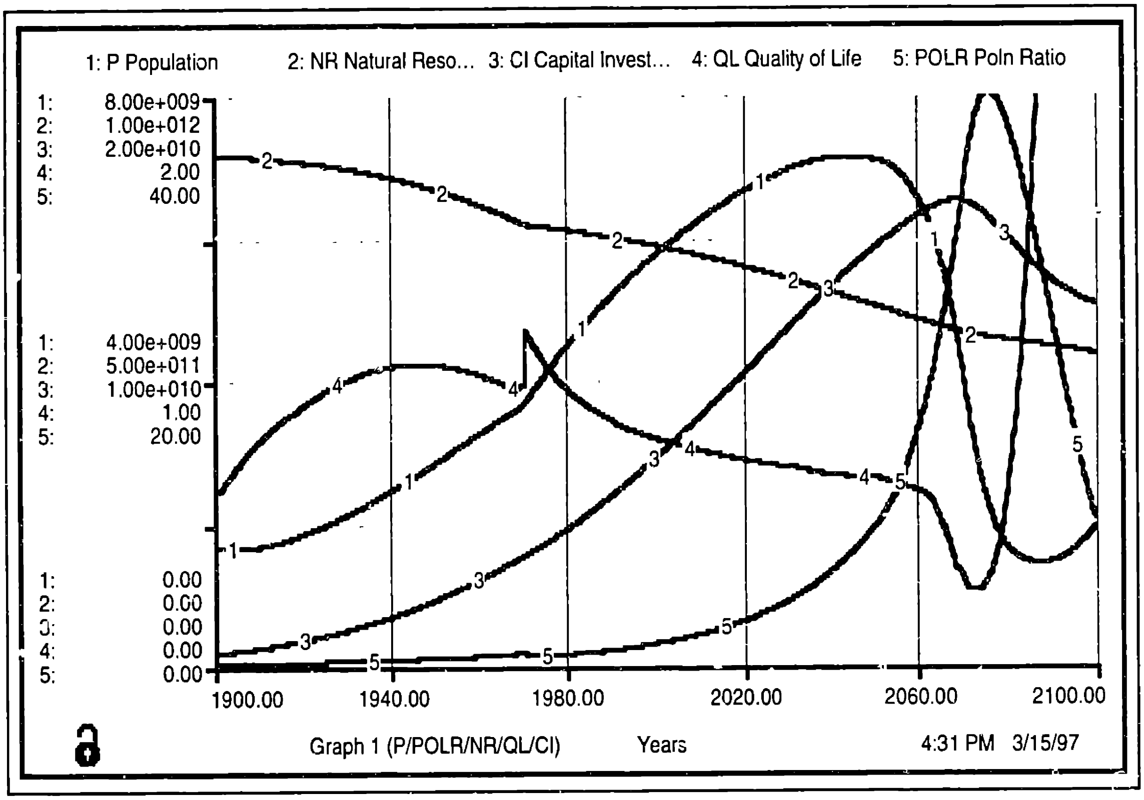

1: P Population
2: NR Natural Reso...
3: CI Capital Invest...
4: QL Quality of Life
5: POLR Poln Ratio
1: 8.00e+009
2: 1.00e+012
3: 2.00e+010
4: 2.00
5: 40.00
1: 4.00e+009
2: 5.00e+011
3: 1.00e+010
4: 1.00
5: 20.00
1: 0.00
2: 0.00
3: 0.00
4: 0.00
5: 0.00
1900.00
1940.00
1980.00
2020.00
2060.00
2100.00
Graph 1 (P/POLR/NR/QL/CI)
Years
4:26 PM 3/15/97

Figure 5-10:



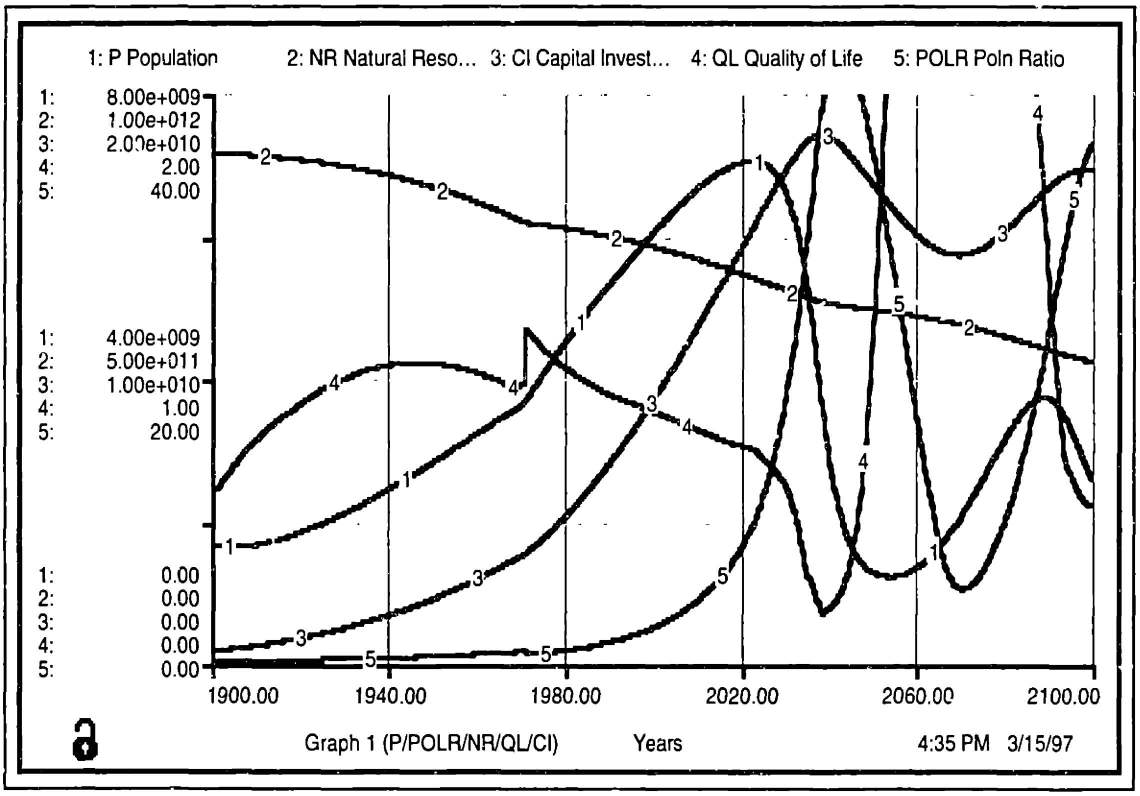
1: QLC Qual Life fr... 2: QLP Qual Life fr... 3: MSL Mat Std of Liv 4: FR Food Ratio 5: CIAF Capital Invs...
1: 2: 3: 4: 2.00
5: 0.60
1: 2: 3: 4: 1.00
5: 0.40
1: 2: 3: 4: 0.00
5: 0.20
1900.00 1940.00 1980.00 2020.00 2060.00 2100.00
Graph 2 (QLC/QLP/MSL/FR/CIAF) Years
4:26 PM 3/15/97

Figure 5-11:



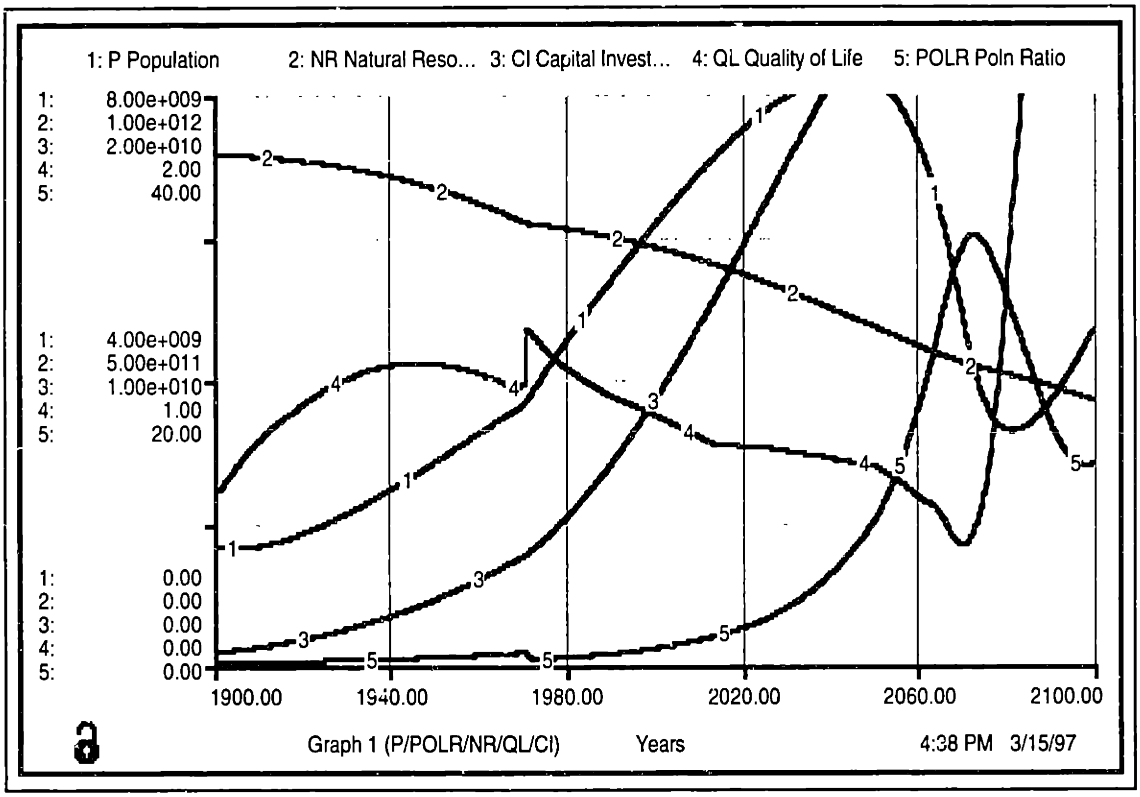
1: P Population
2: NR Natural Reso...
3: CI Capital Invest...
4: QL Quality of Life
5: POLR Poln Ratio
1: 8.00e+009
2: 1.00e+012
3: 2.00e+010
4: 2.00
5: 40.00
1: 4.00e+009
2: 5.00e+011
3: 1.00e+010
4: 1.00
5: 20.00
1: 0.00
2: 0.00
3: 0.00
4: 0.00
5: 0.00
1900.00
1940.00
1980.00
2020.00
2060.00
2100.00
Graph 1 (P/POLR/NR/QL/CI)
Years
4:31 PM 3/15/97

Figure 5-12:



1: P Population
2: NR Natural Reso...
3: CI Capital Invest...
4: QL Quality of Life
5: POLR Poln Ratio
1: 8.00e+009
2: 1.00e+012
3: 2.00e+010
4: 2.00
5: 40.00
1: 4.00e+009
2: 5.00e+011
3: 1.00e+010
4: 1.00
5: 20.00
1: 0.00
2: 0.00
3: 0.00
4: 0.00
5: 0.00
1900.00
1940.00
1980.00
2020.00
2060.00
2100.00
Graph 1 (P/POLR/NR/QL/CI)
Years
4:35 PM 3/15/97

Figure 5-13:



1: P Population
2: NR Natural Reso...
3: CI Capital Invest...
4: QL Quality of Life
5: POLR Poln Ratio
1: 8.00e+009
2: 1.00e+012
3: 2.00e+010
4: 2.00
5: 40.00
1: 4.00e+009
2: 5.00e+011
3: 1.00e+010
4: 1.00
5: 20.00
1: 0.00
2: 0.00
3: 0.00
4: 0.00
5: 0.00
1900.00
1940.00
1980.00
2020.00
2060.00
2100.00
Graph 1 (P/POLR/NR/QL/CI)
Years
4:38 PM 3/15/97

Figure 5-14:

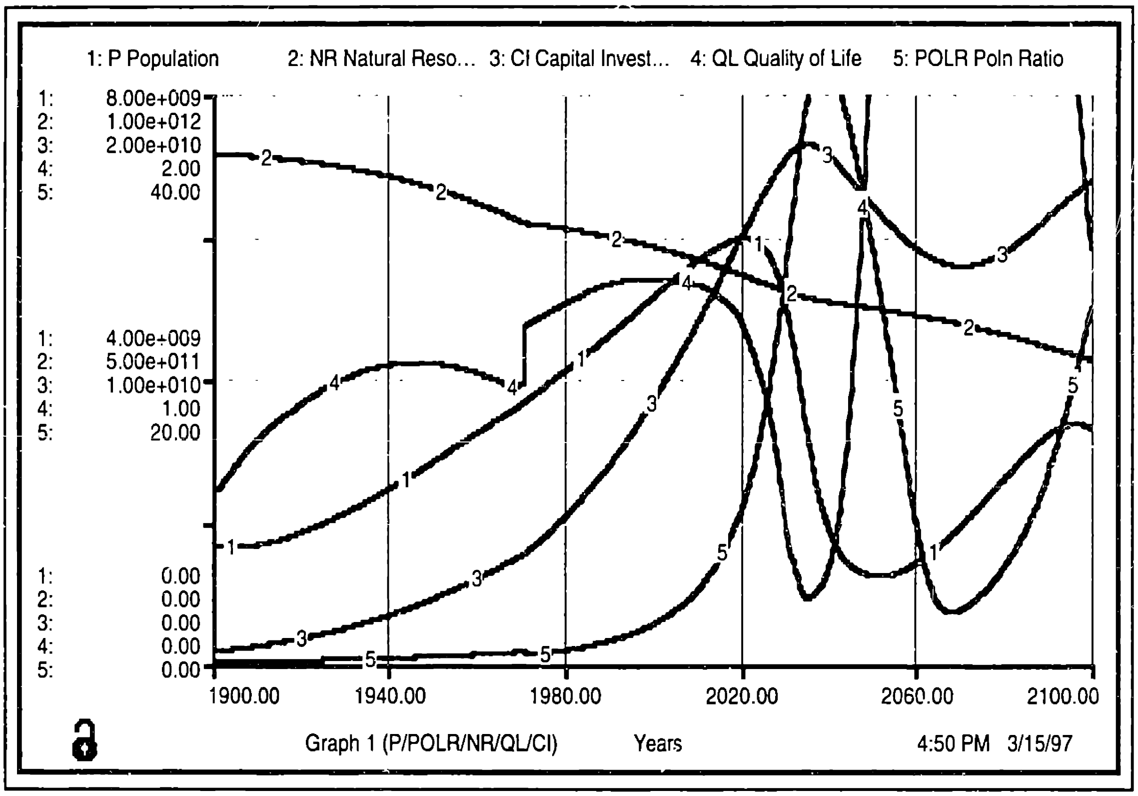
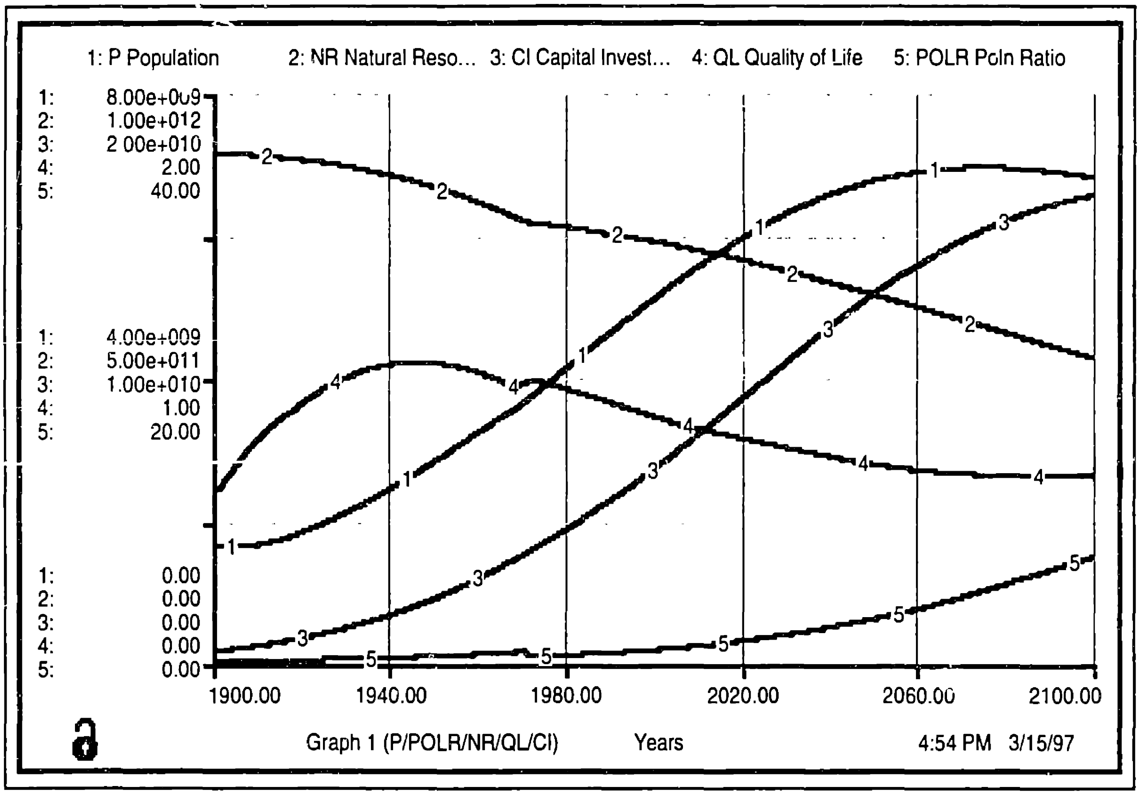

1: P Population
2: NR Natural Reso...
3: CI Capital Invest...
4: QL Quality of Life
5: POLR Poln Ratio
1: 8.00e+009
2: 1.00e+012
3: 2.00e+010
4: 2.00
5: 40.00
1: 4.00e+009
2: 5.00e+011
3: 1.00e+010
4: 1.00
5: 20.00
1: 0.00
2: 0.00
3: 0.00
4: 0.00
5: 0.00
1900.00
1940.00
1980.00
2020.00
2060.00
2100.00
Graph 1 (P/POLR/NR/QL/CI)
Years
4:50 PM 3/15/97

Figure 6-1:



1: P Population
2: NR Natural Reso...
3: CI Capital Invest...
4: QL Quality of Life
5: POLR Poln Ratio
1: 8.00e+009
2: 1.00e+012
3: 2.00e+010
4: 2.00
5: 40.00
1: 4.00e+009
2: 5.00e+011
3: 1.00e+010
4: 1.00
5: 20.00
1: 0.00
2: 0.00
3: 0.00
4: 0.00
5: 0.00
1900.00
1940.00
1980.00
2020.00
2060.00
2100.00
Graph 1 (P/POLR/NR/QL/CI)
Years
4:54 PM 3/15/97

Figure 6-2:

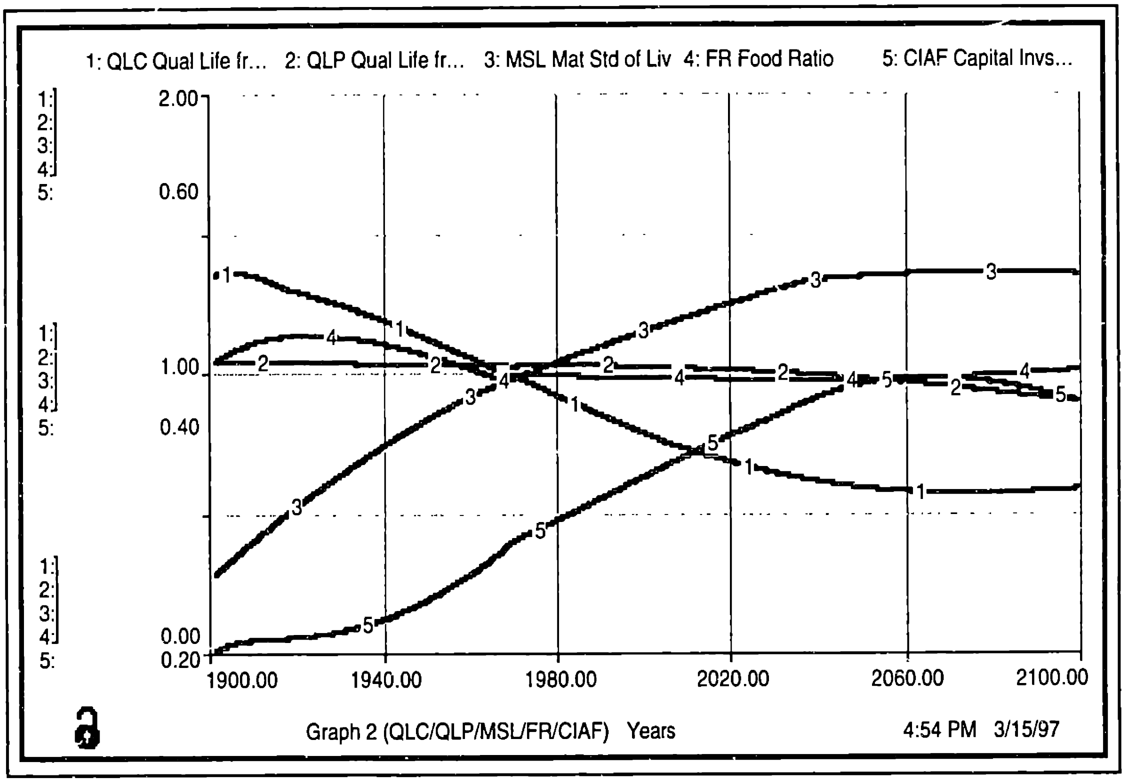
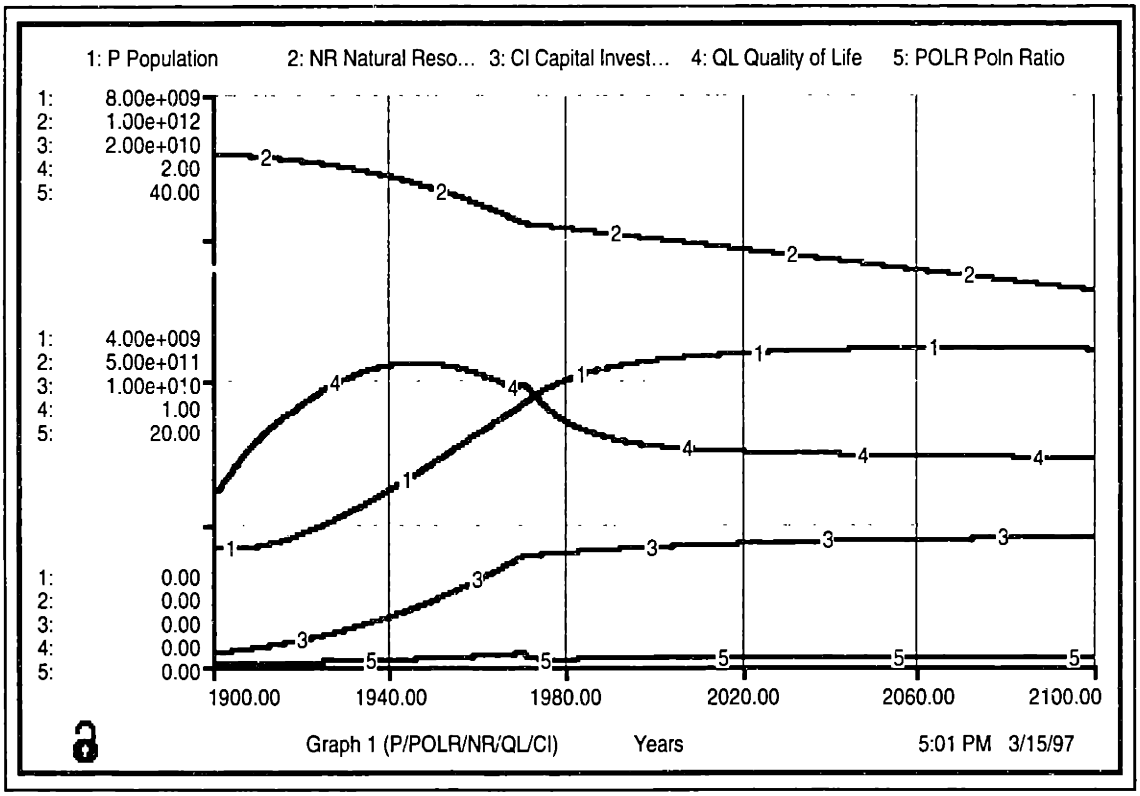

1: QLC Qual Life fr...
2: QLP Qual Life fr...
3: MSL Mat Std of Liv
4: FR Food Ratio
5: CIAF Capital Invs...
2.00
0.60
1.00
0.40
0.00
0.20
1900.00
1940.00
1980.00
2020.00
2060.00
2100.00
Graph 2 (QLC/QLP/MSL/FR/CIAF) Years
4:54 PM 3/15/97

Figure 6-3:



1: P Population
2: NR Natural Reso...
3: CI Capital Invest...
4: QL Quality of Life
5: POLR Poln Ratio
1: 8.00e+009
2: 1.00e+012
3: 2.00e+010
4: 2.00
5: 40.00
1: 4.00e+009
2: 5.00e+011
3: 1.00e+010
4: 1.00
5: 20.00
1: 0.00
2: 0.00
3: 0.00
4: 0.00
5: 0.00
1900.00
1940.00
1980.00
2020.00
2060.00
2100.00
Graph 1 (P/POLR/NR/QL/CI)
Years
5:01 PM 3/15/97

Figure 6-4:

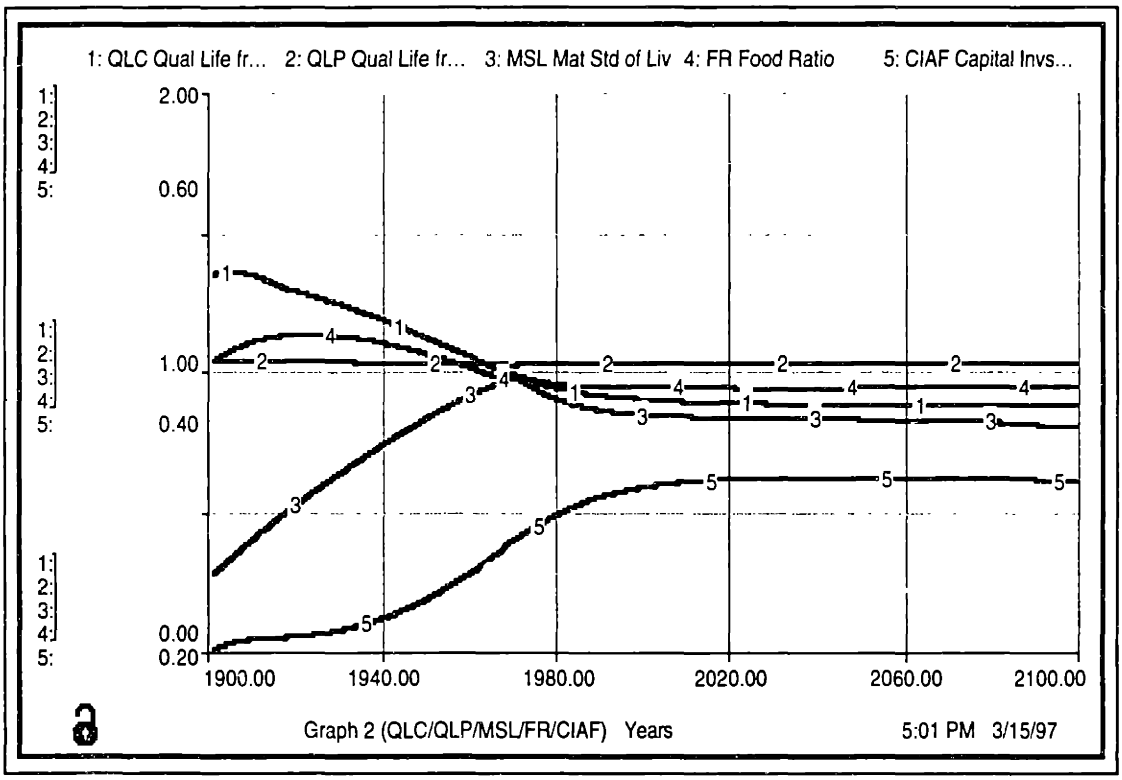
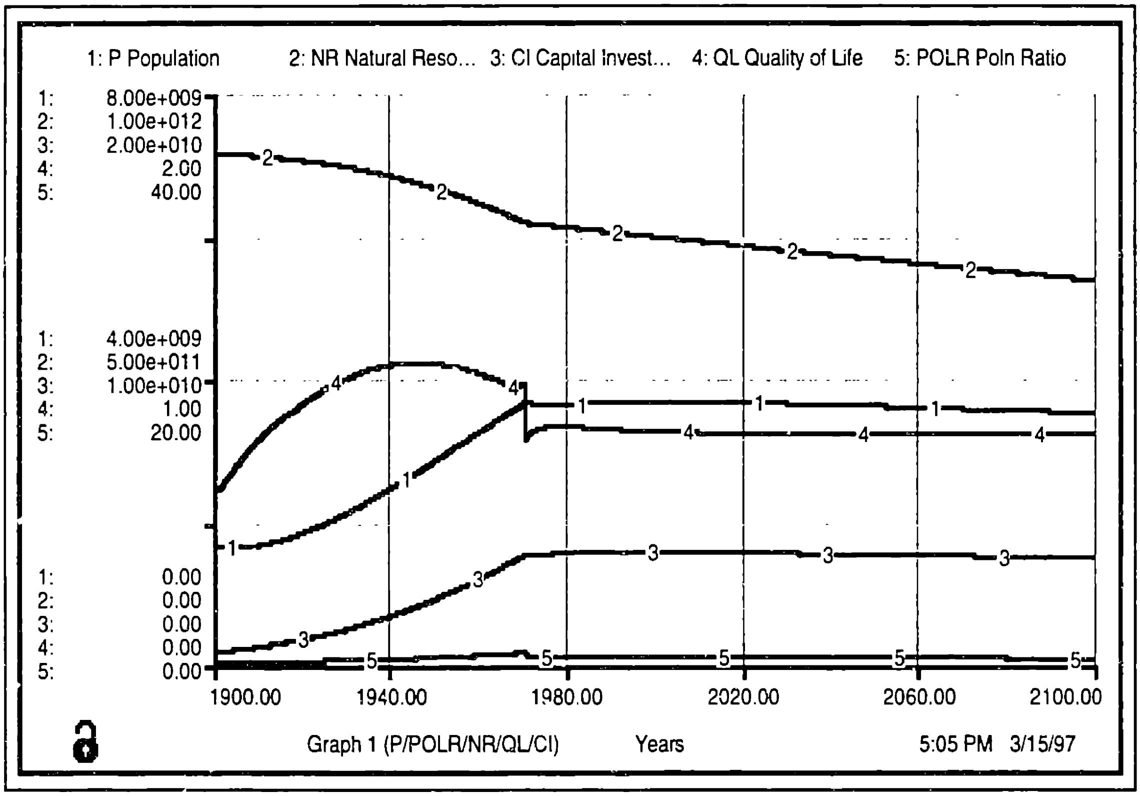
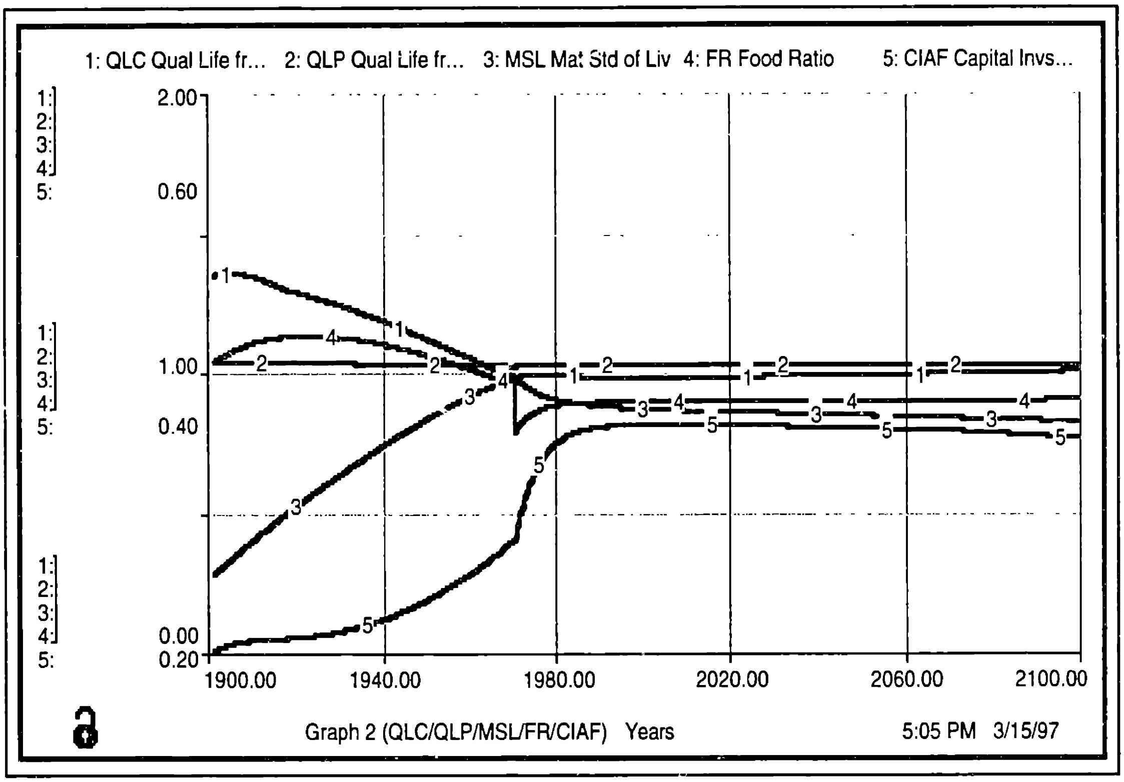

1: QLC Qual Life fr... 2: QLP Qual Life fr... 3: MSL Mat Std of Liv 4: FR Food Ratio 5: CIAF Capital Invs...
2.00
0.60
1.00
0.40
0.00
0.20
1900.00
1940.00
1980.00
2020.00
2060.00
2100.00
Graph 2 (QLC/QLP/MSL/FR/CIAF) Years
5:01 PM 3/15/97

Figure 6-5:



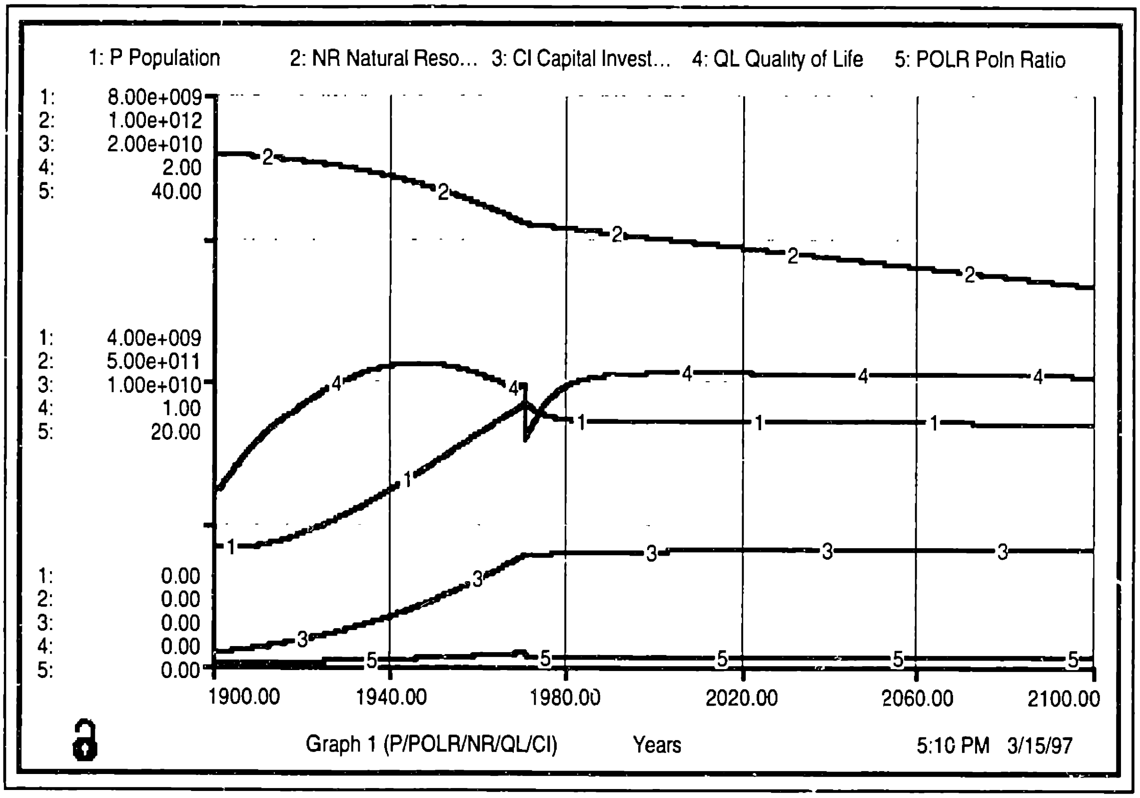
1: P Population
2: NR Natural Reso...
3: CI Capital Invest...
4: QL Quality of Life
5: POLR Poln Ratio
1: 8.00e+009
2: 1.00e+012
3: 2.00e+010
4: 2.00
5: 40.00
1: 4.00e+009
2: 5.00e+011
3: 1.00e+010
4: 1.00
5: 20.00
1: 0.00
2: 0.00
3: 0.00
4: 0.00
5: 0.00
1900.00
1940.00
1980.00
2020.00
2060.00
2100.00
Graph 1 (P/POLR/NR/QL/CI)
Years
5:05 PM 3/15/97

Figure 6-6:



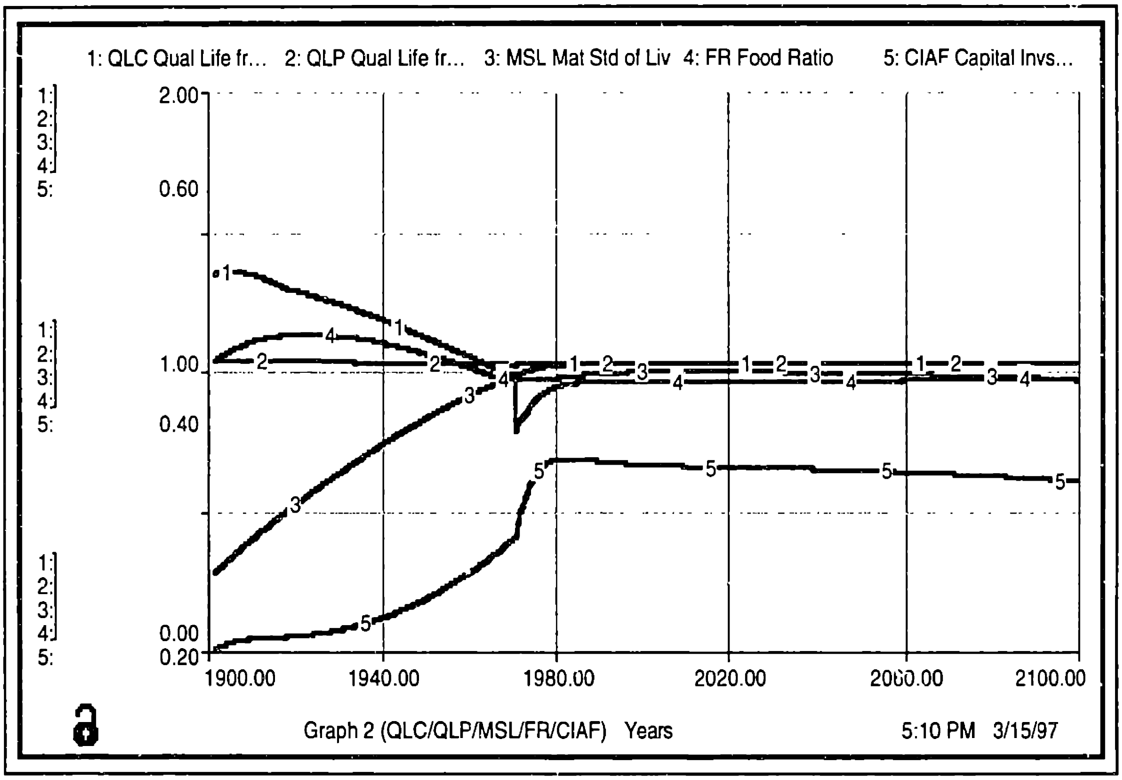
1: QLC Qual Life fr... 2: QLP Qual Life fr... 3: MSL Mat Std of Liv 4: FR Food Ratio 5: CIAF Capital Invs...
2.00
0.60
1.00
0.40
0.00
0.20
1900.00
1940.00
1980.00
2020.00
2060.00
2100.00
Graph 2 (QLC/QLP/MSL/FR/CIAF) Years
5:05 PM 3/15/97

Figure 6-7:



1: P Population
2: NR Natural Reso...
3: CI Capital Invest...
4: QL Quality of Life
5: POLR Poln Ratio
1: 8.00e+009
2: 1.00e+012
3: 2.00e+010
4: 2.00
5: 40.00
1: 4.00e+009
2: 5.00e+011
3: 1.00e+010
4: 1.00
5: 20.00
1: 0.00
2: 0.00
3: 0.00
4: 0.00
5: 0.00
1900.00
1940.00
1980.00
2020.00
2060.00
2100.00
Graph 1 (P/POLR/NR/QL/CI)
Years
5:10 PM 3/15/97

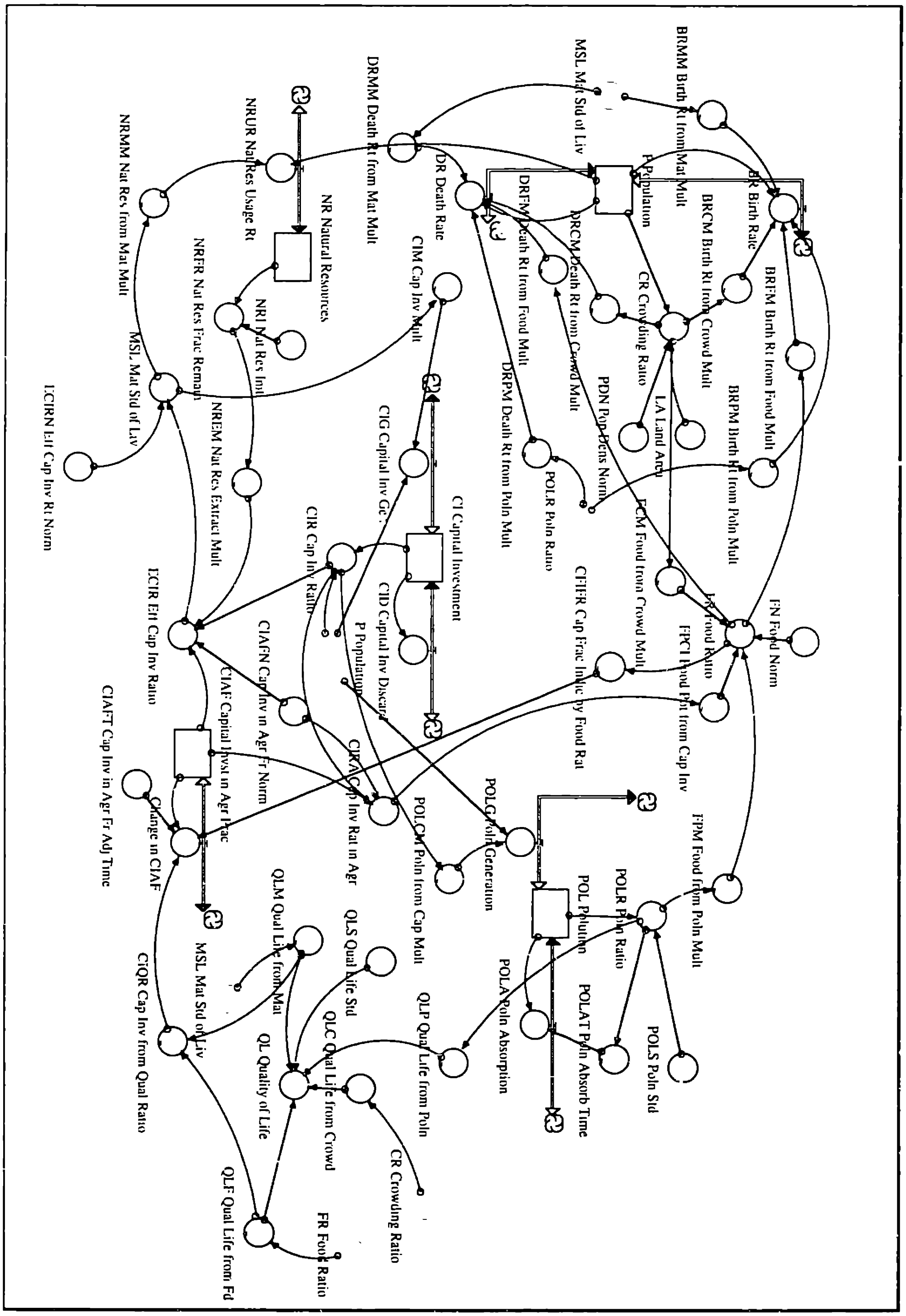
Figure 6-8:



1: QLC Qual Life fr... 2: QLP Qual Life fr... 3: MSL Mat Std of Liv 4: FR Food Ratio 5: CIAF Capital Invs...
2.00
0.60
1.00
0.40
0.00
0.20
1900.00
1940.00
1980.00
2020.00
2060.00
2100.00
Graph 2 (QLC/QLP/MSL/FR/CIAF) Years
5:10 PM 3/15/97

Appendix B

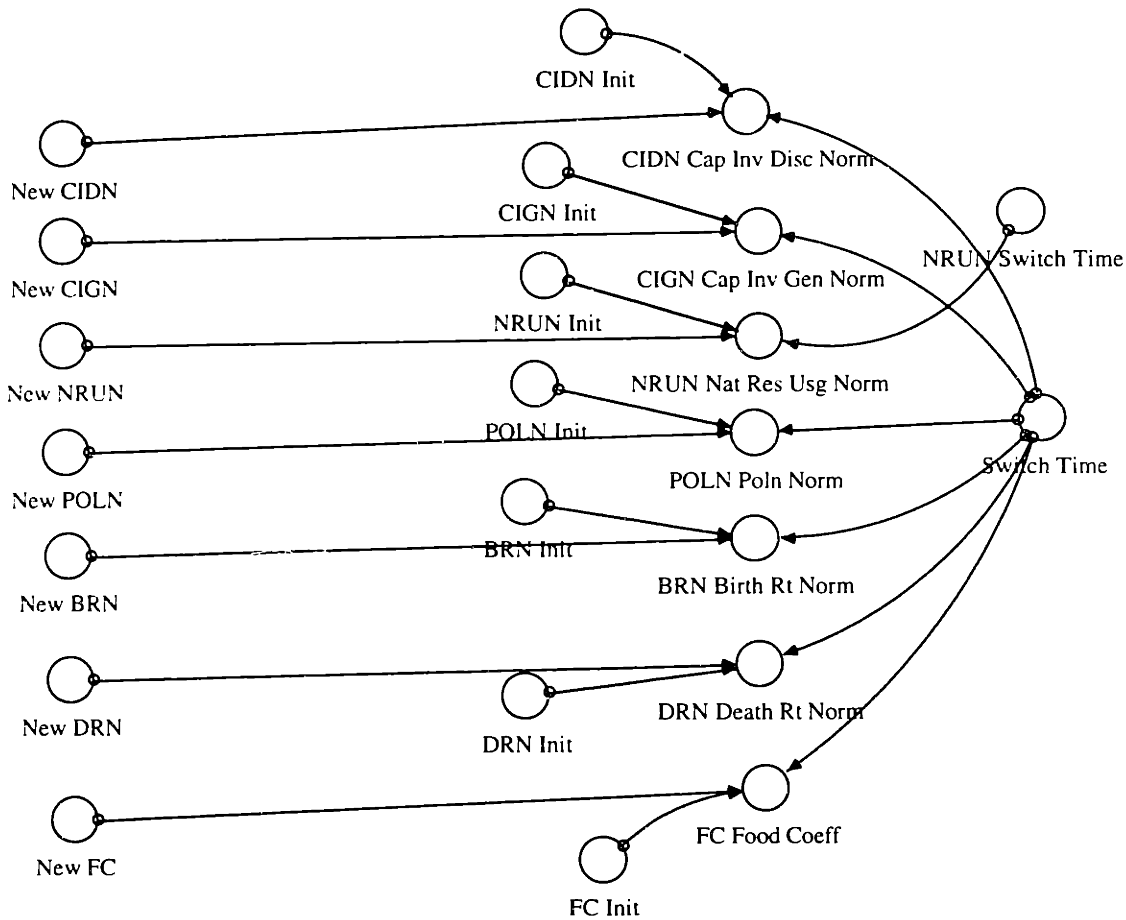
The World Model: STELLA™ v. 4.0 Implementation



Appendix C

Policy Controls in the World Model

STELLA^{TM} v. 4.0



Appendix D

The World Model: STELLA™ v. 4.0 Documentation

CIAF_Capital_Invst_in_Agr_Frac(t) = CIAF_Capital_Invst_in_Agr_Frac(t - dt) + (Change_in_CIAF) * dt

INIT CIAF_Capital_Invst_in_Agr_Frac = .2

DOCUMENT: 35

(Dimensionless)

CIAFI = .2

1st Order Smooth of CFIFR*CIQR

Change_in_CIAF = (CFIFR_Cap_Frac_Indic_by_Food_Rat * CIQR_Cap_Inv_from_Qual_Ratio - CIAF_Capital_Invst_in_Agr_Frac) / CIAFT_Cap_Inv_in_Agr_Fr_Adj_Time

DOCUMENT: (Dimensionless / Year)

1st order smoothing

CI_Capital_Investment(t) = CI_Capital_Investment(t - dt) + (CIG_Capital_Inv_Gen - CID_Capital_Inv_Discard) * dt

INIT CI_Capital_Investment = .4E9

DOCUMENT: 24

(Capital Units)

CII = .4E9

CIG_Capital_Inv_Gen = P_Population * CIM_Cap_Inv_Mult * CIGN_Cap_Inv_Gen_Norm

DOCUMENT: 25

(Capital Units / Year)

CID_Capital_Inv_Discard = CI_Capital_Investment * CIDN_Cap_Inv_Disc_Norm

DOCUMENT: 27

(Capital Units / Year)

NR_Natural_Resources(t) = NR_Natural_Resources(t - dt) + (-NRUR_Nat_Res_Usage_Rt) * dt

INIT NR_Natural_Resources = NRI_Nat_Res_Init

DOCUMENT: 8

(Natural Resource Units)

NRUR_Nat_Res_Usage_Rt = P_Population * NRUN_Nat_Res_Usg_Norm * NRMM_Nat_Res_from_Mat_Mult

DOCUMENT: 9

(Natural Resource Units / Year)

POL_Polution(t) = POL_Polution(t - dt) + (POLG_Poln_Generation - POLA_Poln_Absorption) * dt

INIT POL_Polution = .2E9

DOCUMENT: 30

(Pollution Units)

POLI = .2E9

POLG_Poln_Generation = P_Population * POLN_Poln_Norm * POLCM_Poln_from_Cap_Mult

DOCUMENT: 31

(Pollution Units / Year)

POLA_Poln_Absorption = POL_Polution / POLAT_Poln_Absorb_Time

DOCUMENT: 33

(Pollution Units / Year)

P_Population(t) = P_Population(t - dt) + (BR_Birth_Rate - DR_Death_Rate) * dt

INIT P_Population = 1.65E9

DOCUMENT: 1

(People)

PI=1.65E9

BR_Birth_Rate = P_Population * BRN_Birth_Rt_Norm * BRCM_Birth_Rt_from_Crowd_Mult * BRFM_Birth_Rt_from_Food_Mult * BRMM_Birth_Rt_from_Mat_Mult * BRPM_Birth_Rt_from_Poln_Mult

DOCUMENT: 2

(People/Year)

DR_Death_Rate = P_Population * DRN_Death_Rt_Norm * DRMM_Death_Rt_from_Mat_Mult * DRFM_Death_Rt_from_Food_Mult * DRCM_Death_Rt_from_Crowd_Mult * DRPM_Death_Rt_from_Poln_Mult

DOCUMENT: 10

(People / Year)

BRN_Birth_Rt_Norm = IF (TIME <= Switch_Time) THEN BRN_Init ELSE New_BRN

DOCUMENT: (Fraction / Year)

BRN_Init = .04

DOCUMENT: (Fraction / Year)

CIAFN_Cap_Inv_in_Agr_Fr_Norm = .3

DOCUMENT: (Dimensionless)

CIAFT_Cap_Inv_in_Agr_Fr_Adj_Time = 15

DOCUMENT: (Years)

CIDN_Cap_Inv_Disc_Norm = IF (TIME <= Switch_Time) THEN CIDN_Init ELSE New_CIDN

CIDN_Init = .025

DOCUMENT: (Fraction / Year)

CIGN_Cap_Inv_Gen_Norm = IF (TIME <= Switch_Time) THEN CIGN_Init ELSE New_CIGN

DOCUMENT: (Capital Units / Person / Year)

CIGN_Init = .05

DOCUMENT: (Capital Units / Person / Year)

CIRA_Cap_Inv_Rat_in_Agr = CIR_Cap_Inv_Ratio * CIAF_Capital_Invst_in_Agr_Frac / CIAFN_Cap_Inv_in_Agr_Fr_Norm

DOCUMENT: 22

(Capital Units / Person)

CIR_Cap_Inv_Ratio = CI_Capital_Investment / P_Population

DOCUMENT: 23

(Capital Units / Person)

CR_Crowding_Ratio = P_Population / (PDN_Pop_Dens_Norm * LA_Land_Area)

DOCUMENT: 15

(Dimensionless)

DRN_Death_Rt_Norm = IF (TIME <= Switch_Time) THEN DRN_Init ELSE New_DRN

DOCUMENT: (Fraction / Year)

DRN_Init = .028

DOCUMENT: (Fraction / Year)

ECIRN_Eff_Cap_Inv_Rt_Norm = 1

DOCUMENT: (Capital Units / Person)

ECIR_Eff_Cap_Inv_Ratio = CIR_Cap_Inv_Ratio * (1-CIAF_Capital_Invst_in_Agr_Frac) * NREM_Nat_Res_Extract_Mult / (1-CIAFN_Cap_Inv_in_Agr_Fr_Norm)

DOCUMENT: 5

(Capital Units / Person)

FC_Food_Coeff = IF (TIME <= Switch_Time) THEN FC_Init ELSE New_FC

FC_Init = 1

DOCUMENT: (Dimensionless)

FN_Food_Norm = 1

DOCUMENT: (Food Units / Person / Year)

FR_Food_Ratio = FPCI_Food_Pot_from_Cap_Inv * FCM_Food_from_Crowd_Mult * FPM_Food_from_Poln_Mult * FC_Food_Coeff / FN_Food_Norm

DOCUMENT: 19

(Dimensionless)

LA_Land_Area = 135E6

DOCUMENT: (Square Kilometers)

MSL_Mat_Std_of_Liv = ECIR_Eff_Cap_Inv_Ratio / ECIRN_Eff_Cap_Inv_Rt_Norm

DOCUMENT: 4

(Dimensionless)

New_BRN = .040

DOCUMENT: (Fraction / Year)

New_CIDN = .025

DOCUMENT: (Fraction / Year)

New_CIGN = .05

DOCUMENT: (Capital Units / Person / Year)

New_DRN = .028

DOCUMENT: (Fraction / Year)

New_FC = 1

DOCUMENT: (Dimensionless)

New_NRUN = 1

DOCUMENT: (Natural Resource Units / Person / Year)

New_POLN = 1

DOCUMENT: (Pollution Units / Person / Year)

NRFR_Nat_Res_Frac_Remain = NR_Natural_Resources / NRI_Nat_Res_Init

DOCUMENT: 7

(Dimensionless)

NRI_Nat_Res_Init = 900E9

DOCUMENT: (Natural Resource Units)

NRUN_Init = 1

DOCUMENT: (Natural Resource Units / Person / Year)

NRUN_Nat_Res_Usg_Norm = IF (TIME <= NRUN_Switch_Time) THEN NRUN_Init ELSE New_NRUN

DOCUMENT: (Natural Resource Units / Person / Year)

NRUN_Switch_Time = 2000

DOCUMENT: (Year)

Time when NRUN becomes New NRUN

PDN_Pop_Dens_Norm = 26.5

DOCUMENT: (People / Sq. Kilometer)

POLN_Init = 1

DOCUMENT: (Pollution Units / Person / Year)

POLN_Poln_Norm = IF (TIME <= Switch_Time) THEN POLN_Init ELSE New_POLN

DOCUMENT: (Pollution Units / Person / Year)

POLR_Poln_Ratio = POL_Polution / POLS_Poln_Std

DOCUMENT: 29

(Dimensionless)

POLS_Poln_Std = 3.6E9

DOCUMENT: (Pollution Units)

QLS_Qual_Life_Std = 1

DOCUMENT: (Satisfaction Units)

QL_Quality_of_Life = QLS_Qual_Life_Std * QLC_Qual_Life_from_Crowd * QLF_Qual_Life_from_Fd * QLM_Qual_Life_from_Mat * QLP_Qual_Life_from_Poln

DOCUMENT: 37

(Satisfaction Units)

Switch_Time = 2000

DOCUMENT: (Year)

Time that new policies come into effect

BRCM_Birth_Rt_from_Crowd_Mult = GRAPH(CR_Crowding_Ratio)

(0.00, 1.05), (1.00, 1.00), (2.00, 0.9), (3.00, 0.7), (4.00, 0.6), (5.00, 0.55)

DOCUMENT: 16

(Dimensionless)

BRFM_Birth_Rt_from_Food_Mult = GRAPH(FR_Food_Ratio)

(0.00, 0.00), (1.00, 1.00), (2.00, 1.60), (3.00, 1.90), (4.00, 2.00)

DOCUMENT: 17

(Dimensionless)

BRMM_Birth_Rt_from_Mat_Mult = GRAPH(MSL_Mat_Std_of_Liv)

(0.00, 1.20), (1.00, 1.00), (2.00, 0.85), (3.00, 0.75), (4.00, 0.7), (5.00, 0.7)

DOCUMENT: 3

(Dimensionless)

BRPM_Birth_Rt_from_Poln_Mult = GRAPH(POLR_Poln_Ratio)

(0.00, 1.02), (10.0, 0.9), (20.0, 0.7), (30.0, 0.4), (40.0, 0.25), (50.0, 0.15), (60.0, 0.1)

DOCUMENT: 18

(Dimensionless)

CFIFR_Cap_Frac_Indic_by_Food_Rat = GRAPH(FR_Food_Ratio)

(0.00, 1.00), (0.5, 0.6), (1.00, 0.3), (1.50, 0.15), (2.00, 0.1)

DOCUMENT: 36

(Dimensionless)

CIM_Cap_Inv_Mult = GRAPH(MSL_Mat_Std_of_Liv)

(0.00, 0.1), (1.00, 1.00), (2.00, 1.80), (3.00, 2.40), (4.00, 2.80), (5.00, 3.00)

DOCUMENT: 26

(Dimensionless)

CIQR_Cap_Inv_from_Qual_Ratio = GRAPH(QLM_Qual_Life_from_Mat / QLF_Qual_Life_from_Fd)

(0.00, 0.7), (0.5, 0.8), (1.00, 1.00), (1.50, 1.50), (2.00, 2.00)

DOCUMENT: 43

(Dimensionless)

DRCM_Death_Rt_from_Crowd_Mult = GRAPH(CR_Crowding_Ratio)

(0.00, 0.9), (1.00, 1.00), (2.00, 1.20), (3.00, 1.50), (4.00, 1.90), (5.00, 3.00)

DOCUMENT: 14

(Dimensionless)

DRFM_Death_Rt_from_Food_Mult = GRAPH(FR_Food_Ratio)

(0.00, 30.0), (0.25, 3.00), (0.5, 2.00), (0.75, 1.40), (1.00, 1.00), (1.25, 0.7), (1.50, 0.6), (1.75, 0.5), (2.00, 0.5)

DOCUMENT: 13

(Dimensionless)

DRMM_Death_Rt_from_Mat_Mult = GRAPH(MSL_Mat_Std_of_Liv)

(0.00, 3.00), (0.5, 1.80), (1.00, 1.00), (1.50, 0.8), (2.00, 0.7), (2.50, 0.6), (3.00, 0.53), (3.50, 0.5), (4.00, 0.5), (4.50, 0.5), (5.00, 0.5)

DOCUMENT: 11

(Dimensionless)

DRPM_Death_Rt_from_Poln_Mult = GRAPH(POLR_Poln_Ratio)

(0.00, 0.92), (10.0, 1.30), (20.0, 2.00), (30.0, 3.20), (40.0, 4.80), (50.0, 6.80), (60.0, 9.20)

DOCUMENT: 12

(Dimensionless)

FCM_Food_from_Crowd_Mult = GRAPH(CR_Crowding_Ratio)

(0.00, 2.40), (1.00, 1.00), (2.00, 0.6), (3.00, 0.4), (4.00, 0.3), (5.00, 0.2)

DOCUMENT: 20

(Dimensionless)

FPCI_Food_Pot_from_Cap_Inv = GRAPH(CIRA_Cap_Inv_Rat_in_Agr)

(0.00, 0.5), (1.00, 1.00), (2.00, 1.40), (3.00, 1.70), (4.00, 1.90), (5.00, 2.05), (6.00, 2.20)

DOCUMENT: 21

(Food Units / Person / Year)

FPM_Food_from_Poln_Mult = GRAPH(POLR_Poln_Ratio)

(0.00, 1.02), (10.0, 0.9), (20.0, 0.65), (30.0, 0.35), (40.0, 0.2), (50.0, 0.1), (60.0, 0.05)

DOCUMENT: 28

(Dimensionless)

NREM_Nat_Res_Extract_Mult = GRAPH(NRFR_Nat_Res_Frac_Remain)

(0.00, 0.00), (0.25, 0.15), (0.5, 0.5), (0.75, 0.85), (1.00, 1.00)

DOCUMENT: 6

(Dimensionless)

NRMM_Nat_Res_from_Mat_Mult = GRAPH(MSL_Mat_Std_of_Liv)

(0.00, 0.00), (1.00, 1.00), (2.00, 1.80), (3.00, 2.40), (4.00, 2.90), (5.00, 3.30), (6.00, 3.60), (7.00, 3.80), (8.00, 3.90), (9.00, 3.95), (10.0, 4.00)

DOCUMENT: 42

(Dimensionless)

POLAT_Poln_Absorb_Time = GRAPH(POLR_Poln_Ratio)

(0.00, 0.6), (10.0, 2.50), (20.0, 5.00), (30.0, 8.00), (40.0, 11.5), (50.0, 15.5), (60.0, 20.0)

DOCUMENT: 34

(Years)

POLCM_Poln_from_Cap_Mult = GRAPH(CIR_Cap_Inv_Ratio)

(0.00, 0.05), (1.00, 1.00), (2.00, 3.00), (3.00, 5.40), (4.00, 7.40), (5.00, 8.00)

DOCUMENT: 32

(Dimensionless)

QLC_Qual_Life_from_Crowd = GRAPH(CR_Crowding_Ratio)

(0.00, 2.00), (0.5, 1.30), (1.00, 1.00), (1.50, 0.75), (2.00, 0.55), (2.50, 0.45), (3.00, 0.38), (3.50, 0.3), (4.00, 0.25), (4.50, 0.22), (5.00, 0.2)

DOCUMENT: 39

(Dimensionless)

QLF_Qual_Life_from_Fd = GRAPH(FR_Food_Ratio)

(0.00, 0.00), (1.00, 1.00), (2.00, 1.80), (3.00, 2.40), (4.00, 2.70)

DOCUMENT: 40

(Dimensionless)

QLM_Qual_Life_from_Mat = GRAPH(MSL_Mat_Std_of_Liv)

(0.00, 0.2), (1.00, 1.00), (2.00, 1.70), (3.00, 2.30), (4.00, 2.70), (5.00, 2.90)

DOCUMENT: 38

(Dimensionless)

QLP_Qual_Life_from_Poln = GRAPH(POLR_Poln_Ratio)

(0.00, 1.04), (10.0, 0.85), (20.0, 0.6), (30.0, 0.3), (40.0, 0.15), (50.0, 0.05), (60.0, 0.02)

DOCUMENT: 41

(Dimensionless)

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