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A WORLD DYNAMICS MODEL:
INTRODUCTORY EXERCISE

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CHAPTER I
Introduction

This memorandum describes a simple dynamic model inter-relating population, capital investment, pollution, natural resources, and food production. The intent is not to present a final or useable model of human population in the world ecology. Instead the intent is to show that world aggregate variables can be inter-related and to provide an incentive for going beyond the present simple model to a serious consideration of the major variables in contemporary world evolution.

This memorandum has the further purpose of exhibiting the detailed steps and mistakes in starting a dynamic model formulation. Customarily the literature reports only final results and perfected theories. The student reader is often left with the impression that the perfected and polished final result emerged in the first effort. Some of the scientific literature of the 1800's is especially interesting and revealing, even today, because it is more a journal and diary of an avenue of investigation and less a presentation of final results. The nature of blind alleys, the reasons for taking wrong approaches, and the methods of finding one's way back to a productive investigation can be helpful to the beginner. This document is set down hoping that it will serve a useful educational purpose for the serious beginner in modeling the dynamic behavior of social systems.

This model of world-wide aggregate inter-actions developed out of a meeting of the Club of Rome which was held in Bern, Switzerland on June 29 and 30, 1970. The Club of Rome is a private group of some 50 men representing many countries who have joined together to seek ways of influencing the modern course of human affairs. The members are private citizens not in governmental decision making positions. Their orientation is activist, that is, they wish to do more than study and understand. They wish to clarify the course of human events in a way that can be transmitted to world governments and populations and can have an influence on the problems of rising population, increasing pollution, greater crowding, and growing social strife.

The Club of Rome had, at the time of the Bern meeting, established a project at the Battelle Institute in Geneva, Switzerland for the purpose of selecting a methodology to deal with the dynamics of complex systems. The Bern meeting was organized primarily to review the status of that project. In the meeting, everyone acknowledged that they did not yet have a suitable methodology which would deal with the broad sweep of human affairs and the ways in which major elements of the world ecology interact with each other. Furthermore, the principal financing for the project was being delayed until a suitable methodology could be identified.

At that point I suggested to the group that we believe the "Industrial Dynamics" approach developed at the M.I.T. Sloan School of Management since 1956 is the methodology for which they are searching. We have been applying this approach to social systems first in the context of corporate management and more recently in a broadening circle of applications ranging from internal medicine to the life cycle of cities. I invited the Executive Committee of the Club of Rome to visit us at M.I.T. for two weeks to learn what we are doing, and to judge for themselves the applicability of our approach to social systems. After a two hour lecture and discussion of our work, the Executive Committee and several other members accepted the invitation with plans to be at M.I.T. from July 20-31, 1970. In the intervening two weeks during the first part of July we organized a program for the discussion of methodology and the presentation of social dynamics programs in which we are now engaged.

It has been our feeling that one does not gain an adequate appreciation of our feedback system structuring and computer simulation approach unless he actively participates in the process. During the last several years we have conducted a two-week special summer session program in Industrial Dynamics and have made afternoon workshop sessions a part of that experience. The participants in the summer session programs have developed a simple model of a 2-loop commodity market and have examined the dynamics of commodity behavior. This has been an effective teaching tool. However, it did not seem close enough to the interests of the Club of Rome members to be the best vehicle for the proposed conference.

This memorandum describes a model of world behavior which was developed during the two weeks between the meetings in Bern and at M.I.T. The first step consisted of about 1 hour on the airplane from Paris back to Boston which resulted in the general flow diagram Figure 1-1 suggesting the principal system levels and some of the interconnections between them. It involved population with birth and death rates, capital investment with generation and discard, natural resources and their depletion, pollution with its generation and absorption, and the fraction of capital investment devoted to food production. This sketch was done on July 1.

I returned to the subject on Saturday, July 4 and that day worked through the full formulation of the World1 Model to the point of generating the first complete flow diagram, a complete and operable set of equations, the drafting of the table functions, and obtaining the first two computer runs to be described later.

In the following week the World1 Model was investigated and ideas generated for its improvement. On Saturday, July 11 this model was evolved into the World1A version, then into World1B, and finally into the World2 Model, which is the form being frozen as the starting point of the workshop sessions for the Club of Rome Conference on July 20-31. It is expected that the workshop groups will start with the World2 version and explore the process of system restructuring, system extension, and investigation of how the parameters and policies affect system behavior.

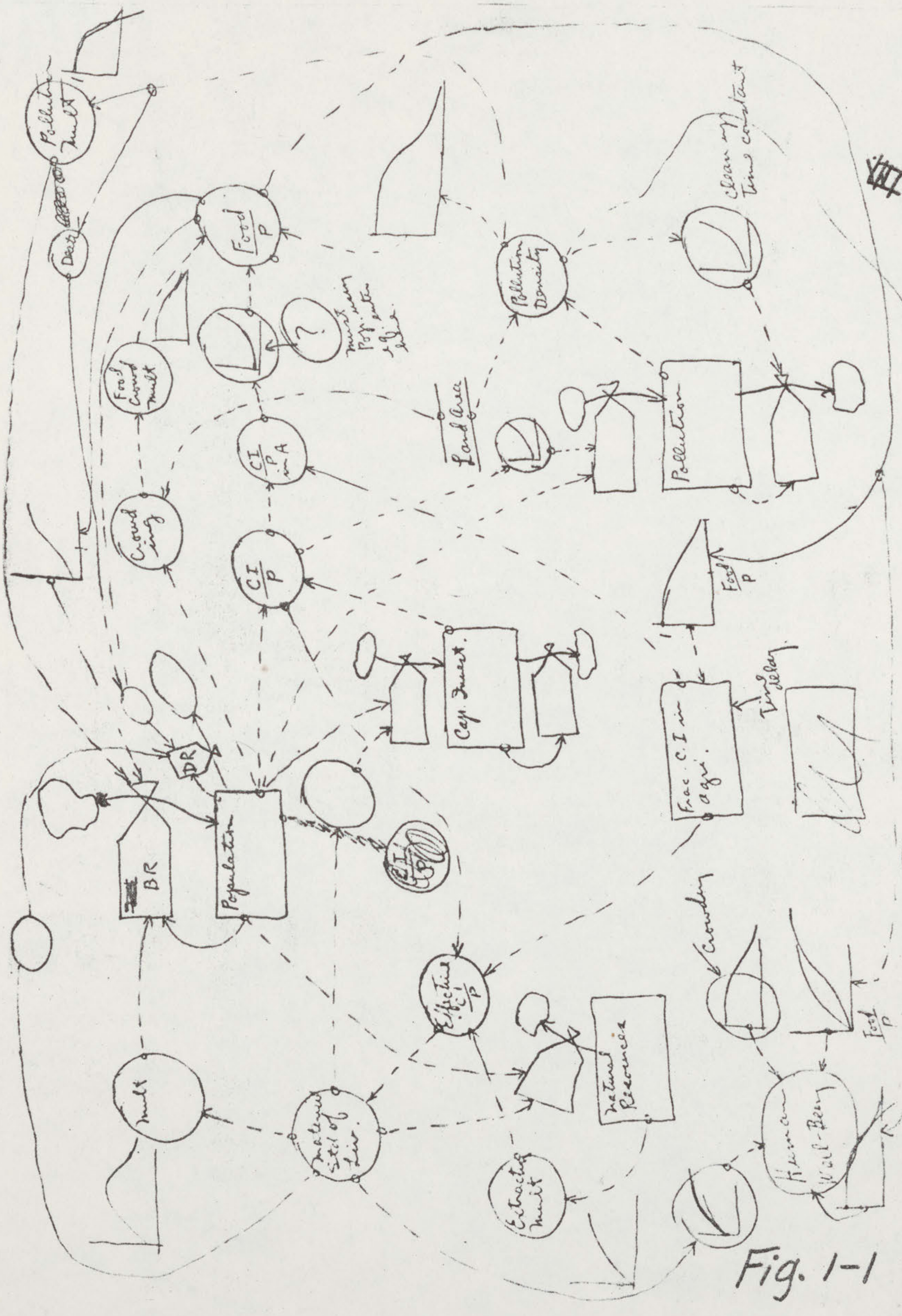

Pollution mult
Death
Food / P
Food Crowd mult
Crowding
C I / P in A
C I / P
Land Area
Pollution Density
Clean up time constant
Pollution
Cap. Invest.
Food / P
Frac. C.I in agri.
Time delay
Population
BR
DR
Effective C.I. / P
Natural Resources
Extraction mult
Material Std of Liv.
mult
Crowding
Food / P
Human Well-Being

Fig. 1-1

A principal objective of this exercise is the conversion from a verbal and conceptual description of a system to a formal simulation model. At this stage and for the purposes of this exercise, defence of the individual assumptions is considered secondary. Individual relationships will be selected within the plausible range. Verification and refinement of the assumptions is left until after we see how the system behaves and after we have examined the sensitivity of the system to the various preliminary assumptions.

The objective of this simplified system is to examine possible inter-relationships between population, capital investment, natural resources, pollution, and food. The principal concepts are described in the following paragraphs.

Population will be increased by a birth rate which rises with the material standard of living, declines at high levels of pollution, declines with a shortage of food, and is reduced by a high degree of crowding.

Population will be decreased by a death rate which rises when the material standard of living falls, rises with increased pollution, rises when there is a food shortage, and rises when crowding is increased.

Capital investment will be increased at a rate proportional to population and will depend on the degree of industrialization as represented by the material standard of living.

Capital investment will be decreased by the discard of capital goods due to wear-out and deterioration.

Natural resources, meaning the expendable type which are not regenerated, will be represented by an initial pool from which a useage rate draws. The useage rate will increase with population and with the material standard of living.

Pollution will represent the total pollution load existing in the environment. This will be caused to increase in proportion to population and as a function of the amount of capital investment.

Pollution will be absorbed and dissipated in accordance with a time constant of decay which itself depends on the amount of pollution in the environment.

Food production will decrease with crowding to represent the land remaining available for food production, decrease with rising pollution, and increase with the capital investment allocated to agriculture.

Another system level, capital investment in agriculture, will represent the fraction of capital investment allocated to agriculture and this will depend on per capita food generation in the system.

On the basis of the preceding general description of the system, the following chapter develops the detailed individual system equations.

CHAPTER 2

THE DEVELOPMENT OF THE PRELIMINARY WORLD1 MODEL

The following notes were dictated on Saturday, July 4 while the first model was being constructed. They have been re-edited for clarity and for the introduction of some additional explanatory material, but the substance of the original dictation has been retained. This means that formulation errors as originally made are still in the text although parenthetical indications of later changes have usually been inserted.

The reader should refer to the flow diagram Figure 2-1 while reading the following text. The first stage was to make the full flow diagram as shown (without the equations 42 and 43 -- these latter two equations were added after the World1 version). The flow diagram was drawn and the nomenclature established before the equations were written and before the following dictation. The dictation was made at the time of writing the equations and sketching the table functions.

Equation 1 is the simple level equation for population which is increased by birth rate and diminished by death rate.

```
P.K=P.J+(DT)(BR.JK-DR.JK)                                    1,L
P=PI                                                         1.1,N
PI=1.65E9                                                    1.2,C
     P      - POPULATION (PEOPLE)
     BR     - BIRTH RATE (PEOPLE/YEAR)
     DR     - DEATH RATE (PEOPLE/YEAR)
     PI     - POPULATION, INITIAL (PEOPLE)
```

The initial value for population corresponds approximately to the year 1900. For Equation 1 on population I am taking a population of 1.65 billion people in 1900 from the article by Peccei in the magazine "Successo" of June 1970.

In picking values for normal birth and death rates we will use figures that represent a 2% per year annual population growth rate. This figure comes from Peccei's book Chasm Ahead published by MacMillan on page 164. If we pick as reasonable, but without searching for justification data, a life expectancy of 40 years for the world as a whole, we get a value of DRN of .025. The birth rate normal BRN should then be 2% higher or .045.

All the references to normal conditions will be estimated as nearly as possible to correspond to the year 1970.

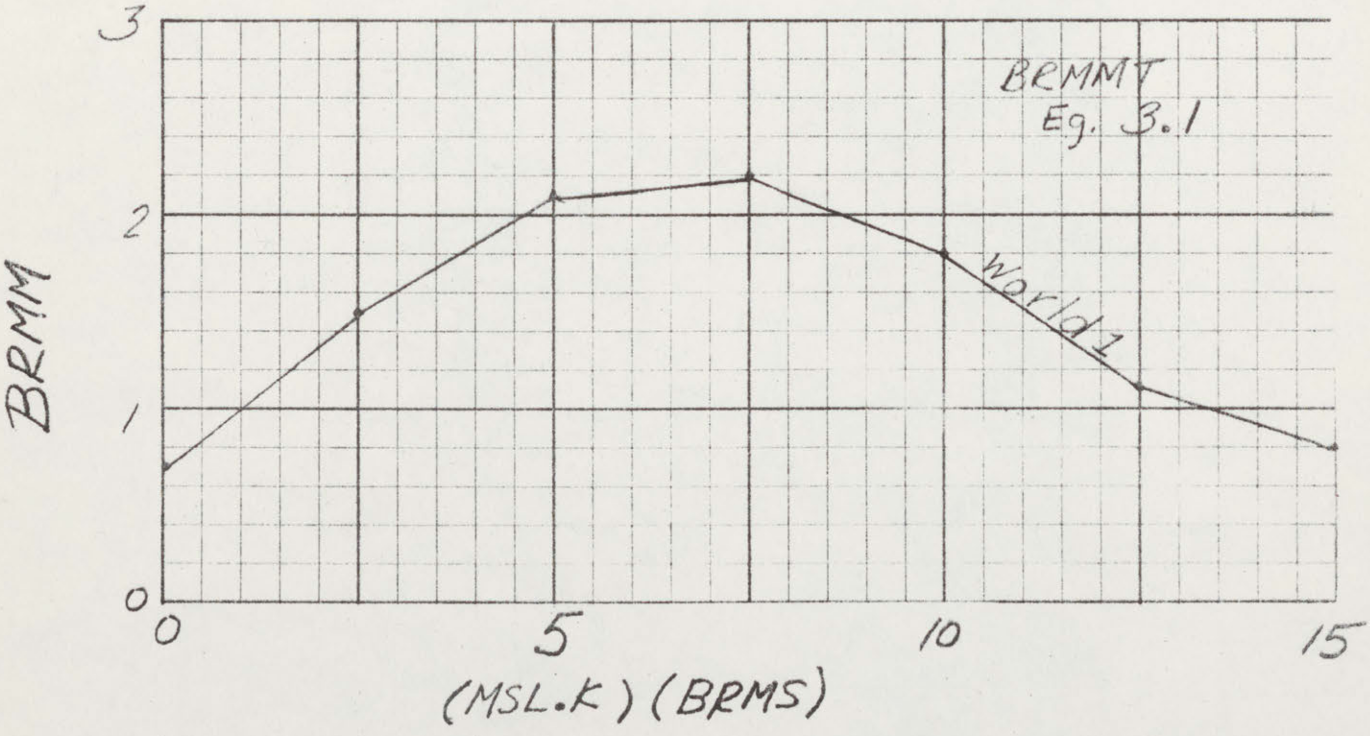
Equation 2 is written on the basis of a birth rate which is given normally as the population multiplied by the birth rate normal BRN and then this number is modified by four multipliers representing food, material standard of living, crowding, and pollution.

```
BR.KL=(P.K)(BRN)(BRFM.K)(BRMM.K)(BRCM.K)(BRPM.K)              2,R

BRN=.045                                                      2.1,C

   BR    - BIRTH RATE (PEOPLE/YEAR)
   P     - POPULATION (PEOPLE)
   BRN   - BIRTH RATE NORMAL (FRACTION/YEAR)
   BRFM  - BIRTH-RATE-FROM-FOOD MULTIPLIER
             (DIMENSIONLESS)
   BRMM  - BIRTH-RATE-FROM-MATERIAL MULTIPLIER
             (DIMENSIONLESS)
   BRCM  - BIRTH-RATE-FROM-CROWDING MULTIPLIER
             (DIMENSIONLESS)
   BRPM  - BIRTH-RATE-FROM-POLLUTION MULTIPLIER
             (DIMENSIONLESS)
```

Equation 3 describes the effect of the material standard of living MSL on the birth rate. Here the model represents the material standard of living of the world as a whole. However, we recognize as in the selection of all tables and coefficients, that the standard of living is not uniformly distributed. We have before us a wide dispersion over the face of the world in all of the concepts represented in this model. We can use what has happened in the industrialized nations as an indication of what could eventually happen if all of the world's population should change to conditions represented by those nations which have experienced the greatest technological change. In Equation 2 the material standard of living includes, because it is less appropriately assumed in the other multipliers, all such considerations as shelter, medical service, use of energy and material goods.

```
BRMM.K=TABLE(BRMMT,MSL.K*BRMS,0,15,2.5)                        3,A

BRMMT=.7/1.5/2.1/2.2/1.8/1.1/.8/                               3.1,T

BRMS=1                                                         3.2,C
```

```
    BRMM   - BIRTH-RATE-FROM-MATERIAL MULTIPLIER
               (DIMENSIONLESS)
    BRMMT  - BIRTH-RATE-FROM-MATERIAL-MULTIPLIER TABLE
    MSL    - MATERIAL STANDARD OF LIVING (DIMENSIONLESS)
    BRMS   - BIRTH-RATE-FROM-MATERIAL SENSITIVITY
               (DIMENSIONLESS)
```



Birth-rate-from-material multiplier
vs. material standard of living

The table BRMMT in Equation 3.1 is shaped here to show a rising birth rate as the material standard of living increases but with the birth rate declining again at the higher levels of material standard of living (changed in WORLD2). This seems to be what has happened in the countries with a more advanced technology. I will try to adjust initial conditions to make this multiplier approximately unity at the beginning point in 1900. (In WORLD2 it becomes unity in 1970) In other words, the material standard of living for the world as a whole at that time would be about 10% of that in the Western technologically advanced countries at the present time. A value of MSL=1 is assumed to represent a typical value for Western Europe and North America in 1970. (In WORLD2 MSL is made consistent with the remainder of the model and unity represents the world-wide average.)

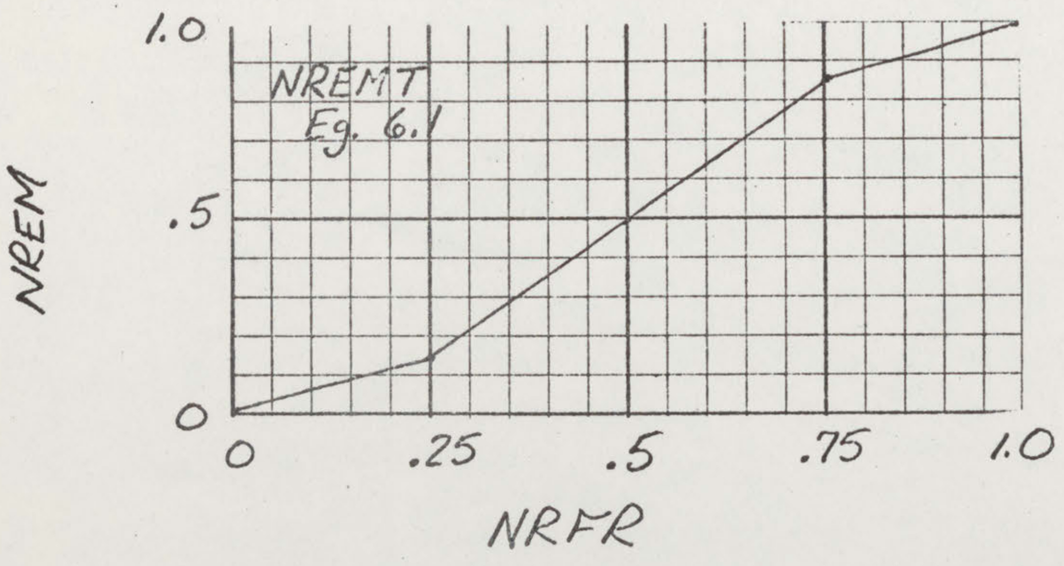
In Equation 4 the material standard of living MSL is taken to depend on the effective-capital-investment ratio ECIR which is not required in agriculture. The units are in terms of average world-wide conditions in 1970. The coefficient MSLN is inserted to allow alteration of the influence of MSL. MSL is increased or decreased by the multiplier ECIR which represents the effective-capital-investment ratio (capital units/person).

```
MSL.K=(MSLN)(ECIR.K)                                    4,A

MSLN=1                                                  4.1,C

    MSL    - MATERIAL STANDARD OF LIVING (DIMENSIONLESS)
    MSLN   - MATERIAL STANDARD OF LIVING NORMAL (CAPITAL
               UNITS/PERSON)
    ECIR   - EFFECTIVE-CAPITAL-INVESTMENT RATIO (CAPITAL
               UNITS/PERSON)
```

Equation 5 gives the effective-capital-investment ratio ECIR which is available for non-food growing purposes. It starts with the total capital-investment ratio CIR and multiplies by the capital-investment-in-agriculture fraction CIAF. The result is then multiplied by the natural-resource-extraction multiplier NREM which is used to represent the effect of depletion of natural resources. As resources are depleted, more and more capital investment is required for any given output.

```
ECIR.K=(CIR.K)(1-CIAF.K)(NREM.K)                         5,A

     ECIR   - EFFECTIVE-CAPITAL-INVESTMENT RATIO (CAPITAL
                UNITS/PERSON)
     CIR    - CAPITAL-INVESTMENT RATIO (CAPITAL UNITS/
                PERSON)
     CIAF   - CAPITAL-INVESTMENT-IN-AGRICULTURE FRACTION
                (DIMENSIONLESS)
     NREM   - NATURAL-RESOURCE-EXTRACTION MULTIPLIER
                (DIMENSIONLESS)
```

The natural-resource-extraction multiplier NREM in Equation 6 represents the difficulty of using natural resources as they become depleted. For the purposes of this model, natural resources can be considered those which are stored in the earth and can be depleted, whereas, we can let the food multiplier stand not only for food but for all other natural resources which are grown and regenerated by natural continuing processes. In other words, wood might be considered part of the natural resources which are included with the concept of food and, on the other hand, metals and stored fossil fuels would be in the natural resources in NR. The natural resources are subject to depletion and their cost of extraction increases as they become scarce. The natural-resource-extraction multiplier NREM drops to zero when natural resources drop to zero.



Natural-resource-extraction multiplier vs. natural-resource fraction remaining.

```
NREM.K=TABLE(NREMT,NRFR.K,0,1,.25)                    6,A
NREMT=0/.15/.5/.85/1                                  6.1,T

   NREM  - NATURAL-RESOURCE-EXTRACTION MULTIPLIER
             (DIMENSIONLESS)
   NREMT - NATURAL-RESOURCE-EXTRACTION-MULTIPLIER
             TABLE
   NRFR  - NATURAL-RESOURCE FRACTION REMAINING
             (DIMENSIONLESS)
```

We will assume that essentially all natural resources remain in 1900. In other words, depletion has only started at the beginning of the simulation run. Equation 7 is the natural-resource fraction remaining NRFR in terms of the actual natural resources divided by the initial value.

```
NRFR.K=NR.K/NRI                                       7,A

   NRFR  - NATURAL-RESOURCE FRACTION REMAINING
             (DIMENSIONLESS)
   NR    - NATURAL RESOURCES (NATURAL RESOURCE UNITS)
   NRI   - NATURAL RESOURCES, INITIAL (NATURAL
             RESOURCE UNITS)
```

Equation 8 is the level equation for natural resources starting with an initial value and depleting this according to the useage rate. The unit of natural resources will be taken as the amount used per capita per year by the world population in 1970. The world population for 1970 from Peccei is 3.6 billion and we will assume that the natural resource useage rate is such that this useage would deplete natural resources in another 250 years. From this an initial value of natural resources can be computed as 3.6 billion people times 1 natural resource unit per person per year times 250 years. The result is 900 billion units.

```
NR.K=NR.J+(DT)(-NRUR.JK)                              8,L
NR=NRI                                                8.1,N
NRI=900E9                                             8.2,C

   NR    - NATURAL RESOURCES (NATURAL RESOURCE UNITS)
   NRUR  - NATURAL-RESOURCE-USAGE RATE (NATURAL
             RESOURCE UNITS/YEAR)
   NRI   - NATURAL RESOURCES, INITIAL (NATURAL
             RESOURCE UNITS)
```

The natural-resource-usage rate NRUR in Equation 9 is proportional to population multiplied by the natural-resource usage normal NRUN and multiplied again by the material standard of living MSL. (In WORLD2 a table function here will control the relation between MSL and NRUR). The natural-resource usage normal NRUN is taken as unity representing the world-wide average consumption usage rate in 1970 for which the material standard of living MSL would have a value of 1.

```
NRUR.KL=(P.K)(NRUN)(MSL.K)                               9,R

NRUN=1                                                   9.1,C

        NRUR   - NATURAL-RESOURCE-USAGE RATE (NATURAL
                   RESOURCE UNITS/YEAR)
        P      - POPULATION (PEOPLE)
        NRUN   - NATURAL-RESOURCE USAGE NORMAL (NATURAL
                   RESOURCE UNITS/PERSON/YEAR)
        MSL    - MATERIAL STANDARD OF LIVING (DIMENSIONLESS)
```

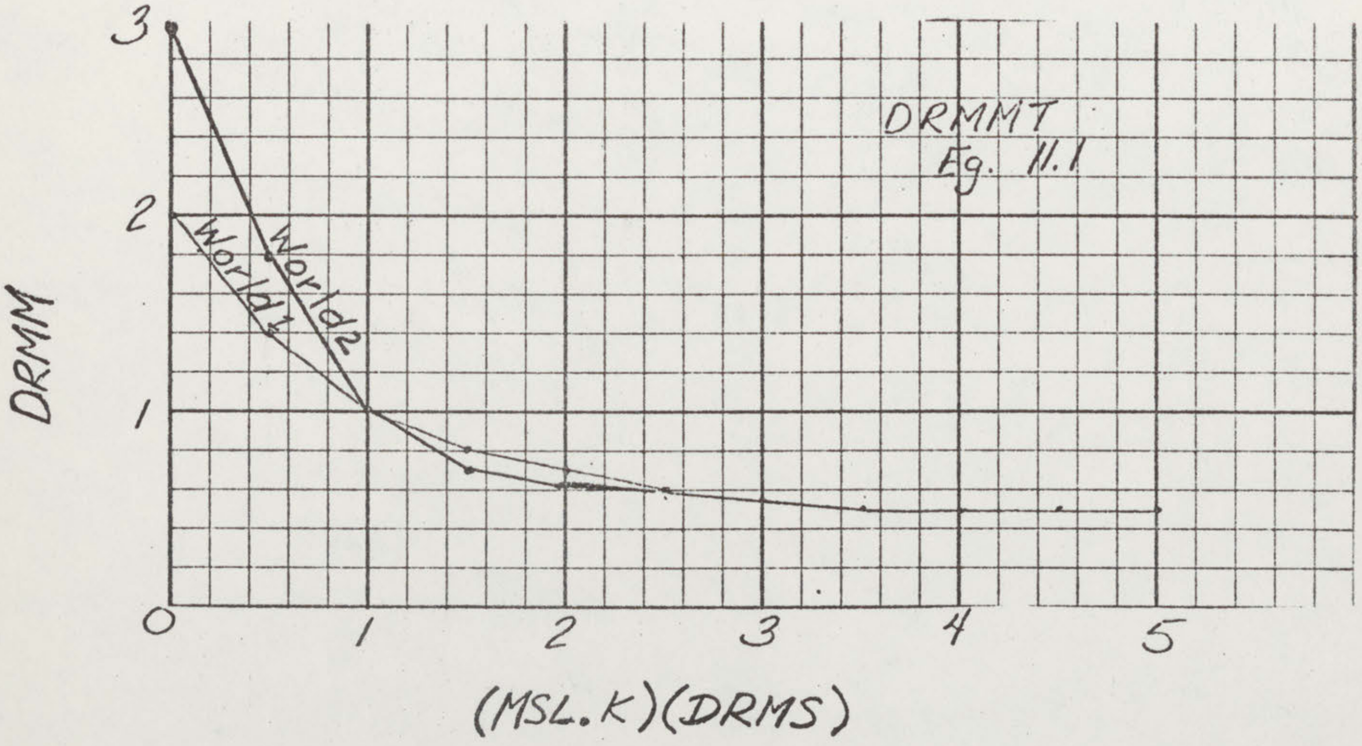
Equation 10 for death rate DR has the same structure as birth rate. Death rate normal DRN is taken as .025 per year and this value is modulated by multipliers representing the material standard of living, pollution, food, and crowding.

```
DR.KL=(P.K)(DRN)(DRMM.K)(DRPM.K)(DRFM.K)(DRCM.K)         10,R

DRN=.025                                                 10.1,C

       DR      - DEATH RATE (PEOPLE/YEAR)
       P       - POPULATION (PEOPLE)
       DRN     - DEATH RATE NORMAL (FRACTION/YEAR)
       DRMM    - DEATH-RATE-FROM-MATERIAL MULTIPLIER
                   (DIMENSIONLESS)
       DRPM    - DEATH-RATE-FROM-POLLUTION MULTIPLIER
                   (DIMENSIONLESS)
       DRFM    - DEATH-RATE-FROM-FOOD MULTIPLIER
                   (DIMENSIONLESS)
       DRCM    - DEATH-RATE-FROM-CROWDING MULTIPLIER
                   (DIMENSIONLESS)
```

The-death-rate-from-material multiplier DRMM in Equation 11 is centered around the 1-1 point representing present average world conditions. This is for a normal life expectancy of about 40 years. With a zero material standard of living we here assume that the death rate will double. On the other hand no increase in the material standard of living can do more than cut the death rate in half.

```
DRMM.K=TABHL(DRMMT,MSL.K*DRMS,0,5,.5)                   11,A
DRMMT=2/1.4/1/.8/.7/.6/.53/.5/.5/.5/.5                  11.1,T
DRMS=1                                                  11.2,C
```

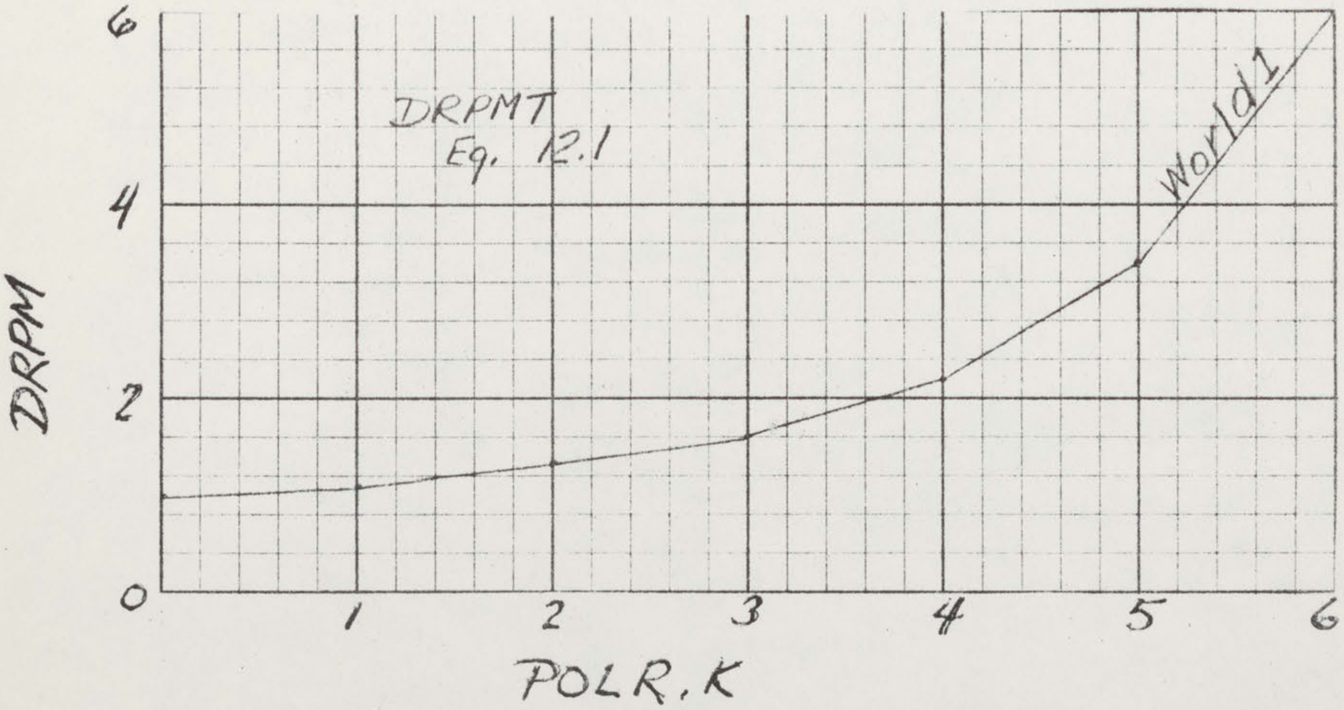
DRMM - DEATH-RATE-FROM-MATERIAL MULTIPLIER (DIMENSIONLESS)
DRMMT - DEATH-RATE-FROM-MATERIAL-MULTIPLIER TABLE
MSL - MATERIAL STANDARD OF LIVING (DIMENSIONLESS)
DRMS - DEATH-RATE-FROM-MATERIAL SENSITIVITY (DIMENSIONLESS)



Death-rate-from-material multiplier
vs. material standard of living

Equation 12 for the death-rate-from-pollution multiplier DRPM is constructed around a situation where present 1970 world pollution is taken as a unity density and where we assume that this is just beginning to have a significant effect on death rate. Higher densities of pollution will relatively rapidly increase death rate while lower values have very little effect.

```
DRPM.K=TABLE(DRPMT,POLR.K,0,6,1)                                   12,A

DRPMT=1/1.1/1.3/1.6/2.2/3.4/6                                      12.1,T

    DRPM   - DEATH-RATE-FROM-POLLUTION MULTIPLIER
              (DIMENSIONLESS)
    DRPMT  - DEATH-RATE-FROM-POLLUTION-MULTIPLIER TABLE
    POLR   - POLLUTION RATIO (DIMENSIONLESS)
```

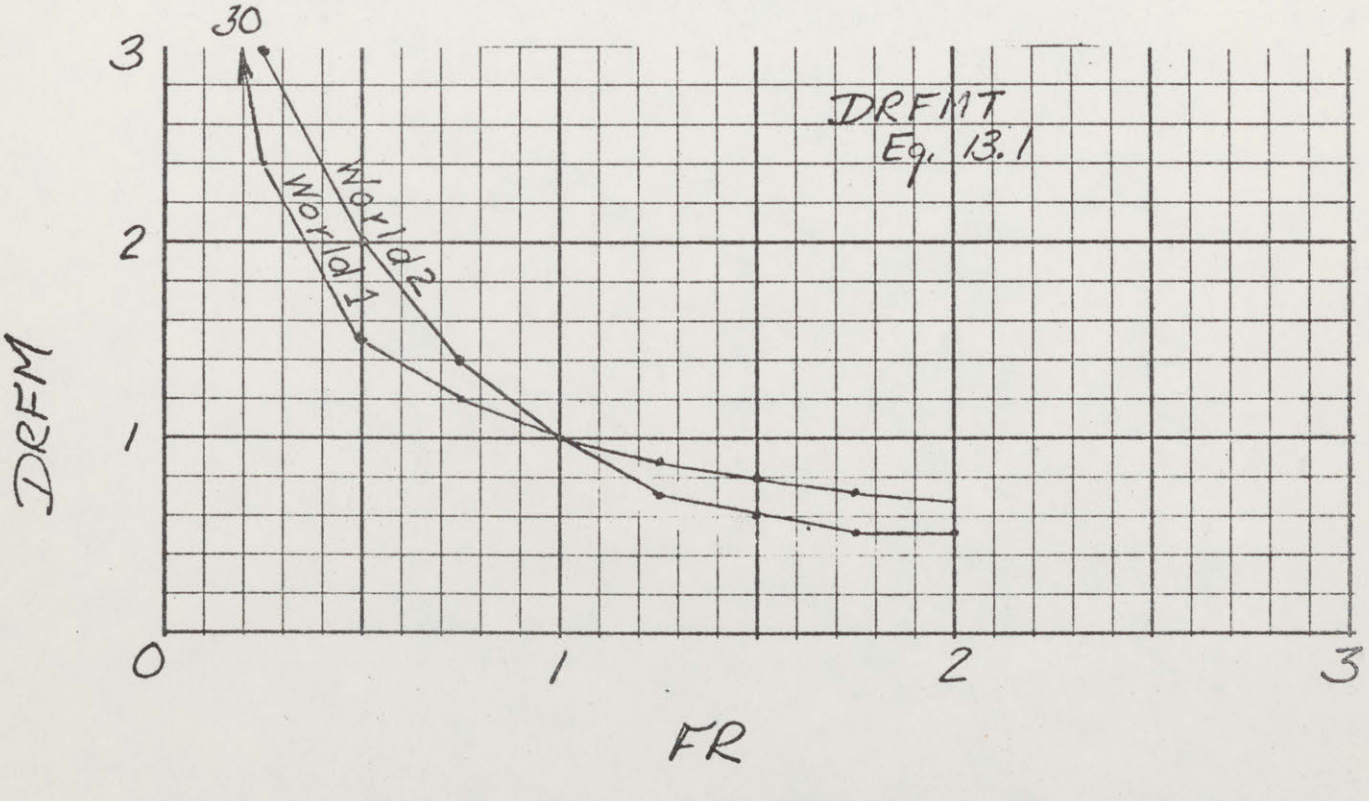


Death-rate-from-pollution multiplier vs. pollution

Equation 13 gives the effect of food availability on death rate. Here a food ratio FR of 1 is taken as the 1970 world condition. As the food ratio decreases, the death-rate-from-food multiplier DRFM increases rapidly. On the other hand as the food ratio increases the death-rate-from-food multiplier will fall only slowly and here is taken as .7 of the normal world value. In other words, the assumption is that at the present time the world is on the verge of a rapidly rising death rate should the food level fall much from the present average. On the other hand increased food by itself probably can not do more than increase life expectancy by about 50%.

```
DRFM.K=TABHL(DRFMT,FR.K,0,2,.25)                          13,A
DRFMT=30/2.4/1.5/1.2/1/.9/.8/.73/.7                        13.1,T
```

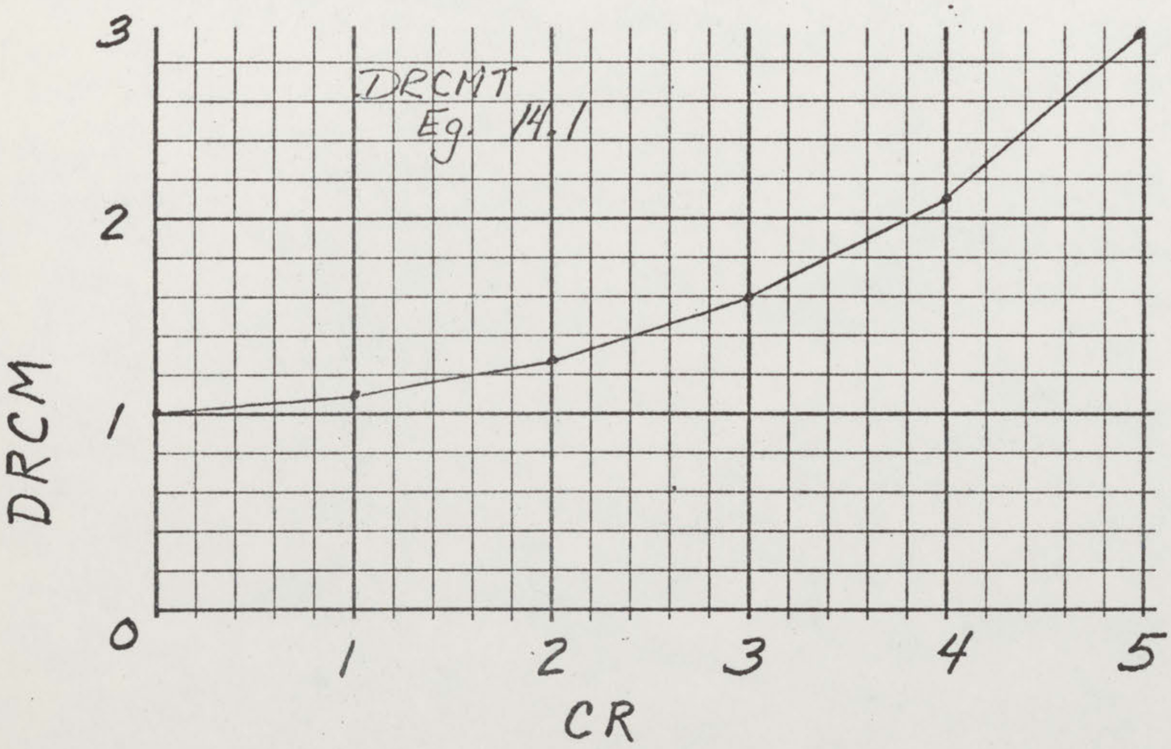
```
     DRFM  - DEATH-RATE-FROM-FOOD MULTIPLIER
               (DIMENSIONLESS)
     DRFMT - DEATH-RATE-FROM-FOOD-MULTIPLIER TABLE
     FR    - FOOD RATIO (DIMENSIONLESS)
```



Death-rate-from-food multiplier vs. food ratio

In Equation 14 the death-rate-from-crowding multiplier DRCM can be taken as representing the effects of disease, psychological trauma, war, and any effects traceable to crowding in its own right and not related to food or pollution. We take here very little effect from the crowding multiplier up to the present population density of the earth. Up to the present density there has been a strong tendency to spread over the face of the earth with rising population so that average densities have not reached a critical point. However, if we should imagine the present world population rising by another factor of 5 we might expect the social strife to substantially raise the death rate. We here take a death-rate-from-crowding multiplier of 3 to accompany a population 5 times that now existing.

```
DRCM.K=TABLE(DRCMT,CR.K,0,5,1)                              14,A

DRCMT=1/1.1/1.3/1.6/2.1/3                                   14.1,T

     DRCM  - DEATH-RATE-FROM-CROWDING MULTIPLIER
               (DIMENSIONLESS)
     DRCMT - DEATH-RATE-FROM-CROWDING-MULTIPLIER TABLE
     CR    - CROWDING RATIO (DIMENSIONLESS)
```

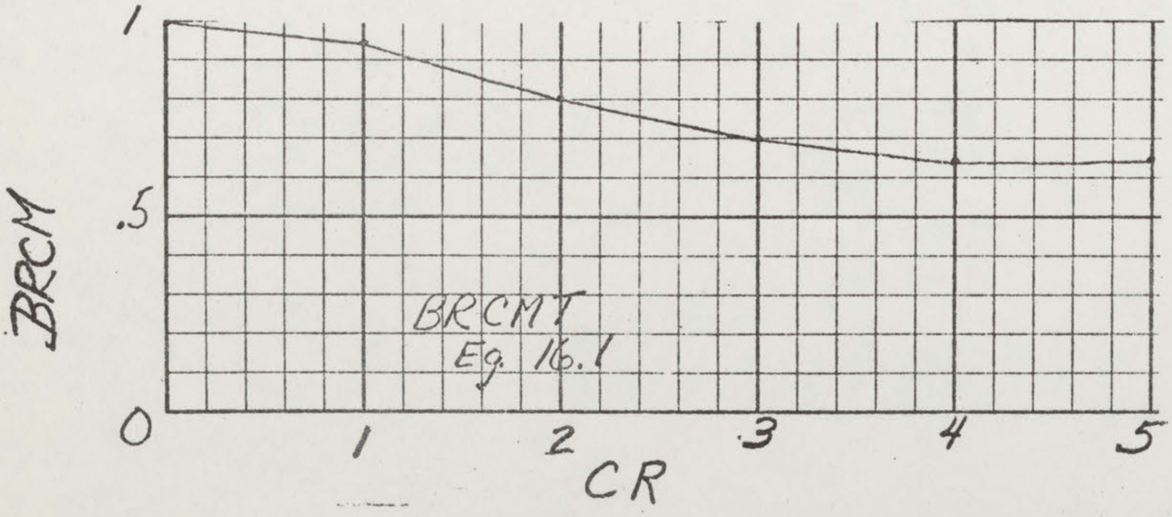


Death-rate-from-crowding multiplier
vs. crowding ratio

Equation 15 calculates the crowding ratio CR. A ratio of 1 is the present crowding of population on the world land area. Using a world land area of 135 million square kilometers (taken from the world almanac) and the present 3.6 billion people from the <u>Successo</u> article by Peccei we find that the present average population density on the earth is 265 people per square kilometer. (This is an error. The proper value of 26.5 is inserted in model WRLD1A) Equation 15 combines these to give a crowding ratio in terms of present world conditions.

```
CR.K=(P.K)/(LA*PDN)                                    15,A

LA=135E6                                               15.1,C

PDN=265                                                15.2,C

     CR    - CROWDING RATIO (DIMENSIONLESS)
     P     - POPULATION (PEOPLE)
     LA    - LAND AREA (SQUARE KILOMETERS)
     PDN   - POPULATION DENSITY NORMAL (PEOPLE/SQUARE
              KILOMETER)
```

Equation 16 is the birth-rate-from-crowding multiplier BRCM and shows a fall in the birth rate as world crowding increases. However, not a very strong dependency is being assumed here with the birth rate falling to .65 of its normal value when the world population rises to 5 times its present value.

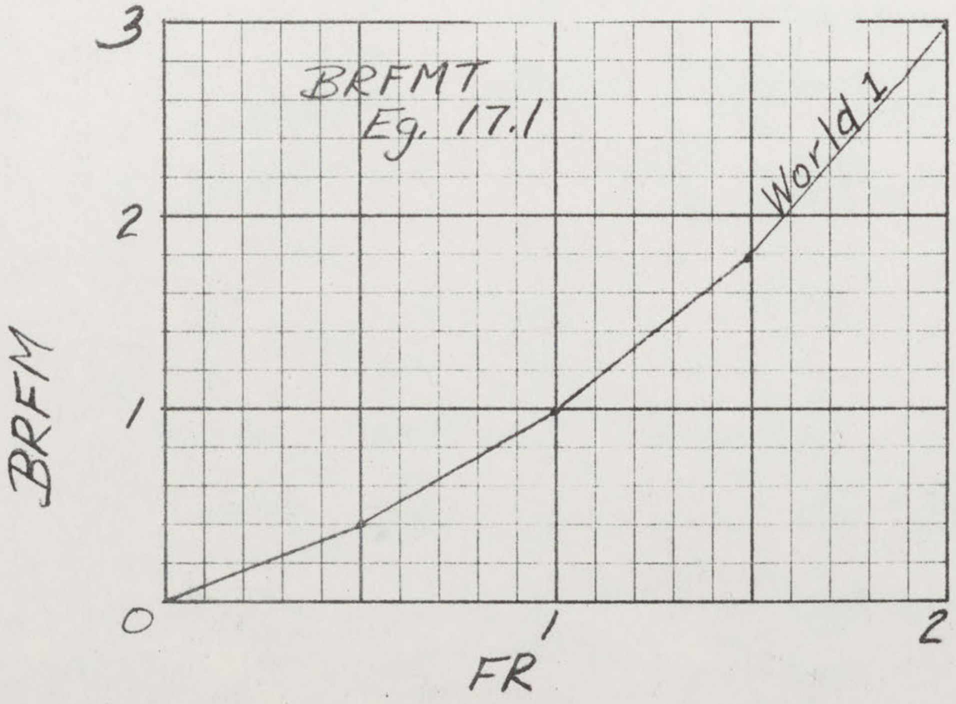


Birth-rate-from-crowding multiplier vs. crowding ratio

```
BRCM.K=TABLE(BRCMT,CR.K,0,5,1)                                  16,A

BRCMT=1/.95/.8/.7/.65/.65                                       16.1,T

    BRCM  - BIRTH-RATE-FROM-CROWDING MULTIPLIER
              (DIMENSIONLESS)
    BRCMT - BIRTH-RATE-FROM-CROWDING-MULTIPLIER TABLE
    CR    - CROWDING RATIO (DIMENSIONLESS)
```

Equation 17 describes the birth-rate-from-food multiplier BRFM. At zero food per capita the effect would naturally be to suppress birth rate and extinguish the population. Because the model is built around 1970 as the reference point for definitions, a food ratio of 1 represents present world conditions and produces a birth-rate-from-food multiplier of 1. It is suggested that an unlimited food supply, for example double the present world level, would tend to increase the birth rate substantially and this increase is here taken as a factor of 3. (The shape of this function is changed in WORLD2)

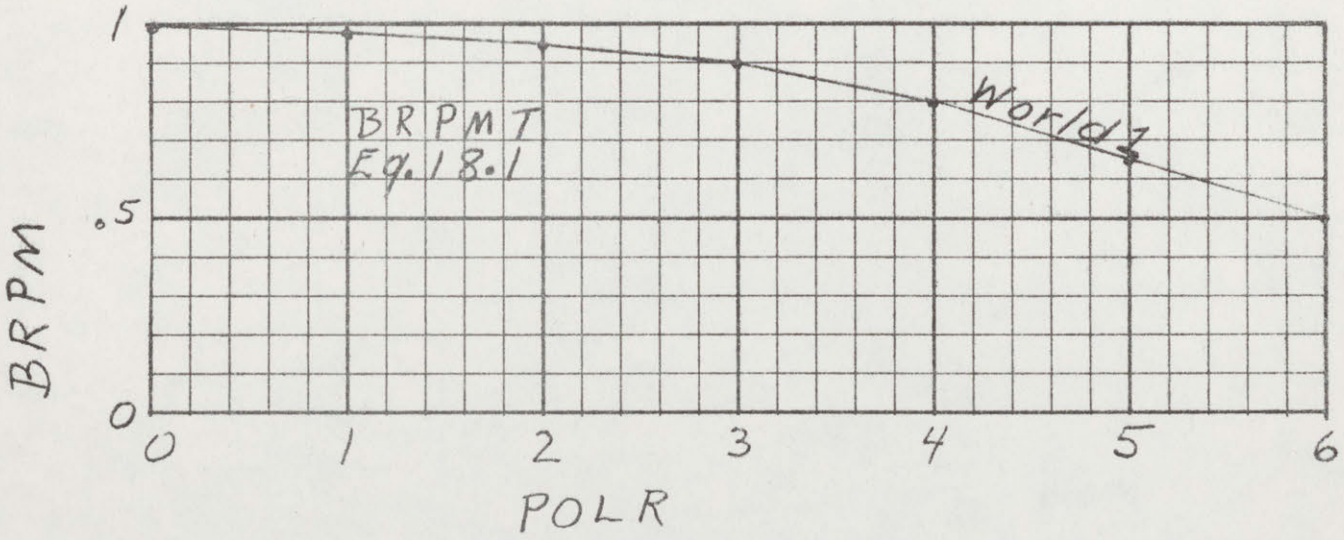
```
BRFM.K=TABLE(BRFMT,FR.K,0,2,.5)                                 17,A

BRFMT=0/.4/1/1.8/3                                              17.1,T

    BRFM  - BIRTH-RATE-FROM-FOOD MULTIPLIER
              (DIMENSIONLESS)
    BRFMT - BIRTH-RATE-FROM-FOOD-MULTIPLIER TABLE
    FR    - FOOD RATIO (DIMENSIONLESS)
```



Birth-rate-from-food multiplier
vs. food ratio

The birth-rate-from-pollution multiplier BRPM in Equation 18 represents the effect of pollution directly on the birth rate. The table suggests that the effect has been very slight up to the present levels of pollution but will become progressively greater as world pollution rises to 6 times its present level. Unity pollution level is here defined as the 1970 world level. (This table is revised in WORLD2)

```
BRPM.K=TABLE(BRPMT,POLR.K,0,6,1)                                      18,A

BRPMT=1/.98/.95/.9/.8/.65/.5                                          18.1,T

      BRPM  - BIRTH-RATE-FROM-POLLUTION MULTIPLIER
               (DIMENSIONLESS)
      BRPMT - BIRTH-RATE-FROM-POLLUTION-MULTIPLIER TABLE
      POLR  - POLLUTION RATIO (DIMENSIONLESS)
```



Birth-rate-from-pollution multiplier
vs. pollution ratio

The food ratio in Equation 19 is stated in terms of 1970 conditions. It increases if the food potential from capital investment FPCI increases, it decreases as the food-crowding multiplier FCM increases, and it decreases as the food-from-pollution multiplier FPM increases.

FR.K=(FPCI.K)(FCM.K)(FPM.K) 19,A

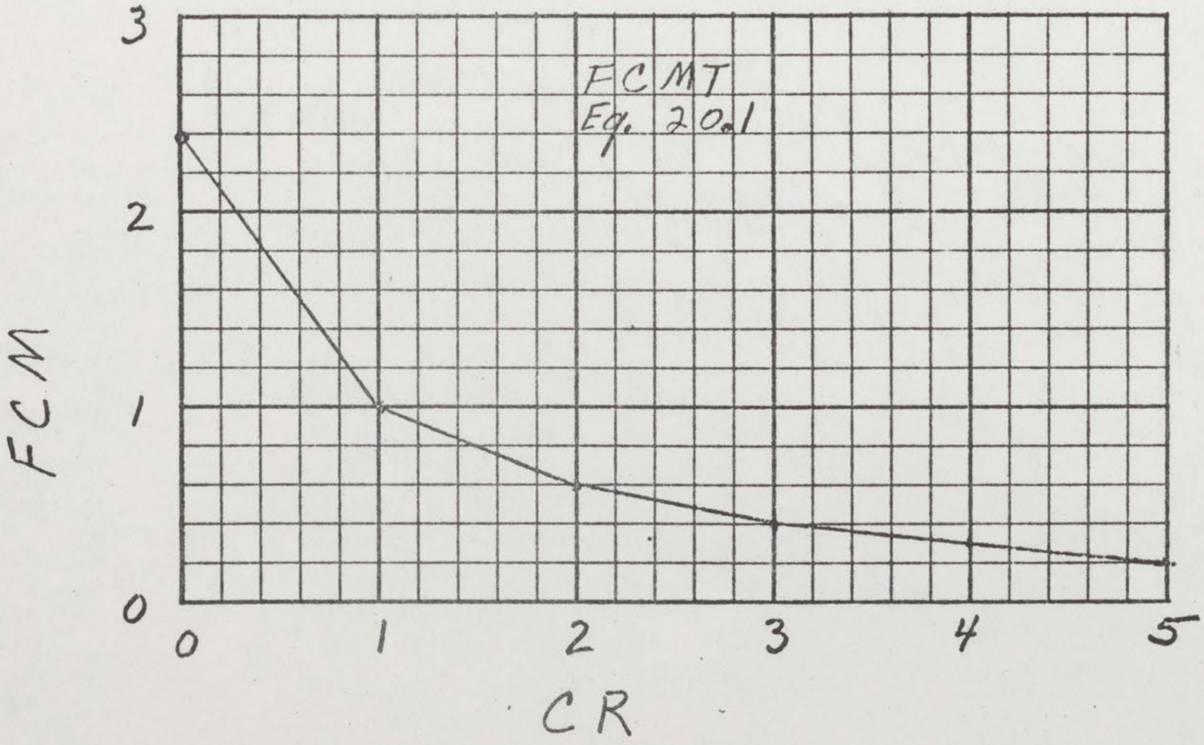
FR - FOOD RATIO (DIMENSIONLESS)
FPCI - FOOD POTENTIAL FROM CAPITAL INVESTMENT (DIMENSIONLESS)
FCM - FOOD-CROWDING MULTIPLIER (DIMENSIONLESS)
FPM - FOOD-FROM-POLLUTION MULTIPLIER (DIMENSIONLESS)

The food-from-crowding multiplier FCM in Equation 20 represents the effect of earth occupancy on the ability to grow food. A crowding ratio CR of 1 represents 1970 conditions. The table suggests that we are in a steep portion of the curve. The best agricultural areas have already been occupied. A smaller population would allow much more efficient agricultural output. As crowding continues, not only will land be occupied by people and taken away from agriculture but also the best quality of land is apt to be occupied by urbanization leaving only less suitable land for agriculture. Possibly the curve should drop even more steeply than shown here.

FCM.K=TABLE(FCMT,CR.K,0,5,1) 20,A

FCMT=2.4/1/.6/.4/.3/.2 20.1,T

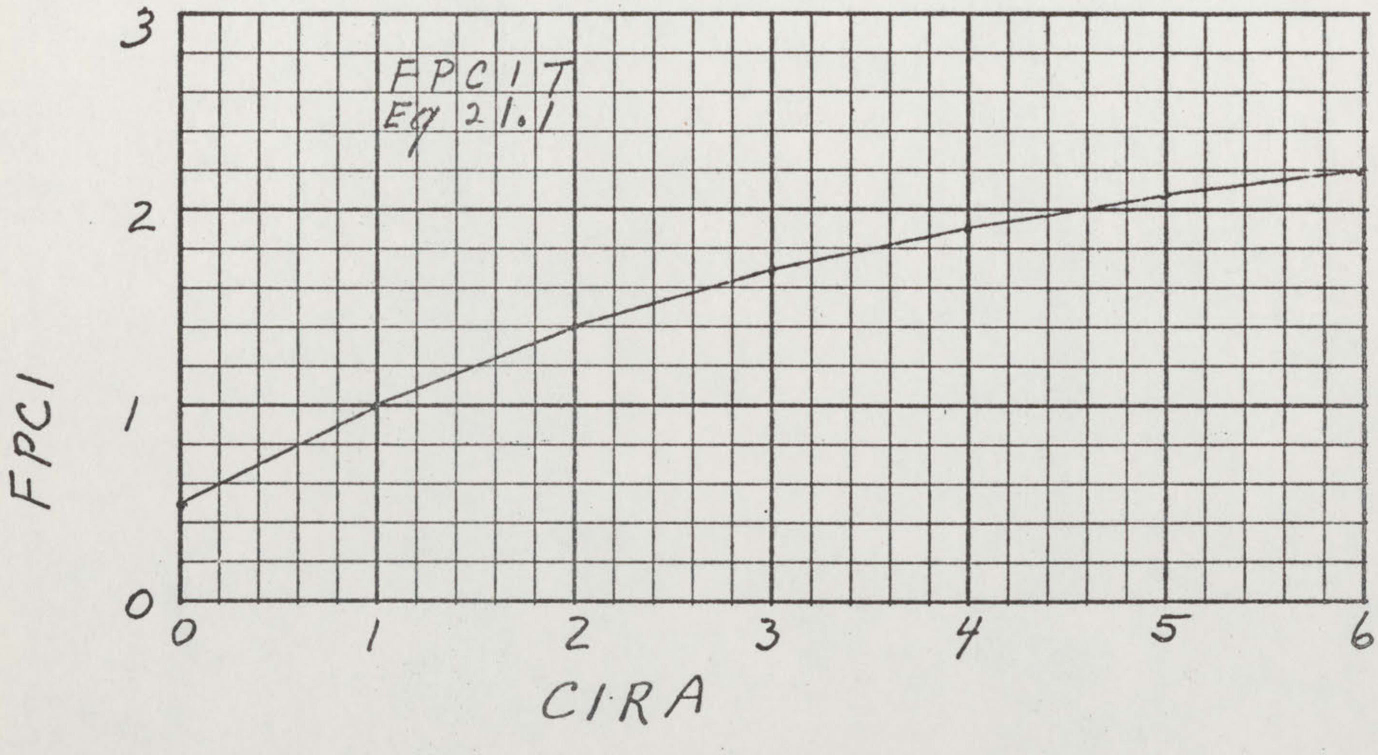
FCM - FOOD-CROWDING MULTIPLIER (DIMENSIONLESS)
FCMT - FOOD-CROWDING-MULTIPLIER TABLE
CR - CROWDING RATIO (DIMENSIONLESS)



Food-from-crowding multiplier vs. crowding ratio

Equation 21 gives the food potential from capital investment FPCI as it depends on capital investment ratio in agriculture CIRA. The table FPCIT suggests that the effect of capital investment per capita decreases with rising capital investment. The 1970 conditions are taken as unity on each axis. The initial value of .5 implies that, even with a zero capital investment, food production is still possible in the form of harvesting natural products (This relationship may not be steep enough). However, a reasonable average standard of living would be possible only if the population falls to allow the increasing productivity of better food producing land to compensate for the falling capital ratio.

```
FPCI.K=TABLE(FPCIT,CIRA.K,0,6,1)                                21,A
FPCIT=.5/1/1.4/1.7/1.9/2.05/2.2                                 21.1,T
    FPCI  - FOOD POTENTIAL FROM CAPITAL INVESTMENT
              (DIMENSIONLESS)
    FPCIT - FOOD-POTENTIAL-FROM-CAPITAL-INVESTMENT
              TABLE
    CIRA  - CAPITAL INVESTMENT RATIO IN AGRICULTURE
              (CAPITAL UNITS/PERSON)
```



Food potential from capital investment
vs. capital investment ratio in agriculture

Equation 22 establishes the capital investment ratio in agriculture CIRA in terms of the capital-investment ratio CIR and the capital-investment-in-agriculture fraction CIAF.

```
CIRA.K=(CIR.K)(CIAF.K)                                   22,A

    CIRA   - CAPITAL INVESTMENT RATIO IN AGRICULTURE
              (CAPITAL UNITS/PERSON)
    CIR    - CAPITAL-INVESTMENT RATIO (CAPITAL UNITS/
              PERSON)
    CIAF   - CAPITAL-INVESTMENT-IN-AGRICULTURE FRACTION
              (DIMENSIONLESS)
```

Equation 23 gives the capital investment ratio CIR in terms of 1970 world values. In other words, if CIR is unity, the capital investment per person is equal to the average world-wide value at the present time. Capital investment is therefore measured in units representing the present per-person amount.

```
CIR.K=CI.K/P.K                                           23,A

    CIR    - CAPITAL-INVESTMENT RATIO (CAPITAL UNITS/
              PERSON)
    CI     - CAPITAL INVESTMENT (CAPITAL UNITS)
    P      - POPULATION (PEOPLE)
```

Equation 24 accumulates the total world-wide capital investment. The initial value taken for the year 1900 is set at 0.25 as much as the initial population at that time. In other words, the capital per person in 1900 is being assumed 0.25 as great as it is in the world today. This number could be checked for plausibility. No information is at hand at the moment.

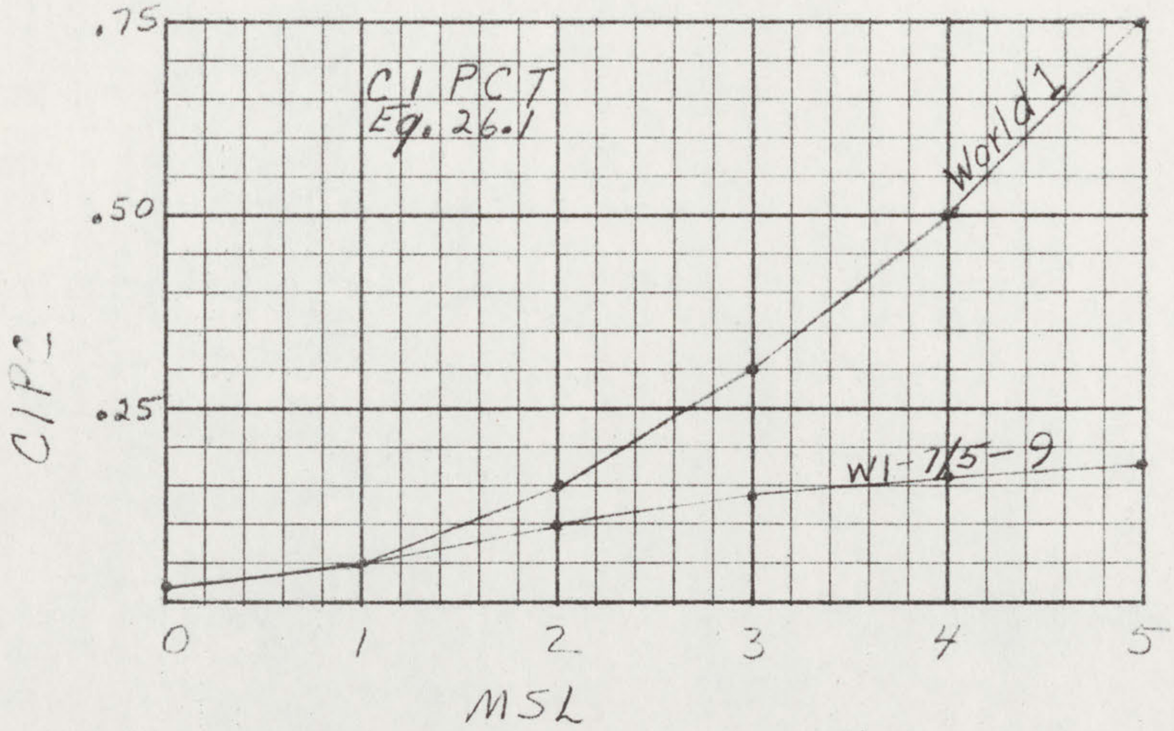
```
CI.K=CI.J+(DT)(CIG.JK-CID.JK)                            24,L

CI=CII                                                   24.1,N

CII=.4E9                                                 24.2,C

    CI     - CAPITAL INVESTMENT (CAPITAL UNITS)
    CIG    - CAPITAL-INVESTMENT GENERATION (CAPITAL
              UNITS/YEAR)
    CID    - CAPITAL-INVESTMENT DISCARD (CAPITAL UNITS/
              YEAR)
    CII    - CAPITAL INVESTMENT, INITIAL (CAPITAL UNITS)
```

Equation 25 for capital-investment generation CIG is stated in terms of the total population and the capital investment per capita CIPC.

```
CIG.KL=(P.K)(CIPC.K)(CIGC)                                  25,R
CIGC=1                                                      25.1,C
     CIG   - CAPITAL-INVESTMENT GENERATION (CAPITAL
              UNITS/YEAR)
     P     - POPULATION (PEOPLE)
     CIPC  - CAPITAL INVESTMENT PER CAPITA (CAPITAL
              UNITS/PERSON/YEAR)
     CIGC  - CAPITAL-INVESTMENT-GENERATION COEFFICIENT
              (DIMENSIONLESS)
```

Equation 26 gives the capital investment per capita CIPC in terms of the material standard of living MSL. The theory here is that part of the material standard of living can be diverted to capital accumulation. If food requires the utilization of all capital equipment and there is none left to raise the physical standard of living there is little likelihood of capital accumulation. To estimate appropriate values we again refer to the 1970 condition of the world. The existing capital investment has been stated in terms of 1 unit per person. If we assume that investment deteriorates over a period of 40 years and if we assume that capital investment today is being accumulated at twice the rate of deterioration, we would have a value of capital-investment discard normal CIDN in Equation 27 of .025 and the value of capital-investment per capita CIPC would need to be .05. This would suggest that capital investment per capita is doubling each 40 years. These figures and assumptions should be checked when possible. The table for Equation 26 suggests that as the material standard of living increases the rate of capital formation can increase even more rapidly. As human physical needs are met a larger and larger fraction of production can go into capital formation. (This relation is changed in WORLD2)

```
CIPC.K=TABLE(CIPCT,MSL.K,0,5,1)                          26,A

CIPCT=.02/.05/.15/.30/.50/.75                            26.1,T

     CIPC  - CAPITAL INVESTMENT PER CAPITA (CAPITAL
               UNITS/PERSON/YEAR)
     CIPCT - CAPITAL-INVESTMENT-PER-CAPITA TABLE
     MSL   - MATERIAL STANDARD OF LIVING (DIMENSIONLESS)
```



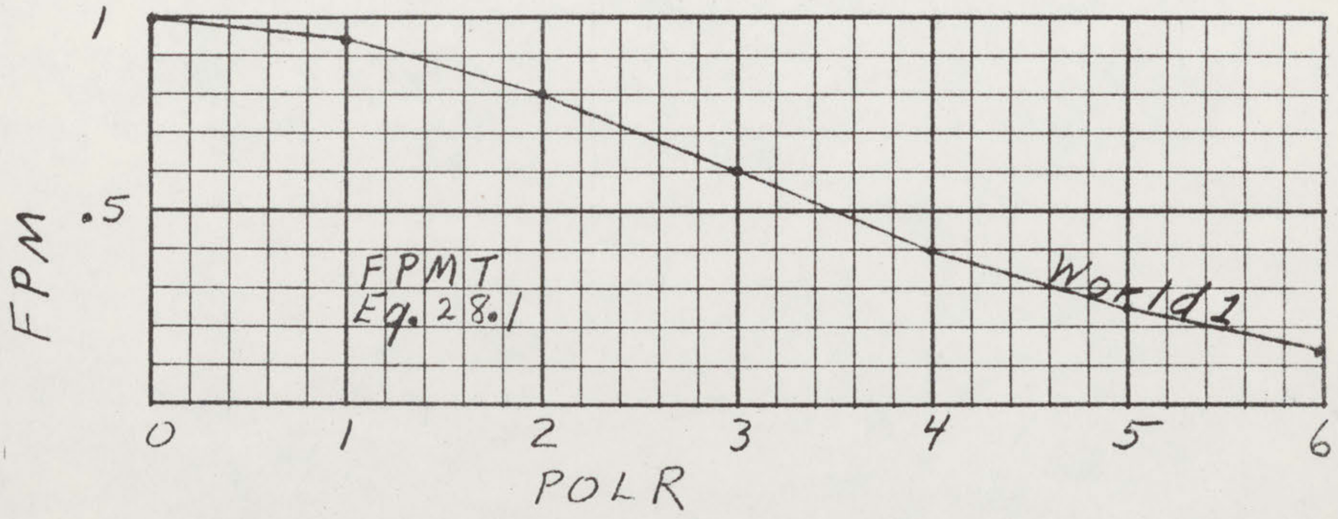
Capital investment per capita
vs. material standard of living

Equation 27 represents capital investment discard CID on the assumption of a 40 year life.

```
CID.KL=(CI.K)(CIDN)                                      27,R

CIDN=.025                                                27.1,C

     CID   - CAPITAL-INVESTMENT DISCARD (CAPITAL UNITS/
               YEAR)
     CI    - CAPITAL INVESTMENT (CAPITAL UNITS)
     CIDN  - CAPITAL-INVESTMENT DISCARD NORMAL
               (FRACTION/YEAR)
```

Equation 28 generates the food-from-pollution multiplier FPM. It suggests that very little pollution effect has yet been felt at a pollution ratio of unity which corresponds to 1970 conditions. On the other hand, if pollution increases several fold, food production is progressively and seriously affected. The figure asserts that if world-wide pollution were to rise to 6 times the present value, food production could be cut by a factor of 10. This may be too extreme but depends on the extent to which cumulative effects may occur within the environment as a result of growing pollution. (The relationship is made less extreme in WORLD2)

```
FPM.K=TABLE(FPMT,POLR.K,0,6,1)                                   28,A

FPMT=1/.95/.8/.6/.4/.25/.15                                      28.1,T

     FPM    - FOOD-FROM-POLLUTION MULTIPLIER
                (DIMENSIONLESS)
     FPMT   - FOOD-FROM-POLLUTION-MULTIPLIER TABLE
     POLR   - POLLUTION RATIO (DIMENSIONLESS)
```



Food-from-pollution multiplier
vs. pollution ratio

The pollution ratio POLR in Equation 29 gives the ratio of the total pollution in the world to a pollution standard POLS. The pollution standard POLS is in terms of per capita units in 1970. In other words, 1 unit of POLS for each person in 1970, multiplied by the 1970 world population, is the total pollution in the world environment. The value of POLS is taken as equal to the 1970 world population.

```
POLR.K=POL.K/POLS                                        29,A

POLS=3.6E9                                               29.1,C

     POLR  - POLLUTION RATIO (DIMENSIONLESS)
     POL   - POLLUTION (POLLUTION UNITS)
     POLS  - POLLUTION STANDARD (POLLUTION UNITS)
```

Equation 30 is the level equation for total pollution. Its initial value for the year 1900 is taken as .2 billion. Population at that time was taken as 1.65 billion. The initial pollution is therefore 1/8 as much per capita as in 1970.

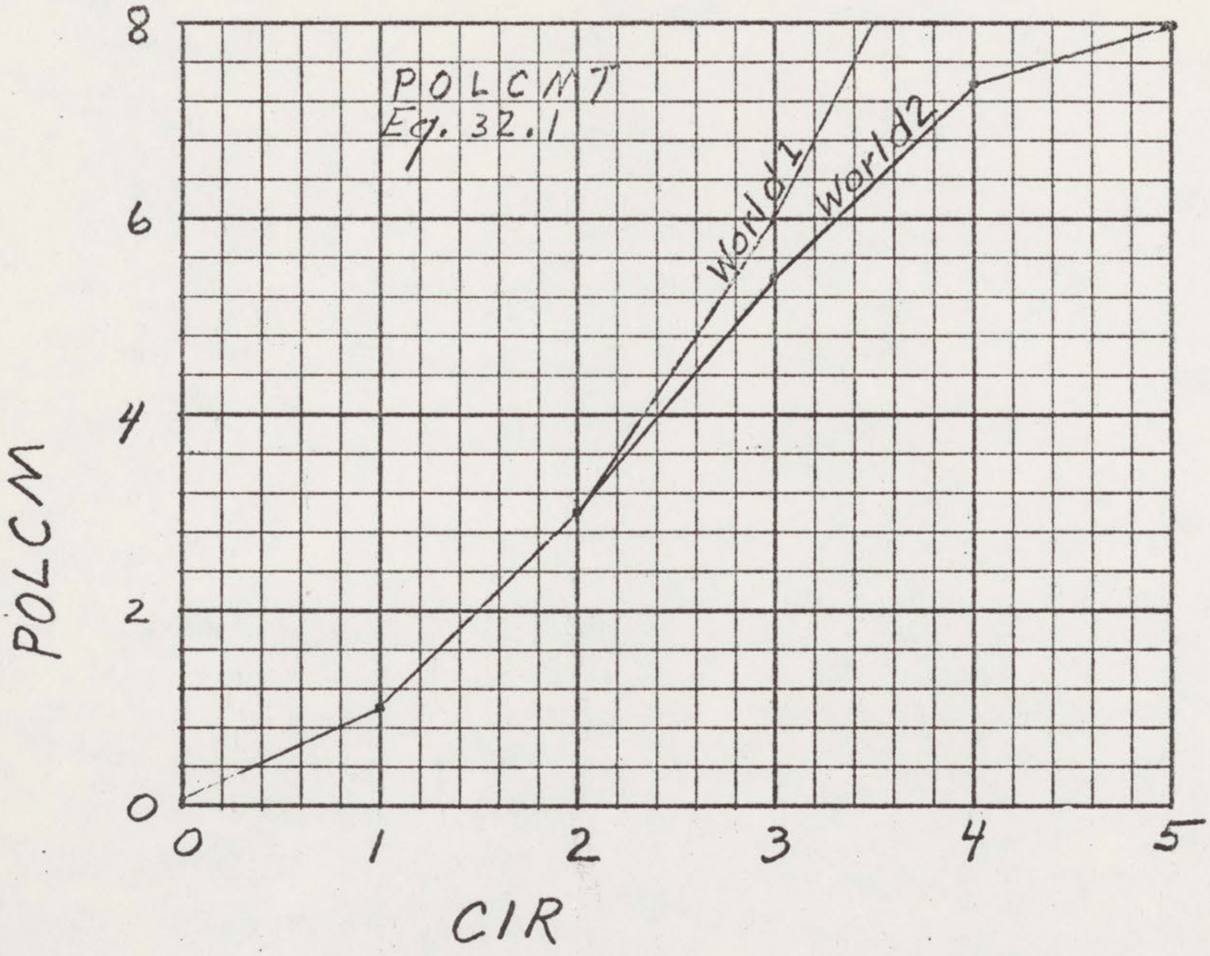
```
POL.K=POL.J+(DT)(POLG.JK-POLA.JK)                        30,L

POL=POLI                                                 30.1,N

POLI=.2E9                                                30.2,C

     POL   - POLLUTION (POLLUTION UNITS)
     POLG  - POLLUTION GENERATION (POLLUTION UNITS/YEAR)
     POLA  - POLLUTION ABSORPTION (POLLUTION UNITS/YEAR)
     POLI  - POLLUTION, INITIAL (POLLUTION UNITS)
```

The pollution generation POLG in Equation 31 is given as the population P times the pollution normal POLN per capita times a multiplier derived from the capital investment ratio CIR. To arrive at a value of POLN we must consider how large the pollution reservoir is in terms of pollution-duration time. It appears that such pollutants as smoke may be dissipated by the environment in a matter of days. On the other hand, many pollutants such as insecticides and industrial wastes and the pollution in lakes may persist for years. We will use a pollution clean-up time-constant of 1 year as representing present day conditions. If POLCM is unity, then the value of POLN should also be unity to produce equal inflow and outflow rates at the pollution reservoir under 1970 conditions.

```
POLG.KL=(P.K)(POLN)(POLCM.K)                                  31,R
POLN=1                                                        31.1,C

     POLG   - POLLUTION GENERATION (POLLUTION UNITS/YEAR)
     P      - POPULATION (PEOPLE)
     POLN   - POLLUTION NORMAL (POLLUTION UNITS/PERSON/
                YEAR)
     POLCM  - POLLUTION-FROM-CAPITAL MULTIPLIER
                (DIMENSIONLESS)
```

The pollution-from-capital multiplier POLCM in Equation 32 represents the influence of capital equipment on the creation of pollution. As the capital investment per capita of population rises, the per capita generation of pollution rises extremely steeply. We take here a per capita pollution generation in the absence of any capital equipment as being .05 of the normal 1970 value. By the time per capita capital investment has risen to 3 times the 1970 value we are assuming that pollution generation rises 6 times. (This is changed in WORLD2)

```
POLCM.K=TABLE(POLCMT,CIR.K,0,5,1)                             32,A
POLCMT=.05/1/3/6/10/15                                        32.1,T

     POLCM  - POLLUTION-FROM-CAPITAL MULTIPLIER
                (DIMENSIONLESS)
     POLCMT- POLLUTION-FROM-CAPITAL-MULTIPLIER TABLE
     CIR    - CAPITAL-INVESTMENT RATIO (CAPITAL UNITS/
                PERSON)
```

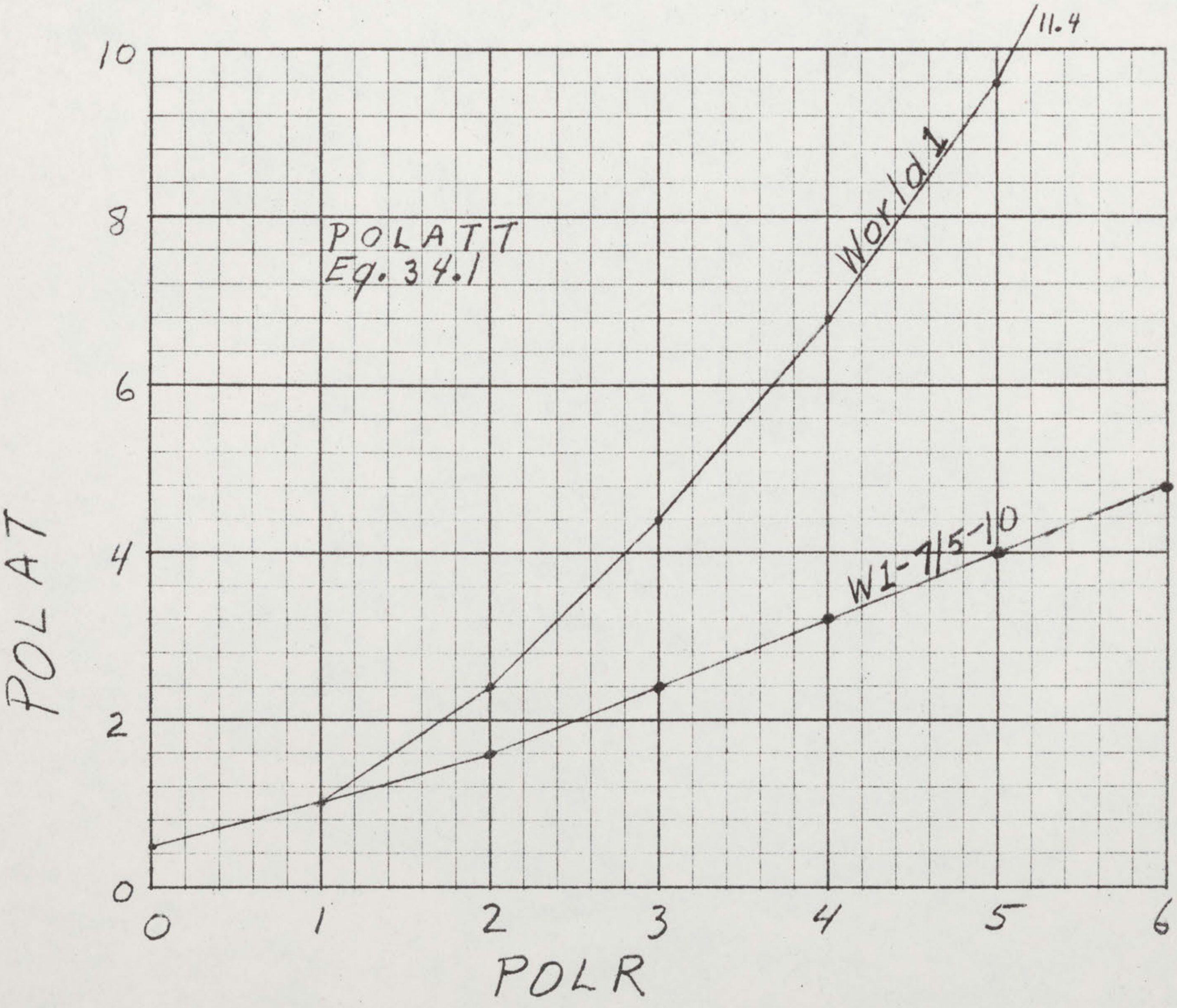


Pollution-from-capital multiplier
vs. capital-investment ratio

The pollution-absorption POLA in Equation 33 will operate from a variable time constant POLAT which depends on the pollution ratio PR. The assumption here is that, as the environment becomes more and more heavily loaded with pollution, it will become less able to cope with additional pollution and the time-constant of clean-up will grow longer. Equation 33 represents the pollution-absorption or clean-up rate.

```
POLA.KL=POL.K/POLAT.K                                          33,R

      POLA   - POLLUTION ABSORPTION (POLLUTION UNITS/YEAR)
      POL    - POLLUTION (POLLUTION UNITS)
      POLAT  - POLLUTION-ABSORPTION TIME (YEARS)
```

Equation 34 gives the pollution-absorption time POLAT as a function of the pollution ratio POLR. There probably is little data on this relationship and I have no good information. The table assumes that, when the pollution ratio rises by a factor of 6 from 1970 conditions, the pollution-absorption time will rise from one year to ten years. This is based on the assumption that there will be corresponding ecological damage which will slow down the normal pollution-absorption processes. Furthermore, as the pollution rate rises it is probable that the pollution products will be of kinds which disappear more slowly. (This table is made less sensitive in WORLD2)



Pollution-absorption time
vs. polution ratio

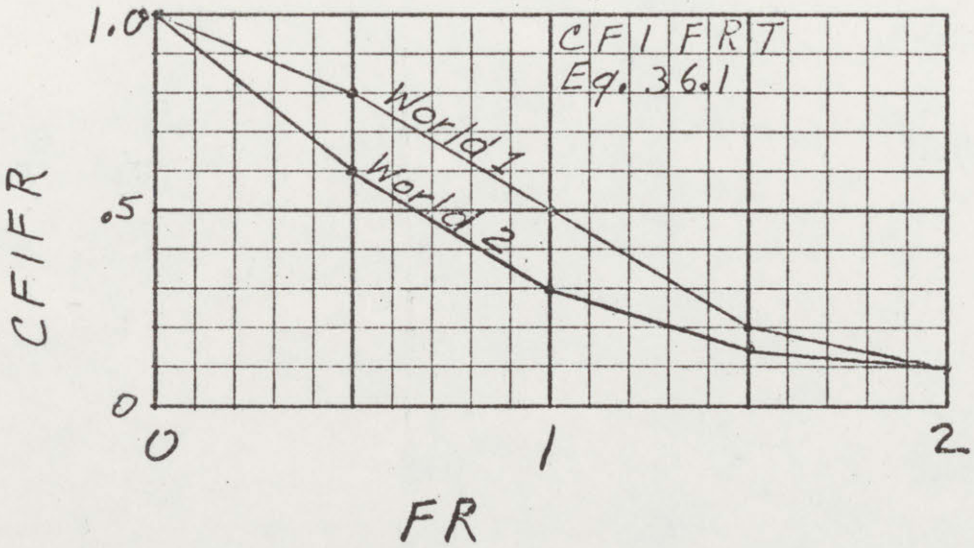
```
POLAT.K=TABLE(POLATT,POLR.K,0,6,1)                         34,A

POLATT=.5/1/2.4/4.4/6.8/9.6/11.4                           34.1,T

    POLAT  - POLLUTION-ABSORPTION TIME (YEARS)
    POLATT- POLLUTION-ABSORPTION-TIME TABLE
    POLR   - POLLUTION RATIO (DIMENSIONLESS)
```

In Equation 35 the capital-investment-in-agriculture fraction CIAF is gradually adjusted in response to the food ratio. As the adequacy of food increases, the fraction of total capital devoted to agriculture is reduced so that the remainder of capital investment can be devoted to the material standard of living. Equation 35 is a first order time delay with a delay time of 30 years in making the adjustment in response to the food ratio condition.

```
CIAF.K=CIAF.J+(DT/CIAFT)(CFIFR.J-CIAF.J)                   35,L

CIAF=CIAFI                                                 35.1,N

CIAFI=.5                                                   35.2,C

CIAFT=30                                                   35.3,C

    CIAF  - CAPITAL-INVESTMENT-IN-AGRICULTURE FRACTION
              (DIMENSIONLESS)
    CIAFT - CAPITAL-INVESTMENT-IN-AGRICULTURE-FRACTION
              ADJUSTMENT TIME (YEARS)
    CFIFR - CAPITAL FRACTION INDICATED BY FOOD RATIO
              (DIMENSIONLESS)
    CIAFI - CAPITAL-INVESTMENT-IN-AGRICULTURE FRACTION,
               INITIAL (DIMENSIONLESS)
```

Equation 36 gives the relationship which is here assumed between food ratio FR and the capital-fraction-indicated-by-food ratio CFIFR. Other formulations might be considered in which the deviation from normal food ratio establishes not an equilibrium value for CIAF but instead a continuous rate of change in CIAF. (In WORLD2 an input is added from quality of life) Equation 36 reflects the pressures to shift capital investment to agriculture as food pressures rise. At zero food all capital investment would be shifted toward food growing. As the average food condition for the world as a whole improves, it will of course happen unequally and those areas and individuals who are meeting their food needs will begin to shift some of the productive assets into non-agricultural channels.

```
CFIFR.K=TABLE(CFIFRT,FR.K,0,2,.5)                                36,A
CFIFRT=1/.8/.5/.2/.1                                              36.1,T
     CFIFR - CAPITAL FRACTION INDICATED BY FOOD RATIO
               (DIMENSIONLESS)
     CFIFRT- CAPITAL-FRACTION-INDICATED-BY-FOOD-RATIO
               TABLE
     FR    - FOOD RATIO (DIMENSIONLESS)
```

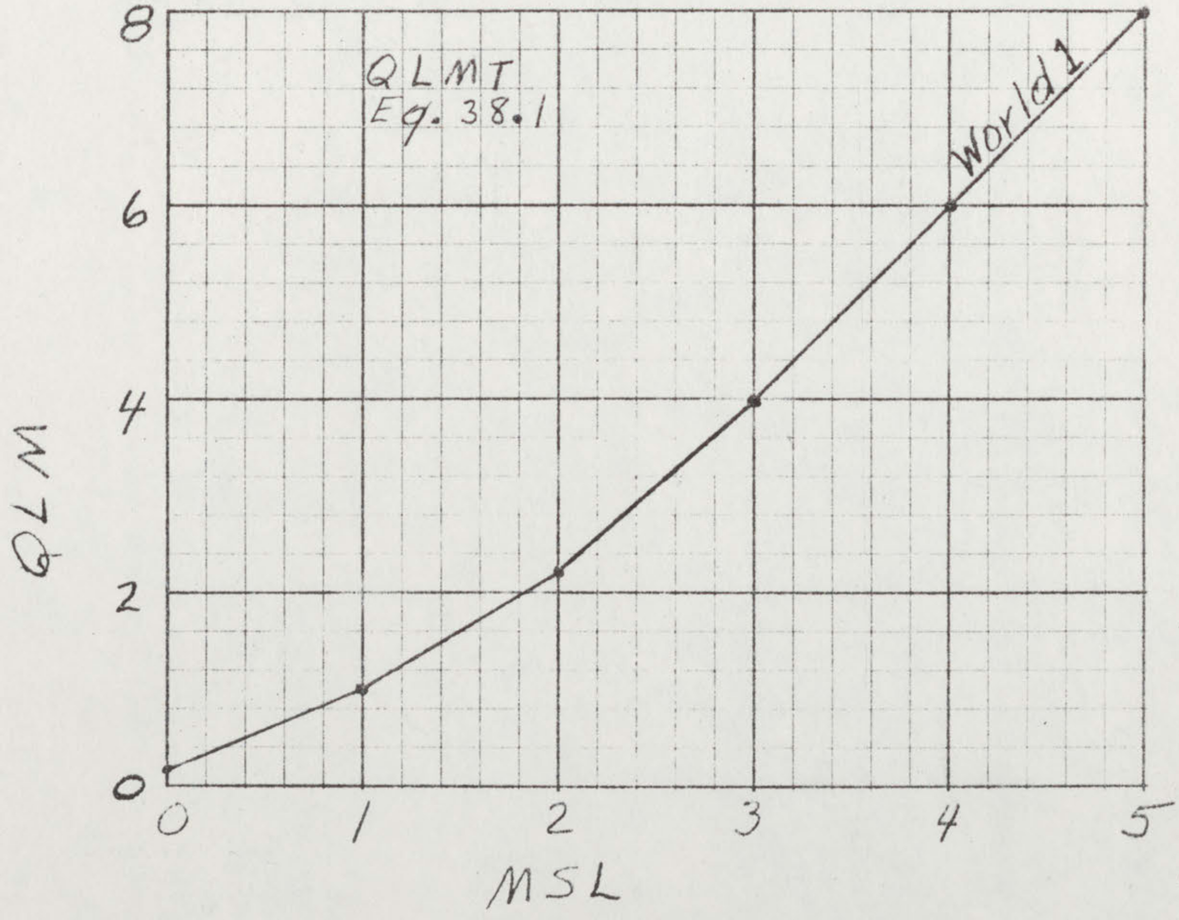


Capital fraction indicated by food ratio
vs. food ratio

Equation 37 for quality of life QL is a measure of human satisfaction. It can be taken as a utility or performance measure of the system. The composite quality of life measure is obtained by combining a coefficient QLS representing the average quality of life in 1970, with multipliers representing inputs from the material standard of living, crowding, food supply, and pollution.

```
QL.K=(QLS)(QLM.K)(QLC.K)(QLF.K)(QLP.K)                  37,S

QLS=1                                                   37.1,C

   QL    - QUALITY OF LIFE (SATISFACTION UNITS)
   QLS   - QUALITY-OF-LIFE STANDARD (SATISFACTION
            UNITS)
   QLM   - QUALITY OF LIFE FROM MATERIAL
            (DIMENSIONLESS)
   QLC   - QUALTIY OF LIFE FROM CROWDING
            (DIMENSIONLESS)
   QLF   - QUALITY OF LIFE FROM FOOD (DIMENSIONLESS)
   QLP   - QUALITY OF LIFE FROM POLLUTION
            (DIMENSIONLESS)
```

Equation 38 describes quality of life from material standard of living QLM. It rises progressively more steeply. (But the reasons here were wrong and the shape is changed in WORLD2)



Quality of life from material
vs. material standard of living

QLM.K=TABLE(QLMT,MSL.K,0,5,1) 38,A

QLMT=.2/1/2.2/4/6/8 38.1,T

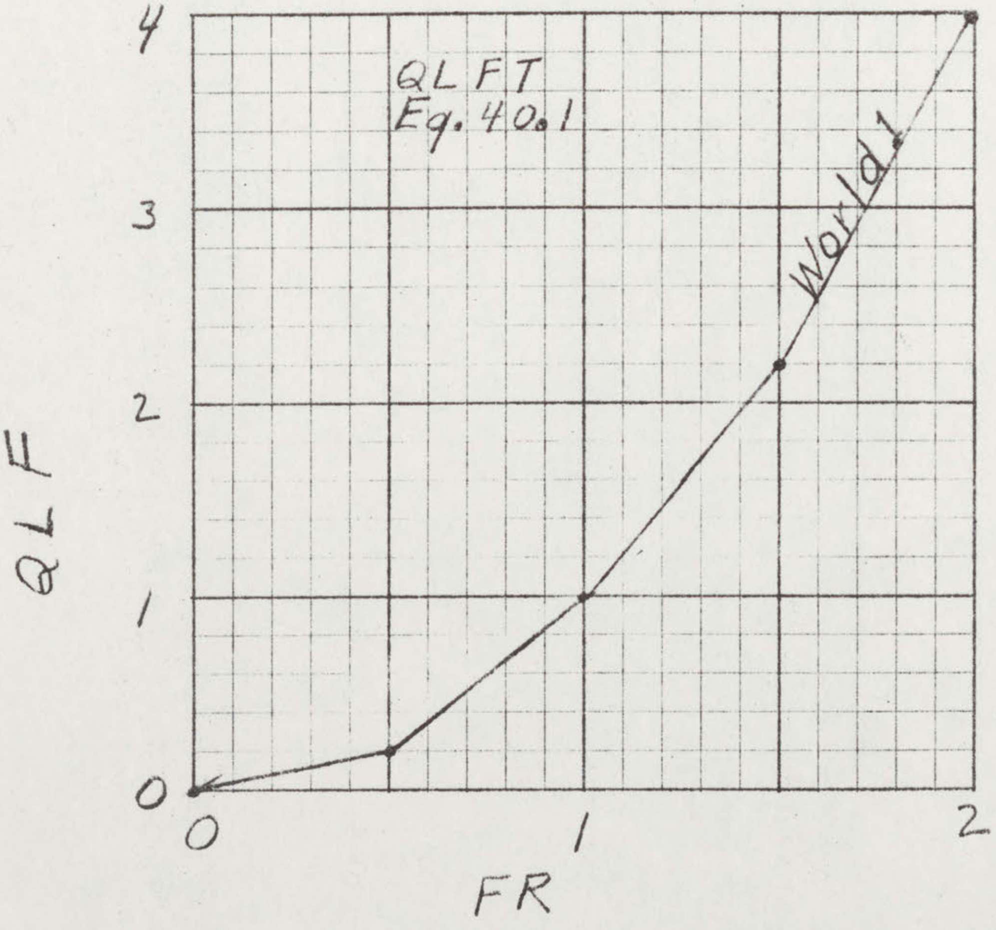
QLM - QUALITY OF LIFE FROM MATERIAL (DIMENSIONLESS)
QLMT - QUALITY-OF-LIFE-FROM-MATERIAL TABLE
MSL - MATERIAL STANDARD OF LIVING (DIMENSIONLESS)

Equation 39 represents the contribution to quality of life from crowding QLC. The crowding ratio of unity represents 1970 conditions with a unity output to the total quality of life. The curve reflects the belief that crowding has already substantially reduced the quality of life and that substantial further reductions will occur if the crowding rises a factor of 5 above that at the present time. One should remember that this measure of quality of life represents the influence of crowding for its own sake. The effect of crowding on the food supply and on pollution are represented in other variables.

Quality of life from crowding
vs. crowding ratio

```
QLC.K=TABLE(QLCT,CR.K,0,5,.5)                              39,A

QLCT=2/1.3/1/.75/.55/.45/.38/.3/.25/.22/.2                 39.1,T

    QLC    - QUALTIY OF LIFE FROM CROWDING
               (DIMENSIONLESS)
    QLCT   - QUALITY-OF-LIFE-FROM-CROWDING TABLE
    CR     - CROWDING RATIO (DIMENSIONLESS)
```

Equation 40 measures the contribution to quality of life from food adequacy QLF. (This is also a function which should rise more steeply at first and then gradually level out as the food becomes more than sufficient. The incorrect shape here is altered in WORLD2)

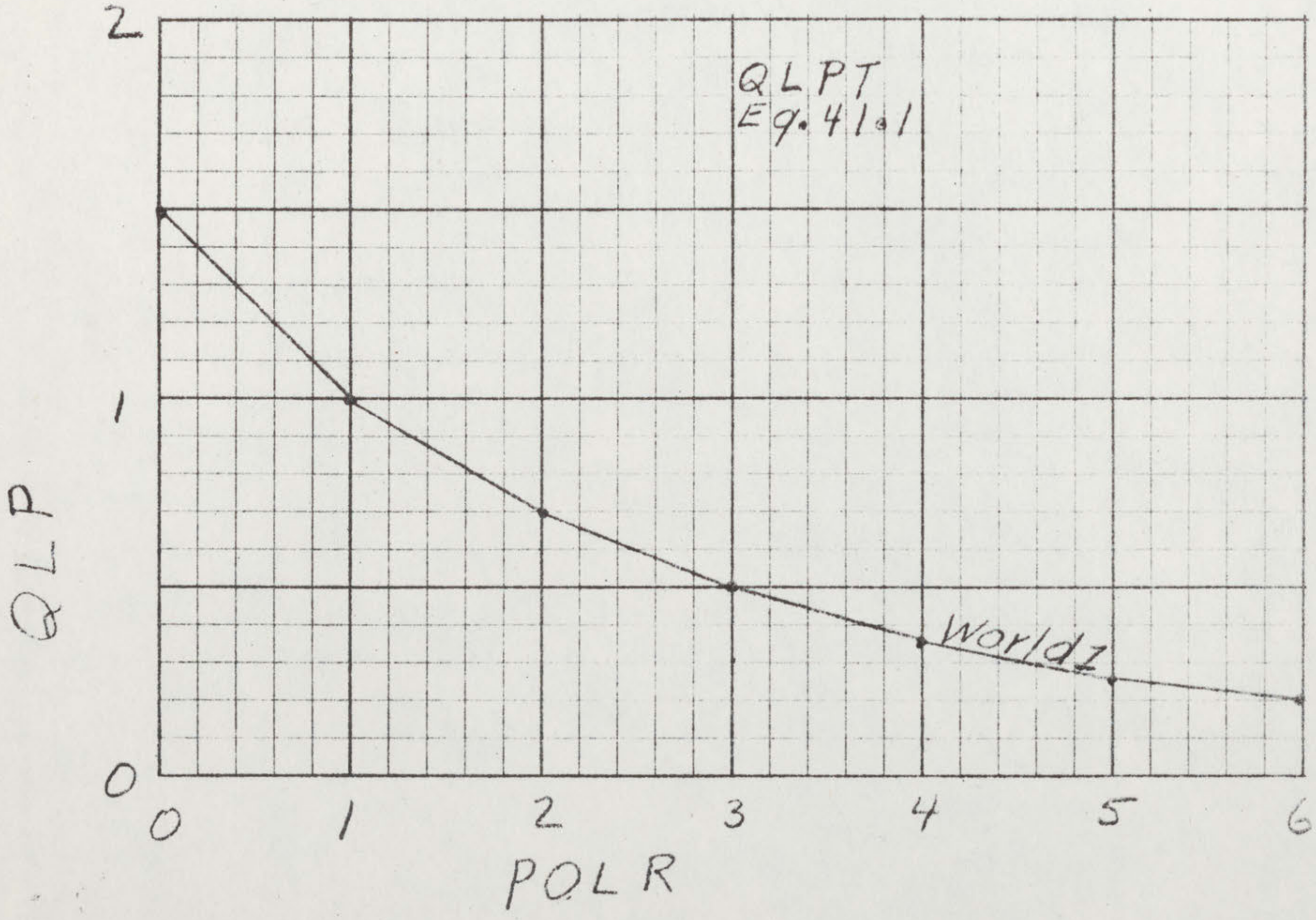


Quality of life from food
vs. food ratio

```
QLF.K=TABLE(QLFT,FR.K,0,2,.5)                              40,A

QLFT=0/.2/1/2.2/4                                          40.1,T

    QLF    - QUALITY OF LIFE FROM FOOD (DIMENSIONLESS)
    QLFT   - QUALITY-OF-LIFE-FROM-FOOD TABLE
    FR     - FOOD RATIO (DIMENSIONLESS)
```

Equation 41 is the contribution to quality of life from environmental pollution QLP. As pollution rises the quality of life will continue to be degraded. (The sensitivity of this curve is changed in WORLD2)

```
QLP.K=TABLE(QLPT,POLR.K,0,6,1)                             41,A

QLPT=1.5/1/.7/.5/.35/.25/.2                                41.1,T

    QLP    - QUALITY OF LIFE FROM POLLUTION
               (DIMENSIONLESS)
    QLPT   - QUALITY-OF-LIFE-FROM-POLLUTION TABLE
    POLR   - POLLUTION RATIO (DIMENSIONLESS)
```



Quality of life from pollution
vs. pollution ratio

The formulation of the WORLD1 model is now complete. The listing of model equations are on the following pages. The dynamic implications can be determined by processing the model through the DYNAMO compiler. Two input typing errors were identified by DYNAMO and were corrected before the first simulation output was obtained.

```
PAGE 1       FILE WORLD1      WORLD DYNAMICS 1              07/15/70   1415.2

  0.1    *       WORLD DYNAMICS 1
  1      L     P.K=P.J+(DT)(BR.JK-DR.JK)
  1.1    N     P=PI
  1.2    C     PI=1.65E9
  2      R     BR.KL=(P.K)(BRN)(BRFM.K)(BRMM.K)(BRCM.K)(BRPM.K)
  2.1    C     BRN=.045
  3      A     BRMM.K=TABLE(BRMMT,MSL.K*BRMS,0,15,2.5)
  3.1    T     BRMMT=.7/1.5/2.1/2.2/1.8/1.1/.8/
  3.2    C     BRMS=1
  4      A     MSL.K=(MSLN)(ECIR.K)
  4.1    C     MSLN=1
  5      A     ECIR.K=(CIR.K)(1-CIAF.K)(NREM.K)
  6      A     NREM.K=TABLE(NREMT,NRFR.K,0,1,.25)
  6.1    T     NREMT=0/.15/.5/.85/1
  7      A     NRFR.K=NR.K/NRI
  8      L     NR.K=NR.J+(DT)(-NRUR.JK)
  8.1    N     NR=NRI
  8.2    C     NRI=900E9
  9      R     NRUR.KL=(P.K)(NRUN)(MSL.K)
  9.1    C     NRUN=1
 10      R     DR.KL=(P.K)(DRN)(DRMM.K)(DRPM.K)(DRFM.K)(DRCM.K)
 10.1    C     DRN=.025
 11      A     DRMM.K=TABHL(DRMMT,MSL.K*DRMS,0,5,.5)
 11.1    T     DRMMT=2/1.4/1/.8/.7/.6/.53/.5/.5/.5/.5
 11.2    C     DRMS=1
 12      A     DRPM.K=TABLE(DRPMT,POLR.K,0,6,1)
 12.1    T     DRPMT=1/1.1/1.3/1.6/2.2/3.4/6
 13      A     DRFM.K=TABHL(DRFMT,FR.K,0,2,.25)
 13.1    T     DRFMT=30/2.4/1.5/1.2/1/.9/.8/.73/.7
 14      A     DRCM.K=TABLE(DRCMT,CR.K,0,5,1)
 14.1    T     DRCMT=1/1.1/1.3/1.6/2.1/3
 15      A     CR.K=(P.K)/(LA*PDN)
 15.1    C     LA=135E6
 15.2    C     PDN=265
 16      A     BRCM.K=TABLE(BRCMT,CR.K,0,5,1)
 16.1    T     BRCMT=1/.95/.8/.7/.65/.65
 17      A     BRFM.K=TABLE(BRFMT,FR.K,0,2,.5)
 17.1    T     BRFMT=0/.4/1/1.8/3
 18      A     BRPM.K=TABLE(BRPMT,POLR.K,0,6,1)
 18.1    T     BRPMT=1/.98/.95/.9/.8/.65/.5
 19      A     FR.K=(FPCI.K)(FCM.K)(FPM.K)
 20      A     FCM.K=TABLE(FCMT,CR.K,0,5,1)
 20.1    T     FCMT=2.4/1/.6/.4/.3/.2
 21      A     FPCI.K=TABLE(FPCIT,CIRA.K,0,6,1)
 21.1    T     FPCIT=.5/1/1.4/1.7/1.9/2.05/2.2
 22      A     CIRA.K=(CIR.K)(CIAF.K)
 23      A     CIR.K=CI.K/P.K
 24      L     CI.K=CI.J+(DT)(CIG.JK-CID.JK)
 24.1    N     CI=CII
 24.2    C     CII=.4E9
 25      R     CIG.KL=(P.K)(CIPC.K)(CIGC)
 25.1    C     CIGC=1
 26      A     CIPC.K=TABLE(CIPCT,MSL.K,0,5,1)
 26.1    T     CIPCT=.02/.05/.15/.30/.50/.75
 27      R     CID.KL=(CI.K)(CIDN)
 27.1    C     CIDN=.025
 28      A     FPM.K=TABLE(FPMT,POLR.K,0,6,1)
 28.1    T     FPMT=1/.95/.8/.6/.4/.25/.15
```

```
29      A      POLR.K=POL.K/POLS
29.1    C      POLS=3.6E9
30      L      POL.K=POL.J+(DT)(POLG.JK-POLA.JK)
30.1    N      POL=POLI
30.2    C      POLI=.2E9
31      R      POLG.KL=(P.K)(POLN)(POLCM.K)
31.1    C      POLN=1
32      A      POLCM.K=TABLE(POLCMT,CIR.K,0,5,1)
32.1    T      POLCMT=.05/1/3/6/10/15
33      R      POLA.KL=POL.K/POLAT.K
34      A      POLAT.K=TABLE(POLATT,POLR.K,0,6,1)
34.1    T      POLATT=.5/1/2.4/4.4/6.8/9.6/11.4
35      L      CIAF.K=CIAF.J+(DT/CIAFT)(CFIFR.J-CIAF.J)
35.1    N      CIAF=CIAFI
35.2    C      CIAFI=.5
35.3    C      CIAFT=30
36      A      CFIFR.K=TABLE(CFIFRT,FR.K,0,2,.5)
36.1    T      CFIFRT=1/.8/.5/.2/.1
37      S      QL.K=(QLS)(QLM.K)(QLC.K)(QLF.K)(QLP.K)
37.1    C      QLS=1
38      A      QLM.K=TABLE(QLMT,MSL.K,0,5,1)
38.1    T      QLMT=.2/1/2.2/4/6/8
39      A      QLC.K=TABLE(QLCT,CR.K,0,5,.5)
39.1    T      QLCT=2/1.3/1/.75/.55/.45/.38/.3/.25/.22/.2
40      A      QLF.K=TABLE(QLFT,FR.K,0,2,.5)
40.1    T      QLFT=0/.2/1/2.2/4
41      A      QLP.K=TABLE(QLPT,POLR.K,0,6,1)
41.1    T      QLPT=1.5/1/.7/.5/.35/.25/.2
41.4    NOTE
41.5    NOTE   CONTROL CARDS
41.6    NOTE
42      C      DT=.2
42.1    C      LENGTH=2100
42.2    C      PLTPER=2
42.3    N      TIME=1900
42.6    PLOT   P=P/POLR=2/CI=C/FR=F/CR=R/MSL=M/QLM=L/QL=Q/CIAF=A/NR=N
```

CHAPTER 3

WORLD1 Computer Runs

First Computer Run - WORLD1-STD.

The standard run from the World1 Model is the first computer run obtained after the model formulation. (See the accompanying package of computer runs.) It was initialized according to the earlier discussion for population and other estimated conditions at the year 1900. We see that population rose exponentially to the year 1970. Food per capita is almost constant during the first 70-year period, while the fraction of total capital devoted to agriculture declines. Pollution rises off the bottom axis just before 1940 and begins to curve upward after 1960. As this was printed line-by-line on the typewriter, behavior looked encouraging for a first result.

Then a surprising and unexpected development occurred. Between 1970 and 1980 pollution rises rapidly, food per capita falls, and the population declines precipitously. This first computer run was obtained about 11:30 PM on July 4, 1970, after devoting the entire day to generating the first version of the world dynamics model. Needless to say, as a bed-time story it was not a soothing image of the future.

The next day the first WORLD1-STD. computer run was studied. Ten other runs with changed parameters were made to examine sensitivity and behavior of the system.

The following paragraphs discuss the WORLD1-STD. computer run.

Pollution by the year 1990 rises to a value of 24 where a value of 1 was defined as actual pollution in the year 1970. The model run in 1970 shows a pollution level of 2 instead of 1 and a population of more than 5.5 billion which is higher than the 3.6 billion which was taken in the formulation as the 1970 value.

The model run shows a pollution recovery over a period of about 50 years from 1990 to 2040. At this point, there is a resurgence in population and a secondary pollution crisis, which again depresses population to a still lower value.

A first approach to evaluating such a computer run might be to examine each of the plotted curves and the scales which were automatically selected for the plotting to see if any obviously unreasonable behavior is occurring. Population is on a scale from 0 to 8 billion and, as already observed, the population in 1970 has risen further than in real life. For a better match to reality, this should be investigated later and parameters changed to give a proper historical growth rate.

The natural resource curve N is on the scale from 500 to 900 billion and shows a fairly steady depletion rate from 1940 to the end of the computer run. Steady depletion during the period of very low population is at first surprising. Natural resource utilization rate NRUR in Equation 9 is proportional to population but it is also proportional to the material standard of living MSL which depends on the effective-capital-investment ratio ECIR. Capital investment CI remains high and the material standard of living MSL increases as the population decreases. This raises some question about the appropriateness of using MSL directly in Equation 9. Perhaps the resource utilization per capita should have a table curving to saturate as the material standard of living rises as high as is sensible in serving human needs.

The curve for capital investment CI plotted with the symbol C shows behavior which should be questioned. During the population collapse after 1970, the accumulation of capital investment increases and even accelerates as we see at 1990 when the upward slope of the capital investment curve increases. Although population is falling throughout the interval, capital investment peaks at about the year 2000. At first thought this seems wrong.

In capital accumulation, we can hypothesize various conditions. If population is uniformly depressed and this happens equally in all economic categories, then the upward surge in capital accumulation is clearly unreasonable. On the other hand, if we assume that those population areas with a high intensity of capital investment utilization are not so seriously affected by the environmental crisis, then it may well be that, on the average basis for the world as a whole, the capital investment per person increases, capital accumulation per person does rise, and the continued upward trend of total capital investment can continue. We certainly want to go back to a careful consideration of the shape of the table for CIPCT in Equation 26.1.

The pollution ratio POLR plotted as 2 shows the sudden upsurge starting in 1960 and peaking in 1990. The reason for this involves the way in which pollution is generated and absorbed. Pollution generation POLG in Equation 31 is proportional to population. It also increases with the capital-investment ratio CIR. In other words, the higher the capital investment per person, the higher is the pollution generation rate per person. On the other hand, the pollution-absorption time POLAT coming from Equation 34 depends on the total pollution in the environment. As the total pollution rises, the time constant for absorption gets longer. In other words, we are assuming here that more pollution interferes with the pollution clean-up process. Clearly this does happen under many circumstances. One tends to reach a run-away situation where pollution continues to be generated and the accumulating pollution slows down the absorption rate. The parameters around this whole process now need to be re-examined to see if they are reasonable quantitatively and also reasonable as to their shapes of curvature.

The pollution ratio POLR rises to a value of about 24. This means 24 times the pollution load in the environment as exists actually in 1970. The value is far higher than was anticipated because the table functions that receive POLR extended only to a value of 6. This leads to much of the over-running of the table functions reported at the beginning of the computer run and to be discussed later.

Pollution peaks at about 1990 where the pollution generation falls to the pollution absorption rate. Environmental recovery then takes place over the following 50 years.

An interesting thing happens in the period from 2030 to the year 2060. A "Golden Age" for the very small population develops as a result of high capital per capita, a very high food ratio, and a high material standard of living.

But we note that the lessons of history have not been well learned, and a secondary environmental crisis occurs beginning with the up-turn at 2050 with a peak at 2065. This occurs because of the very high capital investment ratio CIR which indicates that the small population is highly industrialized. One might speculate on the reality of this and consider whether the relationships of capital and population are reasonable.

The capital-investment-in-agriculture fraction CIAF, plotted with the symbol A, shows an interesting behavior by falling through the first 70 years and then rising sharply as the food supply declines and capital is re-allocated into food production.

The quality of life QL is, like the other variables, here scaled automatically and has been suppressed into the lower axis for most of the run because of the high peak in quality of life occurring at the year 2040. The value at that point reaches 90 which means 90 times the average quality of life experienced in the world in 1970. This suggests that we look at the table functions which generate quality of life in Equations 38, 39, 40, and 41. In Equation 38 the quality of life from the material standard of living QLM curves upward which clearly is incorrect. Additions to the material standard of living should encounter decreasing returns and the curvature of the function should be in the other direction.

The quality of life from crowding QLC in Equation 39 should probably level out rather than becoming steeper as the curve approaches the zero value of CR. At some low value of population the quality of life ceases to increase as the population becomes still smaller.

In the quality-of-life-from-food function in Equation 40.1, again we see that the curvature is incorrect. The incremental value of additional food should decline so that the curve will rise steeply at the left and then more gradually as food increases. In the quality-of-life-from-pollution table, Equation 41.1 for QLPT, again the curve should probably become horizontal as it approaches the left edge of the diagram. At some point pollution becomes so slight that the quality of life will be insensitive to it.

When we examine the curve for material standard of living MSL, plotted as M, there is a peak in the region of year 2030 which rises to a value of nearly 50. This is unexpected, but may be a simple numerical consequence of the large residue of capital equipment and the small population. Observing that the ratio can become this large, we need to trace through the resulting table functions which affect birth rate, death rate, capital investment generation, and the direct connection to natural resource useage rate to see if the results are reasonable. It would appear that a table function should be inserted between Equations 4 and 9 so that the high material standard of living, which may be artificial and meaningless, is not used to deplete natural resources without a table function to reflect the proper suppression or saturating effect.

Regarding natural resource consumption, we can form some estimate of its maximum per capita rate. From Peccei's diagram in Successo it appears that about 20% or less of the world's population live in Europe and North America. If we roughly assume that all of the world's capital investment lies in those areas, then total capital investment would need to increase 5 times to bring other areas up to the same level. If human inclinations were such as to cause capital investment in the advanced countries to double, then a factor of 10 increase in the world as a whole would not be unreasonable in bringing the entire world up to the more advanced sectors of society in the advanced countries. A material standard of living rising to a value of 10 might be imaginable as a goal if other considerations did not come to dominate.

We note that the crowding ratio CR, plotted with the symbol R, is on a scale from 0 to 0.2. In other words, the crowding ratio never reaches the 1970 actual level even though the 1970 model population is above the actual. There is an error in the equation formulation at some point.

In the standard run we note a long decline in the capital-investment-in-agriculture fraction CIAF, plotted as A. This looks more like a decay time-constant representing an unbalanced initial condition than it does like a fundamental behavior of the system. A second run, 7/4-1, changed the initial value of the capital-investment-in-agriculture fraction from 0.5 to 0.3. There was no significant change in behavior from the standard run except that the capital-investment-in-agriculture fraction CIAF remained approximately constant at the initial value indicating its equilibrium with the growth processes in the system. Unless other changes to the model require a further change here, the value of CIAFI should be changed to 0.3.

Examination of Table Over-run Indicators:

At the beginning of the computer run is a list of many over-runs in the non-linear tables indicating that system variables moved outside of the expected range. See the accompanying Figures 3-1 and 3-2. These all occur in the year 1976 and later. The first five tables are above maximum range because pollution has risen above the expected level. The next five in various ways result from capital investment per capita rising higher than anticipated. In the year 2026 pollution comes back within bounds and in 2030 the food ratio rises above that allowed in the tables. In fact, the food ratio continues to rise to a value of more than 5; the tables allow for a value of 2. Probably in terms of world-wide food consumption a factor of 2 above average 1970 values is smaller than the world might desire. This is especially true if food is measured in terms of quality as well as mere quantity.

The preceding analysis of the first computer run was dictated on July 9, after the computer runs through World1-7/5-12 had been made on July 5. The preceding analysis is more thorough than was actually done before the succeeding computer runs were made. Had the analysis been made thoroughly, as it should have been, a different sequence of computer runs would probably have been made. However, to preserve the continuity of the actual development of the study, the computer runs will now be discussed in the sequence in which they actually occurred.

Parameter Changes in WORLD1:

Run World1-7/5-1 Here the capital-investment-generation coefficient CIGC has been reduced from 1.0 to 0.5. This will reduce the generation of capital investment by a factor of 2 if all other conditions remain unchanged. Population is on the same scale as before

```
PAGE 2   WORLD1   WORLD DYNAMICS 1    07/15/70   1134.7
TYPE CHANGES
run std

ABOVE RANGE OF TABLE BRPMT AT TIME = 1976.

ABOVE RANGE OF TABLE FPMT AT TIME = 1976.

ABOVE RANGE OF TABLE DRPMT AT TIME = 1976.

ABOVE RANGE OF TABLE QLPT AT TIME = 1976.

ABOVE RANGE OF TABLE POLATT AT TIME = 1976.

ABOVE RANGE OF TABLE POLCMT AT TIME = 1981.

ABOVE RANGE OF TABLE FPCIT AT TIME = 1989.

ABOVE RANGE OF TABLE QLMT AT TIME = 1989.

ABOVE RANGE OF TABLE CIPCT AT TIME = 1989.

ABOVE RANGE OF TABLE BRMMT AT TIME = 2007.

IN RANGE OF TABLE BRPMT AT TIME = 2026.

IN RANGE OF TABLE FPMT AT TIME = 2026.

IN RANGE OF TABLE DRPMT AT TIME = 2026.

IN RANGE OF TABLE QLPT AT TIME = 2026.

IN RANGE OF TABLE POLATT AT TIME = 2026.

ABOVE RANGE OF TABLE BRFMT AT TIME = 2031.

ABOVE RANGE OF TABLE QLFT AT TIME = 2031.

ABOVE RANGE OF TABLE CFIFRT AT TIME = 2031.

IN RANGE OF TABLE BRMMT AT TIME = 2045.

IN RANGE OF TABLE FPCIT AT TIME = 2049.

IN RANGE OF TABLE QLMT AT TIME = 2051.

IN RANGE OF TABLE CIPCT AT TIME = 2051.

IN RANGE OF TABLE BRFMT AT TIME = 2052.

IN RANGE OF TABLE QLFT AT TIME = 2052.

IN RANGE OF TABLE CFIFRT AT TIME = 2052.

ABOVE RANGE OF TABLE BRPMT AT TIME = 2053.

ABOVE RANGE OF TABLE FPMT AT TIME = 2053.

ABOVE RANGE OF TABLE DRPMT AT TIME = 2053.
```

Fig. 3-1

```
PAGE 3   WORLD1-STD   WORLD DYNAMICS 1     07/15/70   1134.7

ABOVE RANGE OF TABLE QLPT AT TIME = 2053.

ABOVE RANGE OF TABLE POLATT AT TIME = 2053.

ABOVE RANGE OF TABLE QLMT AT TIME = 2055.

ABOVE RANGE OF TABLE CIPCT AT TIME = 2055.

ABOVE RANGE OF TABLE FPCIT AT TIME = 2059.

ABOVE RANGE OF TABLE BRMMT AT TIME = 2076.

IN RANGE OF TABLE BRPMT AT TIME = 2092.

IN RANGE OF TABLE FPMT AT TIME = 2092.

IN RANGE OF TABLE DRPMT AT TIME = 2092.

IN RANGE OF TABLE QLPT AT TIME = 2092.

IN RANGE OF TABLE POLATT AT TIME = 2092.

ABOVE RANGE OF TABLE BRFMT AT TIME = 2097.

ABOVE RANGE OF TABLE QLFT AT TIME = 2097.

ABOVE RANGE OF TABLE CFIFRT AT TIME = 2097.
```

Fig. 3-2

and reaches nearly 7 billion. Capital investment is on a 0 to 4 billion scale, instead of the original 0 to 8 billion scale. In the standard run, when population crosses 4 billion at 1950, the capital investment has risen to about 2.5 billion. In this run, when population crosses 4 billion at 1990, the capital investment has a value of about 1.5. This computer run is similar to the standard during the period of exponential growth. It immediately raises the question of what happens beyond the year 2100. An extended computer run should be made to examine what eventually happens. Because there are no heavy transients from a system collapse, we see in this computer run a better idea of what some of the variables were doing, which in the standard run were suppressed because of the automatic scaling. Food per capita gradually declines from 1.3 to 1.2 during the 200 years. Quality of life QL, plotted with the letter Q, rises at first to a peak of 1.7 and declines to a value of 1.1 as the food decreases and pollution rises. Again we see the initial transient during the first 60 years in which the capital-investment-in-agriculture fraction declines from an initial value which is too high.

Run World1-7/5-2 This run combines the changes from runs W1-7/4-1 and W1-7/5-1. It reduces the capital-investment-generation coefficient CIGC from 1.0 to 0.5 and reduces the initial value of capital-investment-in-agriculture fraction CIAFI from 0.5 to 0.25 of the total capital investment. There is relatively little change except that the transient due to initial conditions in the capital-investment-in-agriculture fraction is now in the opposite direction. It starts too low and rises. This causes the food ratio initially to be lower than the proper value for the growth phase of the system and food ratio rises initially before it starts to decline. Several scales have changed, but values at the end of the run seem about the same as in W1-7/5-1.

Run World1-7/5-3 Here the conditions are identical to the previous computer run, except the length has been extended to the year 2400 and the plotting interval increased from 2 years to 5 years. We see that the preceding computer runs were heading into the same kind of pollution and population crisis as the standard model run, except that the time of the crisis is delayed to the period after the year 2100. A short term oscillation involving food and pollution is evident in the interval after the year 2150. This looks like a technical instability, involving one or two loops within the model, which probably arises from too high a sensitivity to small changes in variables. This will not be explored further at the present time. To do so would require obtaining additional information in this area and plotting a number of variables to an expanded scale. We note that the capital-investment-in-agriculture fraction CIAF is also involved in the oscillation and it suggests that the significant loops involve food, the capital-investment-in-agriculture fraction CIAF, and some interaction with capital generation and pollution generation and possibly even with population. The suppressed scale does not tell us if population is involved.

Run World1-7/5-4 In the standard run, we noted that population growth was more rapid between 1900 and 1970 than it actually has been. Reducing the birth rate normal BRN might affect the rate of population growth. In this computer run, it has been reduced from 0.045 to 0.025. In other words, the normal birth rate has been reduced to equal the normal death rate. In this run we see an initial transient in which population drops slightly during the first 20 years. This is probably due to a set of incompatible initial conditions, probably involving the capital-investment-in-agriculture fraction CIAF being too high, and the initial value of capital investment CI being too low. Also, we note that the population in 1970 is now about 2.3 billion, which is less than the expected 3.6 billion. Population growth still does occur, and it suggests that we sould examine the "normal" values in our various table functions to see if they are indeed running around unity values as originally intended. It is clear from this run that they are shifted sufficiently that birth rate exceeds death rate, even though the normal values are the same. The general shape of the population and pollution crises are still essentially the same (note that scales again have shifted in values). The collapse has been postponed until the year 2000. Again we see the upsurge in capital investment as population falls, suggesting that the formulation is not satisfactory with respect to capital accumulation.

Run World1-7/5-5 This is the same as the previous run with the capital-investment-in-agriculture fraction reduced from 0.5 to 0.3. One sees that the system is more nearly in equilibrium at the beginning, and there is no evidence (at least within the less sensitive scales selected) of a population decline initially. The population peak rises to a higher value and at a somewhat earlier time for the pollution and population collapse. This computer run tells us relatively little that is new, and could have been omitted if one had come more thoughtfully to the essential points of the system where the dominant behavior had already been identified.

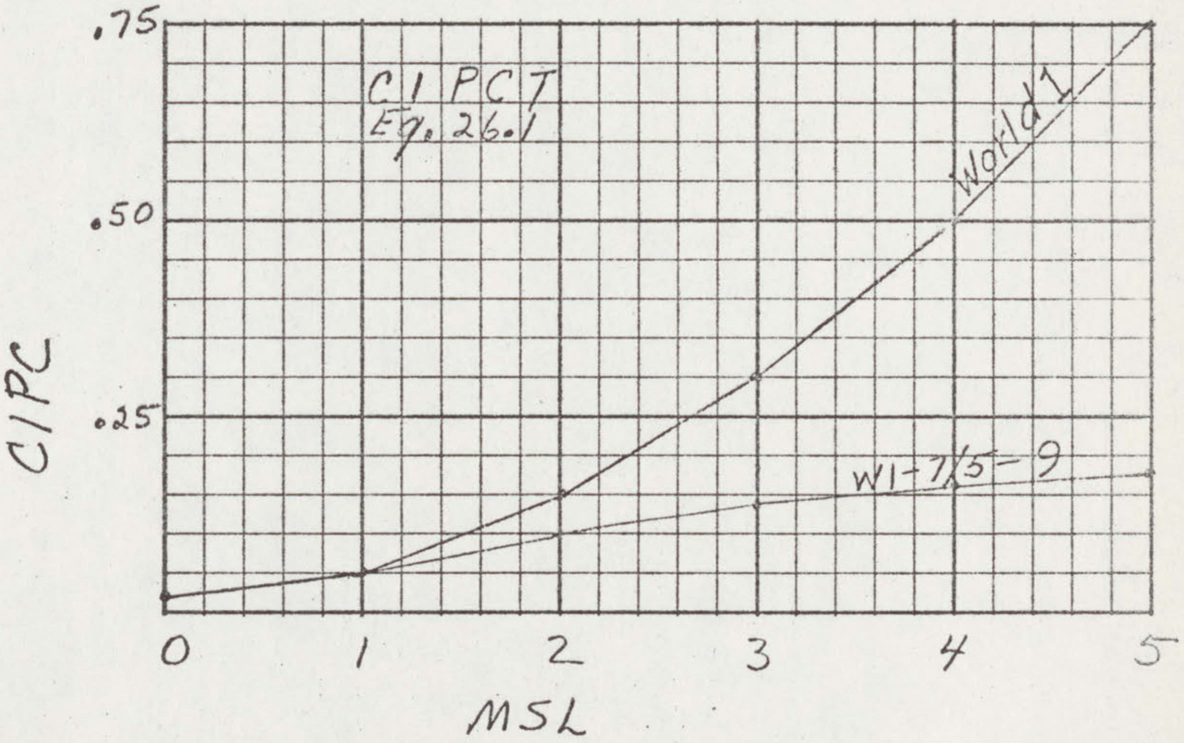
Run World1-7/5-6 This is an exact duplicate of the previous run, except that the length has been shortened to stop at year 2000 and the plotting interval has been reduced. This was done to avoid the scale suppressions created by the wide variations in the last part of the previous run so that the quality of life QL, plotted as Q, could be examined. We see here that it starts at a value of 1.5, rises to a peak of slightly over 3 in the middle of the computer run, and falls to near 0 during the population collapse.

Run World1-7/5-7 Here we examine the effect of pollution by changing the pollution standard POLS from 3.6 billion to 10 billion. This means that actual pollution must rise to about 3 times the previous values in order to produce the same effect on the remainder of the system. Comparisons should be made with the World1-STD computer run. The principal effect here from assuming that the world is only 1/3 as sensitive to pollution, is to delay by 50 years the time when pollution causes an environmental collapse. Peak population rises to 12 billion. Peak pollution rises to about 18 times the 1970 conditions.

Run World1-7/5-8 Here we return to the observation made in discussing the standard model behavior that the crowding ratio was not showing correct values. Examination of the original arithmetic discloses an error. The population density normal PDN should have had a value of 26.5 instead of 265. The correct value of 26.5 is inserted in this computer run for comparison with the standard run. All influences from the crowding multiplier now become more effective. Population growth is substantially slowed, and we see that the various multipliers and ratios will need to be re-examined if population growth is to be adjusted to the historical rate. One should observe here that adjustments of these various parameter values and tables have little effect on the gross overall behavior of the system. In other words, population still grows to a crisis point followed by a population collapse. We have not yet examined the assumption surrounding the pollution sybsystem from which the population collapse is being triggered. In due course, this must be done. Here we see a return of the slight population decline at the beginning of the time period. All remaining computer runs will retain the correction in PDN as we now begin to explore changes to correct absurdities and oversights in the model.

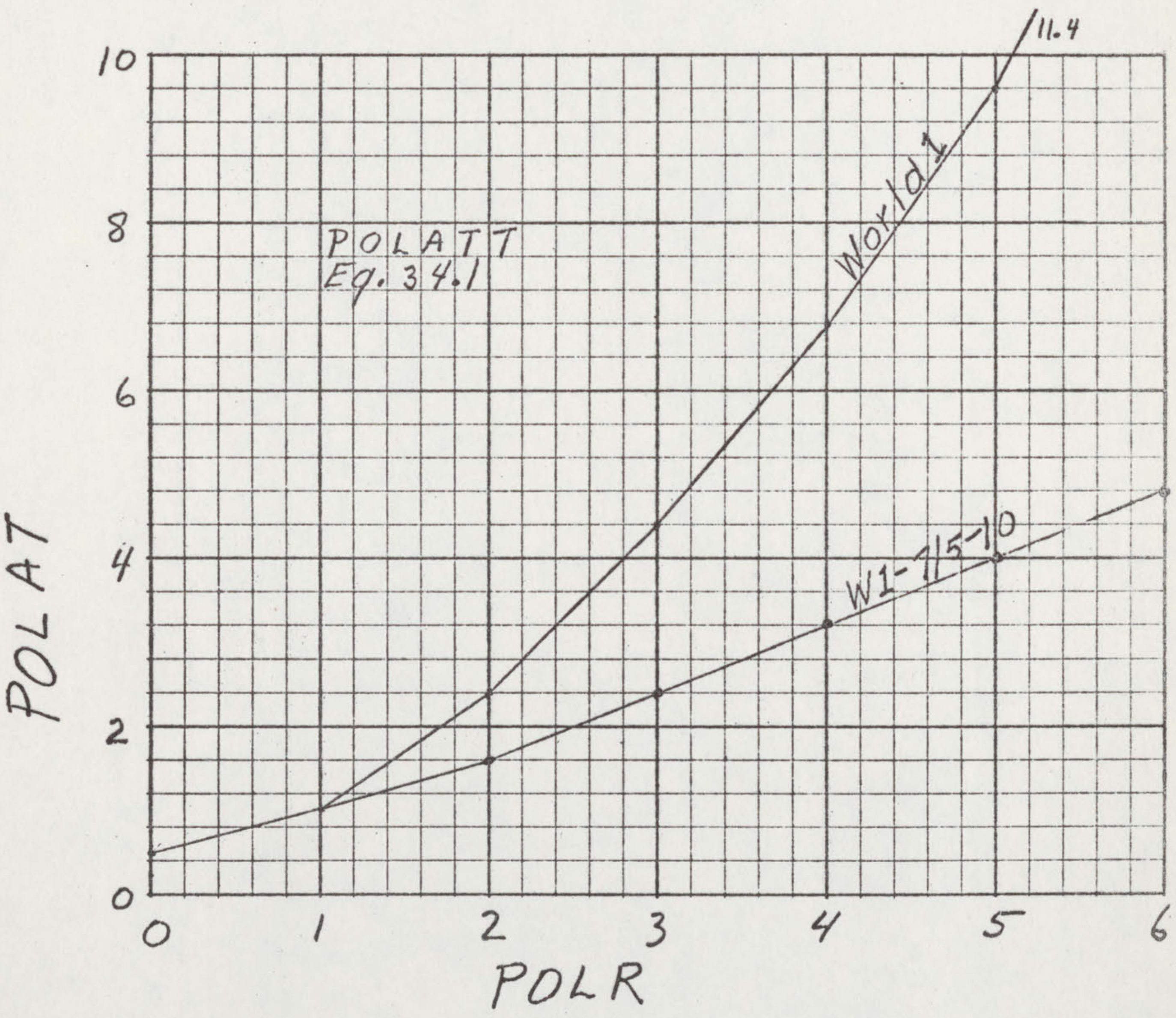
Run World1-7/5-9 A form of questionable behavior noted in previous computer runs is the tendency for capital investment to surge upward as population falls. This is because of the upward sweeping shape of the table in Equation 26.1. This is probably not consistent with human behavior. At some level, capital investment will be so high on a per capita basis, that further accumulation will be meaningless. The response, instead of curving upward, should saturate. The normal value for 1970 has been taken as .05 for the capital investment per capita CIPC. In this computer run, as shown in Figure 3-3, the value saturates at .18 or slightly more than 3 times as high, when the material standard of living MSL rises to a value of 5. The results should be compared with run 7/5-8, because the corrected value of population density normal PDN is still present. The peak values of capital investment at the time of peak population are both about 3 billion units of capital investment. Peak population and timing of the population collapse are essentially the same. However, we see that the behavior of capital investment after the peak is substantially altered and in a more reasonable direction. The upsurge in capital investment as population falls has been eliminated.

Run World1-7/5-10 It is evident from the computer runs that the pollution sector is one of the most critical areas of the model since it triggers the population collapse as the level of pollution rises. One reason for the rapid rise in pollution is the assumption that the pollution absorption process slows down as the total pollution in the environment increases. The table changes in Equation 34.1 for this run are shown in Figure 3-4. The present (new) and original values of parameters and tables are shown above the upper left corner of the computer



Capital investment per capita
vs. material standard of living

Fig. 3-3



Pollution-absorption time
vs. polution ratio

Fig. 3-4

runs.

The pollution-absorption time POLAT is decreased for higher pollution ratios. The effect is to delay the time of population collapse and to make it more gradual. One sees after the year 2020 that population remains constant for a period of time, while capital accumulation continues and pollution continues to rise until it eventually reaches the point where absorption does not match pollution generation and the sudden peaking reasserts itself. For this computer run, the maximum pollution-absorption time is a factor of 4 greater than the conditions assumed normal in 1970. In other words, when the pollution ratio POLR equals 6, then the pollution adjustment time POLAT reaches a maximum value of 4.8.

Run World1-7/5-11 This run is not included in the printed set. It is the same as Run 7/5-10, except that the initial value of capital investment in agriculture fraction CIAFI is reduced from 0.5 to 0.3. Behavior is essentially as in the previous run, except for the transient changes at the beginning during the first 40 years.

Run World1-7/5-12 This computer run is not included. It is the same as 7/5-11, except that the birth rate normal BRN was increased from 0.45 to .060. The change in behavior is not substantial.

CHAPTER 4

MODIFICATIONS OF THE MODEL.

Model WRLD1A as Revised from WORLD1.

A number of misconceptions and errors have now been identified in the World1 model. The following discussion describes considerations in moving toward a revised model, WRLD1A, as a next step toward the model for use by the Club of Rome Seminar in the afternoon workshop sessions. The following notes were made while going through the original World1 model line by line and identifying any changes which have been indicated by the preceding analysis and computer runs.

Equation 3. The original relationship for the birth-rate-material multiplier BRMM in Equation 3 was probably based on incorrect reasoning. The rise in the birth rate shown as a result of a higher material standard of living actually reflects the net difference between birth rate and death rate. Since we are handling the two separately, it is probable that the birth rate multiplier should start high and gradually decline, indicating that birth rate is highest in the societies with the lowest material standard of living. Effects of hospitals, medical services, and the other influences that are considered here as a part of the material standard of living would all be more directly evident in the reduction of death rate. The new table for BRMMT in Equation 3.1 is therefore a very substantially different shape. It is hard here to estimate the effect of material standard of living independent of the other influences on birth rate. Generally speaking, the countries with the higher material standard of living are also ones in which the concept of crowding and the effect of a crowding multiplier are also influential. Since only about 20% of the world population now has a high material standard of living, this multiplier at the present time is probably not far from its maximum. The value of the multiplier should be unity for 1970 when the average material standard of living is taken as unity. We will assume that birth rate could rise 50% as the material standard of living declines, and that it could eventually fall 50% if the entire world were at a high material level.

Equation 4. The variable "material standard of living" MSL may be somewhat misleading under circumstances arising in the preceding runs where the capital investment of the world tends to remain high, even where population declines rapidly. Under some of these circumstances the variable is best looked upon as simply the ratio of non-agricultural capital to the population, without the implication that it defines standard of living.

The equation, as originally written, does not recognize that only a part of the capital investment is left after allocating a fraction to agriculture. The equation should be rewritten to divide ECIR by MSLN. The value of MSLN will then be 0.7 capital units per person which represents the amount normally available on the 1970 basis of measurement. The units of measure for MSL are then dimensionless.

Equation 9. The natural-resource-usage rate NRUR should be modified to permit introduction of a table function between Equations 4 and 9. Natural-resource-usage rate will not rise indefinitely as MSL rises; saturation in the natural-resource-usage rate should occur. This will be introduced in a new equation numbered Equation 42. In Equation 9, we replace MSL with the new variable natural-resource-from-material multiplier NRM.

Equation 42. We will place this equation at the end of the model so that the original equations need not be re-numbered, and their indentity thereby confused. This non-linear table function relates the material standard of living MSL to its effect on natural resource usage rate. As the material standard of living rises, the use of natural resources per capita will increase. However, this will not happen without limit, so the effect might be as shown in the table.

Equation 12. This equation for the dependence of death rate on pollution appears to be unsatisfactory. Multiplying the death rate by a factor of 6 for a pollution ratio which is only 6 times that of 1970 is probably too severe a relationship. Therefore, in Equation 12.1 the relation is changed so the death rate increases by a factor of 30. This is a smaller sensitivity than previously indicated.

Equation 13. In re-examining the relationship between death rate and food supply, it appears that the relationship might be more sensitive than originally shown. The world at the present time seems poised in a marginal food situation where insufficient food is causing substantial ill health and indirectly increasing death rates. A slightly steeper relationship is being inserted in the World2 model modification.

Equation 14. The death-rate-from-crowding multiplier DRCM will be left as originally inserted. However, if we consider all of the problems that come from crowding, including war as well as increases in deaths from disease, crime, and other crowding-related causes, one might argue that this curve should be somewhat steeper.

Equation 15. The constant for population density normal PDN should be corrected to its proper value of 26.5. This factor of 10 error in the original formulation has already been discussed in connection with computer run World1-7/5-8.

Equation 17. As originally entered, the birth-rate-from-food multiplier BRFM is of the wrong shape. It should curve in the opposite direction, leveling out at some food ratio which represents the maximum amount of effect which food can have. A new and more reasonable table is entered wherein the maximum effect of increasing food is to raise the birth rate by a factor of 2. Because the function is becoming unchanging the table can be changed from TABLE to TABHL.

Equation 18. As discussed in connection with Equation 12, the range for the pollution ratio is not wide enough and the effect on birth rate may be too steep. A revised estimate for the birth-rate-from-pollution-multiplier table BRPMT is included.

Equation 26. Again the World1 relationship for capital investment per capita CIPC appears to be of the wrong shape. Because the usefulness of additional capital investment probably becomes marginal, we could here expect the curve for capital generation to saturate. We assume that capital and capital generation capability are unevenly distributed over the world population so that the existence of any capital at the material standard of living MSL point in the system implies that the capital is sufficiently concentrated to cause capital investment generation. In other words, the curve is steepest at the 0 capital point and becomes progressively less steep as the entire world becomes saturated in its capital investment needs. This formulation might be more in keeping with the rest of the model if the table function were re-named as a multiplier varying around unity with the coefficient CIGC re-named to carry the actual value of capital investment per capita. To avoid confusion, this change will not be made in the present modifications. The table function can be changed to TABHL.

Equation 27. The rate of depreciation for capital equipment was originally taken as 40 years represented by the capital-investment discard normal CIDN of 0.025. This is all right for buildings but is too long for consumer durables and most machinery. We will increase the value to a better estimate of an overall average and make it 0.05. (This is changed back to 0.05 in WORLD2).

Equation 28. Here again we must cover a wider range in the pollution ratio. Also the effect of pollution on food growing has probably been made too extreme in the original table. The new values reflect these two changes.

Equation 32. It is probably more reasonable to have the maximum pollution generated per person level out as the capital investment per capita in the world increases. For the new relationship WRLD1A, a curve saturating at 8 times the pollution per capita will be chosen to go with a capital-investment ratio 5 times that of 1970. If the capital investment in the world were to rise by a factor of 5 this would bring the remainder of the world approximately up to the North American and European standard. The table function can be changed to TABHL if we assume that the pollution-from-capital multiplier POLCM is not to rise above a value of 8.

Equation 34. The input range to this table from pollution ratio must be increased. The table gives the pollution absorption time POLAT as it depends on the total pollution load in the environment. The original curve was probably too steep and should be made more gradual. A new estimate is inserted for the WRLD1A modification.

Equation 35. The initial value in Equation 35.2 will be changed from 0.5 to 0.3 as discussed in connection with the computer runs for WORLD1. The time constant CIAFT for adjusting capital investment to the needs of agriculture was probably picked longer originally than required for making a real life change. Substantial changes in the capital investment allocated to agriculture could be made in the period of a decade. We will here take a fifteen year adjustment time constant as more realistic than the preceding value. (This may now be too fast).

Equation 38. The table originally used in Equation 38.1 appears in retrospect to be of the wrong shape. The incremental contribution to quality of life from each additional increase in material standard of living should decline. A curve which begins by rising more steeply and then becoming more level will be substituted. Because of the new shape of the curve it will be permissible to change the table function to TABHL because overrunning the end of the table will no longer be significant and need not be recorded.

Equation 40. The original relationship here again seems to have been shaped in the wrong direction. As the amount of food per capita increases the satisfaction from each increment of increase should become less and the curve should become more insensitive. The new relationship selected here seems far more reasonable and has a more defendable shape. Because the curve is saturating, the table function can be changed to TABHL.

The following pages Figures 4-1 through 4-4 copy the double-spaced listing of the World1 Model dated 7/10/70 1456.4 and show the changes from the WORLD1 model to produce an intermediate test model named WRLD1A. The corrected listing is given in Figures 4-5 and 4-6.

Run WRLD1A-STD. This computer run is the first received from the new revised model. Its behavior is totally unlike those from the original WORLD1 model and also bears very little relationship to real life. The modifications appear to have moved the model into some new mode of operation which quickly establishes equilibrium conditions once some initial transients, probably arising from inconsistant initial conditions, have dissipated. By examining each of the plotted curves, we should find the clues to the behavior and perhaps errors and oversights in the model modification going from WORLD1 to WRLD1A.

The variables all cover rather small ranges. Population rises to less than 2.1 billion. Relatively little is to be learned from the population curve because the initial condition is set as one of the cornerstones of the model in the year 1900 and the suceeding changes in population are driven by other variables in the system. The capital investment curve CI, plotted C, rises steeply to a peak and then goes into a long-term decline. This suggests an inability to sustain capital investment in the model and might be coupled to the failure to show any upward sweeping exponential growth. In considering the capital investment sector this reminds us that we increased the capital investment discard normal CIDN to shorten the average life of capital investment. However, we did not readjust the capital generation process so it is possible that the system is not able to generate capital investment fast enough to replace the discard rate. This calls for reconsidering our increase in the discard rate or providing for a higher generation rate, should a difficulty be confirmed at this point.

Kaya.

```
PAGE 1      FILE WORLD1     WORLD DYNAMICS 1            07/10/70    1456.4

                                 W1A
→0.1   *       WORLD DYNAMICS 1 A                                        3  121
       note lines changed for world 2 are marked ~~W2~~ W1A
                                          1A
 1     L       P.K=P.J+(DT)(BR.JK-DR.JK)
 1.1   N       P=PI
 1.2   C       PI=1.65E9
 2     R       BR.KL=(P.K)(BRN)(BRFM.K)(BRMM.K)(BRCM.K)(BRPM.K)
 2.1   C       BRN=.045       HL          5   1
→3.    A       BRMM.K=TABLE(BRMMT,MSL.K*BRMS,0,15,2.5) ——— W2
→3.1   T       BRMMT=.7/1.5/2.1/2.2/1.8/1.1/.8/  1.5/1/.7/.6/.55/.50 ← W2
 3.2   C       BRMS=1
→4     A       MSL.K=~~(MSLN)(ECIR.K)~~  ECIR.K/MSLN ——— W2
→4.1   C       MSLN=1 — ~~1.43~~ 0.7 ——— W2
 5     A       ECIR.K=(CIR.K)(1-CIAF.K)(NREM.K)
 6     A       NREM.K=TABLE(NREMT,NRFR.K,0,1,.25)
 6.1   T       NREMT=0/.15/.5/.85/1
 7     A       NRFR.K=NR.K/NRI
 8     L       NR.K=NR.J+(DT)(-NRUR.JK)
 8.1   N       NR=NRI
 8.2   C       NRI=900E9             NRMM
→9     R       NRUR.KL=(P.K)(NRUN)(MSL.K) ——— W2
 9.1   C       NRUN=1
       note space equation 42 connects here from Eq. 4 to Eq. 9, ~~World 2 changes~~   W2
 10    R       DR.KL=(P.K)(DRN)(DRMM.K)(DRPM.K)(DRFM.K)(DRCM.K)
 10.1  C       DRN=.025
```

Changes to produce Model WRLD1A

all W2's changed to W1A

Fig. 4-1

```
                                              30
                                            5    5
11      A   DRMM.K=TABHL(DRMMT,MSL.K*DRMS,0,5,.5)
11.1    T   DRMMT=2/1.4/1/.8/.7/.6/.53/.5/.5/.5/.5
11.2    C   DRMS=1
--->12  A   DRPM.K=TABLE(DRPMT,POLR.K,0,6,1) ---------------- W2
12.1    T   DRPMT=1/1.1/1.3/1.6/2.2/3.4/6   ~~1/1.2/2/3/4.2/5.8/8~~
                                          -> ~~1.1~~ .98/1.1/1.3/1.6/2.1/2.8/4 -- W2
13      A   DRFM.K=TABHL(DRFMT,FR.K,0,2,.25)
--13.1  T   DRFMT=30/2.4/1.5/1.2/1/.9/.8/.73/.7  30/3/2/1.4/1/.7/.6/.5/.5 -- W2
14      A   DRCM.K=TABLE(DRCMT,CR.K,0,5,1)
14.1    T   DRCMT=1/1.1/1.3/1.6/2.1/3
15      A   CR.K=(P.K)/(LA*PDN)
15.1    C   LA=135E6
--15.2  C   PDN=265 - 26.5 ---- W2
16      A   BRCM.K=TABLE(BRCMT,CR.K,0,5,1)
16.1    T   BRCMT=1/.95/.8/.7/.65/.65
                          HL               4   1
--17    A   BRFM.K=TABLE(BRFMT,FR.K,0,2,.5) ---- W2
--17.1  T   BRFMT=0/.4/1/1.8/3  0/1/1.6/1.9/2 --- W2
                                         30
                                          5
--18    A   BRPM.K=TABLE(BRPMT,POLR.K,0,6,1)
                                                  W2
--18.1  T   BRPMT=1/.98/.95/.9/.8/.65/.5  1/.97/.92/.82/.72/.6/.4 -- W2
19      A   FR.K=(FPCI.K)(FCM.K)(FPM.K)
20      A   FCM.K=TABLE(FCMT,CR.K,0,5,1)
20.1    T   FCMT=2.4/1/.6/.4/.3/.2
                    HL
21      A   FPCI.K=TABLE(FPCIT,CIRA.K,0,6,1) ---- W2
21.1    T   FPCIT=.5/1/1.4/1.7/1.9/2.05/2.2
22      A   CIRA.K=(CIR.K)(CIAF.K)
23      A   CIR.K=CI.K/P.K
24      L   CI.K=CI.J+(DT)(CIG.JK-CID.JK)
24.1    N   CI=CII
24.2    C   CII=.4E9
```

3 122

FIG. 4-2

```
                                   HL
25     R    CIG.KL=(P.K)(CIPC.K)(CIGC)
25.1   C    CIGC=1
26     A    CIPC.K=TABLE(CIPCT,MSL.K,0,5,1) —— WZ
                                        .005
26.1   T    CIPCT=.02/.05/.15/.30/.50/.75   ~~.025~~/.05/.09/.12/.14/.15 —— WZ
27     R    CID.KL=(CI.K)(CIDN)
27.1   C    CIDN=.025   .05 —— WZ
                                     30
28     A    FPM.K=TABLE(FPMT,POLR.K,0,6,1)   5 —— WZ
28.1   T    FPMT=1/.95/.8/.6/.4/.25/.15   1/.95/.87/.77/.65/.5/.32 —— WZ
29     A    POLR.K=POL.K/POLS
29.1   C    POLS=3.6E9
30     L    POL.K=POL.J+(DT)(POLG.JK-POLA.JK)
30.1   N    POL=POLI
30.2   C    POLI=.2E9
31     R    POLG.KL=(P.K)(POLN)(POLCM.K)
31.1   C    POLN=1
                          HL
32     A    POLCM.K=TABLE(POLCMT,CIR.K,0,5,1) —— WZ
32.1   T    POLCMT=.05/1/3/6/10/15   .05/1/3/5.4/7.4/8 —— WZ
33     R    POLA.KL=POL.K/POLAT.K
                                          30
34     A    POLAT.K=TABLE(POLATT,POLR.K,0,6,1)   5 —— WZ
34.1   T    POLATT=.5/1/2.4/4.4/6.8/9.6/11.4   1/1.4/2.4/3.6/5.2/7.2/10 —— WZ
35     L    CIAF.K=CIAF.J+(DT/CIAFT)(CFIFR.J-CIAF.J)
35.1   N    CIAF=CIAFI
35.2   C    CIAFI=.5   .3
35.3   C    CIAFT=30 —— 15
```

FIG. 4-3

```
36      A     CFIFR.K=TABLE(CFIFRT,FR.K,0,2,.5)
36.1    T     CFIFRT=1/.8/.5/.2/.1
37      S     QL.K=(QLS)(QLM.K)(QLC.K)(QLF.K)(QLP.K)
37.1    C     QLS=1
                         HL
38      A     QLM.K=TABLE(QLMT,MSL.K,0,5,1)  —— W2
38.1    T     QLMT=.2/1/2.2/4/6/8   .2/1/1.7/2.3/2.7/2.9 —— W2
39      A     QLC.K=TABLE(QLCT,CR.K,0,5,.5)
39.1    T     QLCT=2/1.3/1/.75/.55/.45/.38/.3/.25/.22/.2
                         HL           4   1
40      A     QLF.K=TABLE(QLFT,FR.K,0,2,.5)  —— W2
40.1    T     QLFT=0/.2/1/2.2/4   0/1/1.8/2.4/2.7
41      A     QLP.K=TABLE(QLPT,POLR.K,0,6,1)
41.1    T     QLPT=1.5/1/.7/.5/.35/.25/.2
41.4    NOTE
41.5    NOTE  CONTROL CARDS
41.6    NOTE
42      C     DT=.2
42.1    C     LENGTH=2100
42.2    C     PLTPER=2
42.3    N     TIME=1900
42.6    PLOT  P=P/POLR=2/CI=C/FR=F/CR=R/MSL=M/QLM=L/QL=Q/CIAF=A/NR=N
```

Note (Tab) (5spaces) Equation 42 located between Eq. 4 and 9. W2

```
A     NRMM.K = TABHL(NRMMT, MSL.K, 0, 10, 1)      W2
T     NRMMT = 0/1/1.8/2.4/2.9/3.3/3.6/3.8/3.9/3.95/4      W2
```

(42)

FIG. 4-4

```
PAGE 1       FILE WRLD1A     WORLD DYNAMICS W1A           07/12/70   2015.3

  0.1     *            WORLD DYNAMICS W1A
  0.2     NOTE         LINES CHANGED FOR WORLD1A ARE MARKED W1A
  1       L       P.K=P.J+(DT)(BR.JK-DR.JK)
  1.1     N       P=PI
  1.2     C       PI=1.65E9
  2       R       BR.KL=(P.K)(BRN)(BRFM.K)(BRMM.K)(BRCM.K)(BRPM.K)
  2.1     C       BRN=.045
  3       A       BRMM.K=TABHL(BRMMT,MSL.K*BRMS,0,5,1)      W1A
  3.1     T       BRMMT=1.5/1/.7/.6/.55/.5      W1A
  3.2     C       BRMS=1
  4       A       MSL.K=ECIR.K/MSLN      W1A
  4.1     C       MSLN=.7      W1A
  5       A       ECIR.K=(CIR.K)(1-CIAF.K)(NREM.K)
  6       A       NREM.K=TABLE(NREMT,NRFR.K,0,1,.25)
  6.1     T       NREMT=0/.15/.5/.85/1
  7       A       NRFR.K=NR.K/NRI
  8       L       NR.K=NR.J+(DT)(-NRUR.JK)
  8.1     N       NR=NRI
  8.2     C       NRI=900E9
  9       R       NRUR.KL=(P.K)(NRUN)(NRMM.K)      W1A
  9.1     C       NRUN=1
  9.4     NOTE         EQUATION 42 CONNECTS HERE FROM EQ. 4 TO EQ. 9      W1A
 10       R       DR.KL=(P.K)(DRN)(DRMM.K)(DRPM.K)(DRFM.K)(DRCM.K)
 10.1     C       DRN=.025
 11       A       DRMM.K=TABHL(DRMMT,MSL.K*DRMS,0,5,.5)
 11.1     T       DRMMT=2/1.4/1/.8/.7/.6/.53/.5/.5/.5/.5
 11.2     C       DRMS=1
 12       A       DRPM.K=TABLE(DRPMT,POLR.K,0,30,5)      W1A
 12.1     T       DRPMT=.98/1.1/1.3/1.6/2.1/2.8/4      W1A
 13       A       DRFM.K=TABHL(DRFMT,FR.K,0,2,.25)
 13.1     T       DRFMT=30/3/2/1.4/1/.7/.6/.5/.5      W1A
 14       A       DRCM.K=TABLE(DRCMT,CR.K,0,5,1)
 14.1     T       DRCMT=1/1.1/1.3/1.6/2.1/3
 15       A       CR.K=(P.K)/(LA*PDN)
 15.1     C       LA=135E6
 15.2     C       PDN=26.5      W1A
 16       A       BRCM.K=TABLE(BRCMT,CR.K,0,5,1)
 16.1     T       BRCMT=1/.95/.8/.7/.65/.65
 17       A       BRFM.K=TABHL(BRFMT,FR.K,0,4,1)      W1A
 17.1     T       BRFMT=0/1/1.6/1.9/2      W1A
 18       A       BRPM.K=TABLE(BRPMT,POLR.K,0,30,5)      W1A
 18.1     T       BRPMT=1/.97/.92/.82/.72/.6/.4      W1A
 19       A       FR.K=(FPCI.K)(FCM.K)(FPM.K)
 20       A       FCM.K=TABLE(FCMT,CR.K,0,5,1)
 20.1     T       FCMT=2.4/1/.6/.4/.3/.2
 21       A       FPCI.K=TABHL(FPCIT,CIRA.K,0,6,1)      W1A
 21.1     T       FPCIT=.5/1/1.4/1.7/1.9/2.05/2.2
 22       A       CIRA.K=(CIR.K)(CIAF.K)
 23       A       CIR.K=CI.K/P.K
 24       L       CI.K=CI.J+(DT)(CIG.JK-CID.JK)
 24.1     N       CI=CII
 24.2     C       CII=.4E9
 25       R       CIG.KL=(P.K)(CIPC.K)(CIGC)
 25.1     C       CIGC=1
 26       A       CIPC.K=TABHL(CIPCT,MSL.K,0,5,1)      W1A
 26.1     T       CIPCT=.005/.05/.09/.12/.14/.15      W1A
 27       R       CID.KL=(CI.K)(CIDN)
 27.1     C       CIDN=.05      W1A
```

Fig. 4-5

```
  28       A      FPM.K=TABLE(FPMT,POLR.K,0,30,5)        W1A
  28.1     T      FPMT=1/.95/.87/.77/.65/.5/.32      W1A
  29       A      POLR.K=POL.K/POLS
  29.1     C      POLS=3.6E9
  30       L      POL.K=POL.J+(DT)(POLG.JK-POLA.JK)
  30.1     N      POL=POLI
  30.2     C      POLI=.2E9
  31       R      POLG.KL=(P.K)(POLN)(POLCM.K)
  31.1     C      POLN=1
  32       A      POLCM.K=TABHL(POLCMT,CIR.K,0,5,1)       W1A
  32.1     T      POLCMT=.05/1/3/5.4/7.4/8       W1A
  33       R      POLA.KL=POL.K/POLAT.K
  34       A      POLAT.K=TABLE(POLATT,POLR.K,0,30,5)       W1A
  34.1     T      POLATT=1/1.4/2.4/3.6/5.2/7.2/10       W1A
  35       L      CIAF.K=CIAF.J+(DT/CIAFT)(CFIFR.J-CIAF.J)
  35.1     N      CIAF=CIAFI
  35.2     C      CIAFI=.3      W1A
  35.3     C      CIAFT=15      W1A
  36       A      CFIFR.K=TABLE(CFIFRT,FR.K,0,2,.5)
  36.1     T      CFIFRT=1/.8/.5/.2/.1
  37       S      QL.K=(QLS)(QLM.K)(QLC.K)(QLF.K)(QLP.K)
  37.1     C      QLS=1
  38       A      QLM.K=TABHL(QLMT,MSL.K,0,5,1)       W1A
  38.1     T      QLMT=.2/1/1.7/2.3/2.7/2.9      W1A
  39       A      QLC.K=TABLE(QLCT,CR.K,0,5,.5)
  39.1     T      QLCT=2/1.3/1/.75/.55/.45/.38/.3/.25/.22/.2
  40       A      QLF.K=TABHL(QLFT,FR.K,0,4,1)       W1A
  40.1     T      QLFT=0/1/1.8/2.4/2.7       W1A
  41       A      QLP.K=TABLE(QLPT,POLR.K,0,6,1)
  41.1     T      QLPT=1.5/1/.7/.5/.35/.25/.2
  41.4     NOTE        EQUATION 42 LOCATED BETWEEN EQ. 4 AND 9.      W1A
  42       A      NRMM.K=TABHL(NRMMT,MSL.K,0,10,1)      W1A
  42.1     T      NRMMT=0/1/1.8/2.4/2.9/3.3/3.6/3.8/3.9/3.95/4      W1A
  42.4     NOTE
  42.5     NOTE   CONTROL CARDS
  42.6     NOTE
  43       C      DT=.2
  43.1     C      LENGTH=2100
  43.2     C      PLTPER=2
  43.3     N      TIME=1900
  43.6     PLOT   P=P/POLR=2/CI=C/FR=F/CR=R/MSL=M/QLM=L/QL=Q/CIAF=A/NR=N
```

```
R 2.750+1.533
```

FIG - 4-6

In the curve for pollution ratio POLR, plotted as 2, we see a sudden rise from the initial value toward an equilibrium. This takes place with a very short time constant (in the range of one year), which is the time constant for pollution absorption coming from POLAT. No doubt this sudden rise to an equilibrium happens because the initial value for pollution POLI is not in equilibrium with the other conditions.

The capital-investment-in-agriculture fraction CIAF, plotted as A, starts at 0.3 as set for the initial conditions but then rises to a value of about 0.55. This happens while the food ratio FR, plotted as F, declines from an initial value of .94 to a final value of about 0.9. An unexpectedly high value of capital investment in agriculture is required to sustain the food ratio. By looking at the table for Equation 36.1 we see an incompatibility between the various assumptions affecting the food system. We started by assuming an initial value of CIAF equal to 0.3, but observe that Equation 36.1 requires a value of CIAF of 0.5 at a food ratio of unity.

Model WRLD1B as Revised from WRLD1A.

In Equation 36.1 we probably cannot justify the double curvature and should change from the original values to a new set for WRLD1B. This will be made consistent with the other assumptions and will generate a value of CFIFR of 0.3 at a food ratio of unity.

We also note a formulation error in the vicinity of Equation 21 for food potential from capital investment FPCI. The standard 1970 conditions give a value of CIR equal to unity. When this is multiplied by the standard value of CIAF in Equation 22, the value of CIRA will be 0.3 which is the input to the table in Equation 21. We have been assuming under standard conditions that the imput to this table would be unity. An additional factor needs to be entered either in Equation 21 or Equation 22 to correct for the standard value assumed as the normal for CIAF. We will put this in Equation 22 for CIRA by dividing by a coefficient CIAFN meaning capital investment in agriculture fraction normal.

In a similar way we have been assuming that MSL in Equation 4 will have a value of unity under normal 1970 conditions. This is not true as now formulated until the normal value of capital investment remaining after deduction for agriculture is introduced in Equation 4. This was done numerically in Model WRLD1A by setting MSLN as 0.7. However, it should be interlocked with the new value of CIAFN by changing MSLN in Equation 4 to 1-CIAFN. Equation 4.1 can then be ommitted.

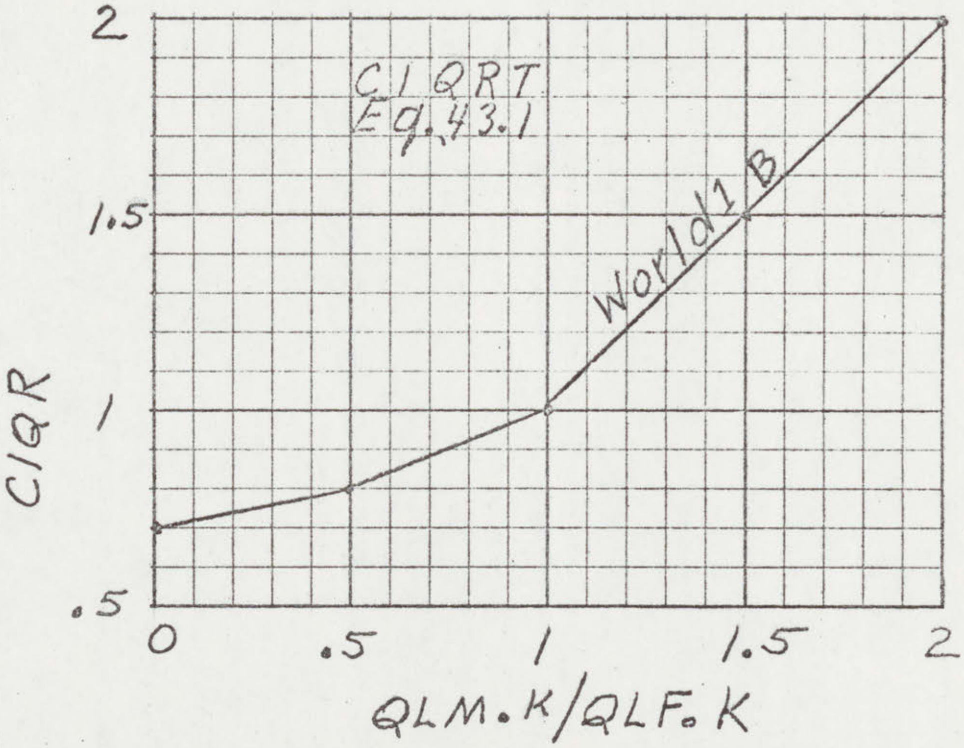
An examination of the capital investment sector shows another conceptual oversight. The fraction of capital investment allocated to food production is originally a function of food ratio only. As the food ratio increases, capital investment is diverted away from agriculture. But this can clearly be carried too far. A highly unbalanced quality of life can occur wherein the material standard of living MSL can rise to high values while food ratio FR and the quality of life from food QLF are held at relatively lower values without recognizing the imbalance between the two quality of life factors. To allow access in the model to this relationship, there should be a table function which can alter upward the capital-investment-in-agriculture fraction CIAF when the material standard of living rises to comparatively high values. We will use the ratio of QLM divided by QLF to indicate that such an adjustment is desired. Equation 43 as shown in Figure 4-7 will be inserted and Equation 35 will be altered to accept the new input. This formulation is a short cut to a more complete representation of the generation of goals in which the allocation of capital between agriculture and other uses might continue to drift until the two quality factors were equal. The present formulation requires a sustained excess of QLM over QLF in order to increase the allocation to agriculture.

Run WRLD1B-STD.

The revisions to model WRLD1A giving WRLD1B yield a system which functions as shown in run WRLD1B-STD. The most obvious deficiency in this system behavior is the failure to grow from 1900 to 1970 with the historical rapidity. We recall that the capital-investment discard normal CIDN is still set at a 20 year time constant and the capital investment generation relationships are just barely able to replace the discard rate.

Model WORLD2 as Revised from WRLD1B

On still further thought, a value of CIDN corresponding to a normal capital investment life of 20 years is probably too short. The big expenditures in railroads, highways, and buildings are useful for a longer period. We will move the value of CIDN back to 0.025, the result of which is shown in run WORLD2.



Capital-investment-from-quality ratio
vs. ratio of quality of life from material
to quality of life from food

Fig. 4-7

```
PAGE 1      FILE WRLD1B     WORLD DYNAMICS W1B           07/12/70   2028.0

  0.1     *           WORLD DYNAMICS W1B
  0.2     NOTE        LINES CHANGED FOR WORLD1B ARE MARKED W1B
  1       L       P.K=P.J+(DT)(BR.JK-DR.JK)
  1.1     N       P=PI
  1.2     C       PI=1.65E9
  2       R       BR.KL=(P.K)(BRN)(BRFM.K)(BRMM.K)(BRCM.K)(BRPM.K)
  2.1     C       BRN=.045
  3       A       BRMM.K=TABHL(BRMMT,MSL.K*BRMS,0,5,1)
  3.1     T           BRMMT=1.2/1/.85/.75/.7/.7      W1B
  3.2     C       BRMS=1
  4       A       MSL.K=ECIR.K/(1-CIAFN)      W1B
  5       A       ECIR.K=(CIR.K)(1-CIAF.K)(NREM.K)
  6       A       NREM.K=TABLE(NREMT,NRFR.K,0,1,.25)
  6.1     T       NREMT=0/.15/.5/.85/1
  7       A       NRFR.K=NR.K/NRI
  8       L       NR.K=NR.J+(DT)(-NRUR.JK)
  8.1     N       NR=NRI
  8.2     C       NRI=900E9
  9       R       NRUR.KL=(P.K)(NRUN)(NRMM.K)
  9.1     C       NRUN=1
  9.4     NOTE        EQUATION 42 CONNECTS HERE FROM EQ. 4 TO EQ. 9
 10       R       DR.KL=(P.K)(DRN)(DRMM.K)(DRPM.K)(DRFM.K)(DRCM.K)
 10.1     C       DRN=.025
 11       A       DRMM.K=TABHL(DRMMT,MSL.K*DRMS,0,5,.5)
 11.1     T       DRMMT=2/1.4/1/.8/.7/.6/.53/.5/.5/.5/.5
 11.2     C       DRMS=1
 12       A       DRPM.K=TABLE(DRPMT,POLR.K,0,30,5)
 12.1     T       DRPMT=.98/1.1/1.3/1.6/2.1/2.8/4
 13       A       DRFM.K=TABHL(DRFMT,FR.K,0,2,.25)
 13.1     T       DRFMT=30/3/2/1.4/1/.7/.6/.5/.5
 14       A       DRCM.K=TABLE(DRCMT,CR.K,0,5,1)
 14.1     T       DRCMT=1/1.1/1.3/1.6/2.1/3
 15       A       CR.K=(P.K)/(LA*PDN)
 15.1     C       LA=135E6
 15.2     C       PDN=26.5
 16       A       BRCM.K=TABLE(BRCMT,CR.K,0,5,1)
 16.1     T       BRCMT=1/.95/.8/.7/.65/.65
 17       A       BRFM.K=TABHL(BRFMT,FR.K,0,4,1)
 17.1     T       BRFMT=0/1/1.6/1.9/2
 18       A       BRPM.K=TABLE(BRPMT,POLR.K,0,30,5)
 18.1     T       BRPMT=1/.97/.92/.82/.72/.6/.4
 19       A       FR.K=(FPCI.K)(FCM.K)(FPM.K)
 20       A       FCM.K=TABLE(FCMT,CR.K,0,5,1)
 20.1     T       FCMT=2.4/1/.6/.4/.3/.2
 21       A       FPCI.K=TABHL(FPCIT,CIRA.K,0,6,1)
 21.1     T       FPCIT=.5/1/1.4/1.7/1.9/2.05/2.2
 22       A       CIRA.K=(CIR.K)(CIAF.K)/CIAFN      W1B
 22.1     C       CIAFN=.3      W1B
 23       A       CIR.K=CI.K/P.K
 24       L       CI.K=CI.J+(DT)(CIG.JK-CID.JK)
 24.1     N       CI=CII
 24.2     C       CII=.4E9
 25       R       CIG.KL=(P.K)(CIPC.K)(CIGC)
 25.1     C       CIGC=1
 26       A       CIPC.K=TABHL(CIPCT,MSL.K,0,5,1)
 26.1     T       CIPCT=.005/.05/.09/.12/.14/.15
 27       R       CID.KL=(CI.K)(CIDN)
 27.1     C       CIDN=.05
```

FIG. 4-8

```
28      A     FPM.K=TABLE(FPMT,POLR.K,0,30,5)
28.1    T     FPMT=1/.95/.87/.77/.65/.5/.32
29      A     POLR.K=POL.K/POLS
29.1    C     POLS=3.6E9
30      L     POL.K=POL.J+(DT)(POLG.JK-POLA.JK)
30.1    N     POL=POLI
30.2    C     POLI=.2E9
31      R     POLG.KL=(P.K)(POLN)(POLCM.K)
31.1    C     POLN=1
32      A     POLCM.K=TABHL(POLCMT,CIR.K,0,5,1)
32.1    T     POLCMT=.05/1/3/5.4/7.4/8
33      R     POLA.KL=POL.K/POLAT.K
34      A     POLAT.K=TABLE(POLATT,POLR.K,0,30,5)
34.1    T     POLATT=1/1.4/2.4/3.6/5.2/7.2/10
35      L     CIAF.K=CIAF.J+(DT/CIAFT)(CFIFR.J*CIQR.J-CIAF.J)      W1B
35.1    N     CIAF=CIAFI
35.2    C     CIAFI=.3
35.3    C     CIAFT=15
36      A     CFIFR.K=TABLE(CFIFRT,FR.K,0,2,.5)
36.1    T     CFIFRT=1/.6/.3/.15/.1      W1B
37      S     QL.K=(QLS)(QLM.K)(QLC.K)(QLF.K)(QLP.K)
37.1    C     QLS=1
38      A     QLM.K=TABHL(QLMT,MSL.K,0,5,1)
38.1    T     QLMT=.2/1/1.7/2.3/2.7/2.9
39      A     QLC.K=TABLE(QLCT,CR.K,0,5,.5)
39.1    T     QLCT=2/1.3/1/.75/.55/.45/.38/.3/.25/.22/.2
40      A     QLF.K=TABHL(QLFT,FR.K,0,4,1)
40.1    T     QLFT=0/1/1.8/2.4/2.7
41      A     QLP.K=TABLE(QLPT,POLR.K,0,6,1)
41.1    T     QLPT=1.5/1/.7/.5/.35/.25/.2
41.4    NOTE        EQUATION 42 LOCATED BETWEEN EQ. 4 AND 9.
42      A     NRMM.K=TABHL(NRMMT,MSL.K,0,10,1)
42.1    T     NRMMT=0/1/1.8/2.4/2.9/3.3/3.6/3.8/3.9/3.95/4
42.4    NOTE        INPUT FROM EQN. 38 AND 40 TO EQN. 35      W1B
43      A     CIQR.K=TABHL(CIQRT,QLM.K/QLF.K,0,2,.5)      W1B
43.1    T     CIQRT=.7/.8/1/1.5/2      W1B
43.4    NOTE
43.5    NOTE  CONTROL CARDS
43.6    NOTE
44      C     DT=.2
44.1    C     LENGTH=2100
44.2    C     PLTPER=2
44.3    N     TIME=1900
44.6    PLOT  P=P/POLR=2/CI=C/FR=F/CR=R/MSL=M/QLM=L/QL=Q/CIAF=A/NR=N




R 3.133+1.850
```

FIG. 4-9

Equation 41. The quality-of-life-from-pollution table QLPT has not yet been modified for the wider range of pollution ratio POLR. The table specification and the values are changed here to cover the range of 0 to 30 for POLR and to make the sensitivity to pollution somewhat less.

Run WORLD2

(The computer run is supplied separately from this memo.)

Here we see that growth from 1900 to 1970 is approximately correct. Population has risen to slightly more than 3.5 billion. The pollution ratio is approximately the defined value of unity in 1970. Food ratio is about .97. Quality of life is about .99. Capital investment in agriculture fraction CIAF has dropped during the first 60 years but has risen again to about the 0.3 value which has been defined as normal. The overall behavior is not unreasonable. Population rises to a peak of about 5.5 billion while capital investment rises proportionately more steeply to a value of about 8 billion in terms of 1970 per capita units. Peak pollution in the year 2050 rises to 4.5 times the 1970 value. By the year 2050 natural resources are about 50% depleted. The reasonableness of this in real life terms depends of course on how vulnerable we believe technological living is to the natural resource mix used today. A shift to atomic power and a movement away from rare metals to common metals such as aluminum might make resource depletion somewhat less crucial.

The general behavior of WORLD2 is sufficiently plausible that we will use it as the reference point for the Club of Rome afternoon workshop sessions.

In the WORLD2 model we have inserted switches which give access at controllable points in time to some of the system parameters which one might attempt to control in real life. These switches now exist at the following places:

a. In Equation 2 for birth rate normal
b. In Equation 9 for natural resouce usage rate normal
c. In Equation 10 for death rate normal
d. In Equation 25 for capital investment generation coefficient
e. In Equation 27 for capital investment discard normal
f. In Equation 31 for pollution normal

These changes define the model WORLD2. The listing of the new equations and a DOCUMENTOR output with definitions of variables are supplied separately from this memo.

D-1358

A WORLD DYNAMICS MODEL: INTRODUCTORY EXERCISE

CHAPTER 5
THE WORLD2 MODEL

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July 20, 1970

A WORLD DYNAMICS MODEL:
INTRODUCTORY EXERCISE

CHAPTER 5

The WORLD2 Model

The following items of information are available for working with the WORLD2 Model.

a. The flow diagram Figure 2-1

b. WORLD2 computer listing, Memorandum D-1353

c. WORLD2 documentor, Memorandum D-1354

d. WORLD2 Table Functions, Memorandum D-1355.

In addition, there is Memorandum D-1348 describing the evolutionary development of the WORLD2 Model and the packet of computer runs from Models WORLD1, WRLD1A, and WRLD1B.

Referring to the flow diagram, we see a fifth order system defined by the five level variables for:

Population

Capital Investment

Natural Resources

Pollution

Capital Investment in Agriculture Fraction

In this system population is subject to stresses arising from a shortage of capital investment, crowding, food shortage, and pollution. In the model, and it seems true in the actual world situation, pressures from each of these system factors seem to be developing in about the same time period. The world is now dipping heavily into its natural resources and these will be substantially diminished in the next one or two centuries. Pollution is becoming important for the first time in human history and could reach crisis proportions in the foreseeable future. Crowding becomes a threat as world population is faced with the realities of a limited land area. A fundamental limitation on food supply becomes a possibility, as larger amounts of land are urbanized and more marginal lands are forced into agriculture.

By changing coefficients and table functions in the model it is possible to eliminate the threats of one or more of these system stresses so that the reaction of the model can be examined under the influence of those which remain.

Several switches have been inserted in the model to permit alteration of the policies governing the system at chosen times. For example, in Equation 2 is the switch which reads

(CLIP(BRN,BRN1,SWT1,TIME.K))

CLIP is the function indicator which specifies a switching action. A transfer is made from BRN to BRN1 when TIME has reached a value specified by SWT1. Switching times have been set at 1970 unless the user specifies otherwise. A model run giving a value for BRN1 other than .045 would cause the birth rate normal to change from a value of .045 to the new value at the year 1970.

A similar switch is inserted in Equation 9 for the natural resource usage rate NRUR. Reducing the value of NRUN1 is equivilent to asserting that science and technological progress have succeeded in reducing the natural resource depletion rate. This might imply a shift to more generously available resources or a shift to more efficient reclaiming of resources which would otherwise have been discarded.

The switch in Equation 10 for death rate DR allows one to arbitrarily change the death rate normal DRN1 at a specified time.

Likewise, in Equation 25 for capital investment generation CIG, a switch permits changing, at a specified time, the capital investment generation coefficient CIGC1. The propensity to accumulate capital can thereby be increased or decreased to determine the effect on the system.

In Equation 27 capital investment discard can be accelerated or diminished at a specified time by changing the value of CIDM1.

In Equation 31 pollution generation POLG can be altered at a specified time by changing the value of pollution normal POLN1. A reduction in POLN1 can be interpreted as a sudden improvement in the technology of pollution control that occurs at the specified time.

In the computer run WORLD2-STD the peaking of the population and the gradual decline in the period from 2040 to 2100 is primarily a result of declining natural resources. Circumstances are such that resources are exhausted fast enough to prevent population and capital investment from precipitating a pollution crisis in the environment. The pollution ratio reaches a value of about 4 times the 1970 condition.

The relative timing of resource exhaustion and pollution peaking can be adjusted by altering the coefficients that control the rate of capital investment CIGC1 and the rate of natural resource usage in NRUN1.

By setting the value of pollution generation POLN1 at a very small value, pollution can be prevented from acting on the system so that the influences of capital investment, food and crowding can be observed.

In the same way other combinations of forces within the system can be explored.

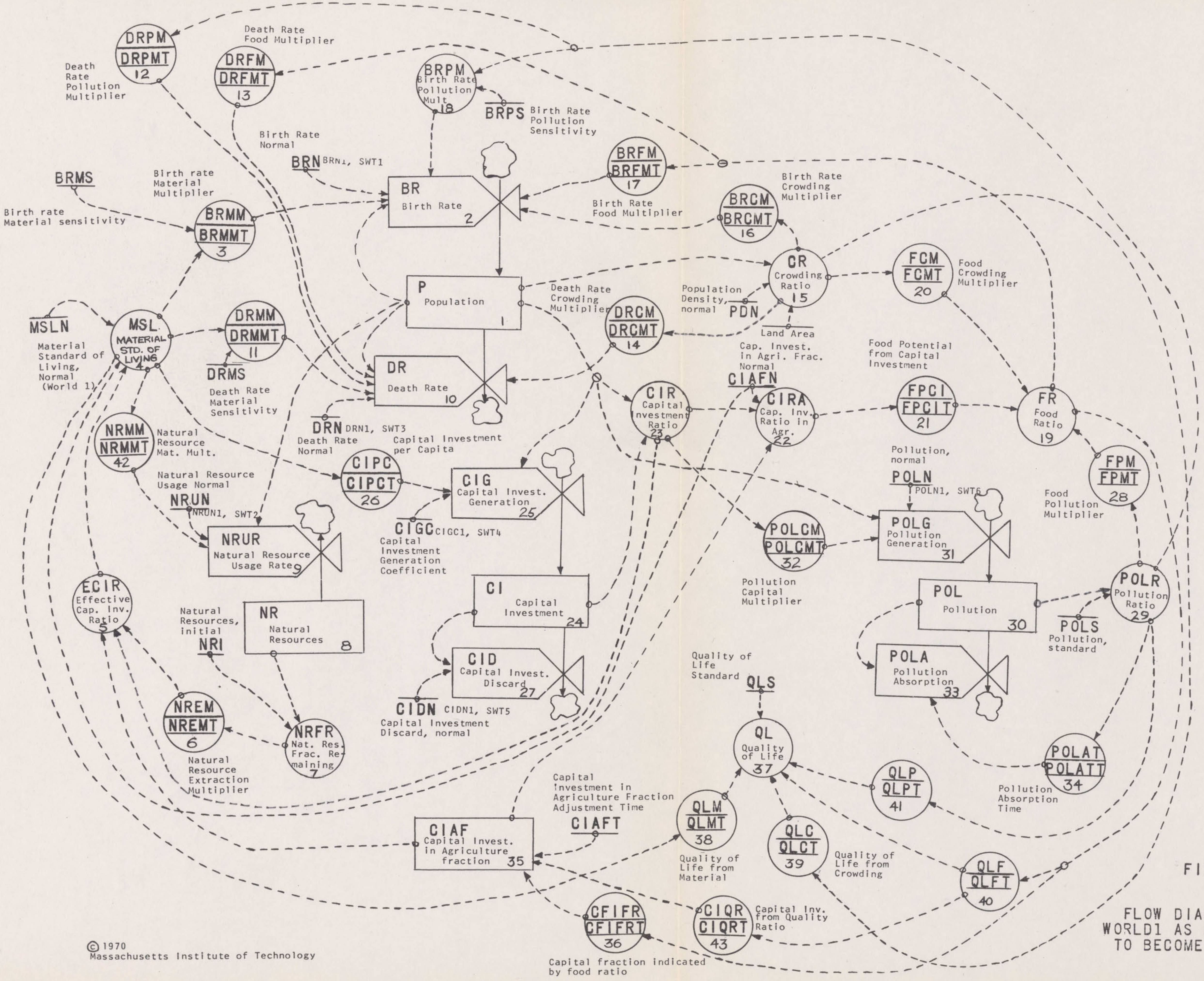
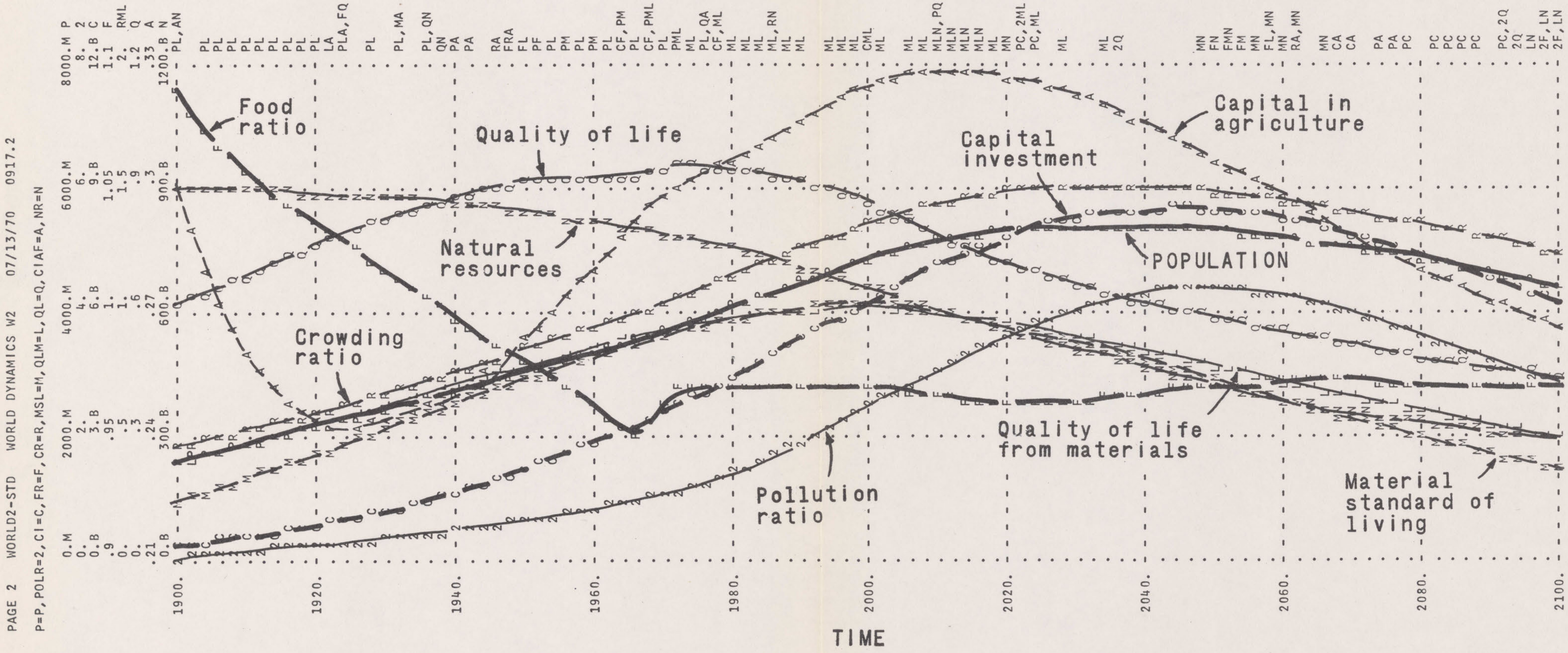


FIG. 2-1

FLOW DIAGRAM OF WORLD1 AS MODIFIED TO BECOME WORLD2

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

WORLD2-STD



D-1354

WORLD2 DOCUMENTOR
a part of
A World Dynamics Model:
Introductory Exercise

by
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July 15, 1970

```
r dc world2 world
W 1422.6

P.K=P.J+(DT)(BR.JK-DR.JK)                                        1,L

P=PI                                                             1.1,N

PI=1.65E9                                                        1.2,C

    P      - POPULATION (PEOPLE)
    BR     - BIRTH RATE (PEOPLE/YEAR)
    DR     - DEATH RATE (PEOPLE/YEAR)
    PI     - POPULATION, INITIAL (PEOPLE)

BR.KL=(P.K)(CLIP(BRN,BRN1,SWT1,TIME.K))(BRFM.K)(BRMM.K          2,R
  )(BRCM.K)(BRPM.K)

BRN=.045                                                         2.1,C

BRN1=.045                                                        2.2,C

SWT1=1970                                                        2.3,C

    BR     - BIRTH RATE (PEOPLE/YEAR)
    P      - POPULATION (PEOPLE)
    BRN    - BIRTH RATE NORMAL (FRACTION/YEAR)
    BRN1   - BIRTH RATE NORMAL NO. 1 (FRACTION/YEAR)
    SWT1   - SWITCH TIME NO. 1 FOR BRN (YEARS)
    BRFM   - BIRTH-RATE-FROM-FOOD MULTIPLIER
               (DIMENSIONLESS)
    BRMM   - BIRTH-RATE-FROM-MATERIAL MULTIPLIER
               (DIMENSIONLESS)
    BRCM   - BIRTH-RATE-FROM-CROWDING MULTIPLIER
               (DIMENSIONLESS)
    BRPM   - BIRTH-RATE-FROM-POLLUTION MULTIPLIER
               (DIMENSIONLESS)

BRMM.K=TABHL(BRMMT,MSL.K*BRMS,0,5,1)                             3,A

BRMMT=1.2/1/.85/.75/.7/.7                                        3.1,T
          ↑
BRMS=1                                                           3.2,C

    BRMM   - BIRTH-RATE-FROM-MATERIAL MULTIPLIER
               (DIMENSIONLESS)
    BRMMT  - BIRTH-RATE-FROM-MATERIAL-MULTIPLIER TABLE
    MSL    - MATERIAL STANDARD OF LIVING (DIMENSIONLESS)
    BRMS   - BIRTH-RATE-FROM-MATERIAL SENSITIVITY
               (DIMENSIONLESS)
```

```
                   CIAF
MSL.K=ECIR.K/(1-CIAFN)                                    4,A

    MSL   - MATERIAL STANDARD OF LIVING (DIMENSIONLESS)
    ECIR  - EFFECTIVE-CAPITAL-INVESTMENT RATIO (CAPITAL
              UNITS/PERSON)
    CIAFN - CAPITAL-INVESTMENT-IN-AGRICULTURE FRACTION
             NORMAL (DIMENSIONLESS)
                  1   ( 1-.3)  =   .7
ECIR.K=(CIR.K)(1-CIAF.K)(NREM.K)                          5,A

    ECIR  - EFFECTIVE-CAPITAL-INVESTMENT RATIO (CAPITAL
              UNITS/PERSON)
    CIR   - CAPITAL-INVESTMENT RATIO (CAPITAL UNITS/
             PERSON)
    CIAF  - CAPITAL-INVESTMENT-IN-AGRICULTURE FRACTION
             (DIMENSIONLESS)
    NREM  - NATURAL-RESOURCE-EXTRACTION MULTIPLIER
             (DIMENSIONLESS)

NREM.K=TABLE(NREMT,NRFR.K,0,1,.25)                        6,A

NREMT=0/.15/.5/.85/1                                      6.1,T

    NREM  - NATURAL-RESOURCE-EXTRACTION MULTIPLIER
             (DIMENSIONLESS)
    NREMT - NATURAL-RESOURCE-EXTRACTION-MULTIPLIER
             TABLE
    NRFR  - NATURAL-RESOURCE FRACTION REMAINING
             (DIMENSIONLESS)

NRFR.K=NR.K/NRI                                           7,A

    NRFR  - NATURAL-RESOURCE FRACTION REMAINING
             (DIMENSIONLESS)
    NR    - NATURAL RESOURCES (NATURAL RESOURCE UNITS)
    NRI   - NATURAL RESOURCES, INITIAL (NATURAL
             RESOURCE UNITS)

NR.K=NR.J+(DT)(-NRUR.JK)                                  8,L

NR=NRI                                                    8.1,N

NRI=900E9                                                 8.2,C

    NR    - NATURAL RESOURCES (NATURAL RESOURCE UNITS)
    NRUR  - NATURAL-RESOURCE-USAGE RATE (NATURAL
             RESOURCE UNITS/YEAR)
    NRI   - NATURAL RESOURCES, INITIAL (NATURAL
             RESOURCE UNITS)
```

```
NRUR.KL=(P.K)(CLIP(NRUN,NRUN1,SWT2,TIME.K))(NRMM.K)           9,R

NRUN=1                                                         9.1,C

NRUN1=1                                                        9.2,C

SWT2=1970                                                      9.3,C

    NRUR   - NATURAL-RESOURCE-USAGE RATE (NATURAL
              RESOURCE UNITS/YEAR)
    P      - POPULATION (PEOPLE)
    NRUN   - NATURAL-RESOURCE USAGE NORMAL (NATURAL
              RESOURCE UNITS/PERSON/YEAR)
    NRUN1  - NATURAL-RESOURCE USAGE NORMAL NO. 1
              (NATURAL RESOURCE UNITS/PERSON/YEAR)
    SWT2   - SWITCH TIME NO. 2 FOR NRUN (YEARS)
    NRMM   - NATURAL-RESOURCE-FROM-MATERIAL MULTIPLIER
              (DIMENSIONLESS)

DR.KL=(P.K)(CLIP(DRN,DRN1,SWT3,TIME.K))(DRMM.K)(DRPM.K        10,R
  )(DRFM.K)(DRCM.K)

DRN=.025                                                       10.1,C

DRN1=.025                                                      10.2,C

SWT3=1970                                                      10.3,C

    DR     - DEATH RATE (PEOPLE/YEAR)
    P      - POPULATION (PEOPLE)
    DRN    - DEATH RATE NORMAL (FRACTION/YEAR)
    DRN1   - DEATH RATE NORMAL NO. 1 (FRACTION/YEAR)
    SWT3   - SWITCH TIME NO. 3 FOR DRN (YEARS)
    DRMM   - DEATH-RATE-FROM-MATERIAL MULTIPLIER
              (DIMENSIONLESS)
    DRPM   - DEATH-RATE-FROM-POLLUTION MULTIPLIER
              (DIMENSIONLESS)
    DRFM   - DEATH-RATE-FROM-FOOD MULTIPLIER
              (DIMENSIONLESS)
    DRCM   - DEATH-RATE-FROM-CROWDING MULTIPLIER
              (DIMENSIONLESS)

DRMM.K=TABHL(DRMMT,MSL.K*DRMS,0,5,.5)                          11,A

DRMMT=2/1.4/1/.8/.7/.6/.53/.5/.5/.5/.5                         11.1,T

DRMS=1                                                         11.2,C

    DRMM   - DEATH-RATE-FROM-MATERIAL MULTIPLIER
              (DIMENSIONLESS)
    DRMMT  - DEATH-RATE-FROM-MATERIAL-MULTIPLIER TABLE
    MSL    - MATERIAL STANDARD OF LIVING (DIMENSIONLESS)
    DRMS   - DEATH-RATE-FROM-MATERIAL SENSITIVITY
              (DIMENSIONLESS)
```

```
DRPM.K=TABLE(DRPMT,POLR.K,0,30,5)                           12,A

DRPMT=.98/1.1/1.3/1.6/2.1/2.8/4                             12.1,T

    DRPM  - DEATH-RATE-FROM-POLLUTION MULTIPLIER
             (DIMENSIONLESS)
    DRPMT - DEATH-RATE-FROM-POLLUTION-MULTIPLIER TABLE
    POLR  - POLLUTION RATIO (DIMENSIONLESS)

DRFM.K=TABHL(DRFMT,FR.K,0,2,.25)                            13,A

DRFMT=30/3/2/1.4/1/.7/.6/.5/.5                              13.1,T

    DRFM  - DEATH-RATE-FROM-FOOD MULTIPLIER
             (DIMENSIONLESS)
    DRFMT - DEATH-RATE-FROM-FOOD-MULTIPLIER TABLE
    FR    - FOOD RATIO (DIMENSIONLESS)

DRCM.K=TABLE(DRCMT,CR.K,0,5,1)                              14,A

DRCMT=1/1.1/1.3/1.6/2.1/3                                   14.1,T

    DRCM  - DEATH-RATE-FROM-CROWDING MULTIPLIER
             (DIMENSIONLESS)
    DRCMT - DEATH-RATE-FROM-CROWDING-MULTIPLIER TABLE
    CR    - CROWDING RATIO (DIMENSIONLESS)

CR.K=(P.K)/(LA*PDN)                                         15,A

LA=135E6                                                    15.1,C

PDN=26.5                                                    15.2,C

    CR    - CROWDING RATIO (DIMENSIONLESS)
    P     - POPULATION (PEOPLE)
    LA    - LAND AREA (SQUARE KILOMETERS)
    PDN   - POPULATION DENSITY NORMAL (PEOPLE/SQUARE
             KILOMETER)

BRCM.K=TABLE(BRCMT,CR.K,0,5,1)                              16,A

BRCMT=1/.95/.8/.7/.65/.65                                   16.1,T

    BRCM  - BIRTH-RATE-FROM-CROWDING MULTIPLIER
             (DIMENSIONLESS)
    BRCMT - BIRTH-RATE-FROM-CROWDING-MULTIPLIER TABLE
    CR    - CROWDING RATIO (DIMENSIONLESS)
```

```
BRFM.K=TABHL(BRFMT,FR.K,0,4,1)                                          17,A

BRFMT=0/1/1.6/1.9/2                                                     17.1,T

     BRFM   - BIRTH-RATE-FROM-FOOD MULTIPLIER
                (DIMENSIONLESS)
     BRFMT  - BIRTH-RATE-FROM-FOOD-MULTIPLIER TABLE
     FR     - FOOD RATIO (DIMENSIONLESS)

BRPM.K=TABLE(BRPMT,POLR.K,0,30,5)                                       18,A

BRPMT=1/.97/.92/.82/.72/.6/.4                                           18.1,T

     BRPM   - BIRTH-RATE-FROM-POLLUTION MULTIPLIER
                (DIMENSIONLESS)
     BRPMT  - BIRTH-RATE-FROM-POLLUTION-MULTIPLIER TABLE
     POLR   - POLLUTION RATIO (DIMENSIONLESS)

FR.K=(FPCI.K)(FCM.K)(FPM.K)                                             19,A

     FR     - FOOD RATIO (DIMENSIONLESS)
     FPCI   - FOOD POTENTIAL FROM CAPITAL INVESTMENT
                (DIMENSIONLESS)
     FCM    - FOOD-CROWDING MULTIPLIER (DIMENSIONLESS)
     FPM    - FOOD-FROM-POLLUTION MULTIPLIER
                (DIMENSIONLESS)

FCM.K=TABLE(FCMT,CR.K,0,5,1)                                            20,A

FCMT=2.4/1/.6/.4/.3/.2                                                  20.1,T

     FCM    - FOOD-CROWDING MULTIPLIER (DIMENSIONLESS)
     FCMT   - FOOD-CROWDING-MULTIPLIER TABLE
     CR     - CROWDING RATIO (DIMENSIONLESS)

FPCI.K=TABHL(FPCIT,CIRA.K,0,6,1)                                        21,A

FPCIT=.5/1/1.4/1.7/1.9/2.05/2.2                                         21.1,T
        ↑
     FPCI   - FOOD POTENTIAL FROM CAPITAL INVESTMENT
                (DIMENSIONLESS)
     FPCIT  - FOOD-POTENTIAL-FROM-CAPITAL-INVESTMENT
                TABLE
     CIRA   - CAPITAL INVESTMENT RATIO IN AGRICULTURE
                (CAPITAL UNITS/PERSON)
```

```
CIRA.K=(CIR.K)(CIAF.K)/CIAFN                                22,A

CIAFN=.3                                                    22.1,C

    CIRA  - CAPITAL INVESTMENT RATIO IN AGRICULTURE
             (CAPITAL UNITS/PERSON)
    CIR   - CAPITAL-INVESTMENT RATIO (CAPITAL UNITS/
             PERSON)
    CIAF  - CAPITAL-INVESTMENT-IN-AGRICULTURE FRACTION
             (DIMENSIONLESS)
    CIAFN - CAPITAL-INVESTMENT-IN-AGRICULTURE FRACTION
             NORMAL (DIMENSIONLESS)

CIR.K=CI.K/P.K                                              23,A

    CIR   - CAPITAL-INVESTMENT RATIO (CAPITAL UNITS/
             PERSON)
    CI    - CAPITAL INVESTMENT (CAPITAL UNITS)
    P     - POPULATION (PEOPLE)

CI.K=CI.J+(DT)(CIG.JK-CID.JK)                               24,L

CI=CII                                                      24.1,N

CII=.4E9                                                    24.2,C

    CI    - CAPITAL INVESTMENT (CAPITAL UNITS)
    CIG   - CAPITAL-INVESTMENT GENERATION (CAPITAL
             UNITS/YEAR)
    CID   - CAPITAL-INVESTMENT DISCARD (CAPITAL UNITS/
             YEAR)
    CII   - CAPITAL INVESTMENT, INITIAL (CAPITAL UNITS)

CIG.KL=(P.K)(CIPC.K)(CLIP(CIGC,CIGC1,SWT4,TIME.K))          25,R

CIGC=1                                                      25.1,C

CIGC1=1                                                     25.2,C

SWT4=1970                                                   25.3,C

    CIG   - CAPITAL-INVESTMENT GENERATION (CAPITAL
             UNITS/YEAR)
    P     - POPULATION (PEOPLE)
    CIPC  - CAPITAL INVESTMENT PER CAPITA (CAPITAL
             UNITS/PERSON/YEAR)
    CIGC  - CAPITAL-INVESTMENT-GENERATION COEFFICIENT
             (DIMENSIONLESS)
    CIGC1 - CAPITAL-INVESTMENT-GENERATION COEFFICIENT
             NO. 1 (DIMENSIONLESS)
    SWT4  - SWITCH TIME NO. 4 FOR CIGC (YEARS)
```

```
CIPC.K=TABHL(CIPCT,MSL.K,0,5,1)                                   26,A

CIPCT=.005/.05/.09/.12/.14/.15                                    26.1,T

    CIPC  - CAPITAL INVESTMENT PER CAPITA (CAPITAL
             UNITS/PERSON/YEAR)
    CIPCT - CAPITAL-INVESTMENT-PER-CAPITA TABLE
    MSL   - MATERIAL STANDARD OF LIVING (DIMENSIONLESS)

CID.KL=(CI.K)(CLIP(CIDN,CIDN1,SWT5,TIME.K))                       27,R

CIDN=.025                                                         27.1,C

CIDN1=.025                                                        27.2,C

SWT5=1970                                                         27.3,C

    CID   - CAPITAL-INVESTMENT DISCARD (CAPITAL UNITS/
             YEAR)
    CI    - CAPITAL INVESTMENT (CAPITAL UNITS)
    CIDN  - CAPITAL-INVESTMENT DISCARD NORMAL
             (FRACTION/YEAR)
    CIDN1 - CAPITAL-INVESTMENT DISCARD NORMAL NO. 1
             (FRACTION/YEAR)
    SWT5  - SWITCH TIME NO. 5 FOR CIDN (YEARS)

FPM.K=TABLE(FPMT,POLR.K,0,30,5)                                   28,A

FPMT=1/.95/.87/.77/.65/.5/.32                                     28.1,T

    FPM   - FOOD-FROM-POLLUTION MULTIPLIER
             (DIMENSIONLESS)
    FPMT  - FOOD-FROM-POLLUTION-MULTIPLIER TABLE
    POLR  - POLLUTION RATIO (DIMENSIONLESS)

POLR.K=POL.K/POLS                                                 29,A

POLS=3.6E9                                                        29.1,C

    POLR  - POLLUTION RATIO (DIMENSIONLESS)
    POL   - POLLUTION (POLLUTION UNITS)
    POLS  - POLLUTION STANDARD (POLLUTION UNITS)

POL.K=POL.J+(DT)(POLG.JK-POLA.JK)                                 30,L

POL=POLI                                                          30.1,N

POLI=.2E9                                                         30.2,C

    POL   - POLLUTION (POLLUTION UNITS)
    POLG  - POLLUTION GENERATION (POLLUTION UNITS/YEAR)
    POLA  - POLLUTION ABSORPTION (POLLUTION UNITS/YEAR)
    POLI  - POLLUTION, INITIAL (POLLUTION UNITS)
```

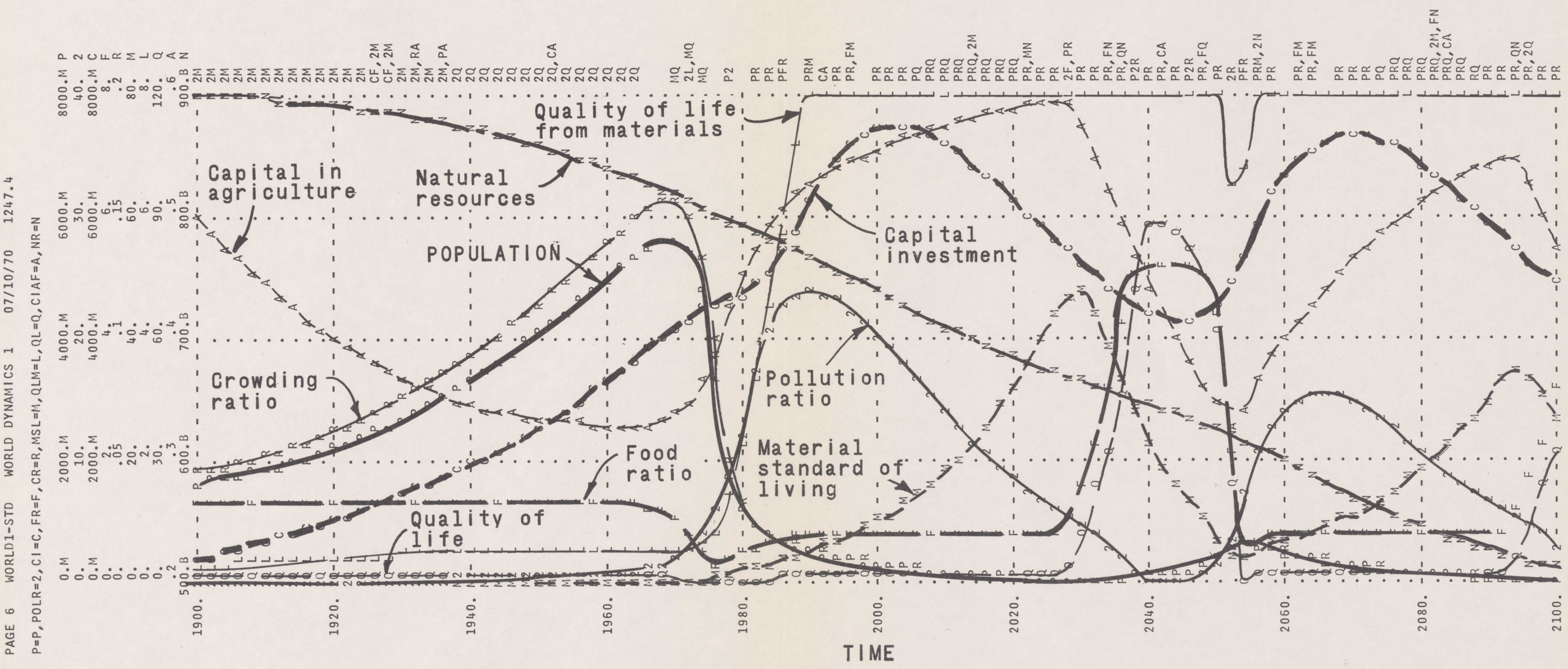
```
POLG.KL=(P.K)(CLIP(POLN,POLN1,SWT6,TIME.K))(POLCM.K)           31,R

POLN=1                                                         31.1,C

POLN1=1                                                        31.2,C

SWT6=1970                                                      31.3,C

     POLG   - POLLUTION GENERATION (POLLUTION UNITS/YEAR)
     P      - POPULATION (PEOPLE)
     POLN   - POLLUTION NORMAL (POLLUTION UNITS/PERSON/
               YEAR)
     POLN1  - POLLUTION NORMAL NO. 1 (POLLUTION UNITS/
               PERSON/YEAR)
     SWT6   - SWITCH TIME NO. 6 FOR POLN (YEARS)
     POLCM  - POLLUTION-FROM-CAPITAL MULTIPLIER
               (DIMENSIONLESS)

POLCM.K=TABHL(POLCMT,CIR.K,0,5,1)                              32,A

POLCMT=.05/1/3/5.4/7.4/8                                       32.1,T

     POLCM  - POLLUTION-FROM-CAPITAL MULTIPLIER
               (DIMENSIONLESS)
     POLCMT- POLLUTION-FROM-CAPITAL-MULTIPLIER TABLE
     CIR    - CAPITAL-INVESTMENT RATIO (CAPITAL UNITS/
               PERSON)

POLA.KL=POL.K/POLAT.K                                          33,R

     POLA   - POLLUTION ABSORPTION (POLLUTION UNITS/YEAR)
     POL    - POLLUTION (POLLUTION UNITS)
     POLAT  - POLLUTION-ABSORPTION TIME (YEARS)

POLAT.K=TABLE(POLATT,POLR.K,0,30,5)                            34,A

POLATT=1/1.4/2.4/3.6/5.2/7.2/10                                34.1,T

     POLAT  - POLLUTION-ABSORPTION TIME (YEARS)
     POLATT- POLLUTION-ABSORPTION-TIME TABLE
     POLR   - POLLUTION RATIO (DIMENSIONLESS)
```

```
CIAF.K=CIAF.J+(DT/CIAFT)(CFIFR.J*CIQR.J-CIAF.J)               35,L

CIAF=CIAFI                                                    35.1,N

CIAFI=.3                                                      35.2,C

CIAFT=15                                                      35.3,C

    CIAF   - CAPITAL-INVESTMENT-IN-AGRICULTURE FRACTION
              (DIMENSIONLESS)
    CIAFT  - CAPITAL-INVESTMENT-IN-AGRICULTURE-FRACTION
              ADJUSTMENT TIME (YEARS)
    CFIFR  - CAPITAL FRACTION INDICATED BY FOOD RATIO
              (DIMENSIONLESS)
    CIQR   - CAPITAL-INVESTMENT-FROM-QUALITY RATIO
              (DIMENSIONLESS)
    CIAFI  - CAPITAL-INVESTMENT-IN-AGRICULTURE FRACTION,
               INITIAL (DIMENSIONLESS)

CFIFR.K=TABLE(CFIFRT,FR.K,0,2,.5)                             36,A

CFIFRT=1/.6/.3/.15/.1                                         36.1,T

    CFIFR  - CAPITAL FRACTION INDICATED BY FOOD RATIO
              (DIMENSIONLESS)
    CFIFRT - CAPITAL-FRACTION-INDICATED-BY-FOOD-RATIO
              TABLE
    FR     - FOOD RATIO (DIMENSIONLESS)

QL.K=(QLS)(QLM.K)(QLC.K)(QLF.K)(QLP.K)                        37,S

QLS=1                                                         37.1,C

    QL     - QUALITY OF LIFE (SATISFACTION UNITS)
    QLS    - QUALITY-OF-LIFE STANDARD (SATISFACTION
              UNITS)
    QLM    - QUALITY OF LIFE FROM MATERIAL
              (DIMENSIONLESS)
    QLC    - QUALTIY OF LIFE FROM CROWDING
              (DIMENSIONLESS)
    QLF    - QUALITY OF LIFE FROM FOOD (DIMENSIONLESS)
    QLP    - QUALITY OF LIFE FROM POLLUTION
              (DIMENSIONLESS)

QLM.K=TABHL(QLMT,MSL.K,0,5,1)                                 38,A

QLMT=.2/1/1.7/2.3/2.7/2.9                                     38.1,T

    QLM    - QUALITY OF LIFE FROM MATERIAL
              (DIMENSIONLESS)
    QLMT   - QUALITY-OF-LIFE-FROM-MATERIAL TABLE
    MSL    - MATERIAL STANDARD OF LIVING (DIMENSIONLESS)
```

```
QLC.K=TABLE(QLCT,CR.K,0,5,.5)                                    39,A

QLCT=2/1.3/1/.75/.55/.45/.38/.3/.25/.22/.2                       39.1,T

     QLC    - QUALTIY OF LIFE FROM CROWDING
                (DIMENSIONLESS)
     QLCT   - QUALITY-OF-LIFE-FROM-CROWDING TABLE
     CR     - CROWDING RATIO (DIMENSIONLESS)

QLF.K=TABHL(QLFT,FR.K,0,4,1)                                     40,A

QLFT=0/1/1.8/2.4/2.7                                             40.1,T

     QLF    - QUALITY OF LIFE FROM FOOD (DIMENSIONLESS)
     QLFT   - QUALITY-OF-LIFE-FROM-FOOD TABLE
     FR     - FOOD RATIO (DIMENSIONLESS)

QLP.K=TABLE(QLPT,POLR.K,0,30,5)                                  41,A

QLPT=1.1/1/.88/.71/.55/.35/.12                                   41.1,T

     QLP    - QUALITY OF LIFE FROM POLLUTION
                (DIMENSIONLESS)
     QLPT   - QUALITY-OF-LIFE-FROM-POLLUTION TABLE
     POLR   - POLLUTION RATIO (DIMENSIONLESS)

NRMM.K=TABHL(NRMMT,MSL.K,0,10,1)                                 42,A

NRMMT=0/1/1.8/2.4/2.9/3.3/3.6/3.8/3.9/3.95/4                     42.1,T

     NRMM   - NATURAL-RESOURCE-FROM-MATERIAL MULTIPLIER
                (DIMENSIONLESS)
     NRMMT  - NATURAL-RESOURCE-FROM-MATERIAL-MULTIPLIER
                TABLE
     MSL    - MATERIAL STANDARD OF LIVING (DIMENSIONLESS)

CIQR.K=TABHL(CIQRT,QLM.K/QLF.K,0,2,.5)                           43,A

CIQRT=.7/.8/1/1.5/2                                              43.1,T

     CIQR   - CAPITAL-INVESTMENT-FROM-QUALITY RATIO
                (DIMENSIONLESS)
     CIQRT  - CAPITAL-INVESTMENT-FROM-QUALITY-RATIO TABLE
     QLM    - QUALITY OF LIFE FROM MATERIAL
                (DIMENSIONLESS)
     QLF    - QUALITY OF LIFE FROM FOOD (DIMENSIONLESS)
```

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

WORLD1-STD



```
PAGE 2   WORLD1-7/5-1   WORLD DYNAMICS 1    07/10/70    1519.4

              CIGC
  PRESENT      .5
 ORIGINAL      1.
```

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

W1-7/5-1

```
PAGE 3   WORLD1-7/5-1   WORLD DYNAMICS 1   07/10/70   1519.4
P=P,POLR=2,CI=C,FR=F,CR=R,MSL=M,QLM=L,QL=Q,CIAF=A,NR=N
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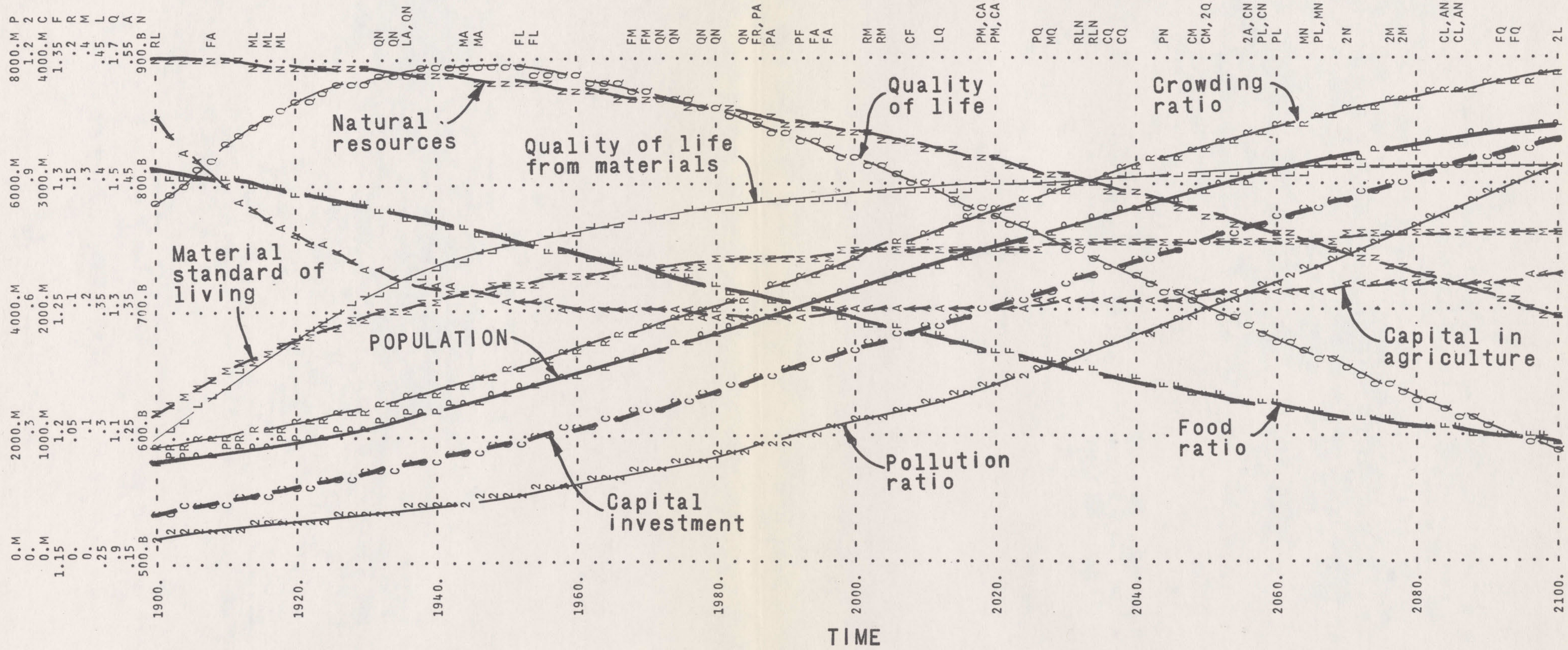
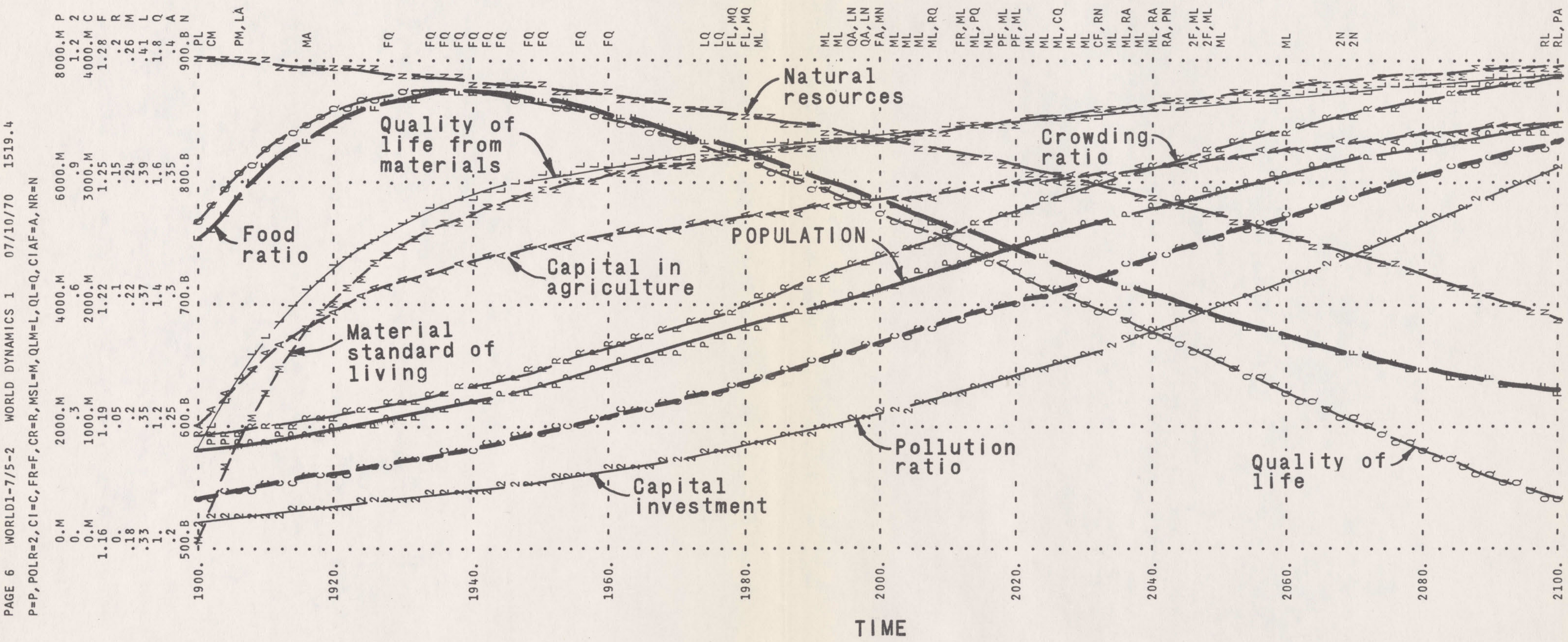


PAGE 5 WORLD1-7/5-2 WORLD DYNAMICS 1 07/10/70 1519.4

	CIGC	CIAFI
PRESENT	.5	.25
ORIGINAL	1.	.5

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

W1-7/5-2

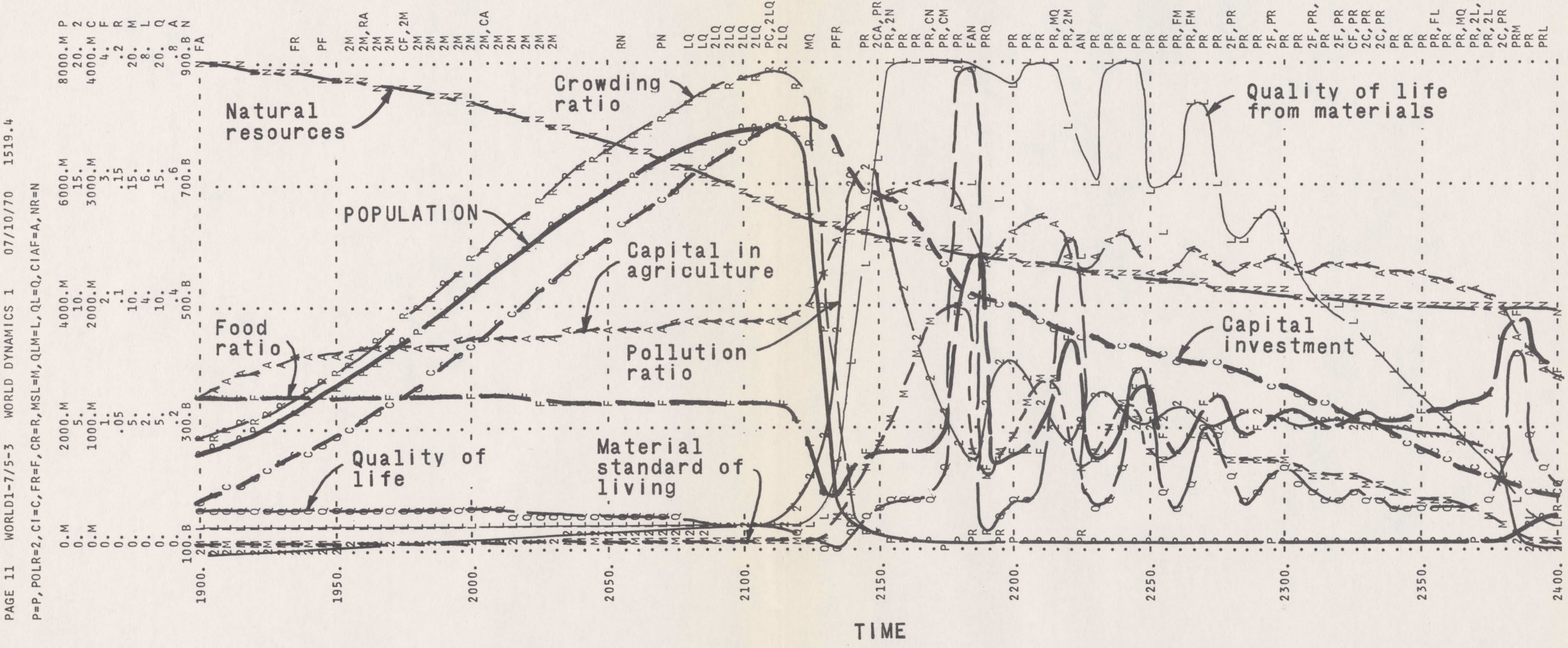


PAGE 8   WORLD1-7/5-3   WORLD DYNAMICS 1   07/10/70   1519.4

	CIGC	CIAFI	LENGTH	PLTPER
PRESENT	.5	.25	2400.	5.
ORIGINAL	1.	.5	2100.	2.

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

W1-7/5-3



PAGE 13 WORLD1-7/5-4 WORLD DYNAMICS 1 07/10/70 1519.4

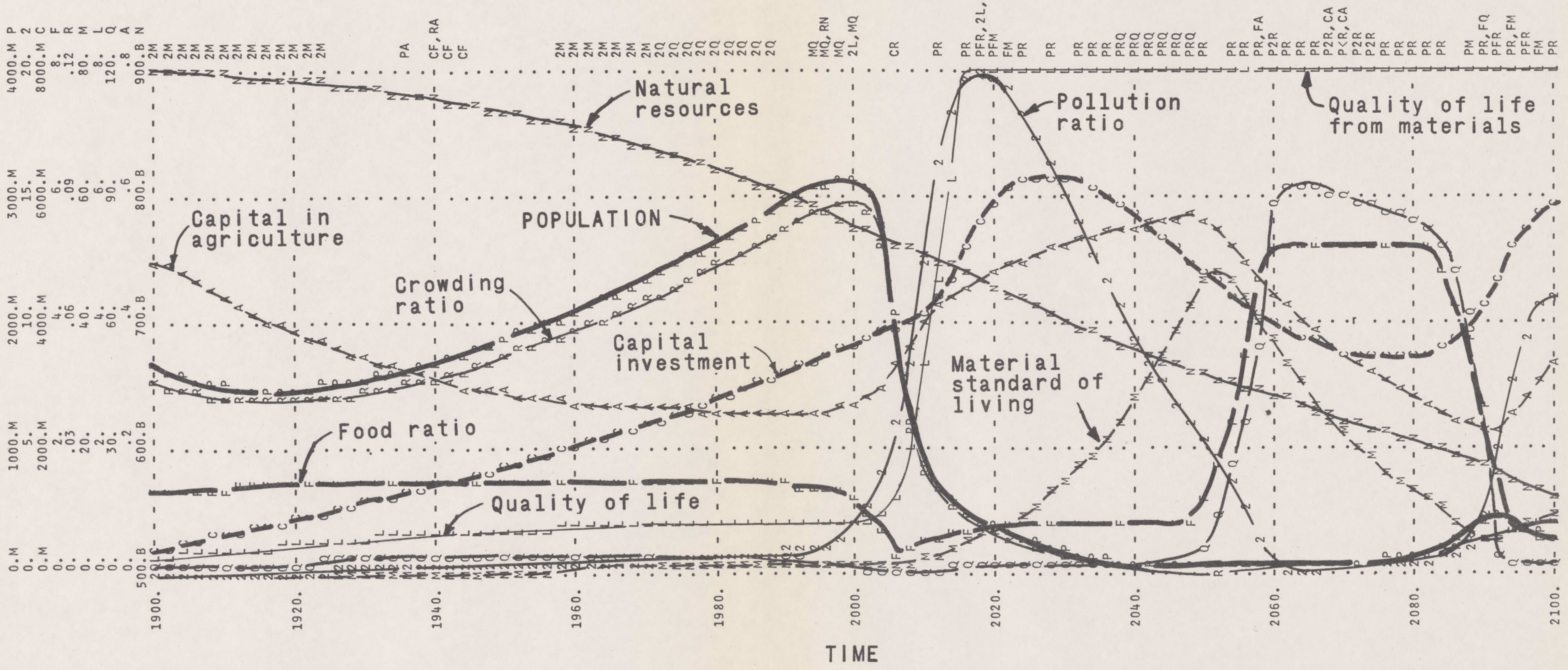
	BRN
PRESENT	25.A
ORIGINAL	45.A

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

W1-7/5-4

PAGE 15 WORLD1-7/5-4 WORLD DYNAMICS 1 07/10/70 1519.4

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

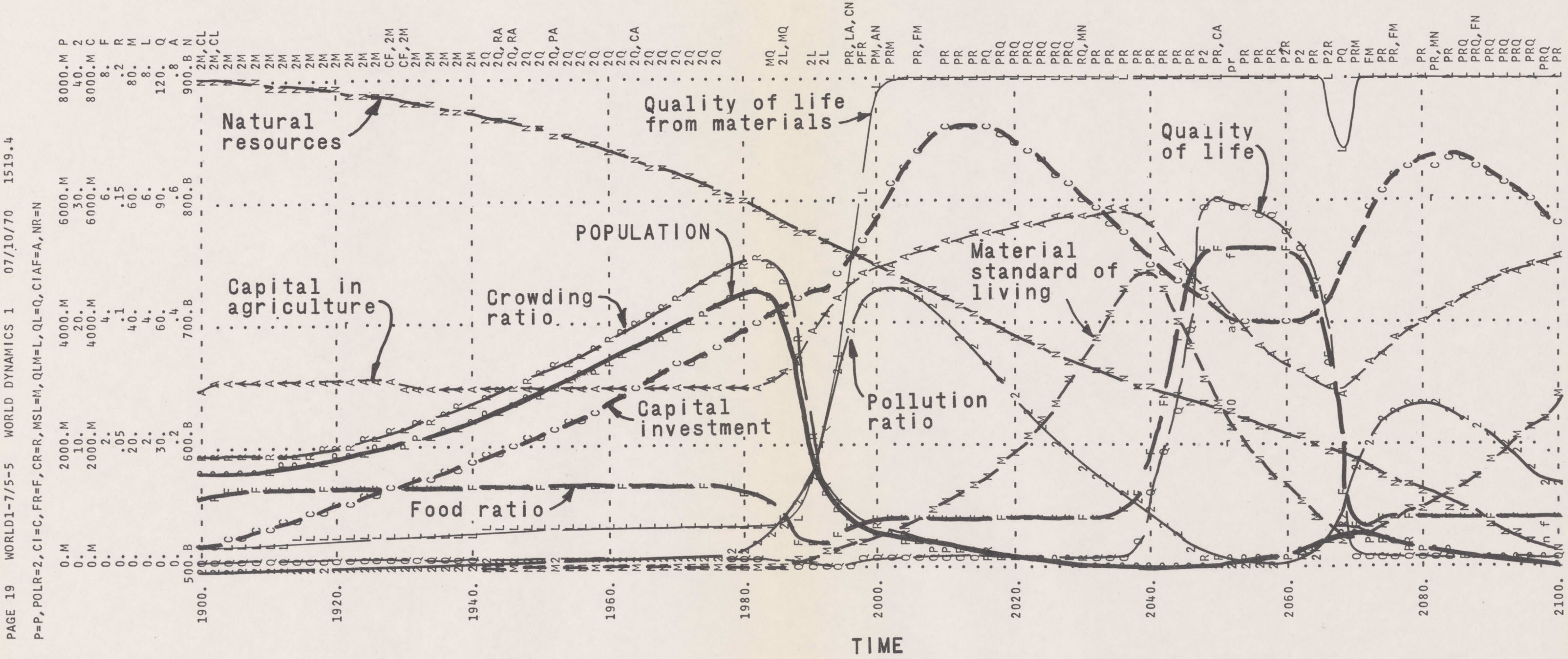


PAGE 17 WORLD1-7/5-5 WORLD DYNAMICS 1 07/10/70 1519.4

	CIAFI	BRN
PRESENT	.3	35.A
ORIGINAL	.5	45.A

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

W1-7/5-5



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PAGE 2   WORLD1-7/5-6   WORLD DYNAMICS 1    07/10/70    1528.3

              CIAFI     BRN  LENGTH   PLTPER
 PRESENT        .3      32.A  2000.      1.
ORIGINAL        .5      45.A  2100.      2.
```
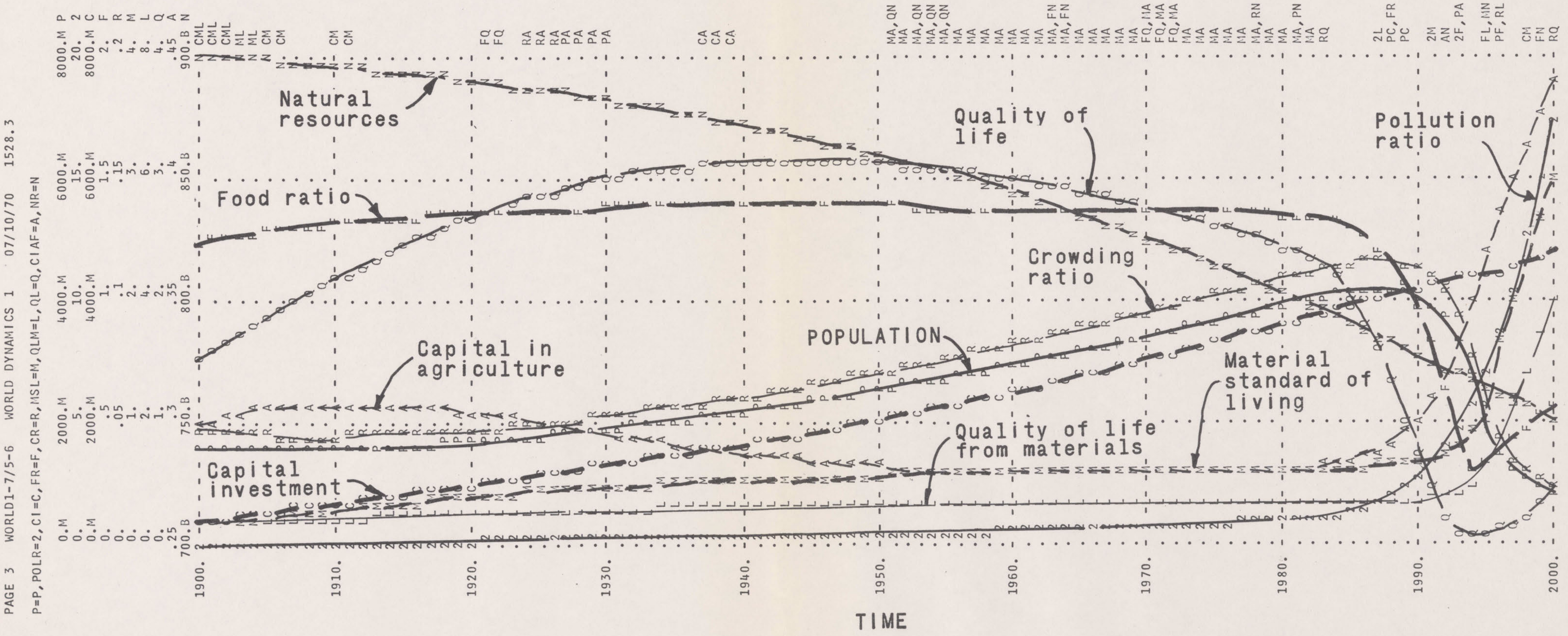

CI	C	Capital investment (capital units)
CIAF	A	Capital-investment-in-agriculture fraction (dimensionless)
CR	R	Crowding ratio (dimensionless)
FR	F	Food ratio (dimensionless)
MSL	M	Material standard of living (dimensionless)
NR	N	Natural resources (natural resource units)
P	P	Population (people)
POLR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

W1-7/5-6

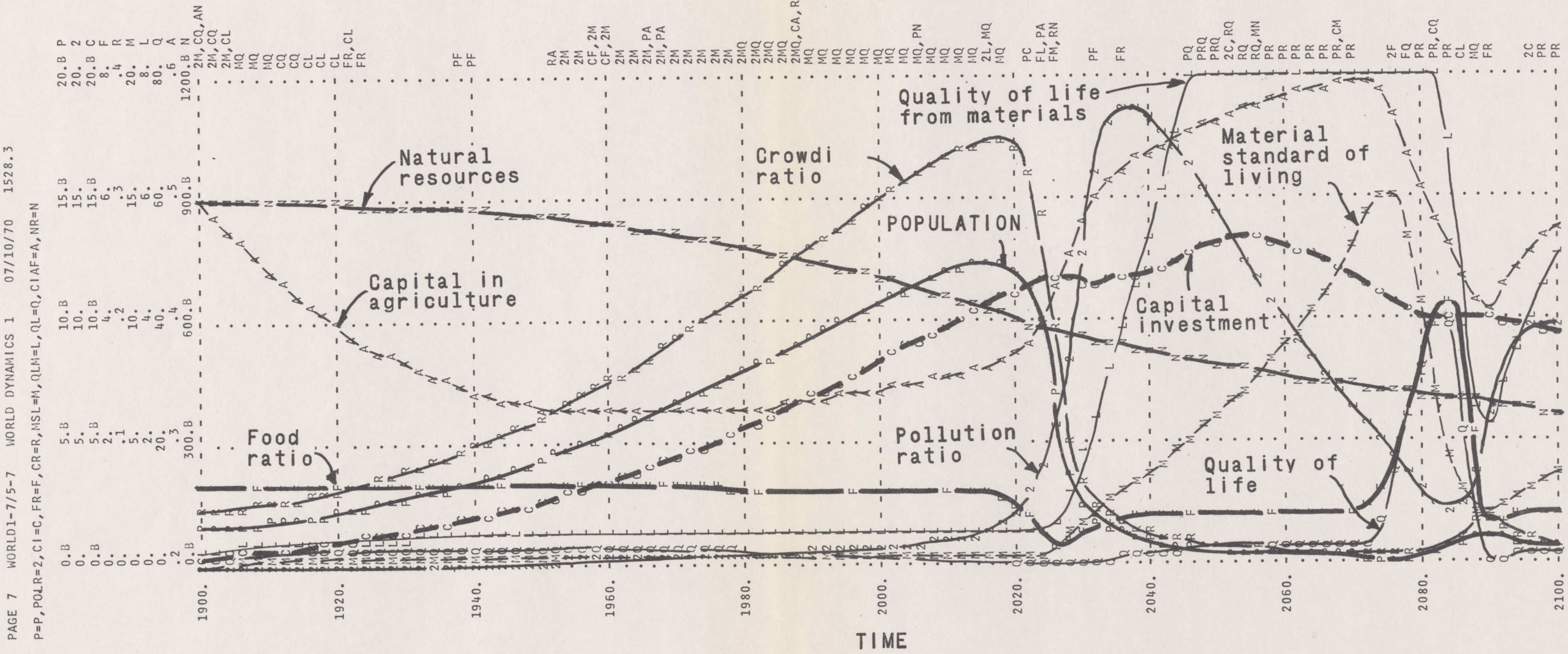


PAGE 5 WORLD1-7/5-7 WORLD DYNAMICS 1 07/10/70 1528.3

	POLS
PRESENT	10.B
ORIGINAL	3600.M

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

W1-7/5-7

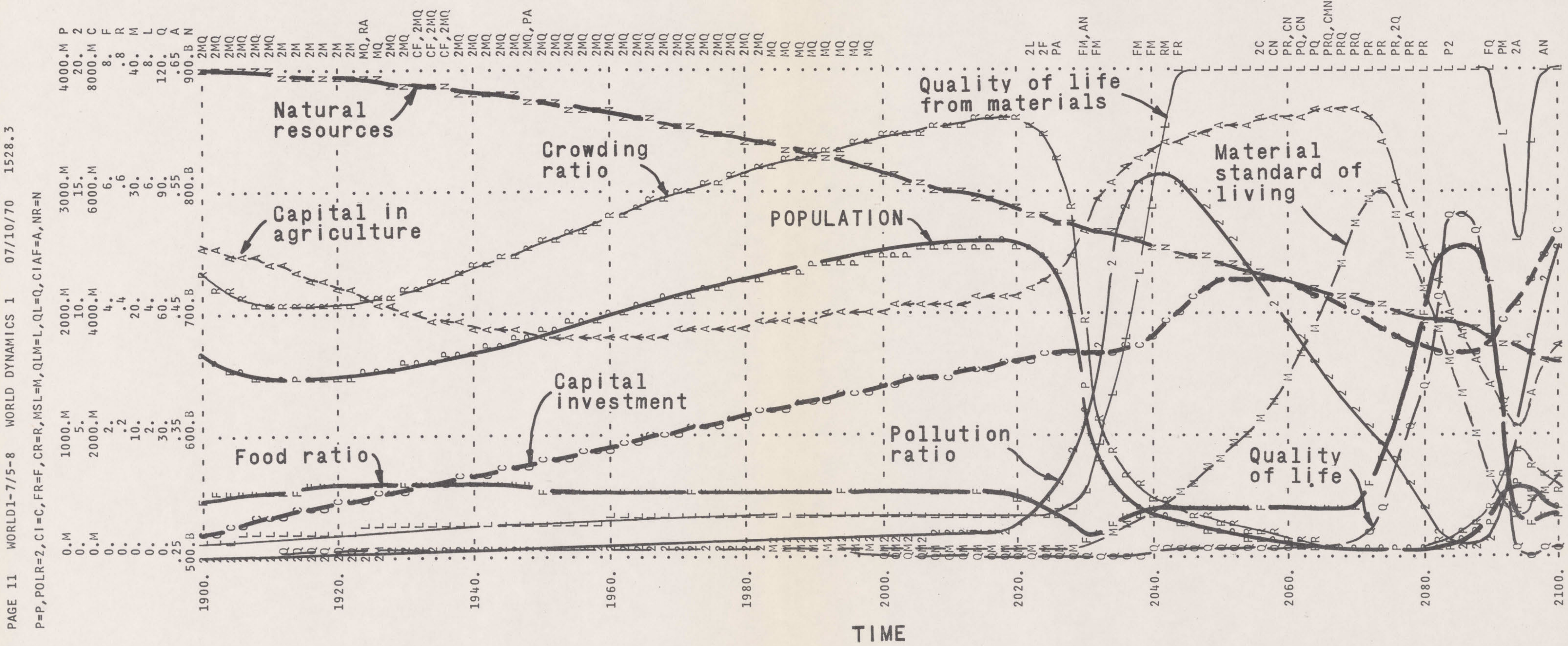


PAGE 9   WORLD1-7/5-8   WORLD DYNAMICS 1   07/10/70   1528.3

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

	PDN
PRESENT	26.5
ORIGINAL	265.

W1-7/5-8



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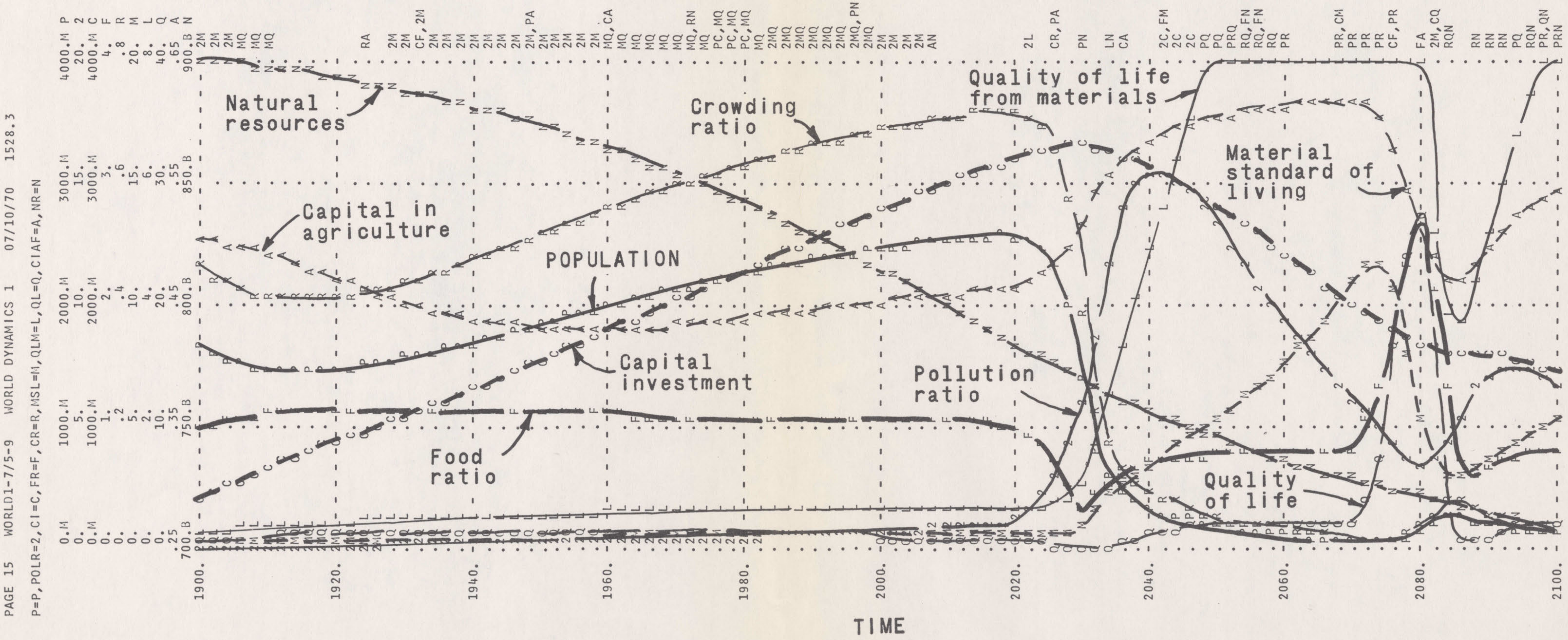
PAGE 13    WORLD1-7/5-9    WORLD DYNAMICS 1     07/10/70     1528.3

           PDN     CIPCT    . . .     . . .     . . .     . . .     . . .
 PRESENT   26.5      20.A    50.A       .1       .14       .16       .18
ORIGINAL   265.      20.A    50.A      .15        .3        .5       .75
```

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

W1-7/5-9



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PAGE 17   WORLD1-7/5-10   WORLD DYNAMICS 1    07/10/70    1528.3
      .
            PDN    CIPCT    . . .    . . .    . . .    . . .    . . .   POLATT    . . .
 PRESENT   26.5     20.A     50.A      .1      .14      .16      .18      .5        1.
ORIGINAL   265.     20.A     50.A     .15       .3       .5      .75      .5        1.
            . . .    . . .    . . .    . . .    . . .
 PRESENT    1.6      2.4      3.2      4.       4.8
ORIGINAL    2.4      4.4      6.8      9.6     11.4
```
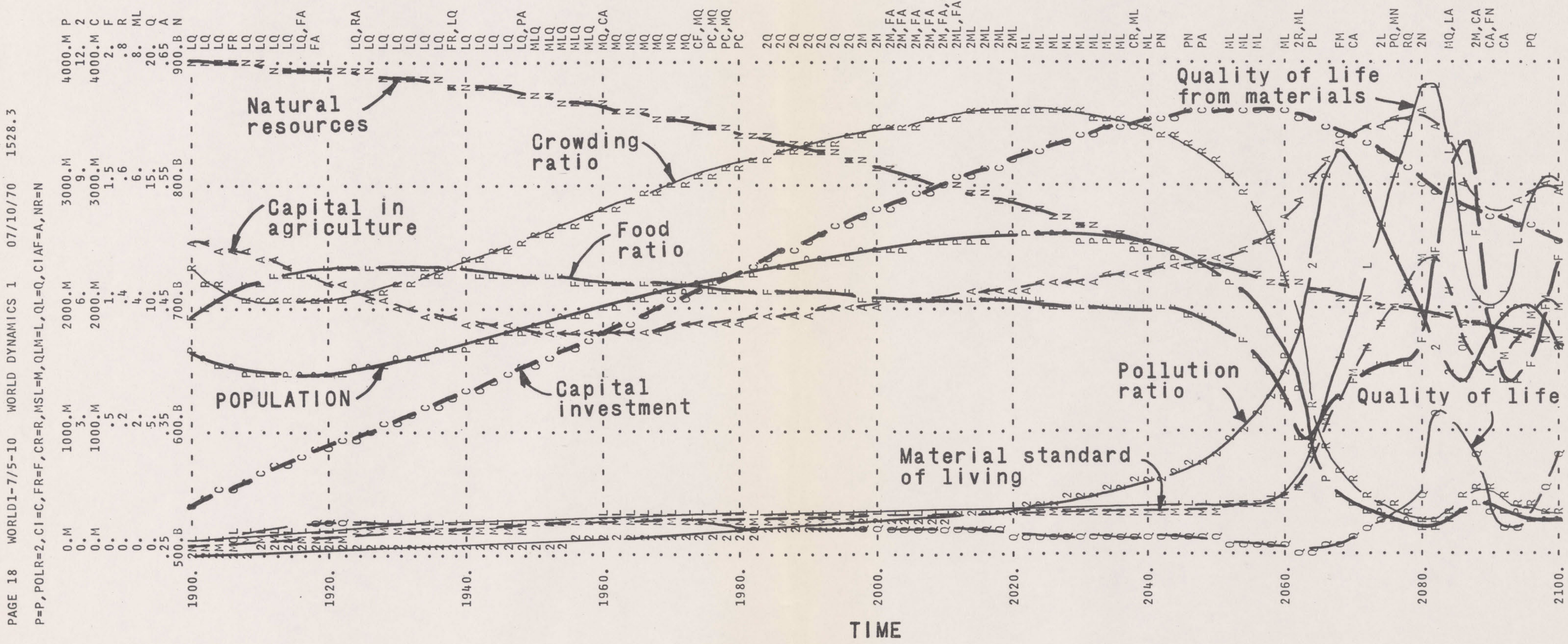

```
  CI  C  Capital investment (capital units)
CIAF  A  Capital-investment-in-agriculture fraction (dimensionless)
  CR  R  Crowding ratio (dimensionless)
  FR  F  Food ratio (dimensionless)
 MSL  M  Material standard of living (dimensionless)
  NR  N  Natural resources (natural resource units)
   P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

W1-7/5-10

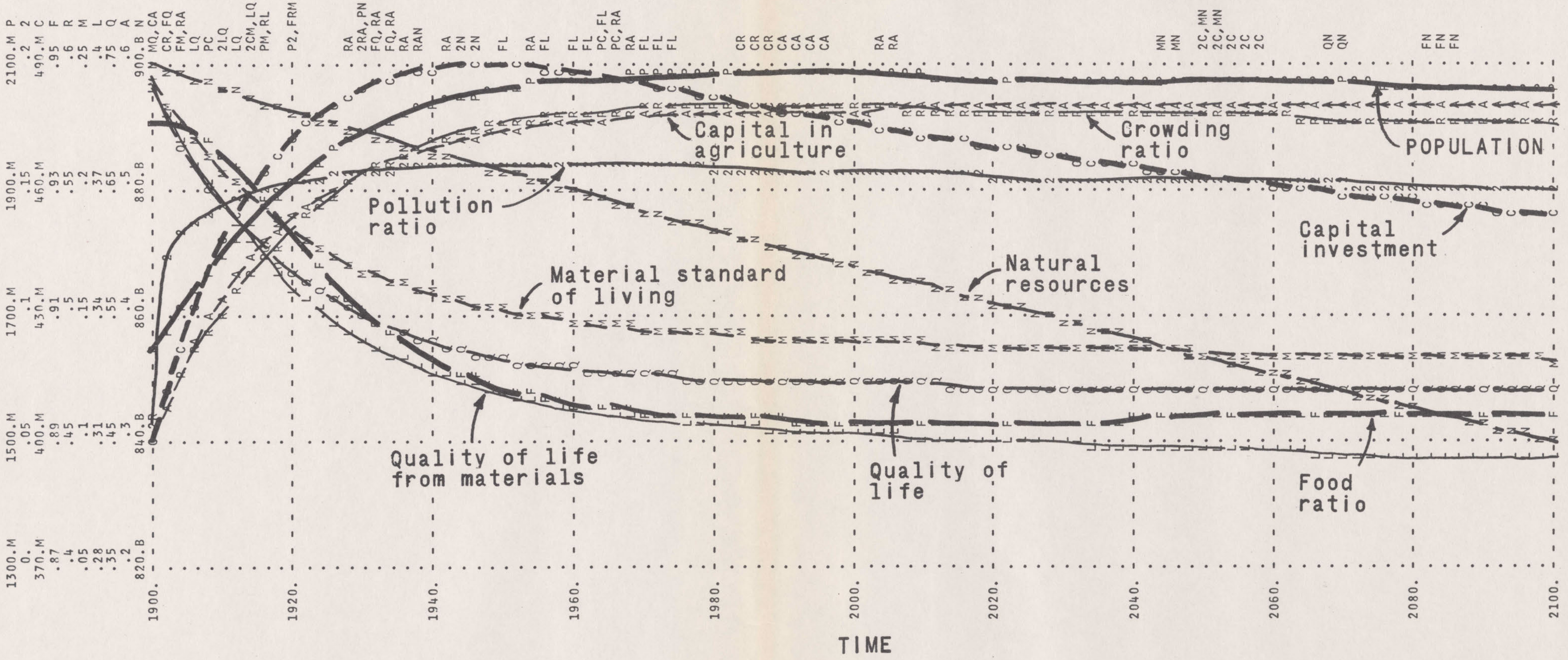


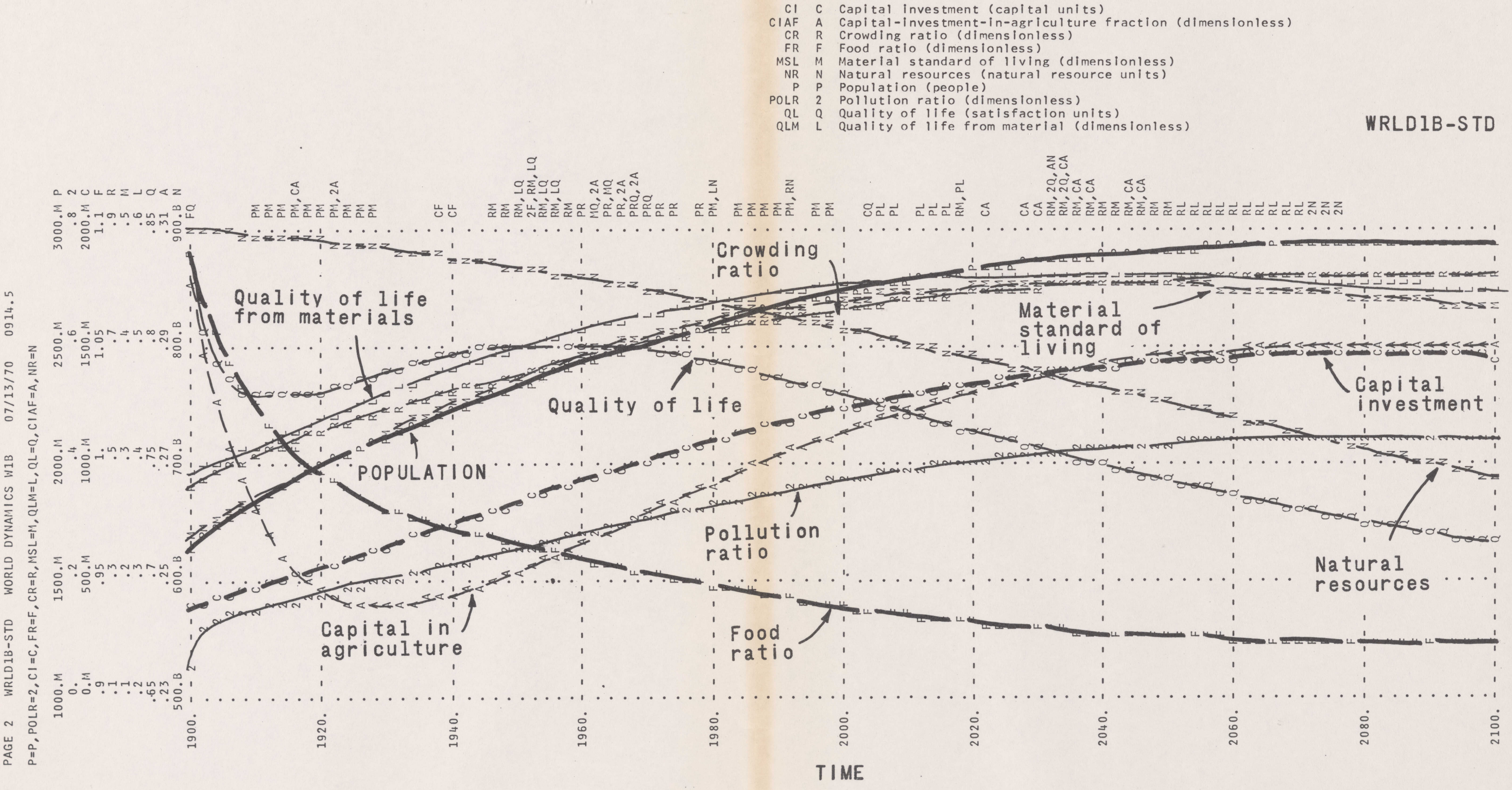
PAGE 2 WRLD1A-STD WORLD DYNAMICS W1A 07/13/70 0904.0

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

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

WRLD1A-STD



CI C Capital investment (capital units)
CIAF A Capital-investment-in-agriculture fraction (dimensionless)
CR R Crowding ratio (dimensionless)
FR F Food ratio (dimensionless)
MSL M Material standard of living (dimensionless)
NR N Natural resources (natural resource units)
P P Population (people)
POLR 2 Pollution ratio (dimensionless)
QL Q Quality of life (satisfaction units)
QLM L Quality of life from material (dimensionless)
WRLD1B-STD
PAGE 2 WRLD1B-STD WORLD DYNAMICS W1B 07/13/70 0914.5
P=P,POLR=2,CI=C,FR=F,CR=R,MSL=M,QLM=L,QL=Q,CIAF=A,NR=N
1000.M 0. 0.M .9 .1 .1 .2 .65 .23 500.B
1500.M .2 500.M .95 .3 .2 .3 .7 .25 600.B
2000.M .4 1000.M 1. .5 .3 .4 .75 .27 700.B
2500.M .6 1500.M 1.05 .7 .4 .5 .8 .29 800.B
3000.M .8 2000.M 1.1 .9 .5 .6 .85 .31 900.B
P 2 C F R M L Q A N
1900.
1920.
1940.
1960.
1980.
2000.
2020.
2040.
2060.
2080.
2100.
TIME
Quality of life from materials
POPULATION
Quality of life
Crowding ratio
Material standard of living
Capital investment
Pollution ratio
Natural resources
Capital in agriculture
Food ratio

D-1355

WORLD2 TABLE FUNCTIONS

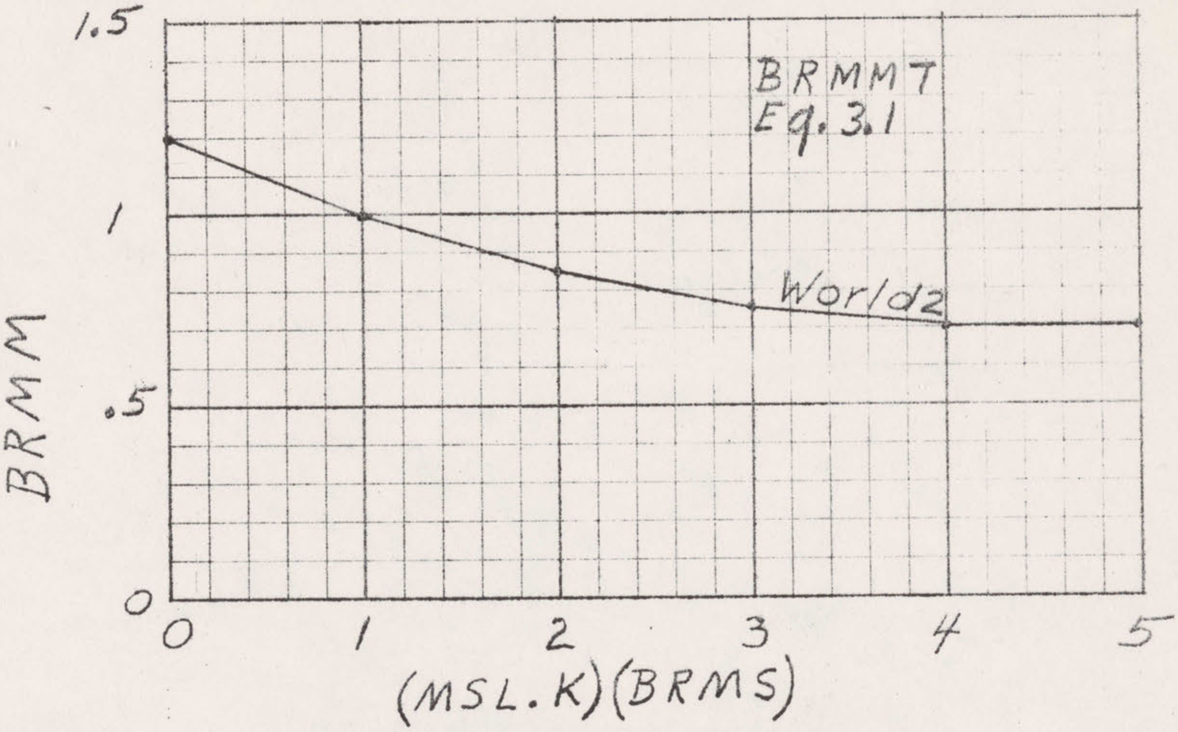
a part of

A World Dynamics Model:
Introductory Exercise

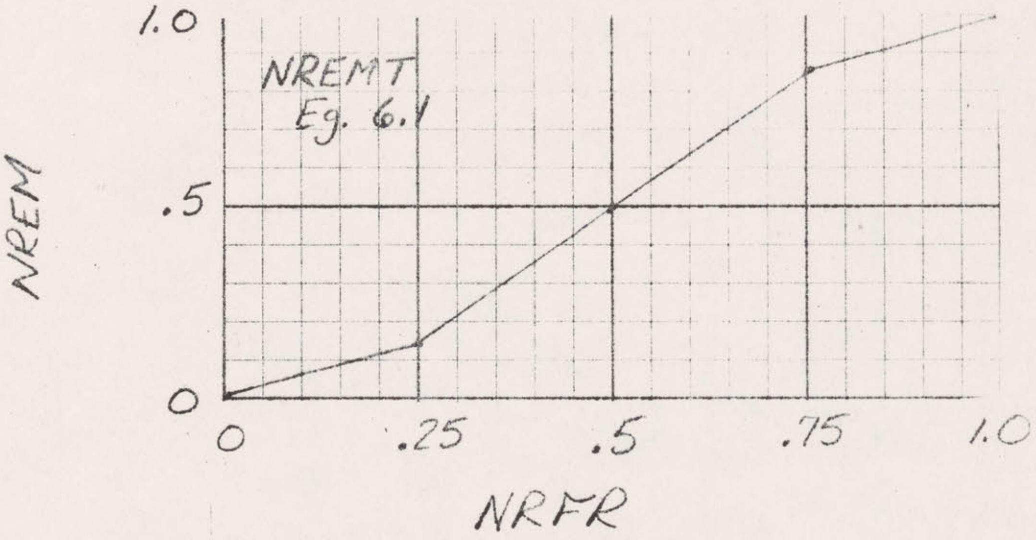
by
Jay W. Forrester
Professor of Management
Sloan School of Management
Massachusetts Institute of
Technology

Cambridge, Mass.

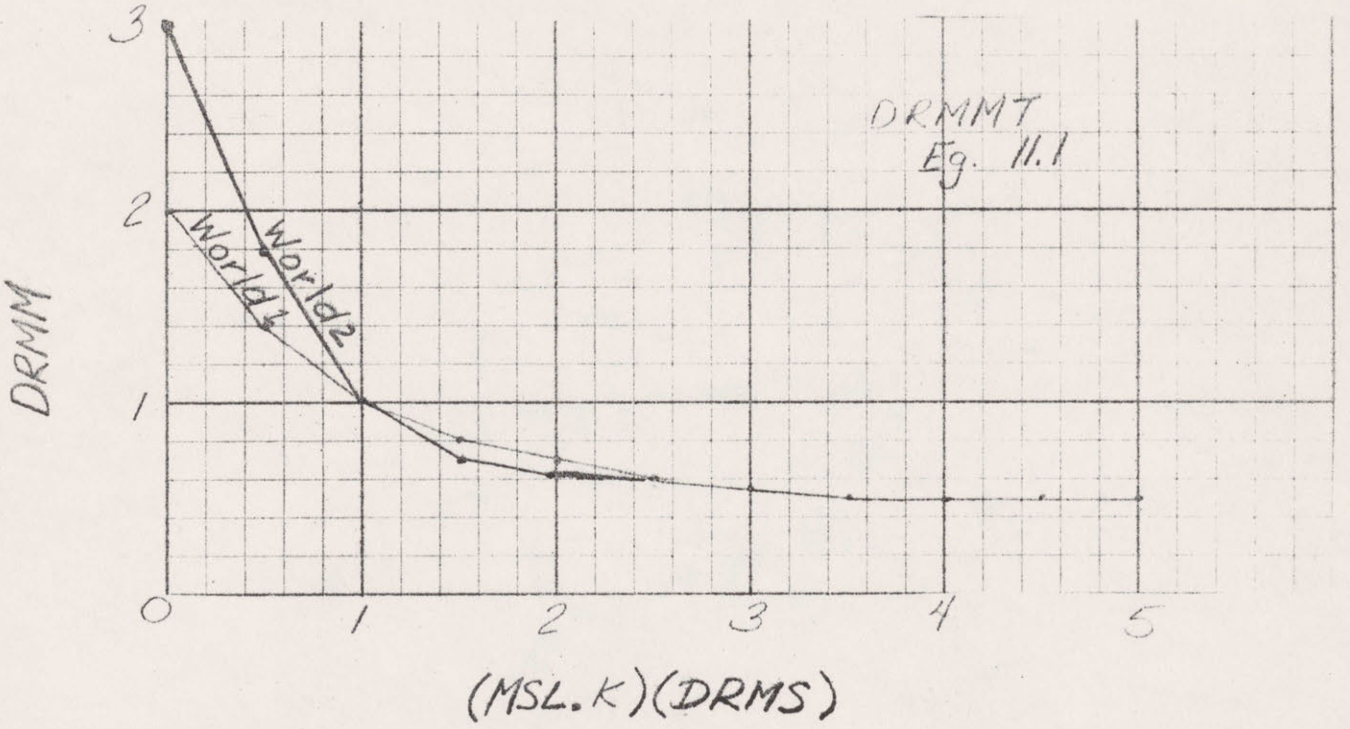
July 15, 1970



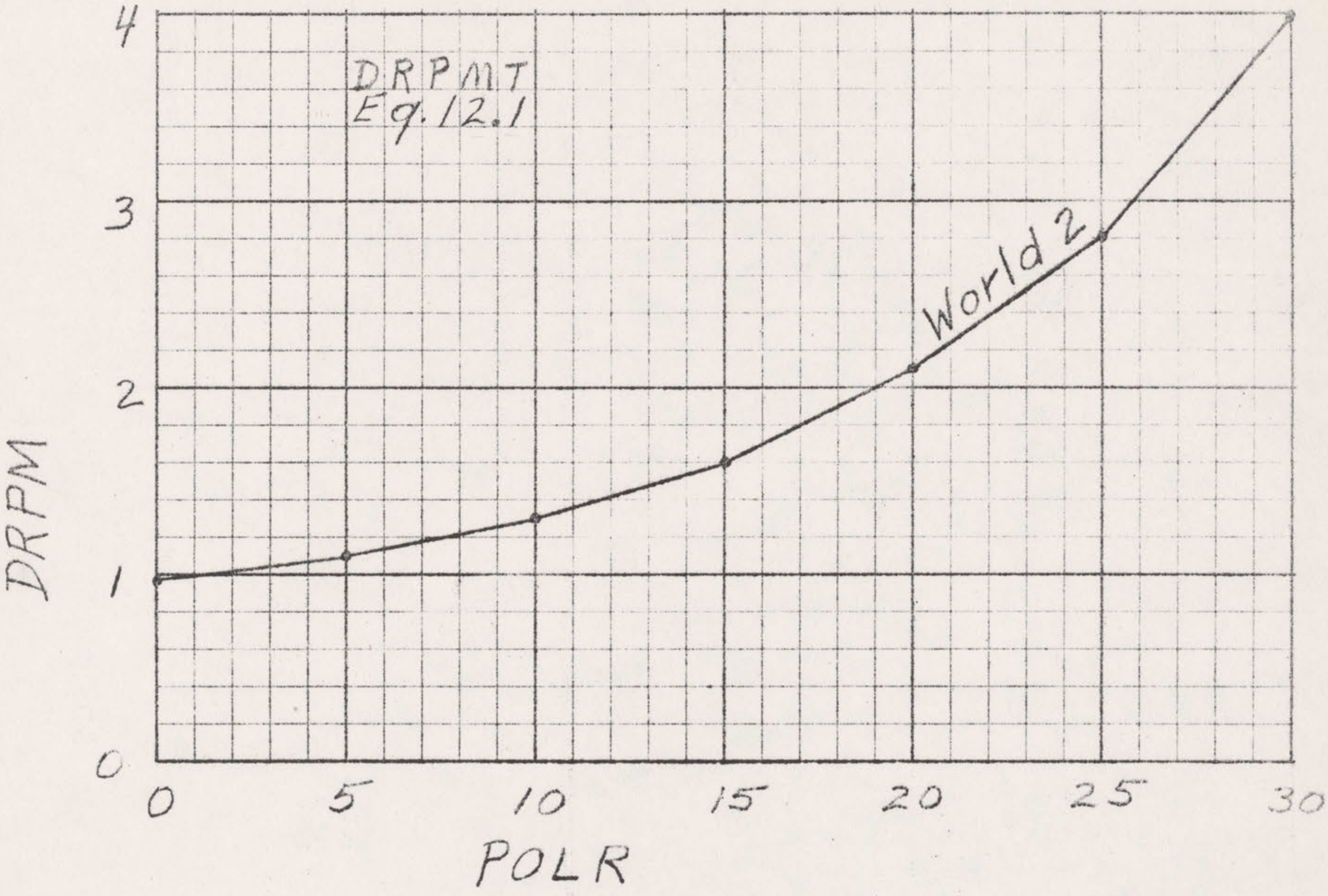
Birth-rate-from-material multiplier vs. material standard of living.



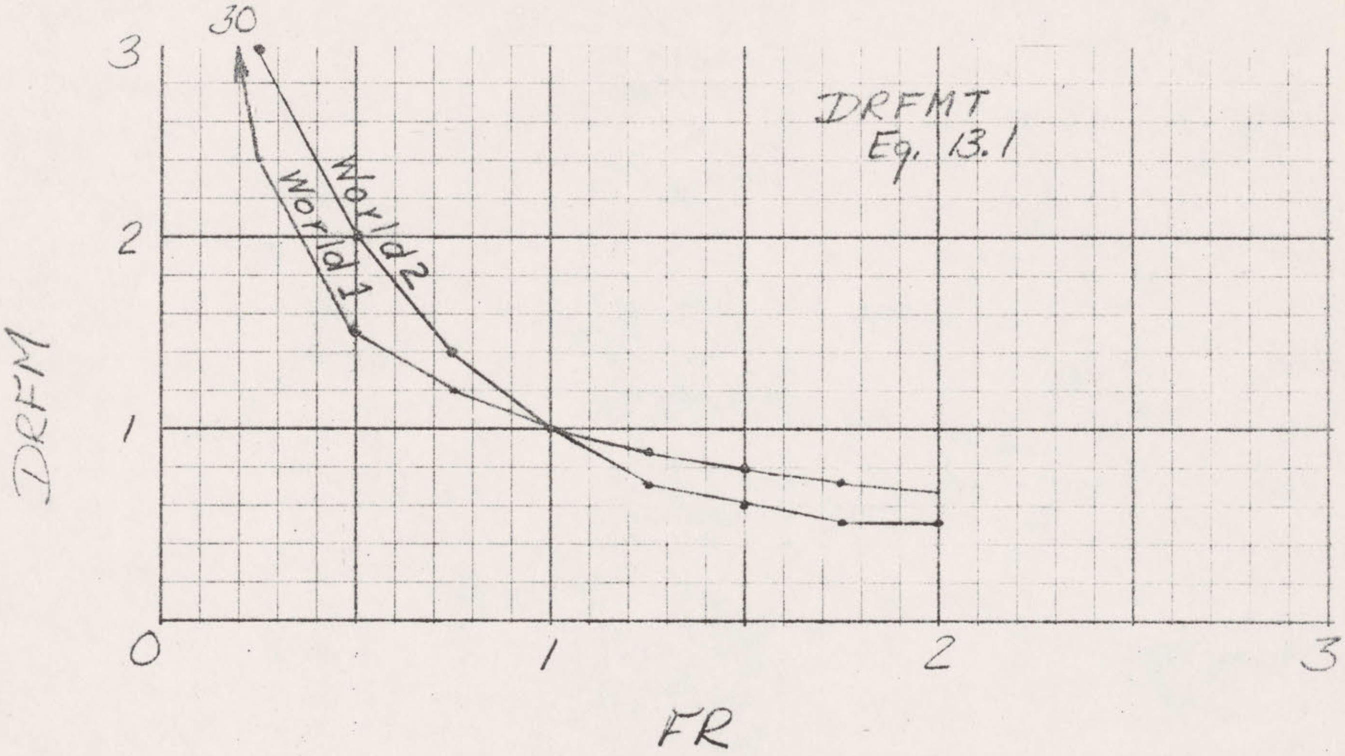
Natural-resource-extraction multiplier vs. natural-resource fraction remaining.



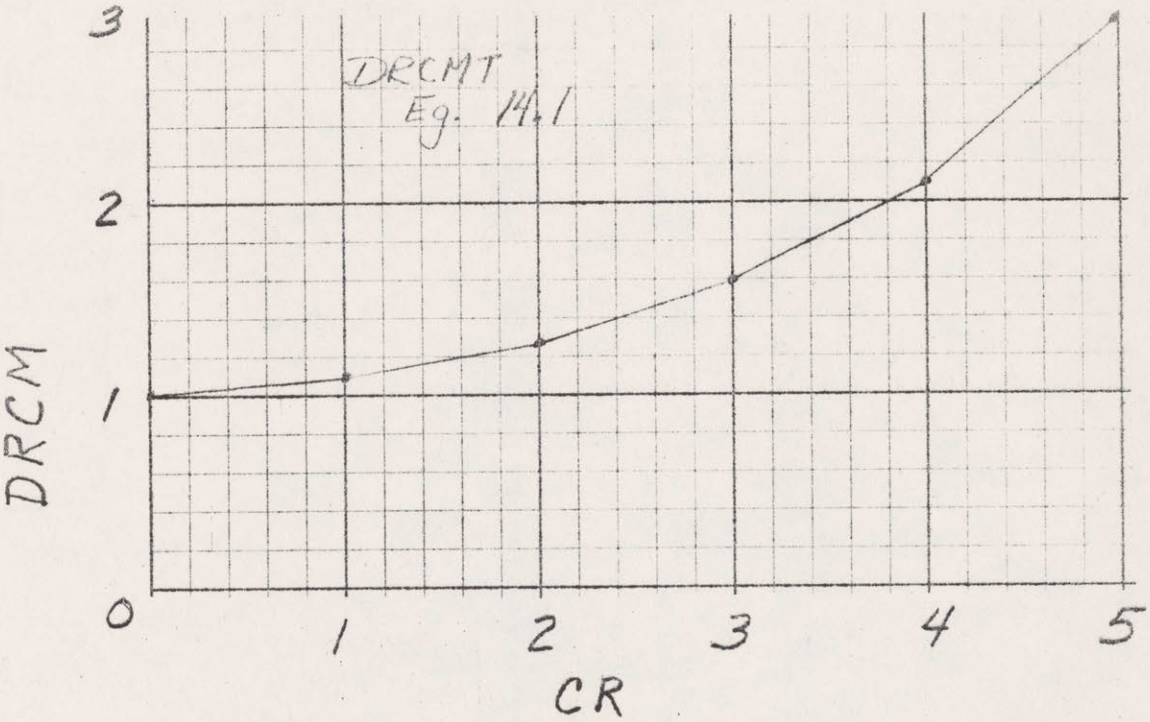
Death-rate-from-material multiplier
vs. material standard of living



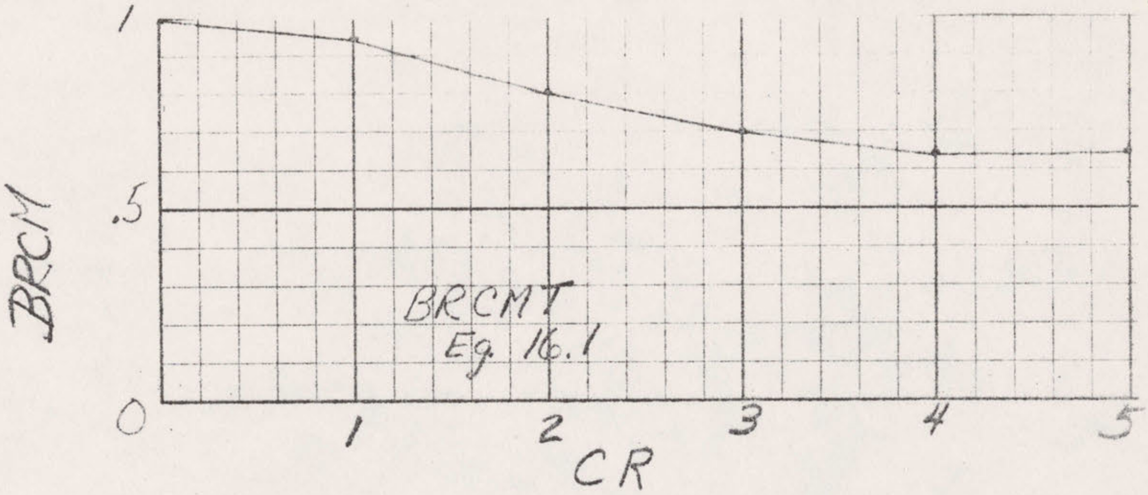
Death-rate-from-pollution multiplier vs. pollution ratio.



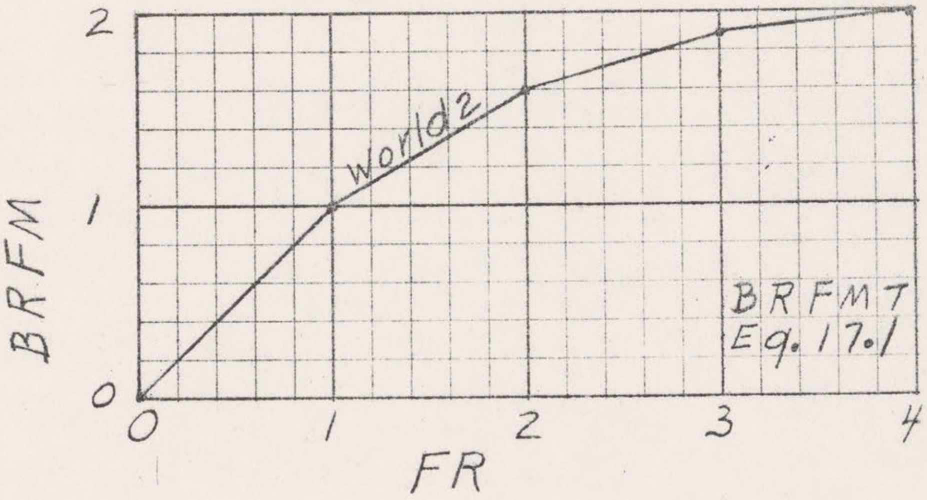
Death-rate-from-food multiplier
vs. food ratio



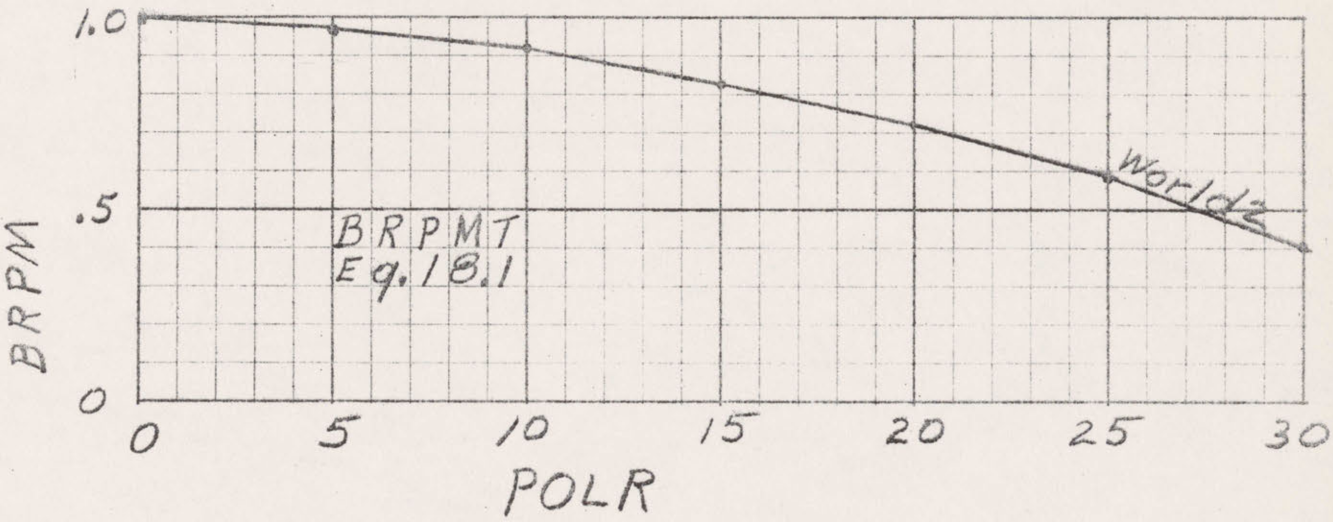
Death-rate-from-crowding multiplier
vs. crowding ratio



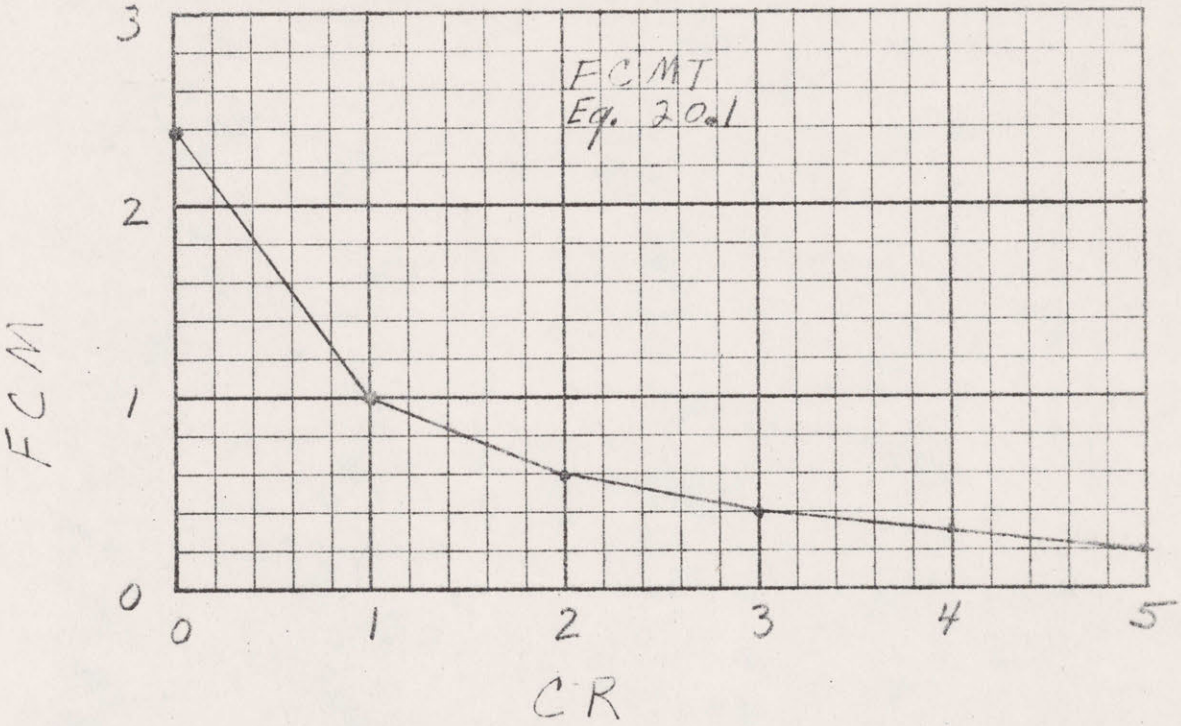
Birth-rate-from-crowding multiplier
vs. crowding ratio



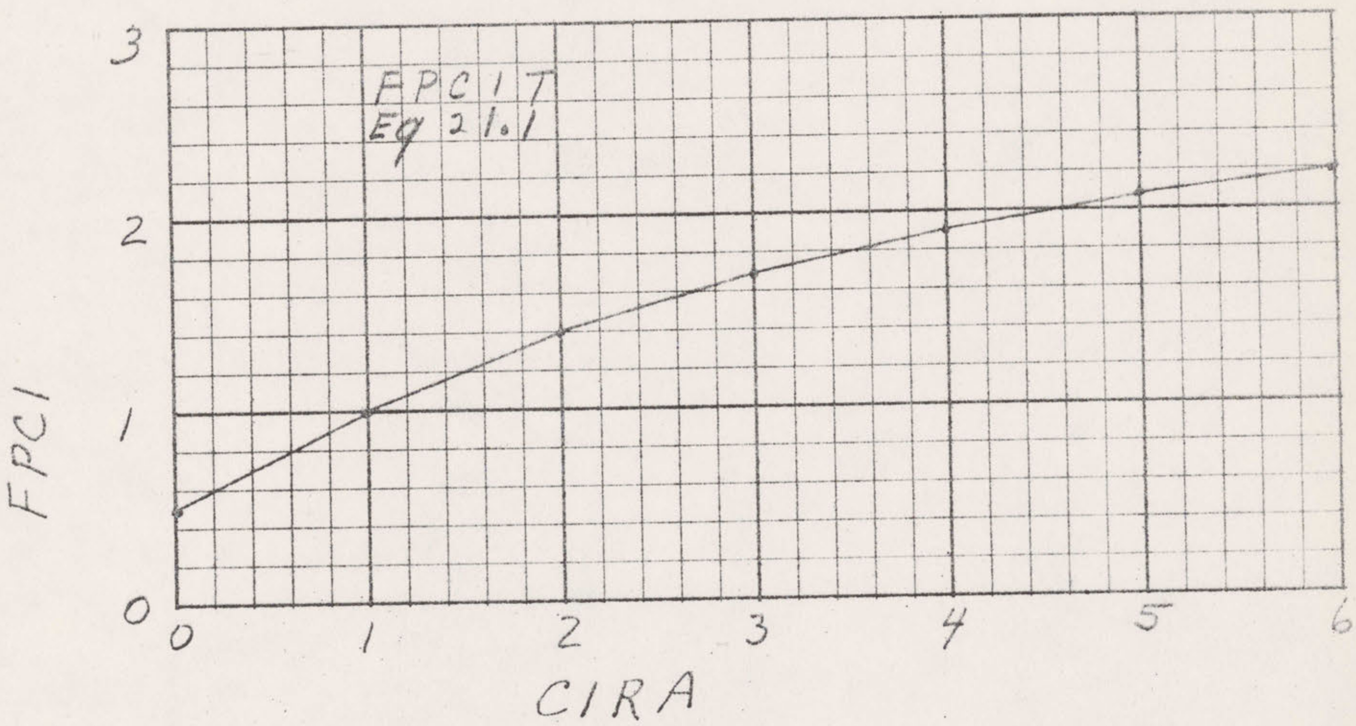
Birth-rate-from-food multiplier
vs. food ratio



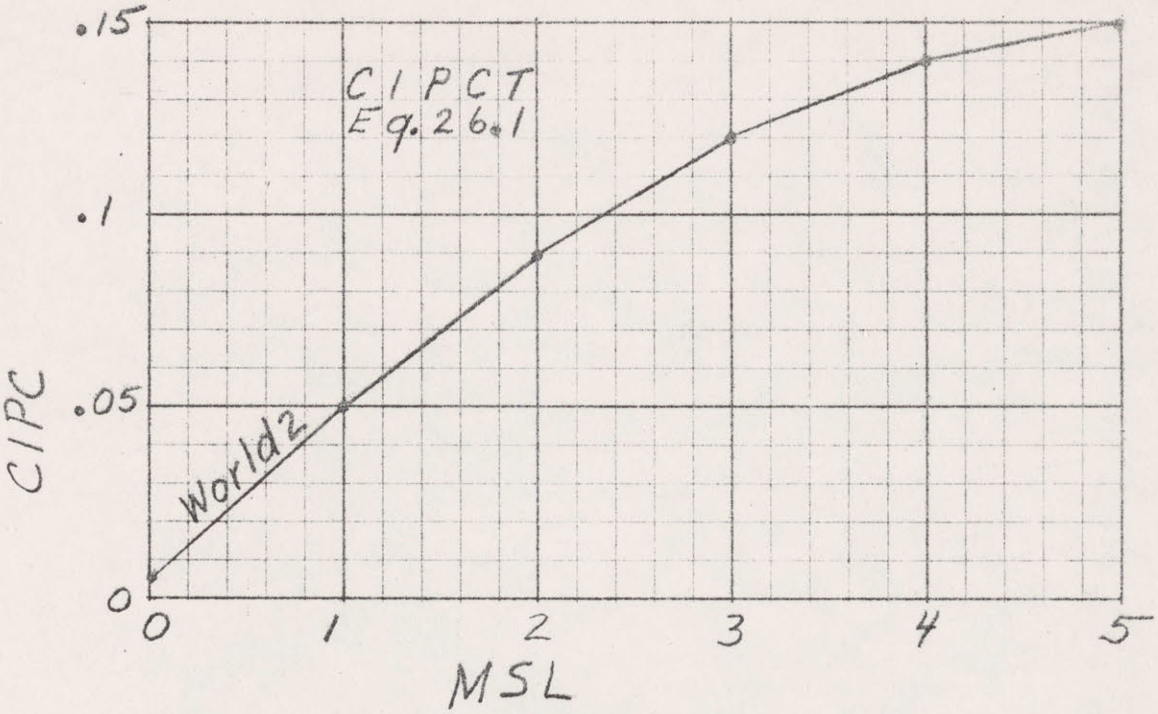
Birth-rate-from-pollution multiplier
vs. pollution ratio



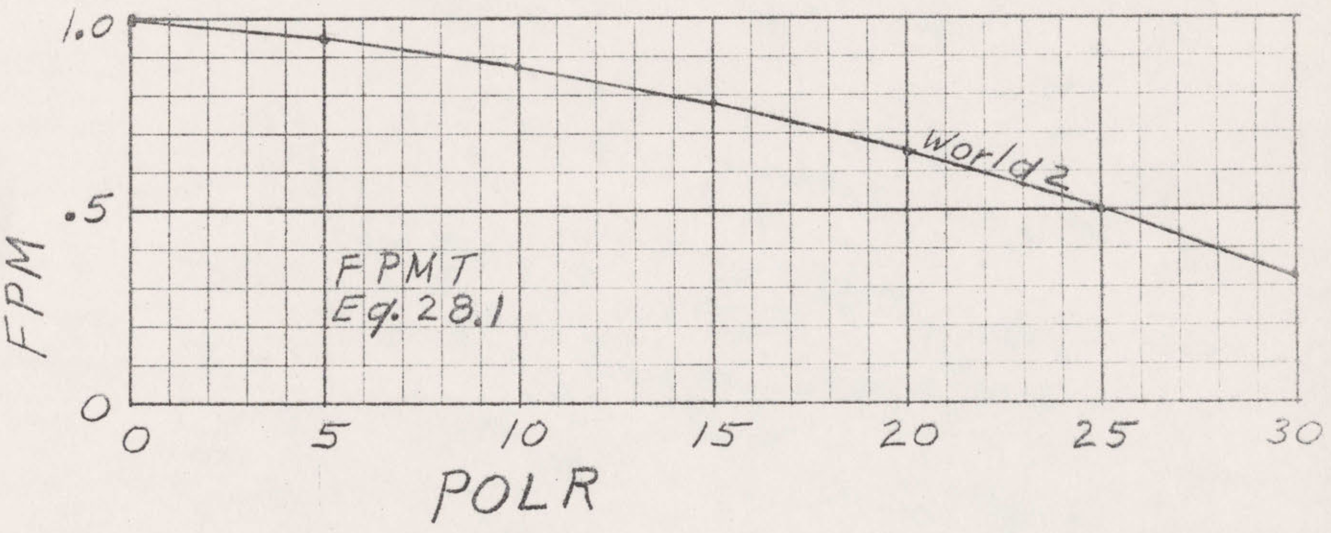
Food-from-crowding multiplier
vs. crowding ratio



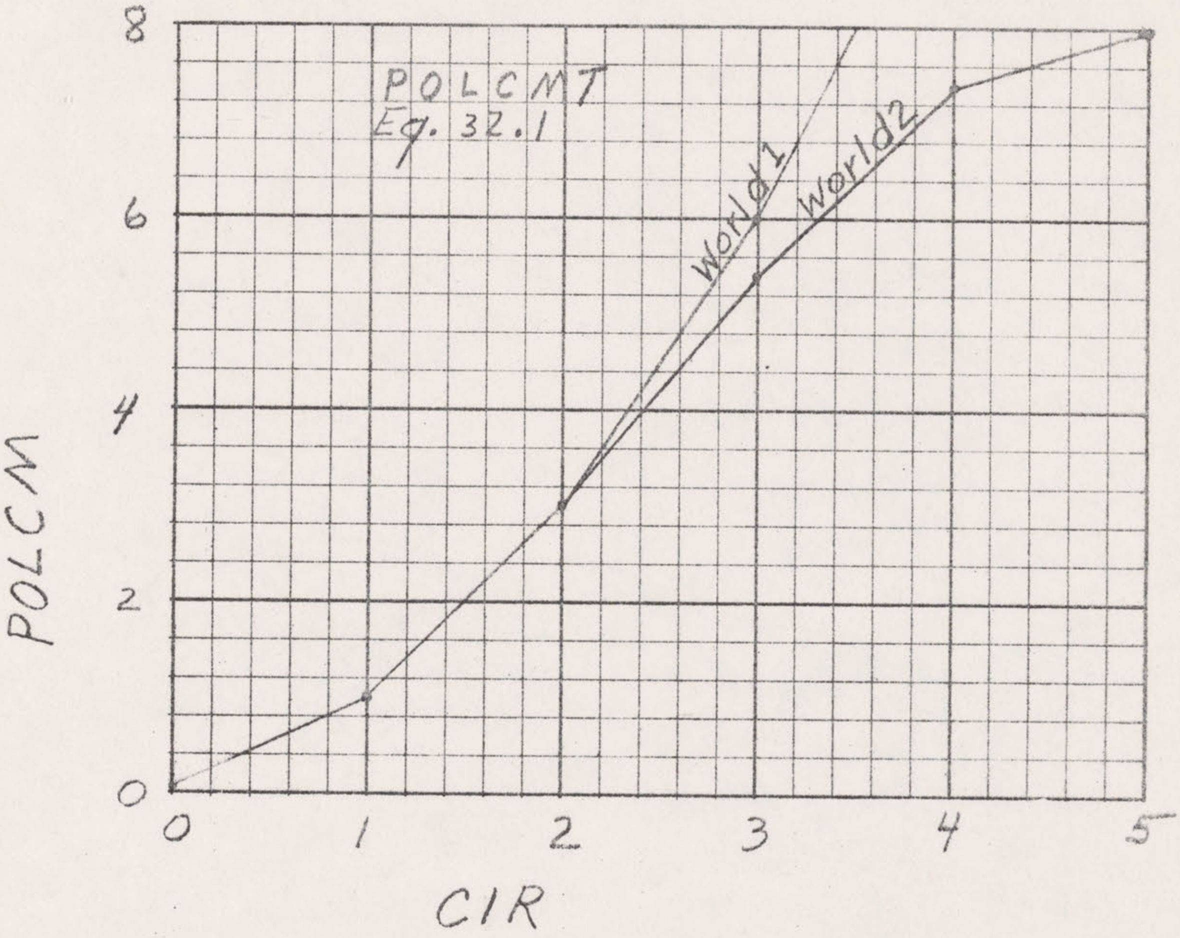
Food potential from capital investment
vs. capital investment ratio in agriculture



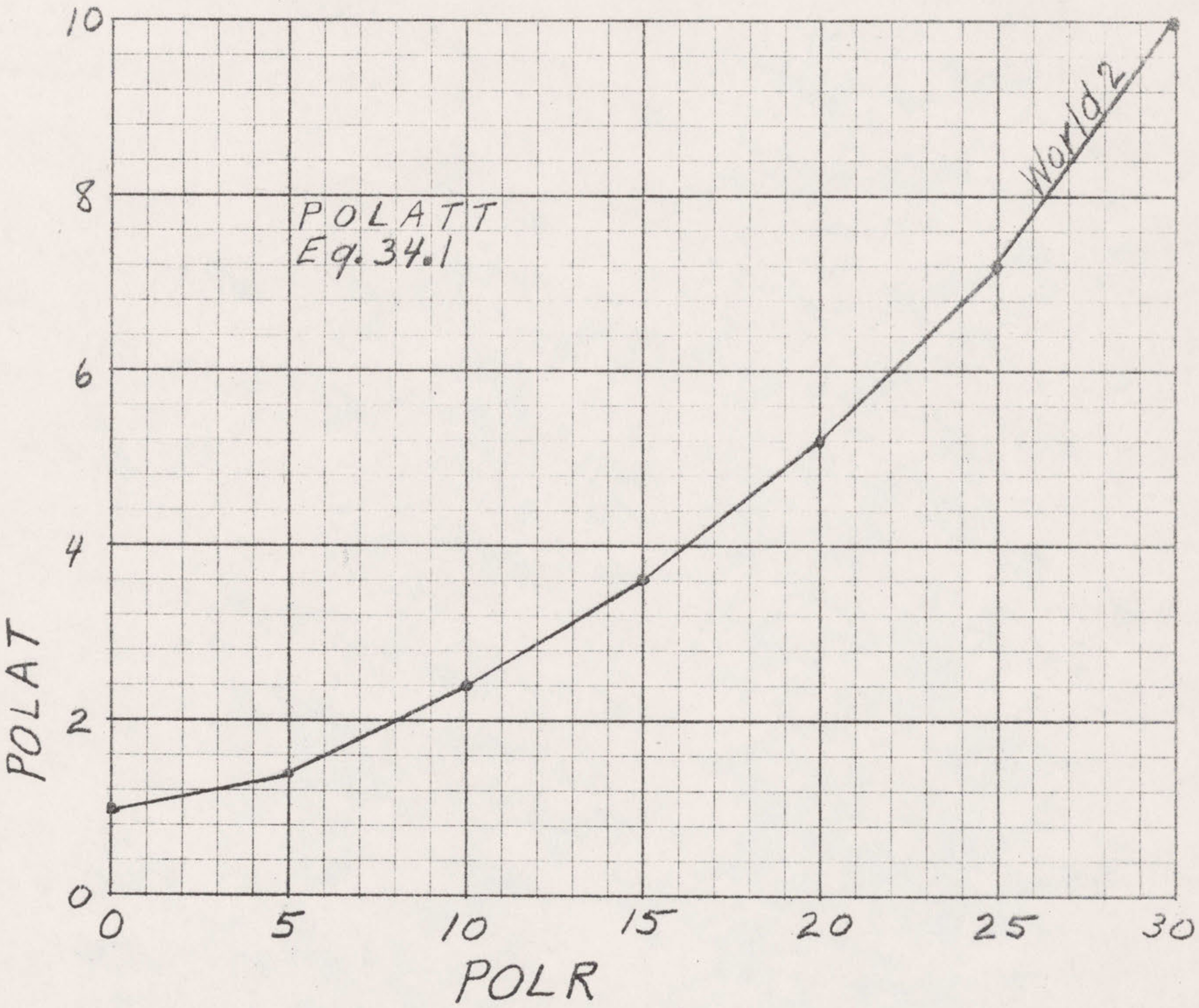
Capital investment per capita
vs. material standard of living



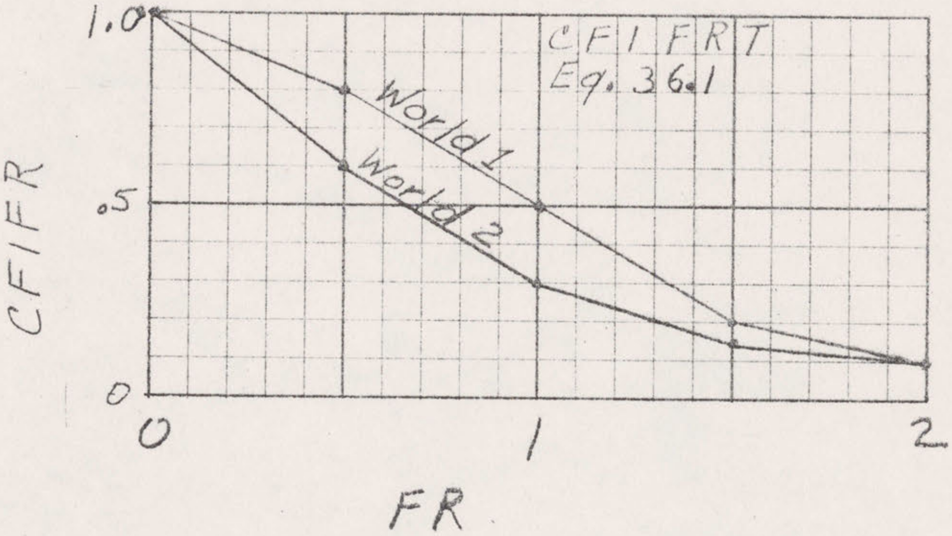
Food-from-pollution multiplier
vs. pollution ratio



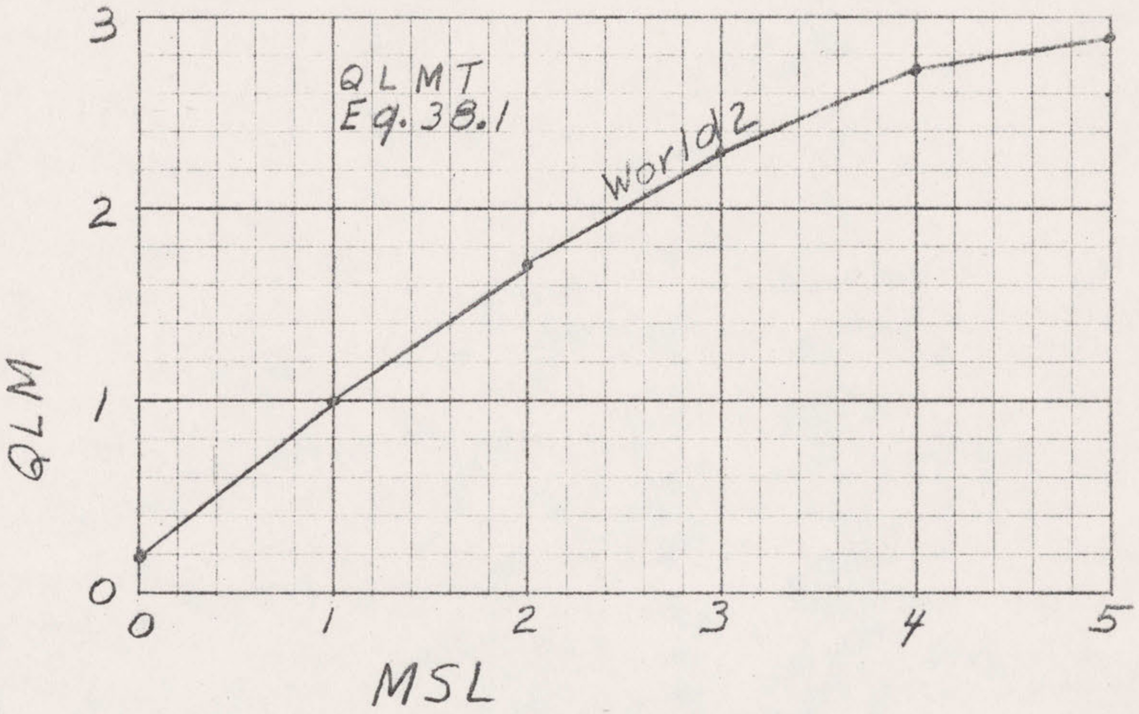
Pollution-from-capital multiplier
vs. capital-investment ratio



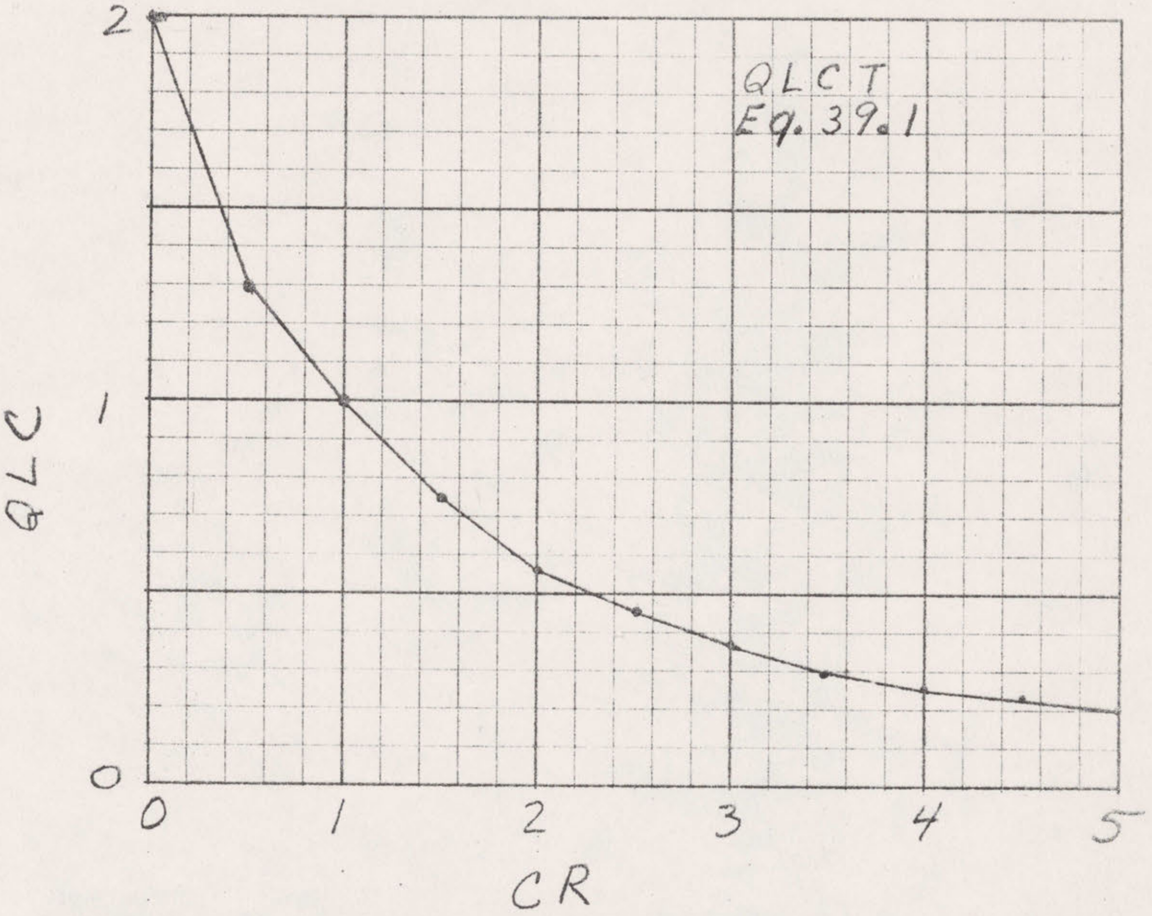
Pollution-absorption time
vs. pollution ratio



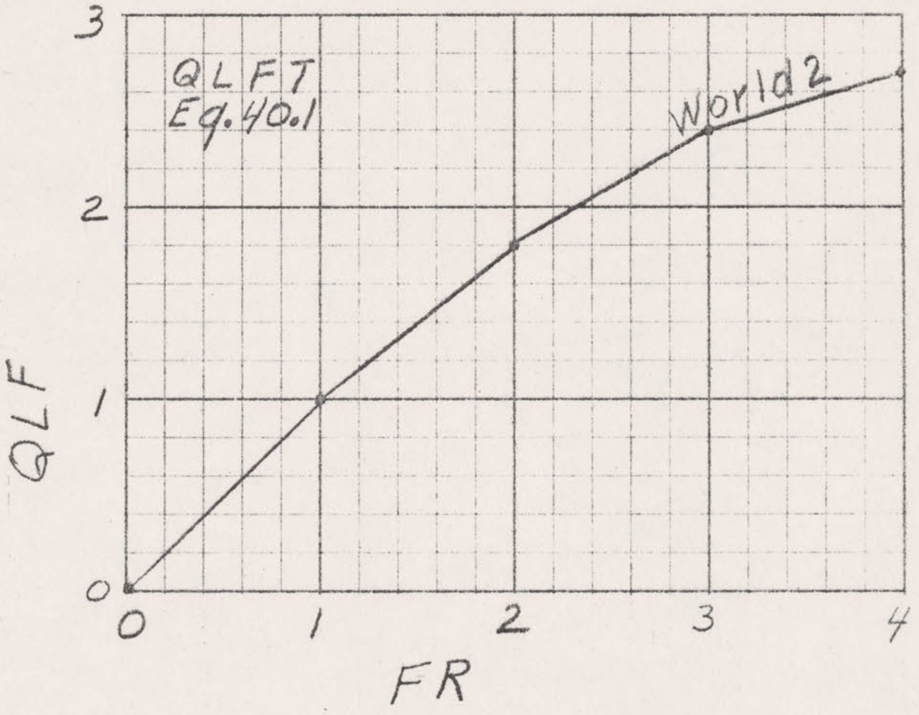
Capital fraction indicated by food ratio
vs. food ratio



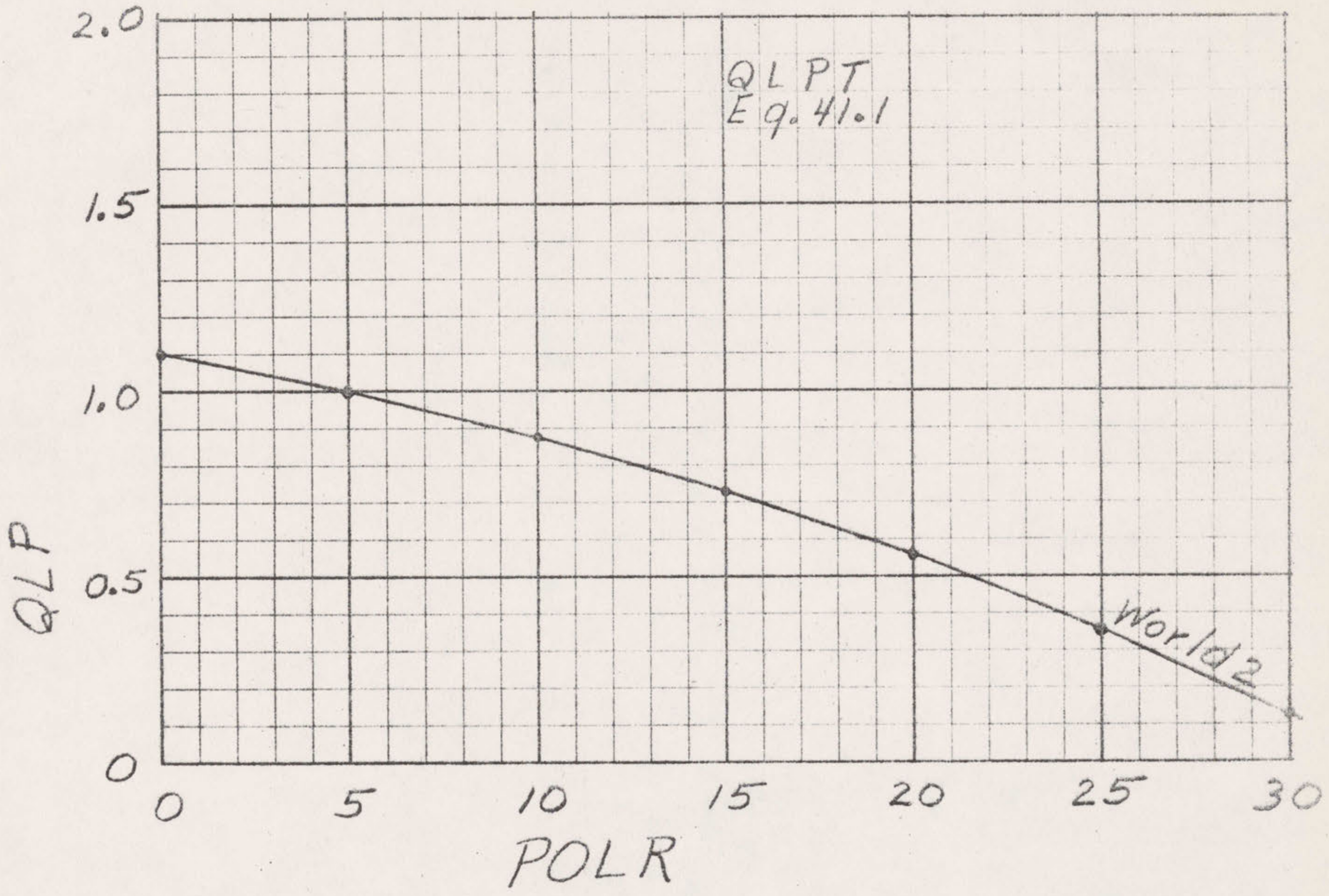
Quality of life from material
vs. material standard of living



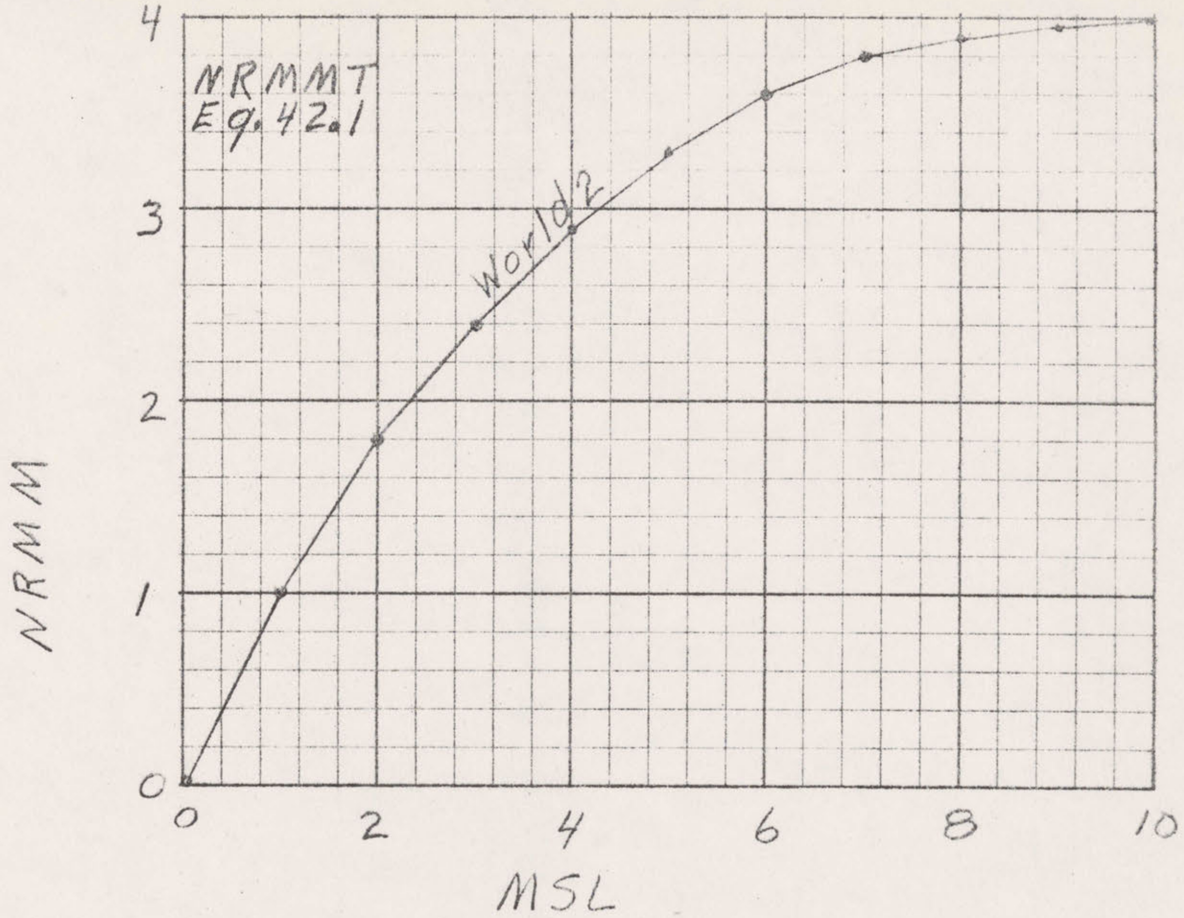
Quality of life from crowding
vs. crowding ratio



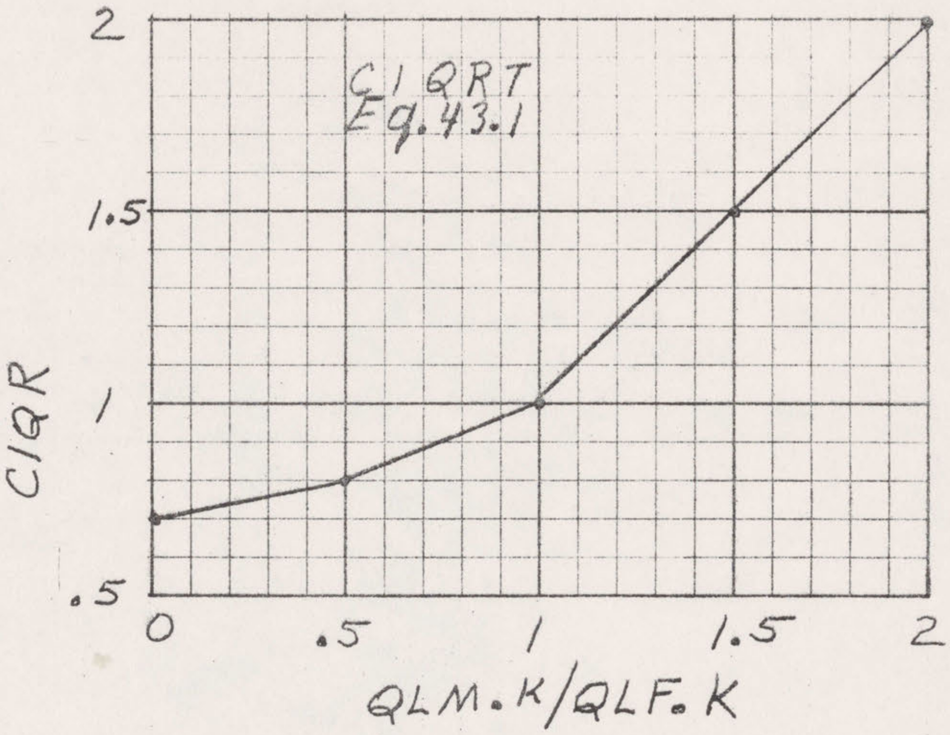
Quality of life from food
vs. food ratio



Quality of life from pollution
vs. pollution ratio



Natural-resource-from-material multiplier
vs. material standard of living



Capital-investment-from-quality ratio
vs. ratio of quality of life from material
to quality of life from food

D-1353

WORLD2 COMPUTER LISTING
a part of
A World Dynamics Model:
Introductory Exercise

by
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July 15, 1970

```
  0.1     *            WORLD DYNAMICS W2
  0.2     NOTE         LINES CHANGED FOR WORLD2 ARE MARKED W2
  1       L       P.K=P.J+(DT)(BR.JK-DR.JK)
  1.1     N       P=PI
  1.2     C       PI=1.65E9
  2       R       BR.KL=(P.K)(CLIP(BRN,BRN1,SWT1,TIME.K))(BRFM.K)(BRMM.K)(BRCM.K)(BR
  2       X       PM.K)      W2
  2.1     C       BRN=.045
  2.2     C       BRN1=.045       W2
  2.3     C       SWT1=1970       W2
  3       A       BRMM.K=TABHL(BRMMT,MSL.K*BRMS,0,5,1)
  3.1     T            BRMMT=1.2/1/.85/.75/.7/.7
  3.2     C       BRMS=1
  4       A       MSL.K=ECIR.K/(1-CIAFN)
  5       A       ECIR.K=(CIR.K)(1-CIAF.K)(NREM.K)
  6       A       NREM.K=TABLE(NREMT,NRFR.K,0,1,.25)
  6.1     T       NREMT=0/.15/.5/.85/1
  7       A       NRFR.K=NR.K/NRI
  8       L       NR.K=NR.J+(DT)(-NRUR.JK)
  8.1     N       NR=NRI
  8.2     C       NRI=900E9
  9       R       NRUR.KL=(P.K)(CLIP(NRUN,NRUN1,SWT2,TIME.K))(NRMM.K)      W2
  9.1     C       NRUN=1
  9.2     C       NRUN1=1       W2
  9.3     C       SWT2=1970       W2
  9.6     NOTE         EQUATION 42 CONNECTS HERE FROM EQ. 4 TO EQ. 9
 10       R       DR.KL=(P.K)(CLIP(DRN,DRN1,SWT3,TIME.K))(DRMM.K)(DRPM.K)(DRFM.K)(DR
 10       X       CM.K)      W2
 10.1     C       DRN=.025
 10.2     C       DRN1=.025       W2
 10.3     C       SWT3=1970       W2
 11       A       DRMM.K=TABHL(DRMMT,MSL.K*DRMS,0,5,.5)
 11.1     T       DRMMT=2/1.4/1/.8/.7/.6/.53/.5/.5/.5/.5
 11.2     C       DRMS=1
 12       A       DRPM.K=TABLE(DRPMT,POLR.K,0,30,5)
 12.1     T       DRPMT=.98/1.1/1.3/1.6/2.1/2.8/4
 13       A       DRFM.K=TABHL(DRFMT,FR.K,0,2,.25)
 13.1     T       DRFMT=30/3/2/1.4/1/.7/.6/.5/.5
 14       A       DRCM.K=TABLE(DRCMT,CR.K,0,5,1)
 14.1     T       DRCMT=1/1.1/1.3/1.6/2.1/3
 15       A       CR.K=(P.K)/(LA*PDN)
 15.1     C       LA=135E6
 15.2     C       PDN=26.5
 16       A       BRCM.K=TABLE(BRCMT,CR.K,0,5,1)
 16.1     T       BRCMT=1/.95/.8/.7/.65/.65
 17       A       BRFM.K=TABHL(BRFMT,FR.K,0,4,1)
 17.1     T       BRFMT=0/1/1.6/1.9/2
 18       A       BRPM.K=TABLE(BRPMT,POLR.K,0,30,5)
 18.1     T       BRPMT=1/.97/.92/.82/.72/.6/.4
 19       A       FR.K=(FPCI.K)(FCM.K)(FPM.K)
 20       A       FCM.K=TABLE(FCMT,CR.K,0,5,1)
 20.1     T       FCMT=2.4/1/.6/.4/.3/.2
 21       A       FPCI.K=TABHL(FPCIT,CIRA.K,0,6,1)
 21.1     T       FPCIT=.5/1/1.4/1.7/1.9/2.05/2.2
 22       A       CIRA.K=(CIR.K)(CIAF.K)/CIAFN
 22.1     C       CIAFN=.3
 23       A       CIR.K=CI.K/P.K
 24       L       CI.K=CI.J+(DT)(CIG.JK-CID.JK)
```

```
24.1    N       CI=CII
24.2    C       CII=.4E9
25      R       CIG.KL=(P.K)(CIPC.K)(CLIP(CIGC,CIGC1,SWT4,TIME.K))       W2
25.1    C       CIGC=1
25.2    C       CIGC1=1      W2
25.3    C       SWT4=1970      W2
26      A       CIPC.K=TABHL(CIPCT,MSL.K,0,5,1)
26.1    T       CIPCT=.005/.05/.09/.12/.14/.15
27      R       CID.KL=(CI.K)(CLIP(CIDN,CIDN1,SWT5,TIME.K))      W2
27.1    C       CIDN=.025
27.2    C       CIDN1=.025      W2
27.3    C       SWT5=1970      W2
28      A       FPM.K=TABLE(FPMT,POLR.K,0,30,5)
28.1    T       FPMT=1/.95/.87/.77/.65/.5/.32
29      A       POLR.K=POL.K/POLS
29.1    C       POLS=3.6E9
30      L       POL.K=POL.J+(DT)(POLG.JK-POLA.JK)
30.1    N       POL=POLI
30.2    C       POLI=.2E9
31      R       POLG.KL=(P.K)(CLIP(POLN,POLN1,SWT6,TIME.K))(POLCM.K)       W2
31.1    C       POLN=1
31.2    C       POLN1=1
31.3    C       SWT6=1970
32      A       POLCM.K=TABHL(POLCMT,CIR.K,0,5,1)
32.1    T       POLCMT=.05/1/3/5.4/7.4/8
33      R       POLA.KL=POL.K/POLAT.K
34      A       POLAT.K=TABLE(POLATT,POLR.K,0,30,5)
34.1    T       POLATT=1/1.4/2.4/3.6/5.2/7.2/10
35      L       CIAF.K=CIAF.J+(DT/CIAFT)(CFIFR.J*CIQR.J-CIAF.J)
35.1    N       CIAF=CIAFI
35.2    C       CIAFI=.3
35.3    C       CIAFT=15
36      A       CFIFR.K=TABLE(CFIFRT,FR.K,0,2,.5)
36.1    T       CFIFRT=1/.6/.3/.15/.1
37      S       QL.K=(QLS)(QLM.K)(QLC.K)(QLF.K)(QLP.K)
37.1    C       QLS=1
38      A       QLM.K=TABHL(QLMT,MSL.K,0,5,1)
38.1    T       QLMT=.2/1/1.7/2.3/2.7/2.9
39      A       QLC.K=TABLE(QLCT,CR.K,0,5,.5)
39.1    T       QLCT=2/1.3/1/.75/.55/.45/.38/.3/.25/.22/.2
40      A       QLF.K=TABHL(QLFT,FR.K,0,4,1)
40.1    T       QLFT=0/1/1.8/2.4/2.7
41      A       QLP.K=TABLE(QLPT,POLR.K,0,30,5)      W2
41.1    T       QLPT=1.1/1/.88/.71/.55/.35/.12      W2
41.4    NOTE         EQUATION 42 LOCATED BETWEEN EQ. 4 AND 9.
42      A       NRMM.K=TABHL(NRMMT,MSL.K,0,10,1)
42.1    T       NRMMT=0/1/1.8/2.4/2.9/3.3/3.6/3.8/3.9/3.95/4
42.4    NOTE         INPUT FROM EQN. 38 AND 40 TO EQN. 35
43      A       CIQR.K=TABHL(CIQRT,QLM.K/QLF.K,0,2,.5)
43.1    T       CIQRT=.7/.8/1/1.5/2
43.4    NOTE
43.5    NOTE    CONTROL CARDS
43.6    NOTE
44      C       DT=.2
44.1    C       LENGTH=2100
44.2    C       PLTPER=2
44.3    N       TIME=1900
44.6    PLOT    P=P/POLR=2/CI=C/FR=F/CR=R/MSL=M/QLM=L/QL=Q/CIAF=A/NR=N
```

World Model: Definition of Terms

```
WORLD     DEF      07/19  1429.8

*         DEFINITIONS FOR WORLD DYNAMICS MODEL
BR        BIRTH RATE (PEOPLE/YEAR)
BRCM      BIRTH-RATE-FROM-CROWDING MULTIPLIER (DIMENSIONLESS)
BRCMT     BIRTH-RATE-FROM-CROWDING-MULTIPLIER TABLE
BRFM      BIRTH-RATE-FROM-FOOD MULTIPLIER (DIMENSIONLESS)
BRFMT     BIRTH-RATE-FROM-FOOD-MULTIPLIER TABLE
BRMM      BIRTH-RATE-FROM-MATERIAL MULTIPLIER (DIMENSIONLESS)
BRMMT     BIRTH-RATE-FROM-MATERIAL-MULTIPLIER TABLE
BRMS      BIRTH-RATE-FROM-MATERIAL SENSITIVITY (DIMENSIONLESS)
BRN       BIRTH RATE NORMAL (FRACTION/YEAR)
BRN1      BIRTH RATE NORMAL NO. 1 (FRACTION/YEAR)
BRPM      BIRTH-RATE-FROM-POLLUTION MULTIPLIER (DIMENSIONLESS)
BRPMT     BIRTH-RATE-FROM-POLLUTION-MULTIPLIER TABLE
CFIFR     CAPITAL FRACTION INDICATED BY FOOD RATIO (DIMENSIONLESS)
CFIFRT    CAPITAL-FRACTION-INDICATED-BY-FOOD-RATIO TABLE
CI        CAPITAL INVESTMENT (CAPITAL UNITS)
CIAF      CAPITAL-INVESTMENT-IN-AGRICULTURE FRACTION (DIMENSIONLESS)
CIAFI     CAPITAL-INVESTMENT-IN-AGRICULTURE FRACTION, INITIAL (DIMENSIONLESS
CIAFN     CAPITAL-INVESTMENT-IN-AGRICULTURE FRACTION NORMAL (DIMENSIONLESS)
CIAFT     CAPITAL-INVESTMENT-IN-AGRICULTURE-FRACTION ADJUSTMENT TIME (YEARS)
CID       CAPITAL-INVESTMENT DISCARD (CAPITAL UNITS/YEAR)
CIDN      CAPITAL-INVESTMENT DISCARD NORMAL (FRACTION/YEAR)
CIDN1     CAPITAL-INVESTMENT DISCARD NORMAL NO. 1 (FRACTION/YEAR)
CIG       CAPITAL-INVESTMENT GENERATION (CAPITAL UNITS/YEAR)
CIGC      CAPITAL-INVESTMENT-GENERATION COEFFICIENT (DIMENSIONLESS)
CIGC1     CAPITAL-INVESTMENT-GENERATION COEFFICIENT NO. 1 (DIMENSIONLESS)
CII       CAPITAL INVESTMENT, INITIAL (CAPITAL UNITS)
CIPC      CAPITAL INVESTMENT PER CAPITA (CAPITAL UNITS/PERSON/YEAR)
CIPCT     CAPITAL-INVESTMENT-PER-CAPITA TABLE
CIQR      CAPITAL-INVESTMENT-FROM-QUALITY RATIO (DIMENSIONLESS)
CIQRT     CAPITAL-INVESTMENT-FROM-QUALITY-RATIO TABLE
CIR       CAPITAL-INVESTMENT RATIO (CAPITAL UNITS/PERSON)
CIRA      CAPITAL INVESTMENT RATIO IN AGRICULTURE (CAPITAL UNITS/PERSON)
CR        CROWDING RATIO (DIMENSIONLESS)
DR        DEATH RATE (PEOPLE/YEAR)
DRCM      DEATH-RATE-FROM-CROWDING MULTIPLIER (DIMENSIONLESS)
DRCMT     DEATH-RATE-FROM-CROWDING-MULTIPLIER TABLE
DRFM      DEATH-RATE-FROM-FOOD MULTIPLIER (DIMENSIONLESS)
DRFMT     DEATH-RATE-FROM-FOOD-MULTIPLIER TABLE
DRMM      DEATH-RATE-FROM-MATERIAL MULTIPLIER (DIMENSIONLESS)
DRMMT     DEATH-RATE-FROM-MATERIAL-MULTIPLIER TABLE
DRMS      DEATH-RATE-FROM-MATERIAL SENSITIVITY (DIMENSIONLESS)
DRN       DEATH RATE NORMAL (FRACTION/YEAR)
DRN1      DEATH RATE NORMAL NO. 1 (FRACTION/YEAR)
DRPM      DEATH-RATE-FROM-POLLUTION MULTIPLIER (DIMENSIONLESS)
DRPMT     DEATH-RATE-FROM-POLLUTION-MULTIPLIER TABLE
ECIR      EFFECTIVE-CAPITAL-INVESTMENT RATIO (CAPITAL UNITS/PERSON)
FCM       FOOD-CROWDING MULTIPLIER (DIMENSIONLESS)
FCMT      FOOD-CROWDING-MULTIPLIER TABLE
FPCI      FOOD POTENTIAL FROM CAPITAL INVESTMENT (DIMENSIONLESS)
FPCIT     FOOD-POTENTIAL-FROM-CAPITAL-INVESTMENT TABLE
FPM       FOOD-FROM-POLLUTION MULTIPLIER (DIMENSIONLESS)
FPMT      FOOD-FROM-POLLUTION-MULTIPLIER TABLE
FR        FOOD RATIO (DIMENSIONLESS)
LA        LAND AREA (SQUARE KILOMETERS)
MSL       MATERIAL STANDARD OF LIVING (DIMENSIONLESS)
MSLN      MATERIAL STANDARD OF LIVING NORMAL (CAPITAL UNITS/PERSON)
NR        NATURAL RESOURCES (NATURAL RESOURCE UNITS)
NREM      NATURAL-RESOURCE-EXTRACTION MULTIPLIER (DIMENSIONLESS)
NREMT     NATURAL-RESOURCE-EXTRACTION-MULTIPLIER TABLE
NRFR      NATURAL-RESOURCE FRACTION REMAINING (DIMENSIONLESS)
NRI       NATURAL RESOURCES, INITIAL (NATURAL RESOURCE UNITS)
NRMM      NATURAL-RESOURCE-FROM-MATERIAL MULTIPLIER (DIMENSIONLESS)
NRMMT     NATURAL-RESOURCE-FROM-MATERIAL-MULTIPLIER TABLE
```

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NRUN       NATURAL-RESOURCE USAGE NORMAL (NATURAL RESOURCE UNITS/PERSON/YEAR)
NRUN1      NATURAL-RESOURCE USAGE NORMAL NO. 1 (NATURAL RESOURCE UNITS/PERSON/
NRUR       NATURAL-RESOURCE-USAGE RATE (NATURAL RESOURCE UNITS/YEAR)      YEAR)
P          POPULATION (PEOPLE)
PDN        POPULATION DENSITY NORMAL (PEOPLE/SQUARE KILOMETER)
PI         POPULATION, INITIAL (PEOPLE)
POL        POLLUTION (POLLUTION UNITS)
POLA       POLLUTION ABSORPTION (POLLUTION UNITS/YEAR)
POLAT      POLLUTION-ABSORPTION TIME (YEARS)
POLATT     POLLUTION-ABSORPTION-TIME TABLE
POLCM      POLLUTION-FROM-CAPITAL MULTIPLIER (DIMENSIONLESS)
POLCMT     POLLUTION-FROM-CAPITAL-MULTIPLIER TABLE
POLG       POLLUTION GENERATION (POLLUTION UNITS/YEAR)
POLI       POLLUTION, INITIAL (POLLUTION UNITS)
POLN       POLLUTION NORMAL (POLLUTION UNITS/PERSON/YEAR)
POLN1      POLLUTION NORMAL NO. 1 (POLLUTION UNITS/PERSON/YEAR)
POLR       POLLUTION RATIO (DIMENSIONLESS)
POLS       POLLUTION STANDARD (POLLUTION UNITS)
QLC        QUALTIY OF LIFE FROM CROWDING (DIMENSIONLESS)
QLCT       QUALITY-OF-LIFE-FROM-CROWDING TABLE
QLF        QUALITY OF LIFE FROM FOOD (DIMENSIONLESS)
QLFT       QUALITY-OF-LIFE-FROM-FOOD TABLE
QL         QUALITY OF LIFE (SATISFACTION UNITS)
QLM        QUALITY OF LIFE FROM MATERIAL (DIMENSIONLESS)
QLMT       QUALITY-OF-LIFE-FROM-MATERIAL TABLE
QLP        QUALITY OF LIFE FROM POLLUTION (DIMENSIONLESS)
QLPT       QUALITY-OF-LIFE-FROM-POLLUTION TABLE
QLS        QUALITY-OF-LIFE STANDARD (SATISFACTION UNITS)
SWT1       SWITCH TIME NO. 1 FOR BRN (YEARS)
SWT2SWITCH TIME NO. 2 FOR NRUN (YEARS)
SWT3       SWITCH TIME NO. 3 FOR DRN (YEARS)
SWT4       SWITCH TIME NO. 4 FOR CIGC (YEARS)
SWT5       SWITCH TIME NO. 5 FOR CIDN (YEARS)
SWT6       SWITCH TIME NO. 6 FOR POLN (YEARS)
R 3.933+1.616
```

D-1360

DESCRIPTION OF WORLD2 MODEL RUNS

CHAPTER 6

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August 10, 1970

DESCRIPTION OF WORLD2 MODEL RUNS

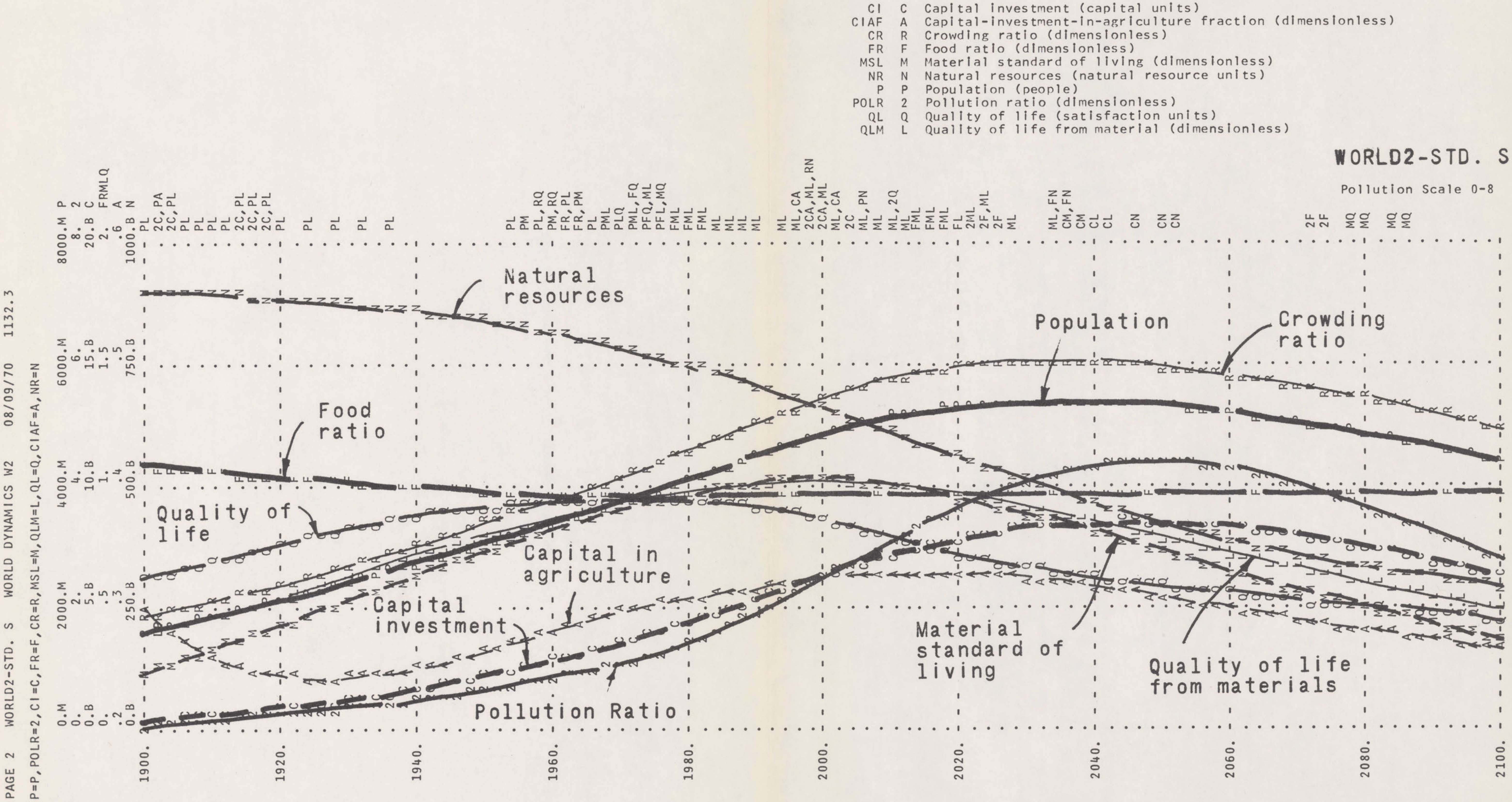
CHAPTER 6

WORLD2-STD.S

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

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

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


CI C Capital investment (capital units)
CIAF A Capital-investment-in-agriculture fraction (dimensionless)
CR R Crowding ratio (dimensionless)
FR F Food ratio (dimensionless)
MSL M Material standard of living (dimensionless)
NR N Natural resources (natural resource units)
P P Population (people)
POLR 2 Pollution ratio (dimensionless)
QL Q Quality of life (satisfaction units)
QLM L Quality of life from material (dimensionless)
WORLD2-STD. S
Pollution Scale 0-8
PAGE 2 WORLD2-STD. S WORLD DYNAMICS W2 08/09/70 1132.3
P=P,POLR=2,CI=C,FR=F,CR=R,MSL=M,QLM=L,QL=Q,CIAF=A,NR=N
0.M 2000.M 4000.M 6000.M 8000.M P
0. 2. 4. 6. 8. 2
0.B 5.B 10.B 15.B 20.B C
0. .5 1. 1.5 2. FRMLQ
.2 .3 .4 .5 .6 A
0.B 250.B 500.B 750.B 1000.B N
1900. 1920. 1940. 1960. 1980. 2000. 2020. 2040. 2060. 2080. 2100.
Natural resources
Population
Crowding ratio
Food ratio
Quality of life
Capital in agriculture
Capital investment
Pollution Ratio
Material standard of living
Quality of life from materials

WORLD2-6S

This computer run is again the standard model but with a compressed time scale showing a period from 1900 to 2300. The natural resource consumption continues to depress the effectiveness of capital and causes a gradually declining material standard of living. This increases the death rate and brings most characteristics of the system in 2300 back to about the values of year 1900.

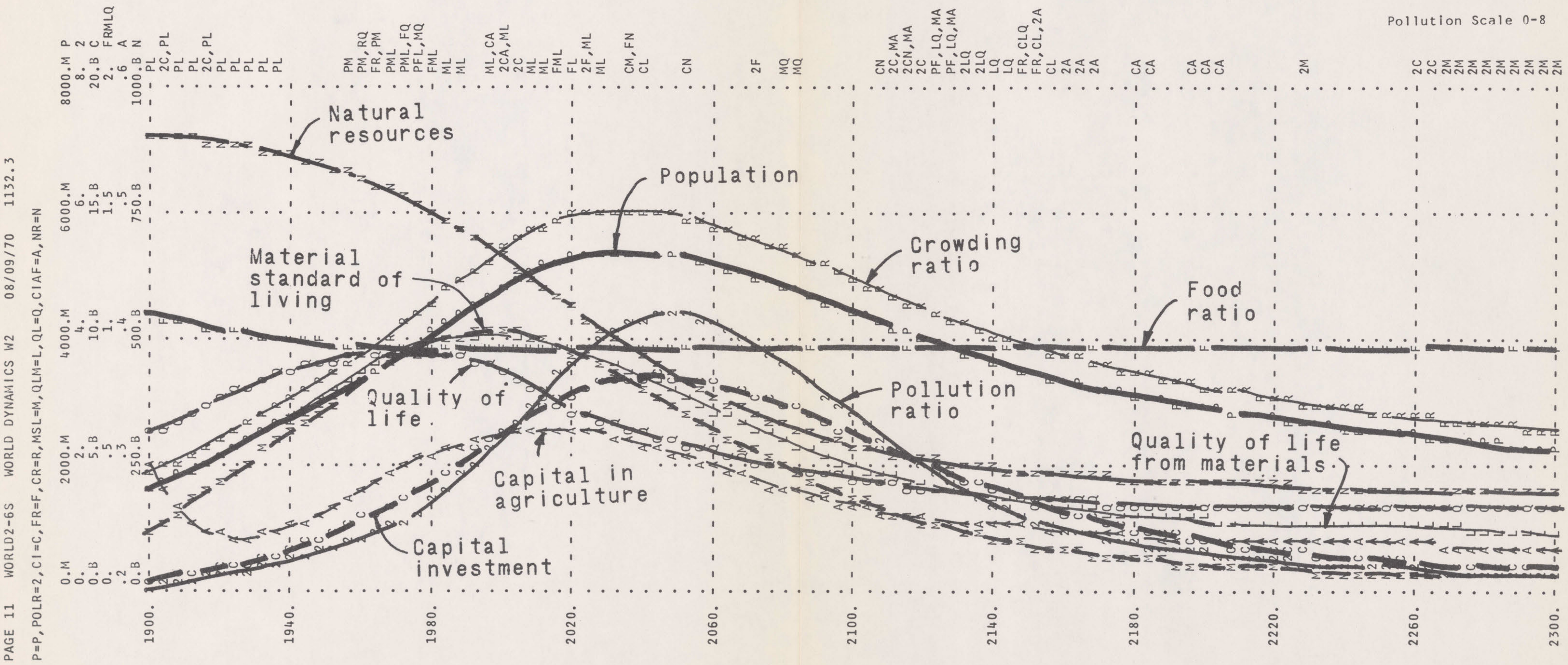
```
PAGE 10   WORLD2-6S   WORLD DYNAMICS W2     08/09/70    1132.3

           LENGTH   PLTPER
  PRESENT  2300.        4.
 ORIGINAL  2100.        2.
```

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

WORLD2-6s

Pollution Scale 0-8



WORLD2-5S

In this computer run we explore the effect of reducing the birth rate normal coefficient BRN1 from 0.045 to 0.035 at the year 1970. There is a slowing of the population growth from 1970 until 1990, and then we see that population curves upward again. Peak population in the year 2040 is only slightly less than in the standard run. Around the year 2000, both food ratio and the material standard of living are slightly higher than in the standard run. Quality of life reaches a peak at the year 2000 and then declines. The rising food ratio and material standard of living appear to account for the resumption in population growth which begins to move upward again after 1990.

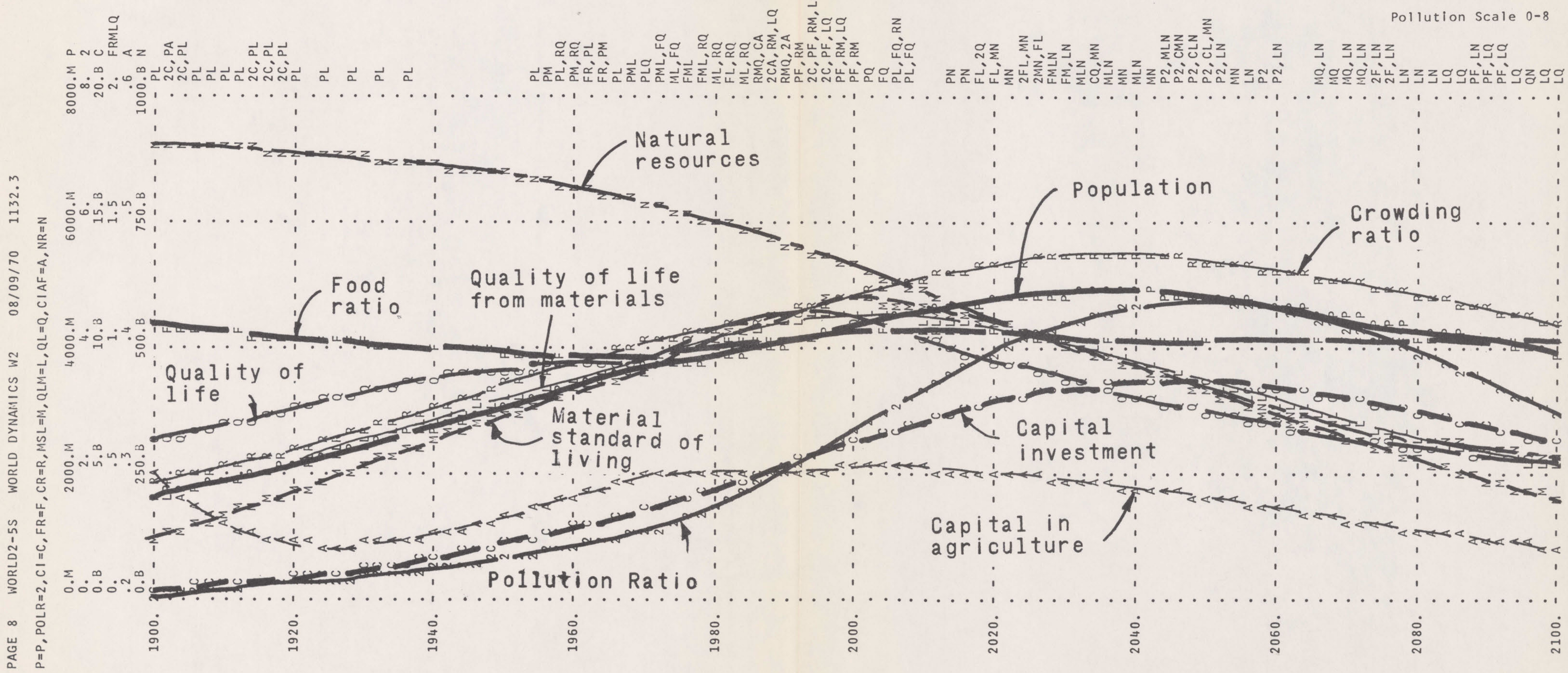
PAGE 13 WORLD2-5S WORLD DYNAMICS W2 08/09/70 1132.3

	BRN1
PRESENT	35.A
ORIGINAL	45.A

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

WORLD2-5S

Pollution Scale 0-8



WORLD2-4S

In this computer run the capital investment generation coefficient CIGC1 has been increased from its original value of 1 to a value of 1.2 in 1970. This means that, all other things being equal, the capital investment generation is increased 20% above its previous value. In this computer run the pollution scale has been changed and runs from 0 to 80 instead of the previous range of 0 to 8. The increased rate of capital investment pushes up the material standard of living, causes the food ratio to rise slightly above that in the standard computer run and causes the population to reach a slightly higher peak in the year 2020. The most conspicuous change, however, is the slight increase in capital investment which causes rising pollution generation and results in overloading the pollution absorption capability of the system. As the total pollution in the system rises, the pollution absorption time from Equation 34 increases and slows down the pollution clean-up processes. Pollution rises precipitously between years 2020 and 2050. This depresses the food ratio, and greatly influences the quality of life from pollution. The effects of pollution and reduced food act to reduce the birth rate and increase the death rate in sufficient degree to cause a collapse of world population from a peak in year 2020 to a minimum of less than one-fourth as much in the year 2070.

In effect this is a dynamic model equivalent of the ecological crisis which is often discussed in the public press. It might occur through ocean pollution which could affect water evaporation, weather, and photosynthesis.

This computer run raises a question about industrialization and its future trends. The world environment may not be able to cope with the pollution which would be generated by the present world population if all of that population reached a level of industrialization comparable to that in Europe and North America.

Should there be a pollution crisis which cuts severely into food production, as well as directly affecting birth and death rates, one can speculate on which societies will be most affected. Is it not possible that the industrialized nations with their large cities and their high degree of inter-connectedness may be the most vulnerable victims of their own industrialization. In other words, if a population decrease should occur, it might strike unevenly the various world populations and might touch less severely on those societies which have not reached a high degree of industrialization.

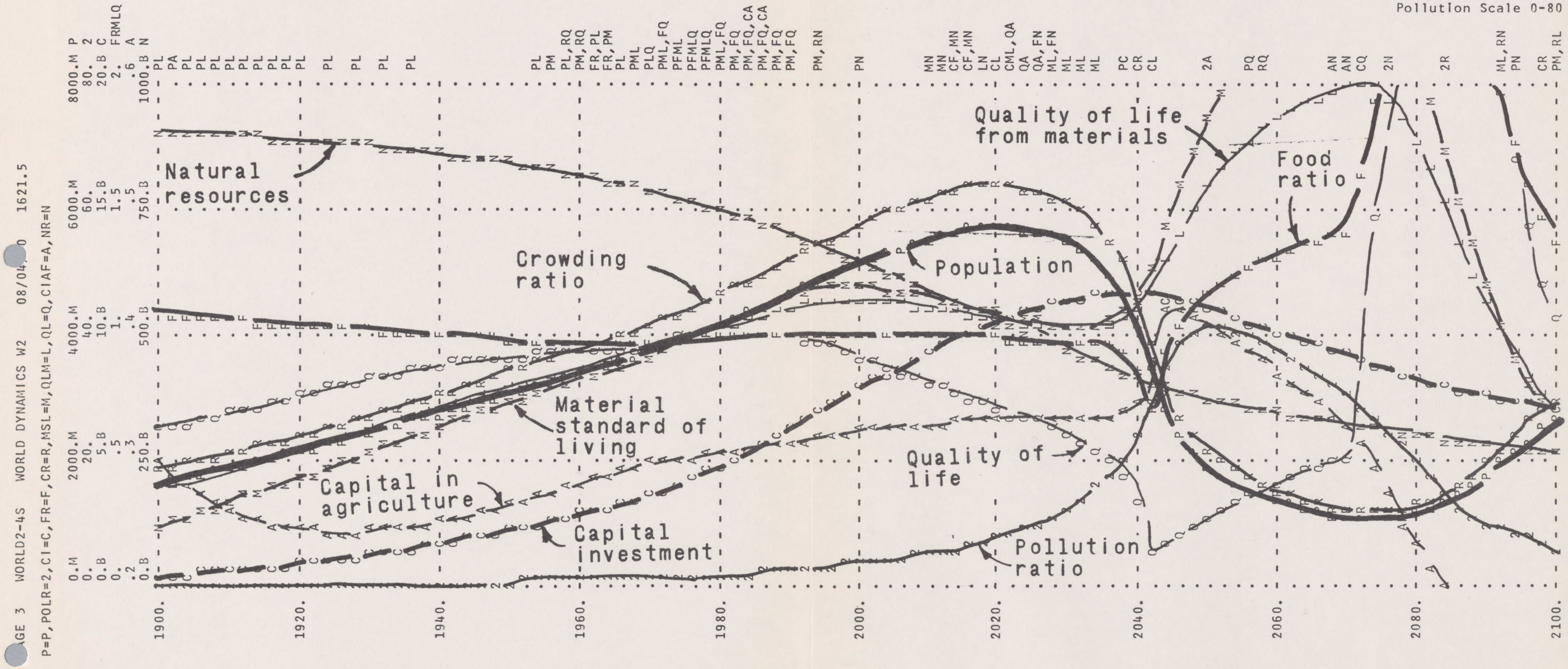
PAGE 2 WORLD2-4S WORLD DYNAMICS W2 08/04/70 1621.5

```
          CIGC1
PRESENT    1.2
ORIGINAL   1.
```

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

WORLD2-4S

Pollution Scale 0-80



WORLD2-21S

In this computer run we retain the increased capital investment accumulation from Run 4S. In addition in 1970, the birth rate normal coefficient BRN1 is reduced from 0.045 to 0.025. This is a severe reduction in normal birth rate, and leads to almost constant population between 1970 and 1990. Thereafter, population turns up again slightly.

But we see that even this substantial reduction in birth rate does not forestall the pollution crisis which was seen in Run 4S. Capital accumulation in the year 2020 is about the same as in Run 4S. Pollution is here again plotted on a scale of 0 to 80. Pollution generation is also about the same as in Run 4S.

With respect to future problems of environmental pollution, we begin to suspect that industrialization is more fundamental than population. A highly industrialized society creates many times the pollution per capita of a non-industrialized society. Furthermore, industrialization tends to push up population and population density. Industrialization here includes hospitals, medical care, and all other aspects of society which sustain large population densities.

This computer run raises questions about population control as a fundamental process for insuring a future world equilibrium. If reduced birth rate could be inaugurated under present world conditions, the resulting increase in industrialization per capita, food per capita, and quality of life, would in turn reduce the apparent pressure for controlling population, and would put upward pressure on birth rate once more. So, a control of birth rate tends to defeat itself by reducing the pressures which make birth control seem to be necessary.

But even more important, should population actually be stabilized, a rising industrialization might itself be sufficient to bring the environmental forces to a crisis overload.

PAGE 8 WORLD2-21S WORLD DYNAMICS W2 08/04/70 1621.5

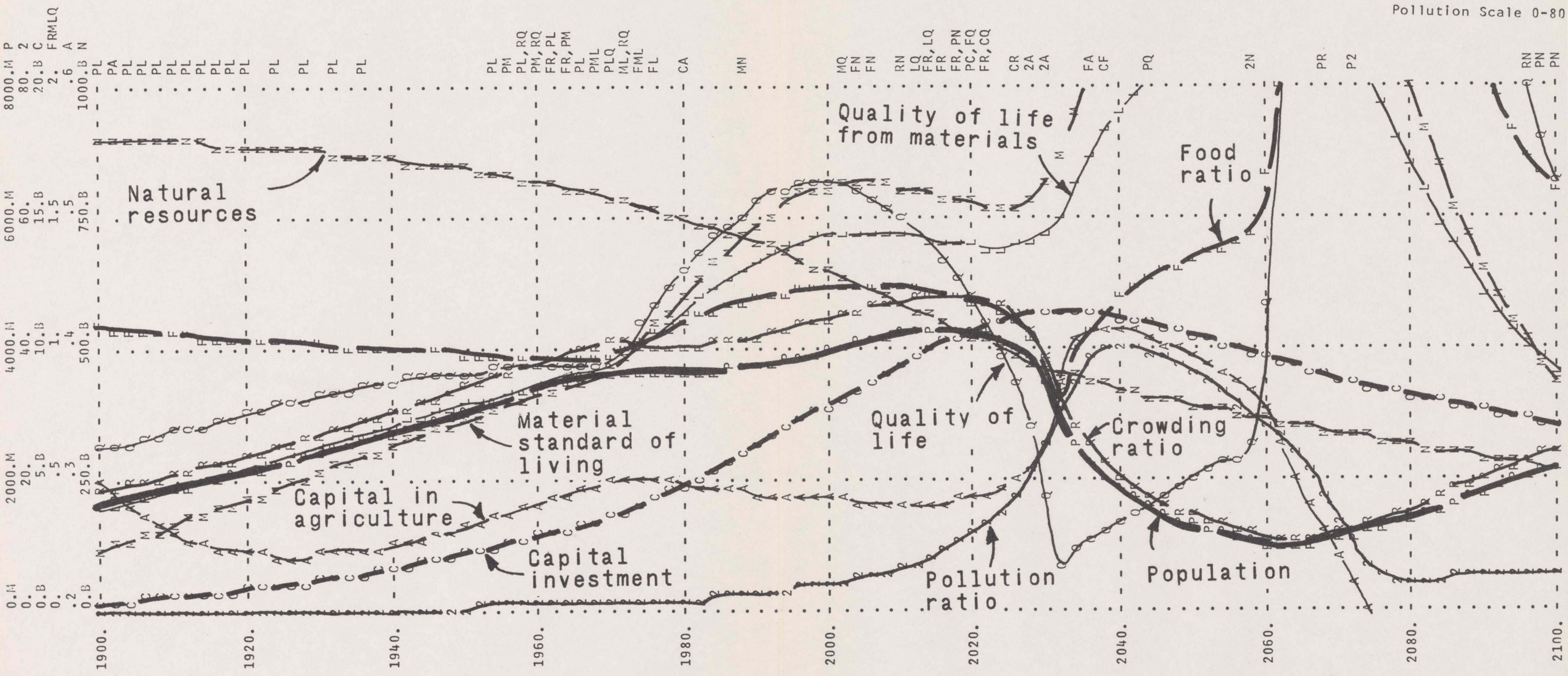
	CIGC1	BRN1
PRESENT	1.2	25.A
ORIGINAL	1.	45.A

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

WORLD2-21S

PAGE 9 WORLD2-21S WORLD DYNAMICS W2 08/04/70 1621.5

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



WORLD2-12S

In this run the natural resource usage normal NRUN1 has been reduced, other things being equal, to 25% of its previous value in the year 1970. This is equivalent to assuming that recycling of waste and new technological advances will reduce the seriousness of declining natural resources. This computer run should be compared with the standard run and also with Run 4S. We see that declining natural resources no longer depress population. Instead, population and capital investment continue to rise until the environmental crisis arising from pollution again reasserts itself. The pollution scale here is again 0 to 80. Results are very similar to Run 4S.

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PAGE 5   WORLD2-12S   WORLD DYNAMICS W2    08/04/70   1621.5

              NRUN1
 PRESENT       .25
 ORIGINAL       1.
```
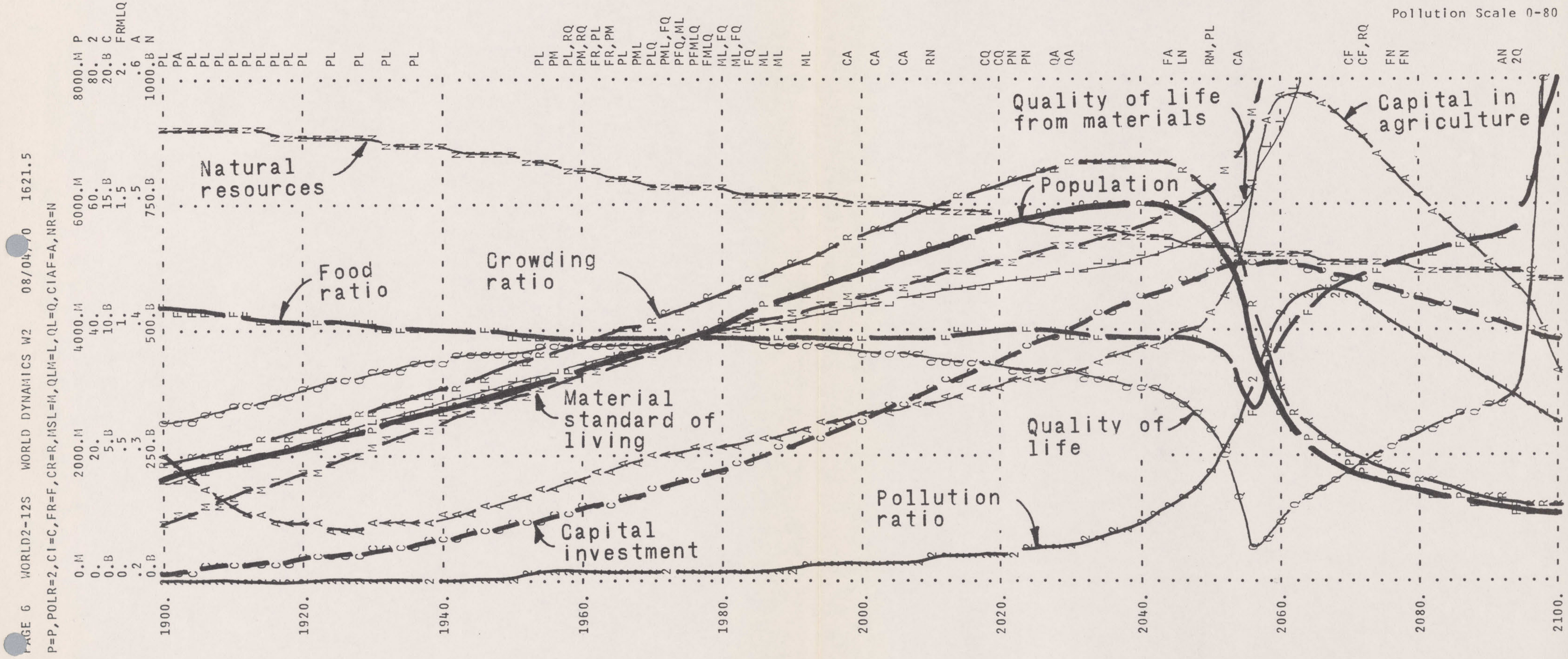

```
    CI   C  Capital investment (capital units)
  CIAF   A  Capital-investment-in-agriculture fraction (dimensionless)
    CR   R  Crowding ratio (dimensionless)
    FR   F  Food ratio (dimensionless)
   MSL   M  Material standard of living (dimensionless)
    NR   N  Natural resources (natural resource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

WORLD2-12S

Pollution Scale 0-80



WORLD2-27S

Here we combine the conditions of Runs 12S and 4S. This means that capital investment is increased 20% and natural resource usage is reduced to one quarter in the year 1970. The effect is to precipitate the environmental crisis about twenty years earlier than in Run 4S. We see that any combination which allows population and capital investment to increase without first being checked by falling natural resources or by crowding will lead into system collapse through rising pollution.

PAGE 8 WORLD2-27S WORLD DYNAMICS W2 08/05/70 0848.4

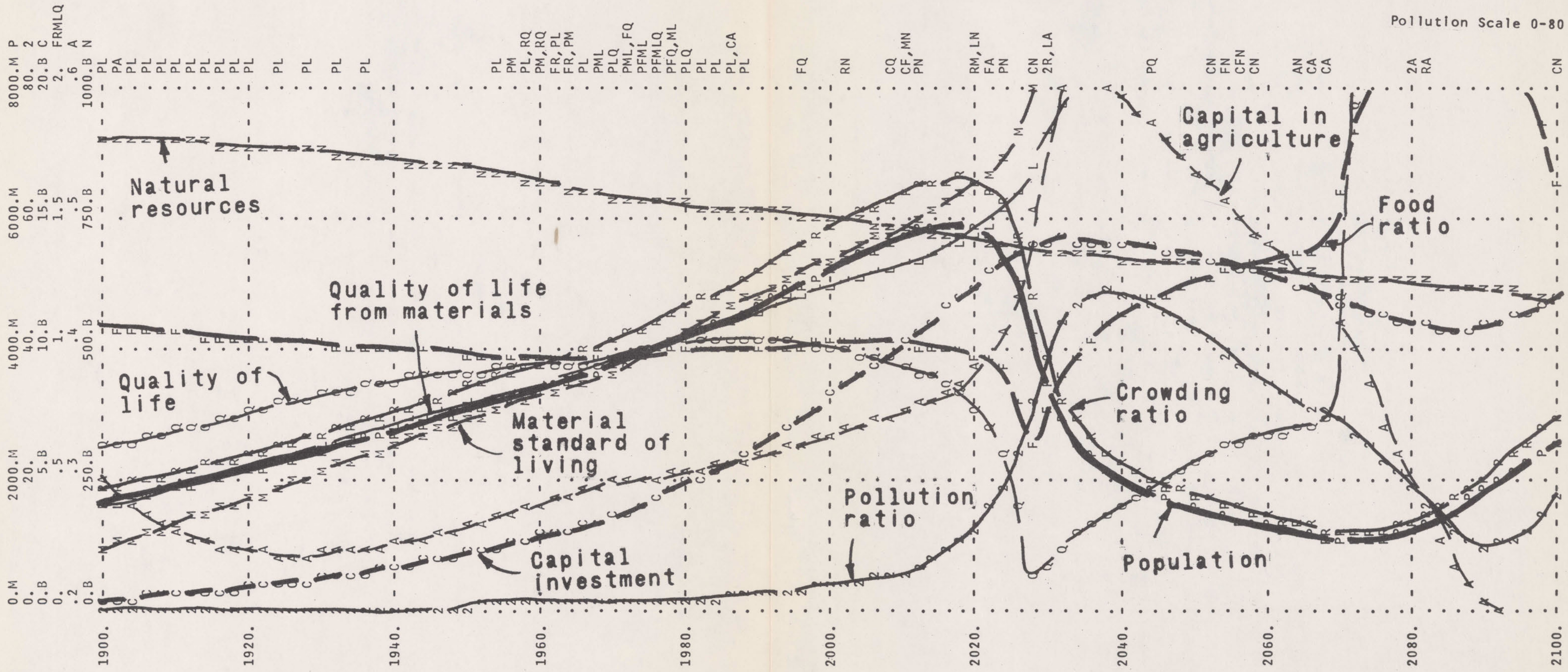
	CIGC1	NRUN1
PRESENT	1.2	.25
ORIGINAL	1.	1.

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

WORLD2-27S

PAGE 9 WORLD2-27S WORLD DYNAMICS W2 08/05/70 0848.4

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



WORLD2-22S

In this run we examine a reduction in pollution generation rate along with the conditions of Run 27S. Here in 1970, three changes have been made. Capital investment generation is increased 20% and natural resource usage is reduced to one quarter of its previous rate as in Run 27S. In addition, pollution generation POLN1 has been reduced from 1 to 0.5. Compared with Run 27S, we see that the reduced pollution generation allows population to rise longer before the collapse occurs. With a smaller rate of pollution generation, other things being equal, population and capital investment continue to rise until environmental overloading again occurs. Here, the peak population occurs about thirty years later than in Run 27S.

In 1970, the usage rate of natural resources was substantially reduced and we see that the natural resource curve levels slightly at that time. However, as population and capital investment both continue to rise, the natural resource usage rate is pushed upward again by sheer magnitude of consumption rate and, by the year 2100, the natural resource level has fallen lower than in the standard computer run. Again, we see the self-defeating effect of many policy changes in complex systems. A reduced natural resource usage rate allows population and capital investment to rise far enough to compensate for the reduced consumption, other things being equal. In other words, other things are not equal. The changed propensity to consume raises the consuming population and related industrialization.

Assembly Instructions: These pages to be interleaved
with the corresponding WORLD2
computer runs.

PAGE 5 WORLD2-22S WORLD DYNAMICS W2 08/05/70 0848.4

	CIGC1	NRUN1	POLN1
PRESENT	1.2	.25	.5
ORIGINAL	1.	1.	1.

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

WORLD2-22S

Pollution Scale 0-80