SP-74-3

INTERNATIONAL INSTITUTE FOR IIASA APPLIED SYSTEMS ANALYSIS

SYMPOSIUM PROCEEDINGS

MULTILEVEL COMPUTER MODEL OF WORLD DEVELOPMENT SYSTEM

EXTRACT
from the
PROCEEDINGS OF THE SYMPOSIUM
HELD AT IIASA, LAXENBURG
April 29 – May 3, 1974

M. MESAROVIC & E. PESTEL, EDITORS

VOLUME III

SCHLOSS LAXENBURG
A-2361 AUSTRIA

TABLE OF CONTENTS

PART A CONSTRUCTION OF WORLD SYSTEM MODEL

PART B SPECIFICATION OF SUBMODELS AND LINKAGES

PART C COMPUTER IMPLEMENTATION AND SIMULATION OF NORMS AND DECISION PROCESSES

PART D THEORETICAL SUPPORT

VOLUME III

PART B SPECIFICATION OF SUBMODELS AND LINKAGES

B-2 POPULATION

B-3 FOOD

III.1. CONSTRUCTION OF POPULATION SUBMODELS

K.H. Oehmen, W. Paul

April 1974

Report on the Population Model

by K.H. Oehmen and W. Paul

Appendix: Population densities

1. The Basic Model

Within the framework of the M-P regionalized world model one of the most important submodels is the population model which serves two main purposes:

(1) To study the population growth in the ten regions under certain population policies and as influenced by the other submodels (e.g. the food model) with which the population model interacts.

(2) To investigate the influence of population development on important issues embodied in the other submodels (e.g. economic, ecological, food, energy, etc.)

In our model the population development is determined as follows: Based on the input represented by the population number living at the middle of year t and by the age-specific probabilities to bear a child (fertility) or, respectively, to die (mortality) within the coming twelve months, the output i.e. the population alive at the middle of year t+1 is calculated. While the output serves to influence other submodels, fertility and mortality depend on population policies and the output of other submodels.

Our calculations are carried out separately for each of the ten regions of the M-P world model, each based on its own complete set of initial and other relevant data (Fig. 1). Accordingly, the degree of detail embodied in the model is limited by the requirement that the needed coefficients and parameters must be available in numerical form for all regions. The software is such that arbitrary aggregations of

Fig. 1: The 10 Regions of the M-P World Model

different regions are possible, e.g. aggregating the ten regions into two macro-regions N (North) and S (South).

In order to give as true a picture of the dynamic nature of population growth as possible, we divided the total population into eighty-six age-groups such that we employ in each such group an age-specific fertility and mortality.

Our two independent variables are the time t and the age a. For both variables we use one year as the time-increment in our stepwise calculations. The time t runs from 1950 to the year 2100, the age a from 1 to 86, a = 86 meaning older than 85. The dependent variable is the population number $P(a,t) = P_a^t$, which denotes the number of people alive at the middle of year t (7/1/t) who were born between July 1 of the year t-a and June 30 of the year t-a+1. In the age-group P_{86}^t we find all living people that were born before July 1 of the year t-85. In our computer program the numbers P_a^t (a = 1, 2, ... , 86) are stored as a vector AP (L); L = 1, 2, ... , 86; they are calculated anew for every year.

Further important quantities are:

T_a^t —— Number of people who died between 7/1/t and 7/1/t+1, as subset contained in P_a^t

B_a^t —— Number of people who gave birth to children between 7/1/t and 7/1/t+1, as subset contained in P_a^t

I_a^t — Difference between immigrants and emigrants in the time-interval between 7/1/t and 7/1/t+1, as subset contained in P_a^t

Pop^t— Total number of people alive on 7/1/t

Bab^t— Babies born between 7/1/t and 7/1/t+1

Tot^t— People who died between 7/1/t and 7/1/t+1

Imi^t— Difference between Immigrants and Emigrants between 7/1/t and 7/1/t+1

The demographic quantity known as "crude birth rate" is defined by the relationship

$$cbr^t = Bab^{t-\frac{1}{2}} \cdot Pop^t \tag{1.1}$$

i.e. as the number of babies in year t referred to the total population alive at the middle of this year. The other important demographic term known as "crude death rate" is defined in analogous manner:

$$cdr^t = Tot^{t-\frac{1}{2}} \cdot Pop^t \tag{1.2}$$

i.e. as the number of people who died in the year t referred to the total population alive at the middle of this year. Both quantities are to a great extent available in the literature [1, 2] for the time-span between 1950 and 1970, and hence they serve here as basic values for the calculation of fertility and mortality. With the aid of equations (1.1)and (1.2) we define the following average values:

$$Bab^t = \frac{1}{2}\left[Bab^{t-\frac{1}{2}} + Bab^{t+\frac{1}{2}} \right] = \frac{1}{2}\left[cbr^t \cdot Pop^t + cbr^{t+1} \cdot Pop^{t+1} \right] \tag{1.3}$$

$$Tot^t = \frac{1}{2}\left[Tot^{t-\frac{1}{2}} + Tot^{t+\frac{1}{2}} \right] = \frac{1}{2}\left[cdr^t \cdot Pop^t + cdr^{t+1} \cdot Pop^{t+1} \right] \tag{1.4}$$

Now in order to obtain through our computations variable age-structures we have to introduce age-specific probabilites, namely fertility and mortality.

The fertility $f\ (a,t) = f_a^t$ defines the probability that a person will produce a child between July 1 of year t and July 1 of year t+1 in an age between $(a-\frac{1}{2})$ and $(a+\frac{1}{2})$. Accordingly we calculate f_a^t from given data, by dividing the number of babies born between 7/1/t and 7/1/t+1, whose mothers belonged at the time of giving birth to the age-group between $(a-\frac{1}{2})$ and $(a+\frac{1}{2})$, by the average total number of people of that same age-group alive in the same time-interval.

The mortality $m\ (a,\ t) = m_a^t$ is defined in analogous manner. Accordingly m_a^t is computed by dividing the number of people, who died in the time interval between 7/1/t and 7/1/t+1 in an age between $(a-\frac{1}{2})$ and $(a+\frac{1}{2})$ by the average total number of people belonging to the same age-group alive in the same time-interval.

In order to facilitate our computational work we split f_a^t and m_a^t each into two factors as follows:

$$f_a^t = cf^t \cdot af_a^t$$

and $$m_a^t = cm^t \cdot am_a^t$$

The introduction of the time-dependent factors cf and cm has certain advantages from a programming point of view since it facilitates the computational work for certain strategies. Otherwise it is without importance. The age-specific probabilities af_a^t and am_a^t are normalized in such way that for each the sum over a from 1 to 86 yields one.

The calculations proceed in the following manner. Starting with the given initial vector P_a^t; a = 1, 2, ..., 86 the quantities P_{a+1}^{t+1}; a = 1, 2, ..., 85 and P_1^{t+1} are calculated. Naturally, for each year t the two probability-vectors f_a^t and m_a^t must be known, either indirectly from data (1950 - 1970), or as prescribed by certain population strategies, and/or due to feedbacks from other submodels. Strictly speaking, the quantities B_a^t and T_a^t are calculated from the following expressions:

$$B_a^t = f_a^t \cdot P_{a+\frac{1}{2}}^{t+\frac{1}{2}} \qquad (1.5)$$

$$T_a^t = m_a^t \cdot P_{a+\frac{1}{2}}^{t+\frac{1}{2}} \qquad (1.6)$$

Here, $P_{a+1/2}^{t+1/2}$ could be found as the arithmetic mean of P_a^t and P_{a+1}^{t+1}; but this would lead to clumsy implicit equations for cf^t and cm^t which are needed for the time-span between 1950 and 1970. We employed therefore the following simplified expressions:

$$B_a^t = cf^t \cdot af_a^t \cdot P_a^t \; ; \quad (a = 1,2,\dots,86) \tag{1.7}$$

$$Bab^t = \sum_{a=2}^{86} B_a^t \tag{1.8}$$

and

$$T_a^t = cm^t \cdot am_a^t \cdot P_a^t \; ; \quad (a = 1,2,\dots,86) \tag{1.9}$$

$$T_o^t = cm^t \cdot am_{\frac{1}{2}}^t \cdot \left(\frac{1}{2} \cdot Bab^t\right) \tag{1.10}$$

$$Tot^t = \sum_{a=0}^{86} T_a^t \tag{1.11}$$

These simplified expressions do not introduce any errors into the aggregated quantities Bab^t and Tot^t, since cf^t and cm^t cancel out the error incurred by substituting P_a^t for $P_{a+1/2}^{t+1/2}$. On the other hand, the probabilities am_a^t and af_a^t are only slightly affected, i.e. by less than 1/2 %, since P_a^t is only slightly larger than $P_{a+1/2}^{t+1/2}$, on the average by $\frac{1}{2}$ cdr^t. Only $P_{1/2}^{t+1/2}$, must be calculated separately, since P_o^t is zero and P^{t+1} comprises all babies who are on July 1 of the year t+1 less than one year old. Hence we substitute for $P_{\frac{1}{2}}^{t+1/2}$ as an approximation $\frac{1}{2} \cdot Bab^t$.

In this manner we obtain simple relationships for B_a^t and T_a^t where the errors influence only the accuracy of the probability distributions, however to a far less degree than is involved by the uncertainty of our data base.

Before we turn to our calculation proper, a few remarks dealing with the regional population in- and out-flow. The difference Imi^t between immigrants and emigrants must also be distributed onto the various age-groups. Since the quotient Imi^t / Pop^t is for all regions less than 1 % , and since our data base is very weak in this respect, we use the following distribution:

$$I_a^t = Imi^t / 50; \; a = 2, 3, \ldots, 51 \qquad (1.12)$$

$$I_a^t = 0 \qquad ; \; a = 1, 52, \ldots$$

This agrees sufficiently well with the UN-data, as far as they are available. These data show that immigrants are rarely older than 50 years and that the age-distribution is rather linear (DY 70).

Besides, from 1970 on, each region is treated as a closed region with $Imi^t = 0$ $(t > 1970)$; only until 1970 immigrants and emigrants are taken into account in order to be able to use all available data on Pop^t, cbr^t and cdr^t, while avoiding redundancy.

This means that between 1950 and 1970 the quantity Imi^t is predetermined by Pop^t, cbr^t, cdr^t and Pop^{t+1}.

In the developed countries with reliable data the thus obtained values Imi^t nearly coincide with the difference between immigrants and emigrants. In the developing countries, however, Imi^t serves chiefly to absorb the inaccuracies in the data for cbr and cdr. Hence, we define Imi^t as follows:

$$\begin{aligned} Imi^t &= Pop^{t+1} - Pop^t - Bab^t + Tot^t \; ; \quad t < 1970 \\ Imi^t &= 0; \quad t > 1970 \end{aligned} \tag{1.13}$$

Returning now to the calculation of the age-group populations, we have the following set of equations:

$$P_1^{t+1} = Bab^t - T_o^t \tag{1.14}$$

$$P_{a+1}^{t+1} = P_a^t - T_a^t + I_a^t; \; a = 1, 2, \ldots, 84 \tag{1.15}$$

$$P_{86}^{t+1} = P_{85}^t - T_{85}^t + P_{86}^t - T_{86}^t \tag{1.16}$$

$$Pop^{t+1} = \sum_{a=1}^{86} P_a^{t+1} \tag{1.17}$$

The equations (1.7) - (1.17) represent our basic population model and allow the calculation of P_a^{t+1} $(a = 1, 2, \ldots, 86)$ for given P_a^t , af_a^t , am_a^t , cf^t and cm^t.

Set of basic equations:

$$\left.\begin{array}{ll} B_a^t = cf^t \cdot af_a^t \cdot P_a^t & (1.7) \\ Bab^t = \sum_{a=2}^{86} B_a^t & (1.8) \end{array}\right\} \left\{\begin{array}{ll} \text{till } 1970: & \longrightarrow cf^t \\ \text{since } 1970: & \longrightarrow Bab^t \end{array}\right.$$

$$\left.\begin{array}{ll} T_0^t = cm^t \cdot am_{\frac{1}{2}}^t \cdot \left[\frac{1}{2} \cdot Bab^t\right] & (1.10) \\ T_a^t = cm^t \cdot am_a^t \cdot P_a^t ;\ a = 1,\ldots,86 & (1.9) \\ Tot^t = \sum_{a=0}^{86} T_a^t & (1.11) \end{array}\right\} \left\{\begin{array}{ll} \text{till } 1970: & \longrightarrow cm^t \\ \text{since } 1970: & \longrightarrow Tot^t \end{array}\right.$$

$$\begin{array}{lll} Imi^t = Pop^{t+1} - Pop^t - Bab^t + Tot^t & \text{till } 1970 & \\ \quad = 0 & \text{since } 1970 & (1.13) \end{array}$$

$$\begin{array}{ll} I_a^t = \frac{1}{50} \cdot Imi^t ;\ a = 2,\ldots,51 & \\ \quad = 0 \qquad ;\ a = 1,52,\ldots,86 & (1.12) \end{array}$$

$$P_1^{t+1} = Bab^t - T_0^t = Bab^t \cdot \left[1 - \frac{1}{2} cm^t \cdot am_{\frac{1}{2}}^t\right] \tag{1.14}$$

$$P_{a+1}^{t+1} = P_a^t - T_a^t + I_a^t = P_a^t \cdot \left[1 - cm^t \cdot am_a^t\right] + I_a^t \tag{1.15}$$

$$P_{86}^{t+1} = P_{85}^t \cdot \left[1 - cm^t \cdot am_{85}^t\right] + P_{86}^t \left[1 - cm^t \cdot am_{86}^t\right] \tag{1.16}$$

$$Pop^{t+1} = \sum_{a=1}^{86} P_a^{t+1} \tag{1.17}$$

Supplementary equations till 1970:

$$Bab^t = \frac{1}{2} \cdot \left[cbr^t \cdot Pop^t + cbr^{t+1} \cdot Pop^{t+1}\right] \tag{1.3}$$

$$Tot^t = \frac{1}{2} \cdot \left[cdr^t \cdot Pop^t + cdr^{t+1} \cdot Pop^{t+1}\right] \tag{1.4}$$

2. Data base of the demographic model

Fig. 1 shows the 10 regions for which we have plotted the midyear population (Figs. 2 - 11). The data used were taken from the United Nations' Demographic Yearbooks which have been published annually since 1949. In these yearbooks available relevant data on population development are given nation-by-nation. In most cases the data come from national government sources. Not always are they very reliable, but they constitute practically the only data source available.

The demographic model uses the following time series and age distributions:

(i) UN midyear population estimates from 1950 to 1970.
(ii) Crude birth rates from 1950 to 1970.
(iii) Death rates from 1950 to 1970.
(iv) Population age distribution in 1950 or in the earliest available year.
(v) Birth distribution over mother age in 1970 or in the latest available year.
(vi) Death distribution over age in 1970 or in the latest available year.
(vii) Population age distribution in the years used in (v) and (vi).

The immigration rates were not available in sufficient detail and were treated in the model as the difference between total population as known and total population computed from (i) to (vii). Comparison with the immigration data of the developed nations, which are relatively precise and complete, shows that the computed immigration rates fit the data rather well. This is a first indication of the quality of the model but also of the lack of precision of population data from some nations.

In the following we review the data used for the demographic model. They are discussed with respect to their origin and reliability, then aggregated data are represented graphically, the mode of data preparation is described, the various data are listed, and finally missing data are discussed. Although almost all data are derived from UN Demographic Yearbooks, comparison with other data sources is made wherever possible.

2.1 Estimates of midyear population from 1950 to 1970

(1) Origin: UN Demographic Yearbook 1970, Table 4. This table is the only complete table available. It includes all nations with more than 10.000 population. The data are given in millions of inhabitants.

(2) Reliability: Data are either the results of official population census, UN estimates, or-in the absence of such sources - the unrevised estimates of national governments. Although the table is complete in the sense that all nations are represented, the share of data labeled inconsistant by the UN is particularly large for the less developed countries. Nevertheless, this table seems to yield the most reliable of all data used for our model.

(3) Mode of data preparation:The annual data of the individual nations are summed within regions. From the midyear values the crude growth rate cgr is computed according to the UN definition

$$cgr(t) = \frac{P(t) - P(t-1)}{P(t-1)}$$

The simple program given in the listing 1 is self-explanatory (UH 252 calls the plot subroutine).

(4) Graphic representation and discussion: The development of midyear population and crude growth rate from 1950 to 1970 is shown in Figs. 2 to 11. A steady growth of total population can be observed in all 10 regions. However, the growth rates vary considerable. In the developed countries the present growth rates are about 1 % or slightly higher. Only Region 4 has values of more than 2 % and thus approaches those of the developing countries. Region 6 has the highest growth rates - above 3 % -, while Region 10 has the lowest growth rates of the developing regions, namely slightly less than 2 %.

Also of interest are the strong fluctuations of individual growth rates. Most likely they are attributable to data error. The true scale of natural fluctuation can only be inferred from Regions 1 through 5. The conspicuously smooth growth rate curve of Region 10 is due to the fact that China has used pure extrapolation for determining her population. It would help to get actual data for this region. Finally, Region 1 through 5 seem to show a certain effect caused by the "pill".

The actual population statistics reveal that more than 50 % of mankind live in Regions 9 and 10. This can also be seen from Fig. 12, in which the populations of the individual regions are summed, starting from Region 1. In the so-called developed countries we have less than 1/3 of the world population. The actual population explosion takes place in Regions 6 through 10. Note that a growth rate of 3 % leads to a doubling time of only 23 years:

$$T = \frac{\ln 2}{cgr} = \frac{0.693}{cgr} = 23 \text{ years.}$$

(5) Listing 1 of data and of program : The data listed are population by nation, classified by region. They run from 1950 to 1970.

(6) Missing data: All data are available for all years of interest.

2.2 Crude birth and death rates

(1) Origin of data: The data are taken from the UN Demographic Yearbooks 1966, Table 7 (cbr 1950 - 1966), DY 70, Tab 13 (cbr 1966 - 1970), DY 66, Tab 17 (cdr 1950 - 1966), and DY 70, Tab 17 (cdr 1966 - 1970). In addition, the data in "World Population Prospects as Assessed in 1968" [2] have been used for fitting.

(2) Reliability: For the developed regions the data are reliable and almost completely known. A large share of the data for the less developed regions are not available. Some important countries are missing altogether, for some only estimates exist which often are unreliable. For a few countries only the averages over several years are known.

(3) Mode of data preparation: The values of cbr and cdr were weighted by the percentage share of the respective country's population in its region and averaged. Of cbr only the time averages from 1950 - 1954 are known; these averages were used for the separate years 1950, 1951, 1952, and 1953. For 1970 the value of 1969 was used. All values of cdr are known from 1951 to 1971. For 1950 the value of 1951 was used. Together with the determination of the values of cbr and cdr we have computed the "degree of data availability" for each region, defined as the sum of all populations for which cbr and cdr are known in a certain year, divided by the total regional population. This "degree of data availability" yields a characteristic measure for the data scarcity of the various regions. It does not, however, distinguish between the different degrees of reliability.

(4) Graphic representation and discussion: The time series for crude birth rates and crude death rates are shown in Figs. 13 to 32. In the following we will discuss them region by region:

Region 1: Constant low death rate and falling birth rate. The degree of data availability (d.d.a.) is practically 100 % (with the exception of 1966, where Canada's cdr is unknown. The characteristic effect of the "pill" can be observed in the birth rate curve.

Region 2: Constant low death rate and a slightly falling birth rate. The d.d.a. is very high. Missing data are mostly Turkish.

Region 3: Fairly constant low death rate and a slightly decreased birth rate. D.d.a. = 100 %. The slight fluctuations in the death rate are probably attributable to shifts in the age pyramid.

Region 4: Here the death rate is similar to those of the other developed regions, but the birth rate is the highest of Regions 1 through 5. "Pill pressure" does not seem to exist. Perhaps the high birth rate is a result of a particular "pioneer" mentality and of the immigration policy of these countries.

Region 5: Constant low death rate and suddenly dropping birth rate ("pill" effect).

Region 6: Relatively low death rate (for a developing region), but a very high birth rate. In this region we find the highest net growth rate. For Brazil, a country of decisive importance in this region, only scanty data exist.

Region 7: A relatively high death rate is coupled with a very high birth rate. D.d.a is sufficient except for 1969 and 1970 cbr. For these values the decline is not real but rather the result of missing data in most countries of the region. The few nonrepresentative numbers deceptively suggest a lower birth rate.

Region 8: Very low d.d.a. This region has the highest death rate of all and a very high birth rate. Again, the suggested decline in cbr and cdr toward 1970 is the result of missing or nonrepresentative data. Interesting to note, the birth and death rates are always high with high d.d.a., so that the true rates of this region probably are closer to the upper envelope of the peaks than to an average.

Region 9: A relatively high but definitely declining death rate is apposed by a constant high birth rate. This means that the population growth in this region is accelerating! Here also one must assume that the higher rates are the more reliable ones, because they correspond to high d.d.a. Again, part of the birth rate decline toward 1970 is attributable to nonrepresentative data and low d.d.a.

Region 10: Except for the period from 1951 to 1957 practically nothing is known about this region. Least is known about China, the largest country in Region 10.

(5) Data and program listing 2: For each nation the 1969 population in millions of people, the crude death rates from 1951 to 1971 and the crude birth rates are listed. The first value for cbr stands for the 1950 to 1954 average, then the values of 1954 through 1969 follow.

(6) Missing data: The data for developed countries are practically complete, whereas in the developing regions some decisive countries are missing (e.g., Brazil in Region 6; Libya, Marocco, and Saudi Arabia in Region 7; most Black African countries; Indonesia, India, and Pakistan in Region 9; and China in Region 10). More reliable data for these population-exploding nations would contribute significantly to any estimation of demographic development.

2.3 Initial age distribution

(1) Origin: Age distributions in 1950 or for the earliest available year are contained completely in DY 1970, Table 6. The population numbers are aggregated into 5-year age groups.

(2) Reliability: According to the UN the reliability of these data is rather high, because estimates have been hardly used. But for many developing countries the distributions are not known.

(3) Mode of preparation: First the age groups of the individual nations were added for each region. Then the percentage shares in the total population with known age distribution were computed for each age group. In those cases where only aggregates of two or three five-year age groups were available, the split into the five-year age groups was fitted to the rest of the age profile. For the dynamic model a split into one year groups is done by subroutine 'Spline' (2.5).

(4) Graphic representation and discussion: The initial age distributions by percentage share are shown in Figs. 33 to 42. The distributions in Regions 1, 2, 4, and 5 are relatively flat and mostly show a pronounced "World War II dent". Region 3's distribution is already heavily shifted toward younger age groups. This is evidence of previously rapid population growth. In Regions 6, 7, 8, 9, and 10 the shift to younger generations due to rapid growth is even more pronounced A "WW II dent" cannot be seen. The small dent for Region 8 more likely results from insufficient data.

(5) Data and program listing 3: The age distributions are listed by thousands of people in the following way: Total number of babies less than 1 year old, 1 to 5 years, 5 to 10 years, 10 to 15 years, up to 80 to 85 years in 5-years groups, and finally all people older than 85.

(6) Missing data: It holds also for these data that they are almost complete for Regions 1 through 5. Compared with other tables, they are also rather complete for Regions 6 through 9, if one disregards the fact that the 1950 values are mostly unavailable. But this is without significance for the developing countries without a "WW II dent". For China we have no age distribution, but most likely the values for North Corea and Mongolia

are representative for this region, as can be inferred from a comparison with other developing regions.

2.4 Age - specific fertility and mortality

(1) Origin: The data for birth by age of mother are taken from the UN Demographic Yearbooks 66 (Table 8), 69 (15), 70 (14); the data for death by age from DY 66 (Table 19), 70 (18); and the age distribution from DY 70 (6). The data are composed of the number of deaths per five-year age group, of the number of births per five-year age group for mothers, and of the age distribution in the same year. The number of deaths of both sexes were added and not listed separately thereafter.

(2) Reliability: Especially in the less developed countries often only aggregates of several five-year age groups are available. In such cases splitting can create errors. For Region 10 again the data situation is the worst: the values we took are from Hong Kong, which does not belong to the region and is not necessarily representative for it.

(3) Mode of preparation: Relative age distributions of births and deaths were used for computation. The deaths of each group were related to total number of deaths. In order to become more independent of random fluctuations in the age pyramid, relative age-specific fertility and mortality were introduced:

$$am_a = \frac{T_a}{Tot} \;/\; \frac{P_a}{Pop}$$

$$af_a = \frac{B_a}{Bab} \;/\; \frac{P_a}{Pop}$$

The data births, deaths, and age distribution are from the same year whenever possible. However, for developing countries simultaneous data are not always available. But this source of error is very slight, because in these regions the age pyramid has been very stable in the past.

(4) Graphic representation and discussion: The results are shown in Figs. 43 to 52. In Regions 1 through 5 the distributions of death by age are rather similar: a slightly increased baby mortality is followed by a very low mortality of young individuals. First mortality increases only very slowly with increasing age, then more rapidly, almost according to an exponential function. Contrary to this pattern, the baby mortality is markedly higher in developing countries, and also their higher mortality in the young age groups has a significant influence on the growth dynamics of their populations. Because of this the age pyramid does not expand "upward" so strongly as in the developed regions: if someone reaches the age of 60, say, in India, he belongs to the "toughones" whose life expectancyis higher than for someone of equal age in a developed country. Occasional dents at high ages (viz. Regions 7 and 9) are most likely due to data errors.

The birth distributions cover the age range of 10 to 50 years. The maximum invariably lies between 20 and 30 years. Of interest is the relatively high fertility of older women in the developing countries. This perhaps is the only characteristic difference between developing and developed regions. We find this fact worth mentioning insofar as one can conclude from it that not the early onset of childbearing but rather the late and gradual birthrate decrease with age accounts for the high birth rates of the developing regions.

(5) Data and program listing 4: In the data list one finds births (4 rows), deaths (7 rows), and age distribution (7 rows) by five-year age groups. Births and deaths are given in actual numbers, while age distribution is given in thousands of people. Births include: total, 10 - 15, 15 - 20, 20 - 25, ..., 45 - 50, 50 + , and unknown births. Deaths and age distribution include:total, 0 - 1, 1 - 5, 5 -10 , ..., 80 - 85, 85 + , and unknowns.

(6) Missing data: Again the developed regions are relatively complete. Here only the distribution of deaths is missing for the USSR. Brazil is missing in Region 6, which is fairly complete otherwise. In Region 7 only Jordania is available, and also Region 8 is underrepresented with only 3 countries of 48. Fortunately, the data for such decisive countries of Region 9 as India, Pakistan are known. Here Indonesia is missing. But in Region 10 the birth and death distributions are lacking for all countries. Again it remains an open question as to how representative Hong Kong is for this last region.

2.5 Generating one-year age-groups from five-year age-groups

For the construction of the basic model it is necessary to have the initial distribution of all people living in 1950 as well as the fertility- and mortality pattern in one-year age-groups. Unfortunately, in the demographic yearbooks these data which are needed for all 10 regions are available only in five-year age-groups, except for the first year group. For the generation of the 86 one-year age-groups of our basic model from the given five-year age-group data we developed a special subroutine "Spline".

Our input-vector consists of 19 components: First the age-group 0 to 1 year, next the age-group from 1 to 5 year thereafter 16 five-year age-groups from 5 to 10, 10 to 15, ..., 80 - 85 years, and finally the age-group comprising all ages above 85 years. Two additional input-parameters are the boundary values n_1 and n_2 defining the range within which the interpolation is to be made in one-year intervals. However, in order to be able to interpolate, we must first have the points through which the interpolating curve is to pass. In order to find these points we form the age-integral for the input-vector, thereby obtaining 20 fixed points which permit an easy interpolation. Numerical differentiation of this interpolated integral curve then yields the desired age-distribution. The procedure may be demonstrated by means of an example concerning the initial age distribution. The 19 input values are denoted by G (n); n = 1, 2, ..., 19. Y (n) and X (n) denote the ordinates and abscissae, respectively, of the abovementioned 20 points of the integral curve.

Then we have

$$\begin{array}{l} X(0)=0;\quad X(1)=1;\quad X(2)=5;\quad X(3)=10;\ldots;\quad X(19)=90;\quad \text{and} \\ Y(0)=0;\quad Y(1)=G(1);\quad Y(2)=G(1)+G(2);\quad \text{in general} \\ Y(n)=Y(n-1)+G(n) \end{array} \tag{2.1}$$

Y(X) then gives the number of people living between the age of zero and X.

By means of the spline-interpolation [4] we now calculate for the 20 points, as given above, the y-values for the abscissae x = 2, 3, 4, ..., 84. The spline-functions f (x) are cubic polynomials whose coefficients are determined for each interval i of the 19 age-intervals. The spline function f (x) is to have the following properties:

$$\left.\begin{array}{l} (1)\ f(x)=P_i(x) \quad \text{for} \quad X(i)\leq x\leq X(i+1);\quad i=0,1,2,\ldots,18 \\ \text{where} \\ \quad P_i(x)=Y(i)+b\cdot\left[x-X(i)\right]+c\cdot\left[x-X(i)\right]^2+d\cdot\left[x-X(i)\right]^3 \end{array}\right\}(2.2)$$

$$\left.\begin{array}{l} (2)\ P_i(X(i))=P_{i-1}(X(i))=Y(i) \\ (3)\ P_i'(X(i))=P_{i-1}'(X(i)) \\ (4)\ P_i''(X(i))=P_{i-1}''(X(i)) \\ (5)\ \displaystyle\int_{X(0)}^{X(19)}\left[f''(x)\right]^2dx \overset{!}{=} \text{Min.} \end{array}\right\}(2.3)$$

Hence, the spline function f (x) possesses in the whole range $0 \leqq x \leqq 90$ continuity with continuous first and second derivatives and minimized total curvature.

After the values y (a) (a = 1, 2, ..., 85) have been found in this way, the desired age-structure is obtained as follows:
The values y (a) and y (a-1) indicate how many people are alive between the age of zero and a, and zero and a-1, respectively. Therefore the difference g (a) = y (a) - y (a-1) gives the number of people between the age of a and a-1 years; i.e. in the age-group a.

Summarizing we have the following procedure:

Input: 19 values for G (n); n = 1, 2, ..., 19
Intergration: 20 values for the pair Y (n), X (n); n = o, 1, ..., 19
Interpolation: 86 values for y (a); a = 0, 1, ..., 85
Output:

$$\left.\begin{array}{l} g\ (a) = y(a) - y(a-1);\ a = 1, \ldots, 85 \\ g\ (86) = G\ (19) \end{array}\right\} \quad (2.4)$$

The values g (a) are then normalized such that

$$\sum_{a=1}^{86} g\ (a) = 1$$

This subroutine can be applied to obtain the year-by-year age-distributions for all living people, the deaths and the birth giving mothers.

In the representation of the probability distributions we have to note, that here the values G (n) represent the abscissae of the step-like "curves" and not the respective areas under these "curves". Therefore, all G-values have first to be multiplied by the length of the corresponding age-interval in order to obtain the area. With this change also the fertility- and mortality patterns can be produced by means of the subroutine "spline".

Because of the steep slope of the integral curve in the cases of fertility and of the distribution of the birth giving mothers a transformation becomes necessary such that finally y (x) is not approximated by means of $f(x) = P_i(x)$, but rather using the relationship

$$f(x) = \frac{y(x) - 1/2 \cdot y(a = 90)}{y(a = 90) \cdot (1 + \varepsilon)} = \tanh(P_i(x)) \tag{2.5}$$

with $0 < \varepsilon \ll 1$

In this way it is possible to interpolate function y (x), which indeed resembles a displaced tanh-function, without overshooting, thereby avoiding the danger of obtaining impossible negative fertilities. The quantity ε is introduced for the purpose that $f(x)$ for $x < 10$ and $x > 60$ does not go towards infinity. Since

Eq. (2.5) is also used for the re-transformation in order to arrive finally at the distributions g (a), the actual value chosen for ε , which lies in the neighborhood of 0.01 , is practically without importance.

For the developed as well as for two developing regions we find in the Figs. 53 - 64 representations of both input and output of the subroutine "spline" as applied to the initial age-structure, the fertility- and mortality patterns. The input- and output-curves should enclose for each of the given age-intervals between X = 0, 1, 5, 10, 15, ..., 85 exactly equal areas. The results of further applications to the age-specific fertility and mortality for all 10 regions are depicted in Figs. 65 - 84. The initial age-distributions in 1950 are included in the Figs. 112 - 151.

We could have found even smoother curves by means of a refined "spline"-technique [3] ; However, we did not deem this necessary for our purposes.

Listings of this subroutine and of the two routines "Aged" and "Frame" for the generation of the diagrams for the age-structure and for the computer runs of the population development are enclosed in Listing 5.

Finally, it should be pointed out that the mortality distributions (s. Figs. 75 - 84) after having been multiplied by the time-dependent factor cm^t yield the probabilityfor the death of a person between the ages of a and a-1 within the coming year. However, the people in the group P_a^t, when dying in the coming year have then on the average ages between (a-1/2) and (a+1/2) years. Hence, in order to obtain the mortalities as used in Eqs. (1.9) - (1.17), the arithmetic mean of two adjacent values g (a) is formed as follows:

$$am_a = 1/2 \cdot \left[g(a) + g(a+1) \right] \; ; \; a = 1, 2, \ldots, 85 \qquad (2.6)$$

$$\text{and} \quad am_{1/2} = g(1) \qquad am_{86} = g(86) \qquad (2.7)$$

where g (a) is the output yielded by the subroutine "spline". The fertility is treated in analogous manner.

3. Population Policies

While our calculations for the time-span between 1950 and 1970 are constrained by the given data, we can from then on apply various alternative strategies in order to achieve certain broad demographic goals, e.g. population equilibrium. Besides, not only different population policies will affect fertility differently, but also feedbacks from other submodels will influence both fertility and mortality. It may be expected, for example, that in certain developing regions mortality will be greatly increased by food shortages, unless extremely urgent and drastic measures are taken there to halt the rapid population growth.

3.1 Population Development between 1950 and 1970

For each of our 10 regions we use as initial values the 86 numbers P_a^{1950} (a = 1, 2, ..., 86) which by means of the subroutine "SPLINE" (s. ch. 2.5) have been calculated from the age-structure of 1950 as given in five-year-groups and from the total 1950 population Pop^{1950}. Further data are Pop^t (t = 1951, 1952, ..., 1970) and the corresponding time-series for the crude birth rate cbr^t and the crude death rate cdr^t. From Figs. 13 - 32, where these parameters are depicted together with their "availibility degree" as a measure of the quality of these data, we can see that the latter drops partly under 10 % as far as cbr^t and cdr^t are concerned. In these extreme cases, which occur mainly in the regions 8, 9 and 10, we do not employ our calculated values (s. Figs. 27 - 32), but, instead, the values estimated by the United Nations [1, 2] .

The age-specific probabilities af_a^t and am_a^t, to give birth and, respectively, to die in the year t, are also calculated by means of the subroutine "SPLINE" from the most recent - assembled in five-year-groups - annual data on the age-distribution on live births, deaths, and of population. The probabilities af_a^t and am_a^t are then employed as constants af_a and am_a during the whole time-span between 1950 and 1970, first because of data-shortage, and secondly for the reason that the assumption may justifiably be made that these probability-distributions will vary only slightly during the 20 years under consideration. The reader is reminded that both af_a and am_a have been normalized such that

$$\sum_{a=1}^{86} af_a = 1 \quad \text{and} \quad \sum_{a=1}^{86} am_a = 1$$ (see Figs. 65 - 84).

Since we did not have any reliable age-distributions of deaths and of live populations for our region 10 (China), we employed for this region the mortality-distribution am_a of region 9 (South and South-East-Asia); however, the time-varying magnitude cm^t of the mortality is calculated from the given time-varying cdr^t and Pop^t of region 10.

In view of the circumstance that in the regions 8 - 10 great uncertainties prevail concerning the five-year-groups for fertility and mortality, the corresponding probability-distributions were smoothed to such extent that mortality increases monotonously from the age of 20 on, and that the fertility distribution possesses only one maximum. The latter conditions, however, could not always be satisfied as far as regions 8 - 10 are concerned, when the regional fertility and mortality distributions were calculated from those of the individual nations involved (compare Figs. 43 - 52 and Figs. 65 - 84).

The time-varying magnitude-factors cf^t and cm^t (t = 1950, 1951, ..., 1970) were obtained with the aid of Eqs. (1.3), (1.4), and (1.7) - (1.11): From Eqs. (1.3) and (1.4) follow Bab^t and Tot^t; then from Eqs. (1.7) and (1.8):

$$cf^t = Bab^t \Big/ \sum_{a=2}^{86} af_a \cdot P_a^t$$

and from Eqs. (1.9) - (1.11):

$$cm^t = Tot^t \Big/ \left(\frac{1}{2}\, am_{\frac{1}{2}} \cdot Bab^t + \sum_{a=1}^{86} am_a \cdot P_a^t \right)$$

In a closed regional population system (i.e. without immigrants and emigrants) the problem of calculating Pop^{t+1} from given values Pop^t, cbr^t, and cdr^t (t = 1950, 1951, ..., 1970) would be redundant. In an open regional population system, on the contrary, these data yield by means of Eqs. (1.12) and (1.13) the values for Imi^t and I_a^t, i.e. the numerical difference of immigrants and emigrants and/or, respectively, a measure for the inaccuracy of the given data. In any case $Imi^t \neq 0$ as well as $I_a^t \neq 0$ cannot be interpreted as an indication for faults in the population model structure.

From Eqs. (1.14) - (1.17) we obtain finally the values P_a^{t+1} (a = 1, 2, ..., 86) and Pop^{t+1} for the following year, with Pop^{t+1} coinciding with the given value from our data-base. This reveals that we do not carry out our calculations for the time-span between 1950 and 1970 in order to calculate Pop^{1970}, but rather in order to study the dynamic behavior of the age-structures, to observe what degree of reliability we may attribute to all relevant data, and to calculate the age-distribution P_a^{1970} for those regions where these are not available.

A listing of the program with all subroutines and the result from 1950 till 1970 is enclosed in listings 5 and 6. In the print-outs we find the year t, total population Pop^t, fertility factor cf^t, crude birth rate cbr, mortality factor cm^t and crude death rate cdr.

In the second line the actual population Pop^t and the calculated difference of immigrants and emigrants are stated in millions.

It was re-assuring to find that with the values as used by us for Pop^t, cbr^t, and cdr^t, the calculated values for immigrants and emigrants remained under 1 % for all regions.

3.2 Standard Computer Runs (Constant fertility and mortality)

In our standard computer runs we keep from 1970 the fertility cf and mortality cm constant, i.e. $cf^t = cf^{1970}$ and $cm^t = cm^{1970}$ for $t > 1970$. The age-specific probability distributions af_a^t and am_a^t stay constant as well, using the same constant distributions as in the time-interval between 1950 and 1970. From 1970 on, immigrants and emigrants are no longer considered.

In Figs. 85 - 94 a number of standard runs are depicted which are based on different values for cf^{1970} and cm^{1970}, which were obtained by averaging certain values cf^t and cm^t (t = 196o, ..., 1969) which were computed as described in Sc. 3.1. These averages were computed over the years $t = 1970 - t_1$ ($t_1 = 1, 2, \ldots, t_M$), using for t_M the values 1, 3, 5, and 10, respectively. We note from Figs. 85 - 94 for the highly industrialized regions a clear trend towards smaller growth rates as t_M diminish, whereas for the developing regions in Africa and Asia the curves are very close to each other for t_M = 1, 3, and 5; the simple reason for this lies in the fact that here estimated average values had to be used for cbr and cdr in the years between 1965 and 1970 (cf. Chapter 1 and Figs. 13 - 32).

From our diagrams (Fig. 95 - 107) it is immediately obvious that in the developing regions we have for constant fertility and mortality practically pure exponential population growth, while in the developed regions North America, Western Europe, Japan and Eastern Europe incl.

the Soviet Union we have great deviations from exponential growth curves. For the first two of these regions we note considerable fluctuations in the growth rate, while the populations in the two latter regions despite constant fertility and mortality soon after the turn of the century stay constant and diminish, respectively, although both have about 1970 a growth rate of approximately 1 %. This effect is due to the dynamic nature of the age-structure.

In Figs. 112 - 151 we have depicted the age-structures for all regions in 1950, 1975, 2000 and 2025 for the standard run, i.e. using $cf^t = cf^{1969}$ and $cm^t = cm^{1969}$ for $t \geq 1970$. Comparing these age-structures with those of the equilibrium state (Figs. 152 - 161), one notes that e.g. in Region 5 (Eastern Europe incl. Soviet Union) the standard run yields for the year 2000 more people in the reproductive age groups (about 20 - 40 yrs) than in age-groups between 0 and 20 years. Therefore, the number of births must consequently decrease when the fertility stays constant. This trend would then be reinforced for each following generation.

Furthermore, one can calculate in advance what fertility value cf^e would be required in order to arrive at some later date at a constant population when the mortality is kept constant (s. Sec. 3.3). For Japan and Eastern Europe cf^e is larger than cf^{1970} although in the equilibrium state the crude birth rate is smaller than cbr^{1970}.

Listing 6 registers the time-change of crude birth rate and crude death rate while fertility and mortality remain unchanged. In these tables we find $cbr^{t+1/2}$ in the column Bab/Pop and $cdr^{t+1/2}$ in the column Tot/Pop. Input data Pop^t are stated in millions. In the last two columns one finds the accumulated number of babies and deaths, respectively from 1970 an. Although not very important in the present context, they should be noted in comparison with the computational results in Sec. 3.5.

The program listings correspond exactly to the calculation for the generation of Figs. 258 - 270 which depict the results for the equilibrium runs, type 2.3 (s. next section). Always the fourth pass of the loop DO 300 ... 300 CONTINUE yields the standard run for the region under consideration.

It would lead too far to discuss the standard runs for each region with reference to population development and changing age-structures as shown in the diagrams and tables. They are to a great extent self-explanatory.

Interesting are also Fig. 108 - 111, representing the percentage share in the total population for all 10 regions - Fig. 108 for normal run and in comparison Fig. 109 - 111 for equilibrium runs, type 1.2 (see Sec. 3.3).

In conclusion it is printed out, that also for the standard runs the life expectancies at birth have been calculated for each region from 1970 on, using Eq. (3.5) from Sec. 3.3. Although Eq. (3.5) has been derived for the equilibrium state [3], the life expectancy depends only on the age-specific mortality $cm \cdot am_a$ which remains from 197o on the same in the standard runs as well as in the equilibrium runs discussed in the next section. In the print-outs the life expectancy at birth is denoted by LEB. Our values agree well with the ones computed and estimated by the United Nations [DY 71;2].

3.3. Equilibrium Runs via Fertility Change

In the following runs fertility is gradually reduced to a value for which the population will eventually attain equilibrium. Mortality is kept at the level of 197o.

The first problem consists in finding the fertility factor cf^e that leads to population equilibrium. For this purpose we determine as a first step the quasi stationary population limit which in reality is reached asymptotically only after a very long time. This limit is determined by the mortality factor cm^{197o} and the age-specific mortality am_a^{197o} which are taken from sections 3.1 and 3.2 for the case $t_M = 1$. In order to have a stationary population, the condition $Bab^t = Tot^t$ has to be satisfied. From this follows, because both the age-specific fertility (not yet known) and the age-specific mortality (given) are time constants, that for all times (see also [3])

$$P_a^t = P_a \qquad (a = 1, 2, \ldots, 86)$$

Inserting these conditions in the basic eqs. (1.7 - 1.17) the following relationships are obtained,

$$P_1 = Bab \cdot (1 - \frac{1}{2} \cdot cm \cdot am_{\frac{1}{2}}) \tag{3.1}$$

$$P_{a+1} = P_a \cdot (1 - cm \cdot am_a) \text{ ; } a = 1, \ldots, 84 \tag{3.2}$$

$$P_{86} = P_{85} \cdot (1 - cm \cdot am_{85}) \, / \, (cm \cdot am_{86}) \tag{3.3}$$

Equations (3.2) are applied recursively, until all age-groups P_a are expressed through Bab, cm, and am_a. Hence we obtain finally

$$P_a = Bab \cdot Prod\,(a)\;;a=1,2,\ldots,85$$

$$\text{with } Prod\,(1) = 1 - \frac{1}{2}\cdot cm \cdot am_{\frac{1}{2}}$$

$$\text{and } Prod\,(a) = Prod\,(a-1)\cdot\left[1 - cm\cdot am_{a-1}\right]$$

$$= \left(1-\frac{1}{2}cm\cdot am_{\frac{1}{2}}\right)\cdot\left[\prod_{n=1}^{a-1}\left(1-cm\cdot am_n\right)\right]$$

$$\text{for } a=2,3,\ldots,85$$

For P_{86} Eq. (3.5) is valid unchanged. With the abbreviation Prod (a) which depends only on the mortality factor cm and the age-specific mortality distribution am_a we can formulate the following three interesting sums:

1. $$Bab = \sum_{a=2}^{86} cf^e \cdot af_a \cdot P_a$$

Since we can safely assume that $af_a = 0$ for $a < 10$ and $a > 60$ years, the sum has to be extended only from a=10 to a=60. Division by Bab then leads to

$$1 = cf^e \cdot \sum_{a=10}^{60} af_a \cdot Prod\,(a)$$

or

$$1/cf^e = \left(1-\frac{1}{2}cm\cdot am_{\frac{1}{2}}\right)\cdot\sum_{a=10}^{60}\left[af_a\cdot\prod_{n=1}^{a-1}\left(1-cm\cdot am_n\right)\right] \qquad (3.4)$$

Thus we have found the desired equilibrium fertility factor cf^e for given values of cm, am_a and af_a.

2. $$LEB = \frac{Pop}{Bab} = \frac{1}{cbr^e} = \frac{1}{cdr^e} = \frac{Pop}{Tot}$$

$$\text{and } Pop = \sum_{a=1}^{86} P_a$$

This sum yields the mean life expectancy at birth LEB as well as the crude birth rate and crude death rate for the case of population equilibrium [3].
Inserting Eqs. (3.2) and (3.3) into the above relationships, we find

$$\mathrm{Pop} = \mathrm{Bab} \cdot \left[\left(\sum_{a=1}^{85} \mathrm{Prod}\,(a) \right) + \mathrm{Prod}\,(85) \cdot \left({}^{1}\!/_{\mathrm{cm}} - \mathrm{am}_{85} \right) / \mathrm{am}_{86} \right]$$

and after division by Bab:

$$\mathrm{LEB} = \frac{1}{\mathrm{cbr}^{e}} = \frac{1}{\mathrm{cdr}^{e}} = \left(1 - \frac{1}{2} \cdot \mathrm{cm} \cdot \mathrm{am}_{\frac{1}{2}} \right) \cdot \qquad (3.5)$$

$$\cdot \left[1 + \left\{ \sum_{a=2}^{85} \prod_{n=1}^{a-1} (1 - \mathrm{cm} \cdot \mathrm{am}_{n}) \right\} + \frac{{}^{1}\!/_{\mathrm{cm}} - \mathrm{am}_{85}}{\mathrm{am}_{86}} \cdot \prod_{n=1}^{84} (1 - \mathrm{cm} \cdot \mathrm{am}_{n}) \right]$$

It is noteworthy that this value for the mean life expectancy at birth for constant mortality holds also for the standard runs, not just for the equilibrium case.

3. The third summation serves only as computational check.

$$\mathrm{Bab} = \mathrm{Tot}$$

$$\mathrm{Bab} = \frac{1}{2} \mathrm{cm} \cdot \mathrm{am}_{\frac{1}{2}} \cdot \mathrm{Bab} + \mathrm{Bab} \cdot \sum_{a=1}^{85} \mathrm{cm} \cdot \mathrm{am}_{a} \cdot \mathrm{Prod}\,(a) + \mathrm{Bab} \cdot \mathrm{Prod}\,(85) \cdot [1 - \mathrm{cm} \cdot \mathrm{am}_{85}]$$

or

$$1 = \frac{1}{2} \mathrm{cm} \cdot \mathrm{am}_{\frac{1}{2}} + \sum_{a=1}^{84} \mathrm{cm} \cdot \mathrm{am}_{a} \cdot \mathrm{Prod}\,(a) + \mathrm{Prod}\,(85) \qquad (3.6)$$

This equation is identically satisfied for all 1o regions. The age-structure in the equilibrium state is depicted in Figs. 152 - 161. and it is solely determined by the age-specific mortality (s. Eqs. 3.1 to 3.3). The higher the development of a region, the smaller is its mortality and also the crude birth rate, and the more resembles the calculated age-structure a rectangle.

For the case of population equilibrium we have so far determined the age-structure and the magnitude of the fertility cf^e. Now, what is the final size of the equilibrium-population Pop^e?

The final population Pop^e is only defined when its initial value and age-structure is known at the time of the transition from cf^{1970} to cf^e, and, of course, when also the nature and the beginning of this transition period is given.

According to UN-recommendations [2] we use for the transition a polygon consisting of three straight lines (s. Fig. 192).

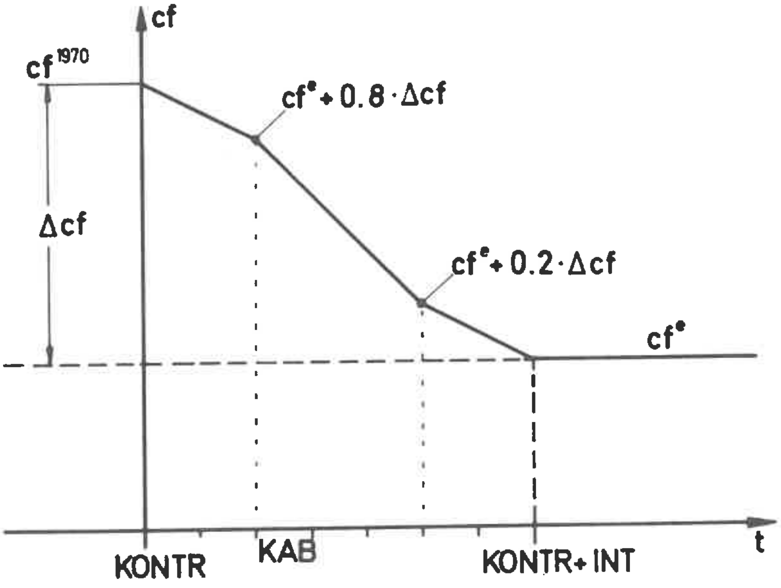


Fig. 192: Scheme for fertility transition period

Since cf^{197o} and cf^{e} are known, only two free parameters remain, KONTR and INT (s. Fig. 192). For the beginning of the equilibrium policy KONTR we used the years 1975, 1985 and 1995; for the length of the transition interval INT = 7 · KAB the spans of 0, 14, and 35 years. The calculations show that the shape of the transition curve (S-curve, or straight-line polygon) is hardly of any importance. Important is only the length of the transition-interval, and that the area below the transition-polygon amounts to about $1/2 \cdot (cf^{197o} + cf^{e}) \cdot INT$.

In Figs. 162 - 191 are depicted the age-structures in the case of equilibrium policy for the years 2ooo, 2o25, and 21oo. Here we employed 1975 for the parameter KONTR and 14 years for the parameter INT. The age-structures for the year 21oo are hardly different from ideal equilibrium states (Figs. 152 - 161). For the same parameters we have then provided numerical print-outs, employing 5-year steps. These tables contain the year t, the population Pop, the fertility factor cf, the crude birth rate cbr, the mortality factor cm, the crude death rate cdr as well as the accumulative sum of all babies and all deaths from 197o on. Following the row for 197o, in addition, a few data for the equilibrium state are also reported: first the life expectancy at birth LEB, the fertility factor cf^{e} leading to equilibrium, the crude birth rate cbr^{e} for equilibrium, the ratio of babies to deaths, and finally the ratio P_{86} / P_{85}.

The graphical results of equilibrium runs are represented in Figs. 193 - 27o. Each figure contains four curves, one of them always depicting the standard run for the sake of comparison. The three remaining curves show for runs of type 1 the differences due to the variation of the parameter KONTR, and for runs of type 2 the differences due to the variation of the parameter INT.

Below, the various types of runs are listed in systematic manner:

Type 1.1: INT = 0 ;
1.2: INT = 14 ;
1.3: INT = 35 ;
} KONTR = 1975/1985/1995/2200.

Type 2.1: KONTR = 1975 ;
2.2: KONTR = 1985 ;
2.3: KONTR = 1995 ;
} INT = 0/14/35/∞

The graphical representations of these runs are ordered accordingly; they include also aggregations of the regions 1 - 5, 6 - 1o, and 1 - 10. The standard-run curve is always the one with maximum slope from 2o5o on. The curves for INT = 0 and KONTR = 1975, respectively, are furthest apart from the standard run, and, conversely, those for KONTR = 1995 and INT = 35, respectively, are, as could be expected, nearest to the standard run.

In the numerical tables of listing 8 all equilibrium-type runs and the standard run are listed for all regions as well as for the whole world.

Listing 7 shows the influence of equilibrium policy, started in 1975 with INT = 14, especially on cbr, cdr, and on the summation of all births and deaths since 197o.

3.4 Runs with Mortality Changes due to Lack of Protein

The following computations were made for Region 9 (South East Asia). Analysis of possible future protein yield has shown that from 1970 until 2000 the protein output can probably be increased annually by an average of 1/2 % of the 1970 amount. After that a further increase is hardly possible. But in 1970 the per-capita consumption of protein was only 44 grams per day. With these two numbers one can calculate the amount of protein which Region 9 might produce.

Since population grows much faster than the protein yield, the average daily per-capita consumption must steadily decrease. But this decreases the resistance to disease, which in turn increases the probability of dying, particularly after a famine. Since famines result from fluctuations in a marginal food situation, they will strike with increasing frequency and intensity, affecting children worse than adults. Unfortunately nothing quantitative is known about the affect of protein deficiency on mortality rates by age group. Also, the distribution of protein consumption in the population is not known, e.g., what percentage of the total population gets 5 % more than average and how many get 5 % less than average. As long as lack of protein affects mortality nonlinearly, its distribution must be taken into account.

Because of the lack of knowledge we have on this problem, and because the effects on death rate are much more complex than described above, the following computations can only be useful as guidelines and might help in the search for more reliable indicators for nutrition effects on health. We have kept fertility unchanged, i.e., we have used the distributions from the standard runs, but two new functions of age have been introduced:

The function E(a) indicates the age-specific sensitivity to protein deficiency and is defined by

$$E(a) = (E_o - E_u) \cdot \exp\left(- \frac{a}{E_a}\right) + E_u \qquad (3.7)$$

Here E_o is the sensitivity of babies and E_u the sensitivity of older people. E_a is a time constant, indicating the number of years that pass until $E(a) - E_u$ drops to 37 % of $E_o - E_u$. As examples we have used $E_a = 5$, 10, and 20. E_o was taken to be 1, 1.5, and 2, while E_u took the values 0.5 and 0.25.

The second function indicates by what amount the mortality of an age group P_a^t is increased with given sensitivity E(a) and with a daily per-capita protein consumption X. We have defined this mortality multiplier MM [X, E(a)] in the following way:

$$MM\ (x,E) = \left[\frac{44 - x_o}{x(t-t_o) - x_o} - 1 \right] \cdot E + 1 \qquad (3.8)$$

Accordingly, the mortalities are now given by

$$\begin{aligned} am_a^t &= am_a^{1970} \cdot MM(X,\ E(a)) \\ \text{and} \quad cm^t &= cm^{1970} \end{aligned} \qquad (3.9)$$

Equation (3.8) is a hyperbola which has a vertical asymptote at X_0. In the following Figs. we have used $X_0 = 0, 5$, and 10. In Figs. 271 and 272 MM (X, E) is graphed as a function of X, with X_0 at 0 and 10. For E the values 0, 0.5, 1.0, 1.5, and 2.0 were used. t_0 stands for a time delay in the effect of protein deficiency. Usually t_0 is set equal to zero; only in Figs. 278 - 280 t_0 takes the values 0, 5, and 10 years. One can clearly observe an overshooting oscillation of population followed by a damping toward an equilibrium. The effect increases with increasing time delay. In the Figs. following Fig. 273 we have also included the daily per-capita protein values in grams; the lowest values belong to the highest populations and vice versa. Finally, some print-outs are shown in listing 9 which have the same output format as the equilibrium runs. The used parameters EO, EU, EA, XO and T_0 = Time Lag are shown in the titles of the number columns in five-year-steps.

From both graphs and lists one can see that these calculations due to lack of protein will also lead to equilibrium, but by a much more cruel way as indicated by comparison of number of deaths since 1970.

3.5 Change of Mortality due to Lack of Protein and Fertility Change for Population Equilibrium

In this last group of computer runs we combine the change in age-specific mortality due to lack of protein as in Sec. 3.4 with the change in the fertility-factor cf^t as in Sec. 3.3 such that this assumes the value cf^e which would eventually lead to population equilibrium for constant mortality cm^{1970}. In Fig. 281 - 287 we have plotted the standard run with $cf^t = cf^{1970} = cf^{1969}$, $cm^t = cm^{1970} = cm^{1969}$; $af_a^t = af_a^{1950}$, and $am_a^t = am_a^{1950}$, in addition to three other curves. Curve (1) represents the equilibrium run already known from Sec.3.3 with KONTR = 1975, 1985 and 1995 respectively, and INT = 14, while curve (2) depicts the run in which the lack of protein is considered with $x_o = t_o = 0$. Curve (3) represents the new results where fertility as well as mortality are varied. It is not surprising that curve (3) is below the three other curves. However, it is noteworthy that while for different sensitivities to lack of protein considerable differences in population growth can be observed (s. curves (2) in Figs. 281 - 283), these differences become rather small under the impact of an deliberate equilibrium policy (s. curves (3) in Figs. 281 - 283). Figures 281 - 287 furthermore reveal the necessity to start with the equilibrium policy as early as possible, for then the combination of mortality change due to lack of protein and of equilibrium fertility leads to a population curve (3) which is only slightly below the equilibrium curve (1) (s. Figs. 284 - 285). This demonstrates that then we shall have only a very slight increase in mortality due to lack of protein. However, when the equilibrium policy is initiated only in 1995, a great gap develops between curves (1) and (3) as shown in Figs. 286 - 287. These figures give a vivid impression how despite a - though belated - equilibrium policy the number of deaths from hunger and increased subceptibility to sickness due to lack of food and protein rises enormously compared with an equilibrium policy that is initiated 20 years earlier in 1975.

In order to facilitate an overall view of the results and their interpretation, numerical print-outs in five-year steps for all these runs are given in listing 10 in the same order as the corresponding figures. We used the same format as in Secs. 3.3 and 3.4. The last two columns give the accumulated sums of all babies and deaths since 1970. In the fourth and sixth column crude birth rate and crude death rate, respectively, are listed.

A comparison of the four types of computer runs beginning with the standard run and ending with the combined run for equilibrium fertility and mortality-change due to lack of protein, particularly with respect to the four columns mentioned above, demonstrates convincingly the urgency of drastic population policy measures in order not to let nature take its cruel course.

List of computer print-outs

Listing 1: UN Estimates of midyear population 1950 - 1970,
programm and data by country.

Listing 2: Crude birth rate and crude death rate 1950 - 1970,
program and data by country.

Listing 3: Initial age distribution in 1950 or earliest available
year, program and data by country.

Listing 4: Age distributions for mothers at birth, deaths and
people alive, program and data by country for latest
available year.

Listing 5: Program of population model (here for equil. type 2.3).

Listing 6: Normal runs 1950 - 2030, one-year steps - for 10 Regions.

Listing 7: Equilibrium run 1950 - 2100, five-year steps - for 10 Regions.
KONTR = 1975; INT = 14.

Listing 8: Population growth for all 10 Regions with summation -
five-year steps 1950 - 2100.
Normal run and all equilibrium runs.

Listing 9: Lack-of-protein: print-outs in five-year steps 1950 - 2100
for parameters used in Fig. 273 - 280.

Listing 10: Different strategies: print-outs in five-year steps 1950 - 2100
for parameters used in Fig. 281 - 287.

Listing of Figures:

Literature

[1] Demographic Yearbooks 1966 - 1971.
Statistical Office of the United Nations,
Department of Economic and Social Affairs
New York (abbr: DY 66 - 71).

[2] World Population Prospects as Assessed in 1968.
United Nations, Department of Economic and Social
Affairs, New York, 1973.

[3] N. Keyfitz: Introduction to the mathematics
of population. Reading, Mass., 1968.

[4] R. Sauer and I. Szabó: Mathematische Hilfsmittel
des Ingenieurs, Teil III. Berlin-Heidelberg-
New York, 1968.

Listing 5

Program of population model (here for equil. type 2.3).

```
∆JOB  5,15     MA   4126 OEHMEN,POPULATION.
∆ASSIGN S DF1Y,BI DF1Y,BO DF1Y,SI CR,LO LP,X1 DF1Y.
∆FTN SI,BO,LO.
•               DIMENSION G50[21],GP[21],GF[21],GM[21],POP[21],G[21]
•               DIMENSION XX[151],YY[151]
•               DIMENSION WELT [151,4], GR[31,4,11]
•               DIMENSION WE[151,4]
•               DIMENSION NAME[10],MODE[10]
•               DIMENSION AM[0/86]
•               DIMENSION FERT[21],AMORT[21],CF[20],CM[20]
•               DIMENSION AP[86],AP1[86],        AM1[86],AF[86],AF1[86]
•               DIMENSION KOV[4],KAV[4]
•     X          DIMENSION XP[151]
•               COMMON KAB,KONTR,NAME,MODE
•               COMMON YY
•               EQUIVALENCE [AF[1],AF1[1]]
•     X          EQUIVALENCE [WE[1],WELT[1]]
•               CALL PLOTTFAC[5./6.]
•               CALL XYOVZR [0.65,1.5]
•     X          KTOT = 0
•     X          EO = 0.0
•     X          EU = 0.0
•               DO 666 I=1,151
•               DO 666 J=1,4
•     666       WE[I,J] = 0.0
•               DO 671 I=1,31
•               DO 671 J=1,4
•               DO 671 N=1,11
•     671       GR[I,J,N] = 0.0
•               READ 104,MODE
•               DO 400 IREG=1,6,5
•               IEND = IREG+4
•               DO 670 I=1,151
•               DO 670 J=1,4
•     670       WELT[I,J] = 0.0
•               DO 200 KREG=IREG,IEND
•     X          READ 120,EO,EU,EA,XO
•               READ 107,LY,LZ
•               YC = LY*1.E6
•               READ 104,NAME
•               READ 109,POP
•               PRINT 110,NAME,MODE
•     101       FORMAT [8F14.3/8F14.3/5F14.3,3I8]
•     102       FORMAT [8F10.5]
•     103       FORMAT [F10.5]
•     104       FORMAT [10A4]
•     105       FORMAT [21F]
•     106       FORMAT [20F]
•     107       FORMAT [4I8]
•     108       FORMAT[$  YEAR      TOTAL POP.    FERTILITY    BAB / POP    MORTAL
•              ITY    TOT / POP        SUM BAB 70        SUM TOT 70$/]
•     109       FORMAT [19X,6F10.5]
•     110       FORMAT [1H1,20A4/]
•     112       FORMAT [1X,F11.2,$ = ACTUAL POP$,F11.2,$ = CALCULATED IMMIGRANTS$
•     113       FORMAT [$FERTILITY,MORTALITY,CB,CBR,CD,CDR,$,4F12.5]
•     114       FORMAT [41X,19HSTART OF CONTROL = ,I4,5X,20HTRANSITION PERIOD = ,
•              I7/]
•     X116        FORMAT [41X,5HEO = ,F5.2,5X,5HEU = ,F5.2,5X,5HEA = ,F5.2,5X,5HX(
•     X        A= ,F5.2,5X,11HTIME LAG = ,I3/]
```

```
120     FØRMAT [4F10.5]
C     INITIAL DATA,DATA FØR FERTILITY AND MØRTALITY
        K = 1950
        READ 109,G50
        PRINT 101,G50
        CALL SPLINE [G50,AP1,1,20]
        DØ 140 L=2,20
140     GF[L] = 0.0
        READ 109,P,[GF[I],I=5,13]
        READ 109,GM
        READ 109,[AMØRT[I],I=2,21],P
        READ 109, [FERT[I],I=4,21]
        DØ 141 L=1,3
141     FERT[L] = FERT[4]
        AMØRT[1] = AMØRT[2]
        DØ 143 L=2,21
        IF [AMØRT[L]] 146,146,147
146     AMØRT[L] = AMØRT[L-1]
147     CØNTINUE
        IF [FERT[L]] 143,142,143
142     FERT[L] = FERT[L-1]
143     CØNTINUE
        DØ 145 L=1,21
        AMØRT[L] = AMØRT[L] * .001
        FERT[L] = FERT[L]*.001
145     CØNTINUE
        GM[2] = GM[2]*.2
        GM[3] = GM[3]*.8
        GM[20] = GM[20]*.2
        CALL SPLINE [GM,AM1,2,20]
        N = 4
152     N=N+1
        IF [GF[N]] 152,152,153
153     N1 = N-1
        N = 14
154     N=N-1
        IF [GF[N]] 154,154,155
155     N2 = N
        GF[1] = 0.1
        CALL SPLINE [GF,AF1,N1,N2]
        PRINT 101, GM
        PRINT 101, GF,N1,N2
        PRINT 102,FERT
        PRINT 102,AMØRT
        DØ 160 L=1,86
160     AP1[L] = AP1[L]*PØP[1] *1.E6
        DØ 170    L=1,85
170     AF1[L] = [AF1[L]+AF1[L+1]]*.5
        DØ 300 LL=1,4
C     INPUT PARAMETERS FØR 4 CURVES
        GØ TØ [181,182,183,184],LL
181     CØNTINUE
        KØNTR = 1975
        KAB = 0
        GØ TØ 185
182     CØNTINUE
        KAB = 2
        LAUS = 3
        KØNTR = 1985
        GØ TØ 185
```

```
183   CONTINUE
      LAUB = 5
      KAB = 5
      GO TO 185
184   CONTINUE
      LAUB = 10
      KONTR = 2200
      KAB = 999999
185   CONTINUE
      KONTR = 1995
      LAUB = 1
      KAV[LL] = KAB*7
      KOV[LL] = KONTR
      INT = 7*KAB
      PRINT 110,NAME,MODE
      PRINT 114,KONTR,INT
X      PRINT 116,EO,EU,EA,XO,KTOT
      PRINT 108
      SBAB = 0.
      STOT = 0.
      AM[0] = AM1[1]
      DO 191 L=1,86
      AM[L] = [AM1[L]+AM1[L+1]]*.5
      AF[L] = AF1[L]
      AP[L] = AP1[L]
191   CONTINUE
      AM[86] = AM1[86]
C   MODEL
      DO 100 K=1950,2100
      KK = K-1949
      GT = 0.
      TOT = 0.
      BAB = 0.
      DO 5 L=1,86
      TOT = TOT + AP[L]*AM[L]
5     BAB = BAB+AP[L]*AF[L]
      DO 7 L=1,18
7     G[L] = 0.
      DO 8 L=1,86
      L2 = [L+4]/5
8     G[L2] = G[L2]+AP[L]
      DO 9 L=1,18
9     GT = GT+G[L]
C    MIGRATION
      IF [K-1970] 90,90,97
90    AMIG = POP[KK]*100.-GT*0.0001
      IF [AMIG] AMIG = AMIG-1.
      AMIG = AMIG+.5
      MIG = AMIG
      DO 95 L=2,51
95    AP[L] = AP[L]+MIG*200.
      AMIG = MIG*.01
      GT = GT + MIG*1.E4
97    CONTINUE
      IF [MOD[K,5]] 151,150,151
150   PRINT 151,K,GT,CB,CBR,CD,CDR,SBAB,STOT
151   FORMAT [2X,I4,3X,F12.0,4[3X,F10.7],2[5X,F12.0]]
X      XP[KK] = 44.
      IF [K-1970] 10,30,50
C   MORTALITY,FERTILITY TILL 1969
```

```
10     CONTINUE
       BB = [FERT[KK]*POP[KK]+FERT[KK+1]*POP[KK+1]]*.5E6
       TT = [AMORT[KK]*POP[KK]+AMORT[KK+1]*POP[KK+1]]*.5E6
       IF [AMORT[KK+1]] 11,11,12
11      TT = [POP[KK]-POP[KK+1]]*1.E6 + BB
12     CONTINUE
       TOT = TOT+BB*.5*AM[0]
       CB = BB/BAB
       CD = TT/TOT
       CF[KK] = CB
       CM[KK] = CD
       GO TO 80
C    CALCULATION OF EQUILIBRIUM STATE AND MORTALITY MULTIPLIER FOR LACK
C    PROTEIN.
30     CONTINUE
       CB = 0.
       CD = 0.
       DO 35 L=1,LAUS
       L1 = KK-L
       CB = CB+CF[L1]
35     CD = CD+CM[L1]
       CB = CB/LAUS
       CD = CD/LAUS
       PG = [1./CD-AM[85]]/AM[86]
       P = 1.-.5*CD*AM[0]
       S1 = P
       S2 = AM[1]*CD*P +1. -P
       S3 = 0.
       DO 40 L=2,85
       P = P*[1.-AM[L-1]*CD]
       S1 = S1+P
       S3 = S3 + AF[L]*P
40     S2 = S2+AM[L]*CD*P
       A85 = [1.-[1.-S2]/P]/CD
       P = P*[1.-AM[85]*CD]
       S1 = S1+P/AM[86]/CD
       S2 = S2+P
       FY = 1./S1
       FX = 1./S3
       PRINT 41,S1,FX,FY,S2,PG
41     FORMAT [$LEB,CFSTAT,CBRSTAT;TOT/BAB,P86/P85   $,5[3X,F12.7]]
       F = CB
       FA = F-FX
       PR = 44.-GT
       PRD = PR*0.005
       GO TO 80
C    MORTALITY,FERTILITY LATER THAN 1970
50     CONTINUE
       IF [K-2000] 230,229,235
229    CONTINUE
230    PR = PR+PRD
235    CONTINUE
X       XP[KK] = PR/GT
X       DO 240   L=1,85
X       E = [E0-EU]*EXP[-L/EA] + EU
X       ZM = [[44.-X0]/[XP[KK-KTOT]-X0] -1.] * E + 1.
X240    AM[L] = [AM1[L]+AM1[L+1]]*ZM*.5
X       ZM = [[44.-X0]/[XP[KK-KTOT]-X0] -1.] * E0+ 1.
X       AM[0] = AM1[1]*ZM
X       ZM = [[44.-X0]/[XP[KK-KTOT]-X0] -1.] * EU+ 1.
```

```
X        AM[86] = AM1[86]*ZM
        IF [K-KONTR] 320,307,307
 307    IF [KAB] 308,308,309
 308    F = FX
        GO TO 320
 309    CONTINUE
        FK = 0.1/KAB
        IF [K-KONTR-7*KAB] 310,320,320
 310    IF [K-KONTR-5*KAB] 311,318,318
 311    IF [K-KONTR-2*KAB] 318,315,315
 315    FK = FK*2.
 318    F = F-FA*FK
 320    CONTINUE
        CB = F
 80     CONTINUE
        IF [1.-CD*AM[86]] GO TO 350
C     CALCULATION OF POPULATION AT T=T+1
        BAB = BAB*CB
        TOT = BAB-.5*AM[0]*CD
        DO 75 L=1,86
 75     TOT = TOT + AP[L]*AM[L]*CD
        YY[KK] = GT/YC*18. - 9.
        IF [YY[KK]-9.] 82,82,81
 81     YY[KK] = 9.
 82     XX[KK] = [KK-76]*9./75.
        IF [MOD[K,5]] 84,83,84
 83     GR[KK/5+1,LL,KREG] = 0.000001*GT
 84     WELT[KK,LL] = WELT[KK,LL]+GT
        AP[86] = AP[85]*[1.-CD*AM[85]] + AP[86]*[1.-CD*AM[86]]
        DO 85 L=85,2,-1
        L1 = L-1
 85     AP[L] = AP[L1]*[1.-CD*AM[L1]]
        AP[1] = BAB*[1.-.5*CD*AM[0]]
        IF [K-1970] 87,86,86
 86     CONTINUE
        SBAB = SBAB+BAB
        STOT = STOT+TOT
 87     CONTINUE
        GT = GT+.5*BAB-.5*TOT
        CBR = BAB/GT
        CDR = TOT/GT
 100    CONTINUE
        CALL KURVE [151,XX,YY]
 300    CONTINUE
        CALL FRAME [XX,YY,LY,LZ]
 200    CONTINUE
X        CALL EXIT
        READ 107,LY,LZ
        READ 104,NAME
        YC = LY*1.E6
        DO 660 J=1,4
        DO 655 I=1,151
        WE[I,J] = WELT[I,J] + WE[I,J]
        YY[I] = WELT[I,J]/YC*18. - 9.
        IF [YY[I]-9.] 655,655,652
 652    YY[I] = 9.
 655    CONTINUE
        CALL KURVE [151,XX,YY]
 660    CONTINUE
        CALL FRAME [XX,YY,LY,LZ]
```

```
  400   CONTINUE
        DO 680 N=1,4
        DO 680 I=1,31
        DO 680 J=1,10
  680   GR[I,N,11] = GR[I,N,J] + GR[I,N,11]
        DO 685 LL=1,4
        PRINT 682,KOV[LL],KAV[LL]
  682   FORMAT [1H1,$POPULATION OF ALL REGIONS FOR KONTR = $,I4,$  AND INT
       T = $,I6//1X,4HYEAR,5X,4HN A ,6X,4HW EU,7X,3HJAP,4X,7HE EU,SU,5X,5H
       HR DEV,5X,4HL A ,6X,4HM AF,6X,4HM EA,5X,5HS E A,5X,5HCHINA,5X,5HTO
       TAL,/]
        DO 685 I=1,31
        K = 5*I + 1945
        PRINT 683,K,[GR[I,LL,J],J=1,11]
  683   FORMAT [1X,I4,11[2X,F8.2]]
  685   CONTINUE
        READ 107,LY,LZ
        READ 104,NAME
        YC = LY*1.E6
        DO 700 J=1,4
        DO 695 I=1,151
        YY[I] = WE[I,J]/YC*18.-9.
        IF [YY[I]-9.] 695,695,694
  694   YY[I] = 9.
  695   CONTINUE
        CALL KURVE [151,XX,YY]
  700   CONTINUE
        CALL FRAME [XX,YY,LY,LZ]
        CALL EXIT
  350   TYPE 111,NAME,CD,AM[86]
  111   FORMAT [$UNREASONABLE RESULTS FOR $,10A4,5HCD = ,F8.3,3X,8HAM[86]
       A= ,F8.3]
        GO TO 200
        END


OMMON ALLOCATION

  77777 KAB          77776 KONTR         77764 NAME          77752 MODE
  77274 YY

ROGRAM ALLOCATION

  00017 AF           00017 AF1           00273 G50           00345 GP
  00417 GF           00471 GM            00543 POP           00615 G
  00667 XX           01345 WELT          03635 GR            11105 WE
  13375 AM           13653 FERT          13725 AMORT         13777 CF
  14047 CM           14117 AP            14373 AP1           14647 AM1
  15123 KOV          15127 KAV           15133 I             15134 J
  15135 N            15136 IREG          15137 IEND          15140 KREG
  15141 LY           15142 LZ            15143 K             15144 L
  15145 N1           15146 N2            15147 LL            15150 LAUS
  15151 INT          15152 KK            15153 L2            15154 MIG
  15155 L1           15156 YC            15160 P             15162 SUAB
  15164 STOT         15166 GT            15170 TOT           15172 BAB
  15174 AMIG         15176 CB            15200 COR           15202 CD
  15204 CUR          15206 BB            15210 TT            15212 PG
  15214 S1           15216 S2            15220 S3            15222 ABS
  15224 FY           15226 FX            15230 F             15232 FA
  15234 PK           15236 PRD           15240 FK
```

```
SUBPROGRAMS REQUIRED

  PLOTTFAC  XYBVZR    SPLINE    MOD       KURVE     FRAME
  EXIT
```

```
      SUBROUTINE FRAME [ X,YY,LY,LZ]
      DIMENSION  X[151],YY[151]
      DIMENSION XX[5]
      DIMENSION NAME[10],MODE[10]
      COMMON KAB,KONTR,NAME,MODE
      DO 640 LL=1,151,50
      K=LL+1949
      XPOS =  X[LL]-0.6
      CALL XYBCD [XPOS,-9.2,0.3,0.3,0,0]
      PUNCH 631,K
631   FORMAT [2X,1H\/I4]
      XX[1] =  X[LL]
      XX[2] =  X[LL]
      YY[1] = +9.
      YY[2] = -9.
      CALL KURVE [2,XX,YY]
640   CONTINUE
      CALL XYBCD [6.0,-9.5,0.3,0.3,1,4HYEAR]
      YA = 18./LZ
      YB = -9.
      CALL XYBCD [-10.0,YB-0.15,0.3,0.3,1,4HO    ]
      DO 650 L=1,LZ
      LL = LY/LZ*L
      YB = YB+YA
      YY[1] = YB
      YY[2] = YB
      XX[1] = -9.
      XX[2] = 9.
      CALL KURVE [2,XX,YY]
      CALL XYBCD [-10.0,YB-0.15,0.3,0.3,0,0]
      IF [LY - 999] 641,641,646
641   PUNCH 642,LL
642   FORMAT [I3]
      INT = 6
      GO TO 650
646   YL = LL*0.001
      INT = 9
      IF [9999-LY] GO TO 670
      PUNCH 647,YL
647   FORMAT [F3.1]
650   CONTINUE
      CALL XYBCD [-10.0,7.7,0.3,0.3,1,4HPOP ]
      CALL XYBCD [-10.0,6.7,0.3,0.3,1,4H10  ]
      CALL XYBCD [-9.35,6.85,.27,.27,0,0]
      PUNCH 632,INT
632   FORMAT [I1]
      INT = 7*KAB
      CALL XYBCD [-8.8,8.0,.27,.27,0,0]
      PUNCH 633
      PUNCH 634,NAME,MODE
      IF [KAB-10] 610,620,620
610   CONTINUE
      PUNCH 636,INT
      GO TO 625
620   CONTINUE
      PUNCH 638,KONTR
625   CONTINUE
633   FORMAT [$POPULATION GROWTH FOR$]
634   FORMAT [10A4]
```

```
*     60  636    FØRMAT [$INT = $,I2]
*     61  638    FØRMAT [$ KØNTR = $,I4]
*     62         XX[1] = -9.
*     63         XX[2] = -9.
*     64         XX[3] = 9.
*     65         XX[4] = 9.
*     66         XX[5] = -9.
*     67         YY[1] = 9.
*     68         YY[2] = -9.
*     69         YY[3] = -9.
*     70         YY[4] = 9.
*     71         YY[5] = 9.
*     72         CALL KURVE [5,XX,YY]
*     73         PAUSE 2
*     74         CALL PLØTTFAC[0.]
*     75         IF [SENSE SWITCH 3] CALL PLØTTFAC[5./6.]
*     76         RETURN
*     77  670    PUNCH 671,YL
*     78  671    FØRMAT [F3.0]
*     79         GØ TØ 650
*     80         END

CØMMØN ALLØCATIØN

  77777 KAB        77776 KØNTR      77764 NAME       77752 MØDE


PRØGRAM ALLØCATIØN

  DUMMY X          DUMMY YY         00017 XX         00031 LL
  00032 K          DUMMY LZ         00033 L          DUMMY LY
  00034 INT        00035 FRAME      00037 XPØS       00041 YA
  00043 YB         00045 YL

SUBPRØGRAMS REQUIRED

  XYBCD      KURVE      PLØTTFAC
```

```
*        SUBROUTINE SPLINE [G,AG,N1,N2]
*        DIMENSION G[21],AG[86]
*        DIMENSION NAME[10],MODE[10]
*        DIMENSION B[20],C[20];D[20],XX[20],YY[20]
*        COMMON KAB,KONTR,NAME,MODE
*        COMMON B,C,D,XX,YY
*        DO 10 L=3,20
*   10   XX[L] = 5*L-10
*        XX[1] = 0.
*        XX[2] = 1.
*        Y1 = G[1]
*        YY[1] = Y1
*        DO 20 L=2,20
*   20   YY[L] = G[L]+YY[L-1]
*        G1 = YY[20]-YY[1]
*        Y2 = .5*G1 + Y1
*        G[21] = G[1] - G1
*        IF [N1-2] 24,21,22
*   21   YY[20] = YY[20] + 4.*G[20]
*        GO TO 24
*   22   DO 23 L=N1,N2
*        EAG = YY[L]/Y2-1.
*        YY[L] =-[EAG+1.] / [EAG-1.]
*   23   YY[L] = ALOG[YY[L]]
*   24   CONTINUE
*        CALL SPLIKO [B,C,D,XX,YY,N1,N2]
*        L2 = 2
*        L3 = 86
*        IF [N1-2] 30,30,25
*   25   L2 = N1*5 - 9
*   30   IF [N2-20] 35,40,40
*   35   L3 = N2*5 - 9
*   40   DO 50 L=L3,86
*   50   AG[L] = G1+Y1-G[20]
*        DO 55 L=1,L2
*   55   AG[L] = YY[1]
*        DO 70 L=L2,L3-1
*        L1 = L+9
*        IF [L-5] 60,60,65
*   60   L1 = L1-1
*   65   I=L1/5
*        Q = L1-I*5
*        EAG = [[D[I]*Q+C[I]]*Q+B[I]]*Q+YY[I]
*        IF [N1-2] 70,70,66
*   66   EAG = EXP[EAG]
*        EAG = [EAG-1.] / [EAG+1.]
*        EAG = [EAG+1.]*Y2
*   70   AG[L] = EAG
*        DO 80 L=1,85
*        AG[L] = [AG[L+1]-AG[L]]/G1
*        IF [AG[L]] AG[L] = 0.0
*   80   CONTINUE
*        AG[86] = G[20]/G1
*        RETURN
*        END
```

COMMON ALLOCATION

```
  77777 KAB          77776 KONTR        77764 NAME         77752 MODE
  77702 B            77632 C            77562 D            77512 XX
  77442 YY

PROGRAM ALLOCATION

  DUMMY G            DUMMY AG           00015 L            DUMMY N1
  DUMMY N2           00016 L2           00017 L3           00020 L1
  00021 I            00022 SPLINE       00024 Y1           00026 G1
  00030 Y2           00032 EAG          00034 Q

SUBPROGRAMS REQUIRED

  ALOG      SPLIKO    EXP
```

```
*        SUBROUTINE SPLIKO [B,C,D,X,F,N1,N2]
*        DIMENSION B[20],C[20],D[20],X[20],F[20]
*        M1 = N1 + 1
*        M2 = N2 - 1
*        S=0
*        DO 10 I=N1,M2
*        D[I] = X[I+1] - X[I]
*        R = [F[I+1]-F[I]] / D[I]
*        C[I] = R-S
*   10   S = R
*        S = 0
*        R = 0
*        C[N1] = 0
*        C[N2] = 0
*        DO 20 I=M1,M2
*        C[I] = C[I] + R*C[I-1]
*        B[I] = [X[I-1]-X[I+1]] * 2. - R*S
*        S = D[I]
*   20   R = S/B[I]
*        DO 30 I=M2,M1,-1
*   30   C[I] = [D[I]*C[I+1] - C[I]] / B[I]
*        DO 40 I=N1,M2
*        S = D[I]
*        R = C[I+1] - C[I]
*        D[I] = R/S
*        C[I] = C[I] * 3.
*        B[I] = [F[I+1]-F[I]] / S - [C[I]+R] * S
*   40   CONTINUE
*        RETURN
*        END

PROGRAM ALLOCATION

  DUMMY B        DUMMY C        DUMMY D        DUMMY X
  DUMMY F        00024 M1       DUMMY N1       00025 M2
  DUMMY N2       00026 I        00027 SPLIKO   00031 S
  00033 R
```

```
      SUBROUTINE AGED [AP,K,XMA]
      DIMENSION XX[173],YY[173],AP[86],NAME[10],MODE[10]
      COMMON KAB,KONTR,NAME,MODE
      GT = 0.
      S2 = 0.
      DO 355 L=1,86
      IF [S2-AP[L]] S2=AP[L]
  355 GT = GT+AP[L]
      L2 = S2*100./GT + 1.
      S2 = L2
      PAUSE 1
      XX[1] = -9.
      XX[2] = +9.
      YY[1] = -9.
      YY[2] = -9.
      CALL KURVE [2,XX,YY]
      XX[1] = 0.
      XX[2] = 0.
      YY[1] = -9.
      YY[2] = +9.
      CALL KURVE [2,XX,YY]
      CALL XYBCD [-2,8.5,0.3,0.3,1,4HAGE ]
      CALL XYBCD [-9.0,7.0,0.3,0.3,0,0]
      PUNCH 361,K
  361 FORMAT [$AGE DISTRIBUTION$/$IN PERCENT FOR$,I5]
      PUNCH 363,NAME,MODE
  363 FORMAT [5A4,20X,5A4]
      L2 = 8.0/XMA
      DO 365 L=-1,1,2
      DO 365 L1 = 1,L2
      X1 = XMA*L1*L-0.3
      CALL XYBCD [X1,-9.2,0.3,0.3,0,0]
      PUNCH 362, L1
  362 FORMAT [2H \/I2]
  365 CONTINUE
      XX[173] = 0.
      YY[1] = -9.
      DO 375 L=1,172
      L1 = [L+1]/2
      XX[L] = AP[L1]/GT*100.*XMA
  375 YY[L+1] = L1*0.2-9.
      CALL KURVE [173,XX,YY]
      DO 385  L=1,173
  385 XX[L] = -XX[L]
      CALL KURVE [173,XX,YY]
      DO 370 L=20,172,20
      XX[1] = XX[L]
      XX[2] =-XX[1]
      YY[1] = YY[L]
      YY[2] = YY[1]
  370 CALL KURVE [2,XX,YY]
      IF [SENSE SWITCH 2] 381,384
  381 DO 382 L=1,86
  382 XX[L] = AP[L]/GT*100.
      PRINT 361,K
      PRINT 383,[XX[L],L=1,86]
  383 FORMAT [11[8[3X,F8.5]/]]
  384 CONTINUE
      DO 388 L=10,86,10
```

```
*              S2 * L*0,2-9.4
*              CALL XYBCD [-0.1,S2,0.3,0.3,0,0]
*              PUNCH 387,L
*         387  FORMAT [1H ,I2]
*        388   CONTINUE
*              CALL XYBCD [8.5,-9.4,0.2,0.2,0,0]
*              PUNCH 330
*        330   FORMAT [1H0/2H 0]
*              CALL XYBCD [8.03,-9.7,0.47,0.5,1,4H /   ]
*              RETURN
*              END

COMMON ALLOCATION

  77777 KAB          77776 KONTR        77764 NAME         77752 MODE

PROGRAM ALLOCATION

  00012 XX           00544 YY           DUMMY AP           01276 L
  01277 L2           DUMMY K            01300 L1           01301 AGED
  01303 GT           01305 S2           DUMMY XMA          01307 X1

SUBPROGRAMS REQUIRED

  KURVE      XYBCD
```

Fig. 65

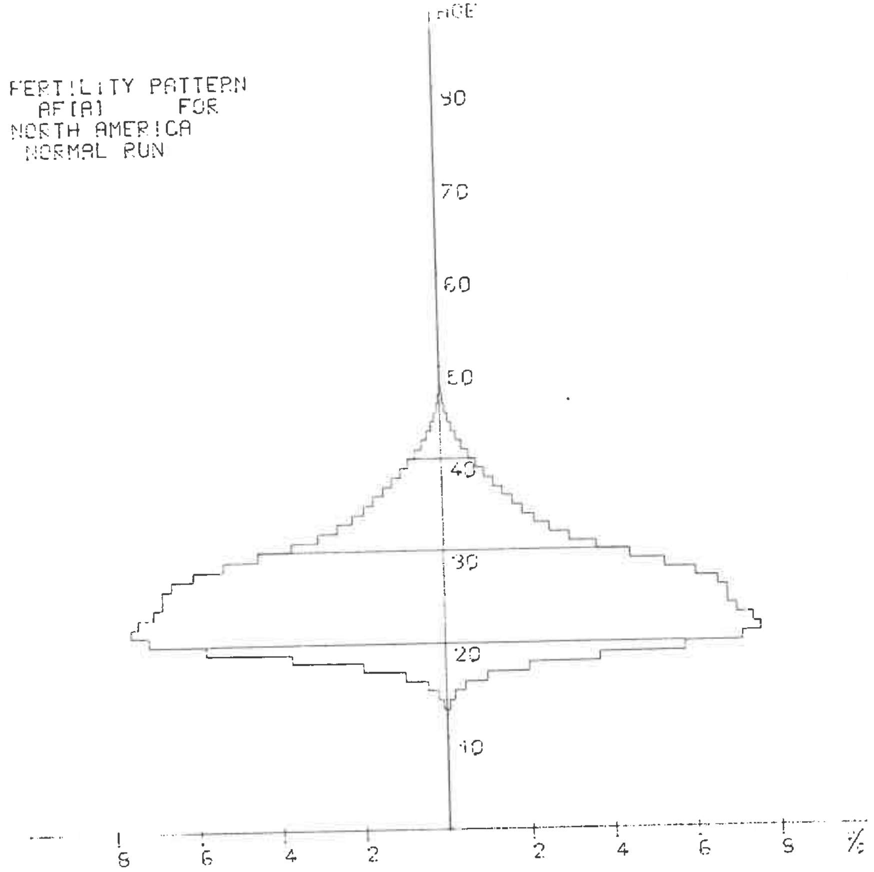

FERTILITY PATTERN
AF(A) FOR
NORTH AMERICA
NORMAL RUN
AGE
80
70
60
50
40
30
20
10
8
6
4
2
2
4
6
8
%

Fig. 66

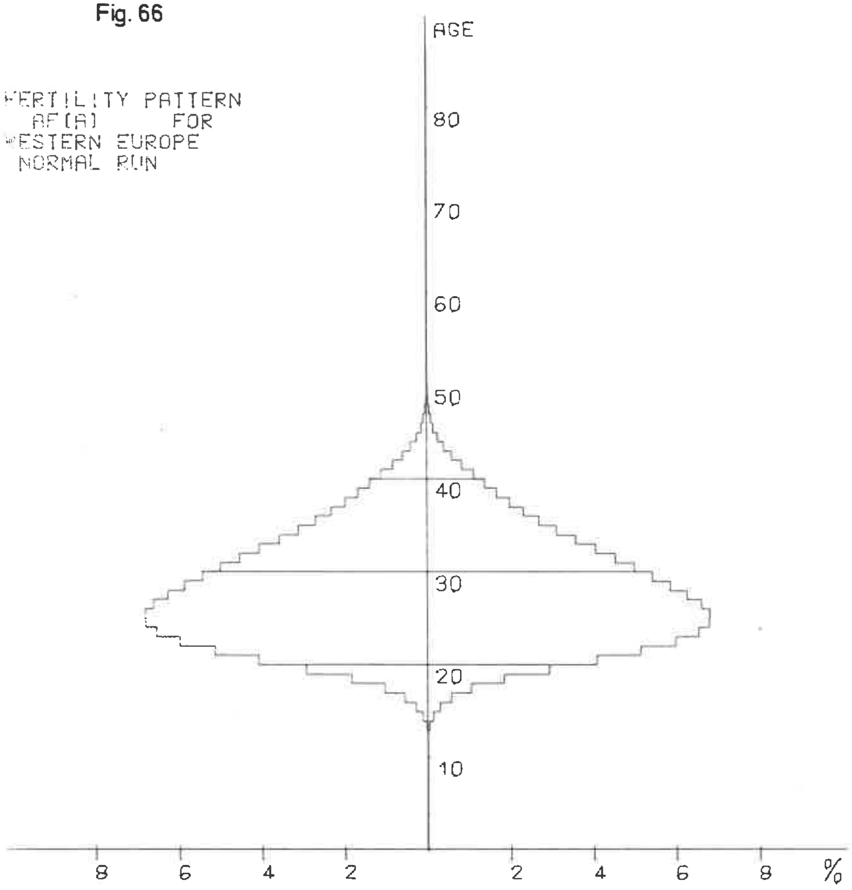

FERTILITY PATTERN
AF(A) FOR
WESTERN EUROPE
NORMAL RUN
AGE
80
70
60
50
40
30
20
10
8
6
4
2
2
4
6
8
%

Fig. 67

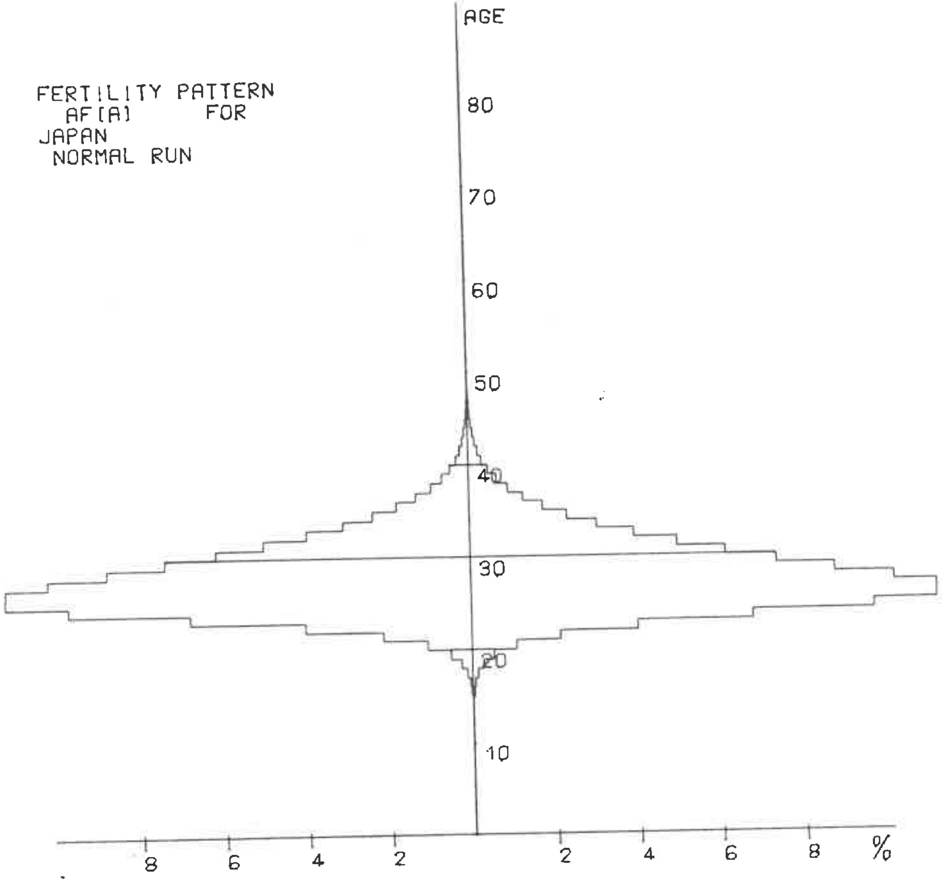
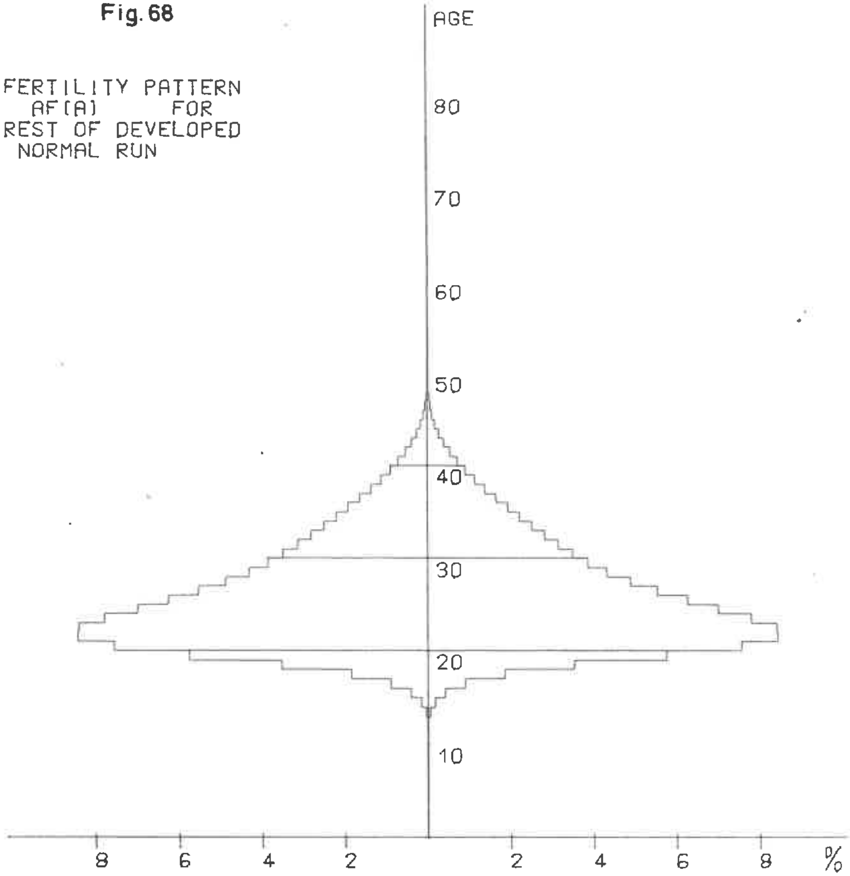

FERTILITY PATTERN
AF[A] FOR
JAPAN
NORMAL RUN
AGE
80
70
60
50
40
30
20
10
8
6
4
2
2
4
6
8
%

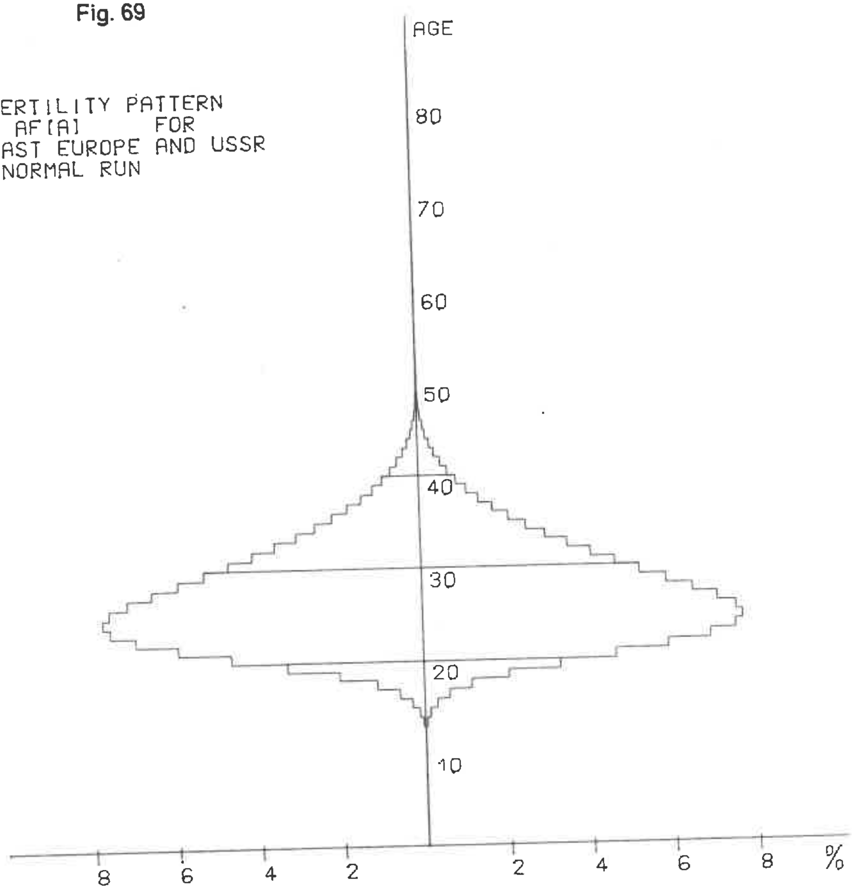
Fig. 68



FERTILITY PATTERN
AF(A) FOR
REST OF DEVELOPED
NORMAL RUN

Fig. 69

FERTILITY PATTERN
AF[A] FOR
EAST EUROPE AND USSR
NORMAL RUN



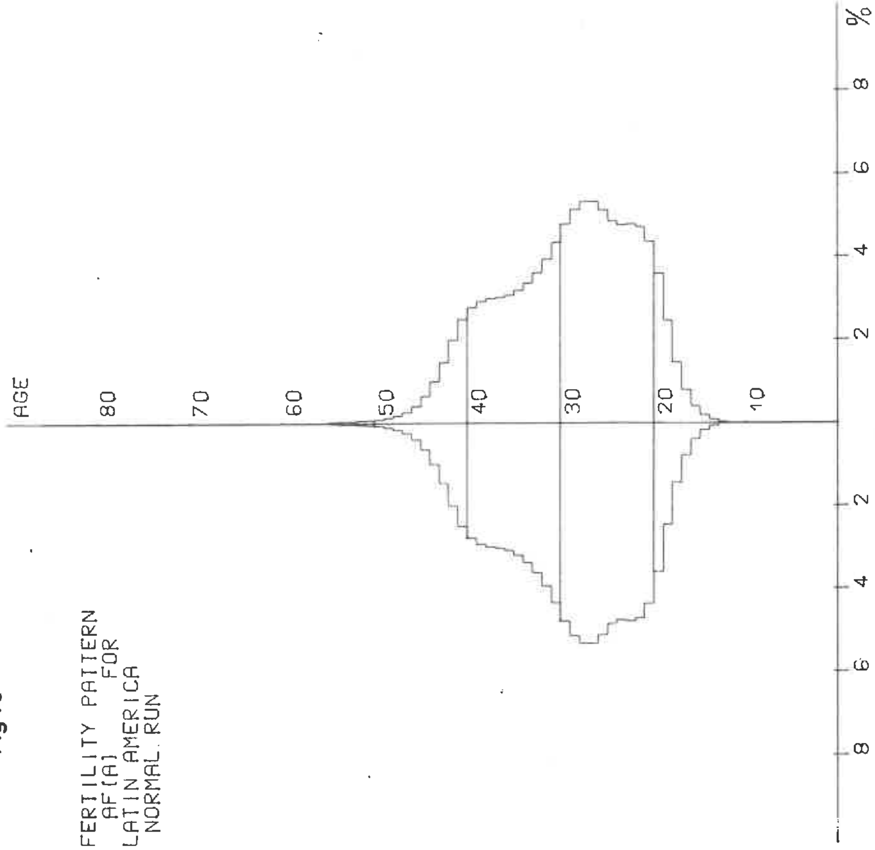
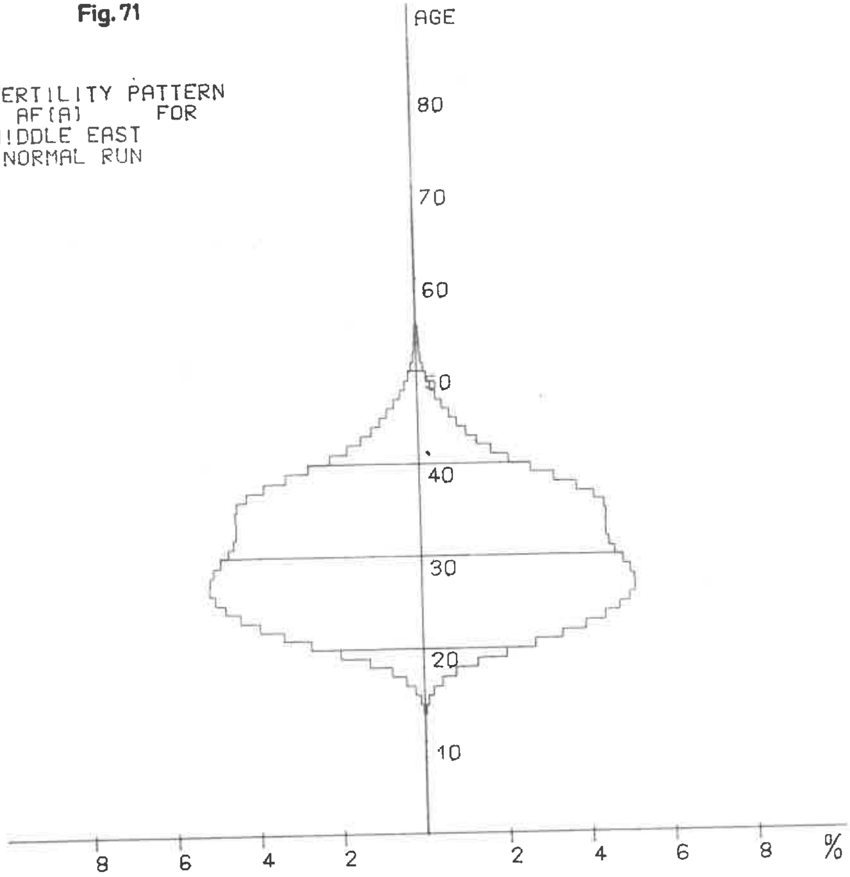


Fig.70

FERTILITY PATTERN
AF(A) FOR
LATIN AMERICA
NORMAL RUN

Fig. 71

FERTILITY PATTERN
AF(A) FOR
MIDDLE EAST
NORMAL RUN



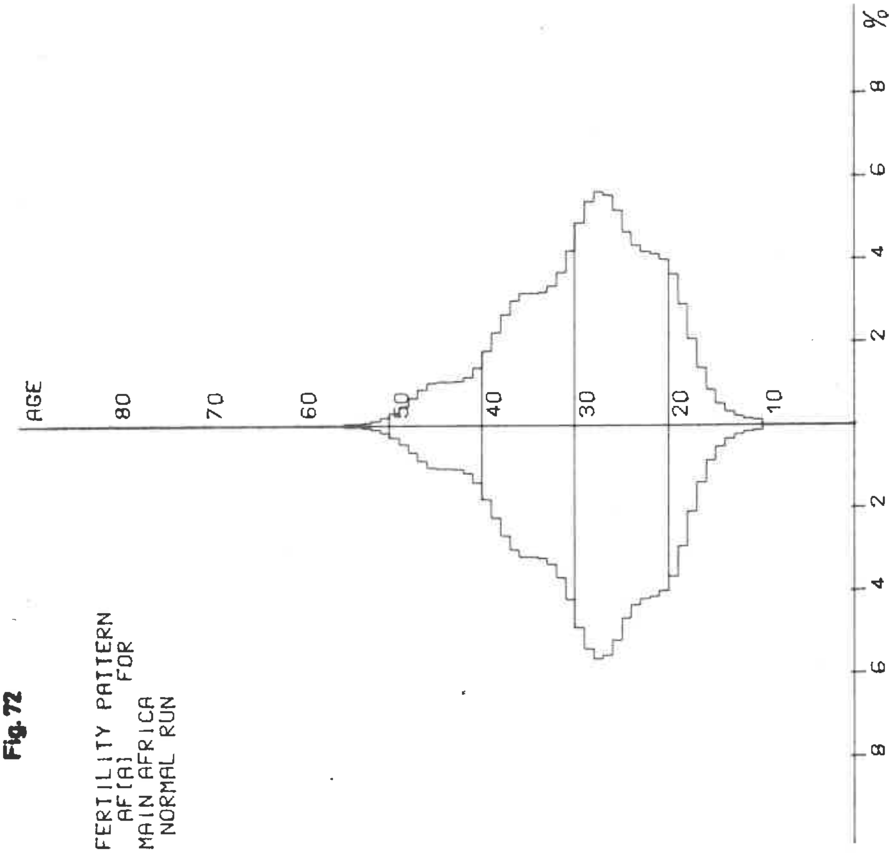
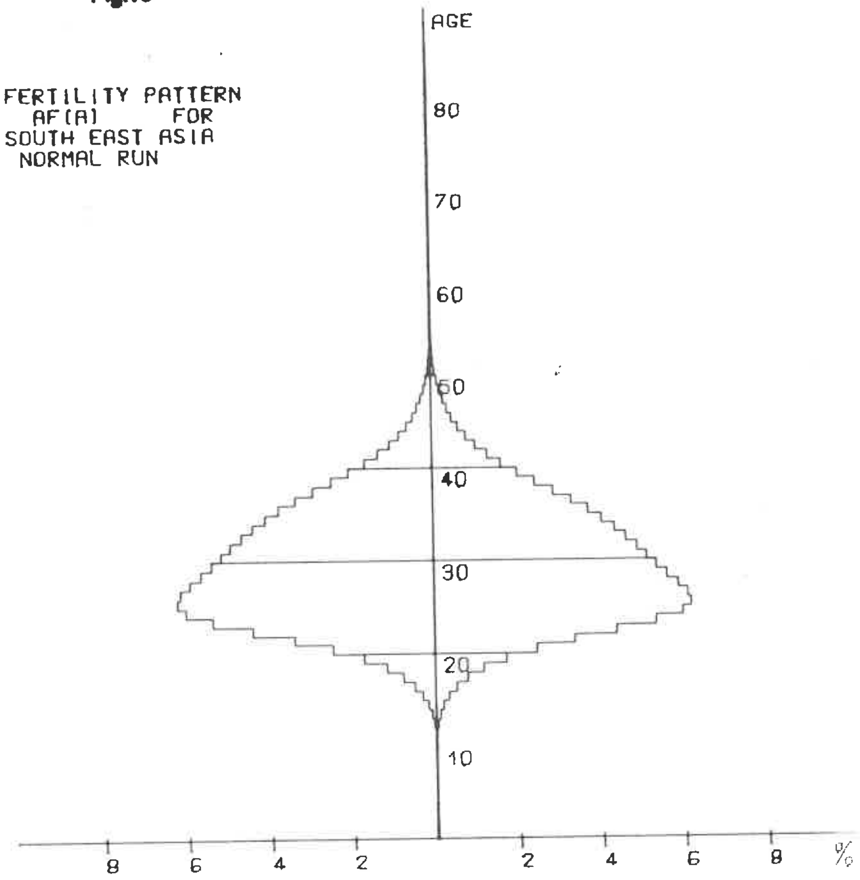


Fig. 72

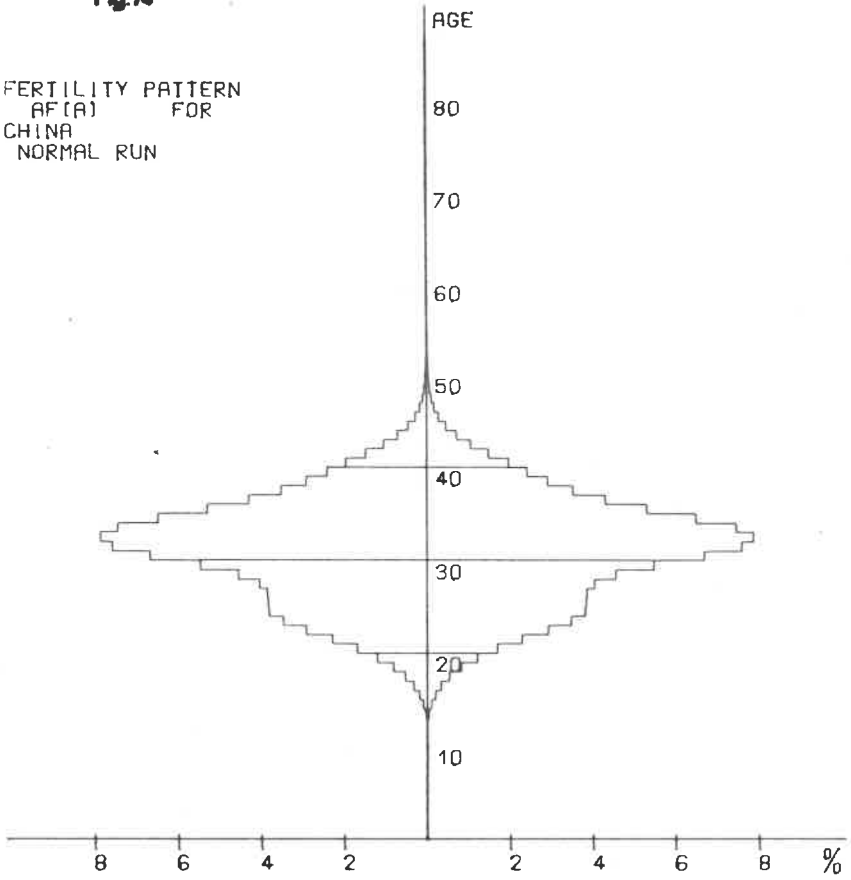
FERTILITY PATTERN
AF(A) FOR
MAIN AFRICA
NORMAL RUN

Fig.73



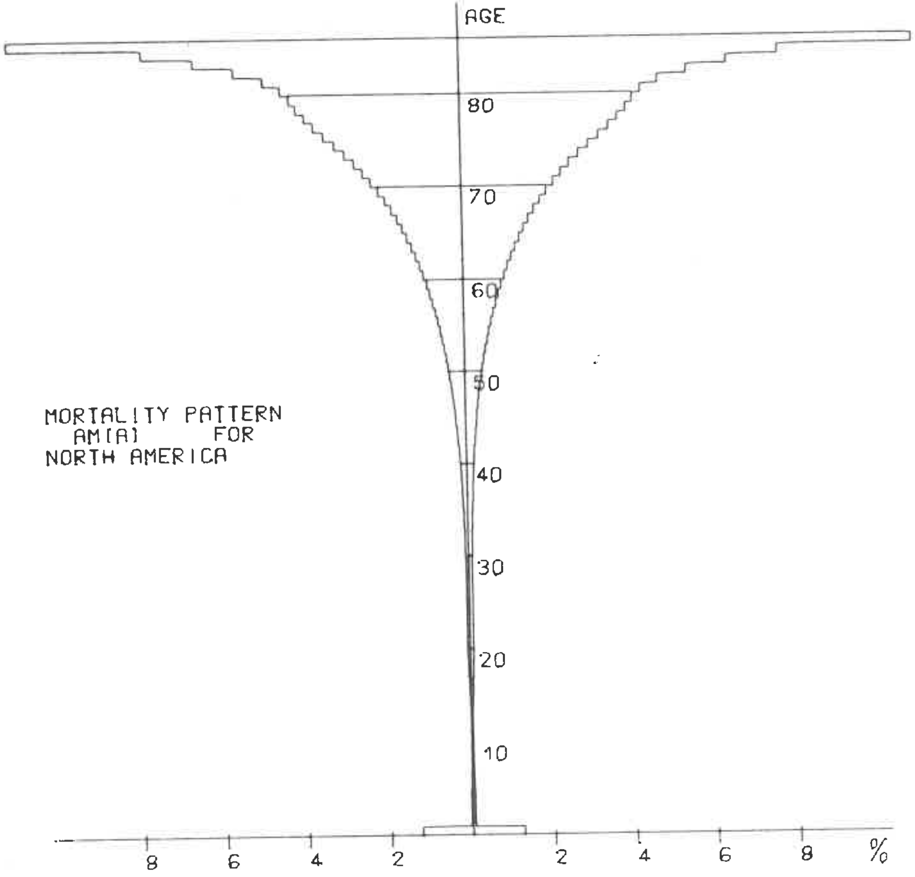
FERTILITY PATTERN
AF(A) FOR
SOUTH EAST ASIA
NORMAL RUN

Fig.76



FERTILITY PATTERN
AF(A) FOR
CHINA
NORMAL RUN

Fig.75


AGE
80
70
60
50
40
30
20
10
8
6
4
2
2
4
6
8
%
MORTALITY PATTERN
AM(A) FOR
NORTH AMERICA

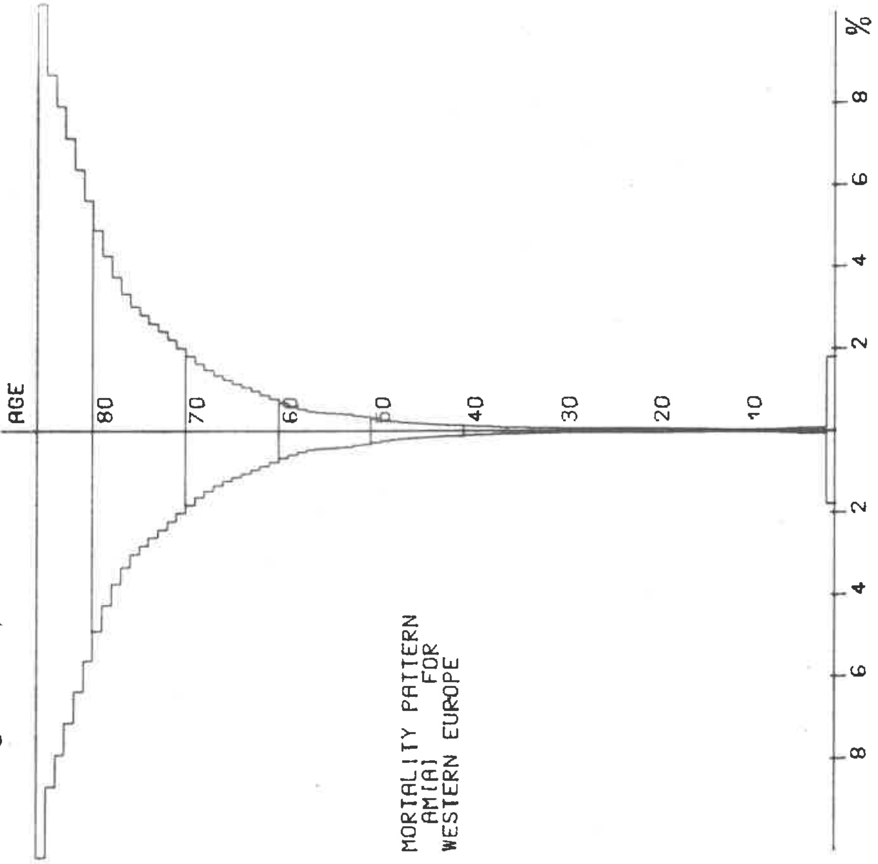
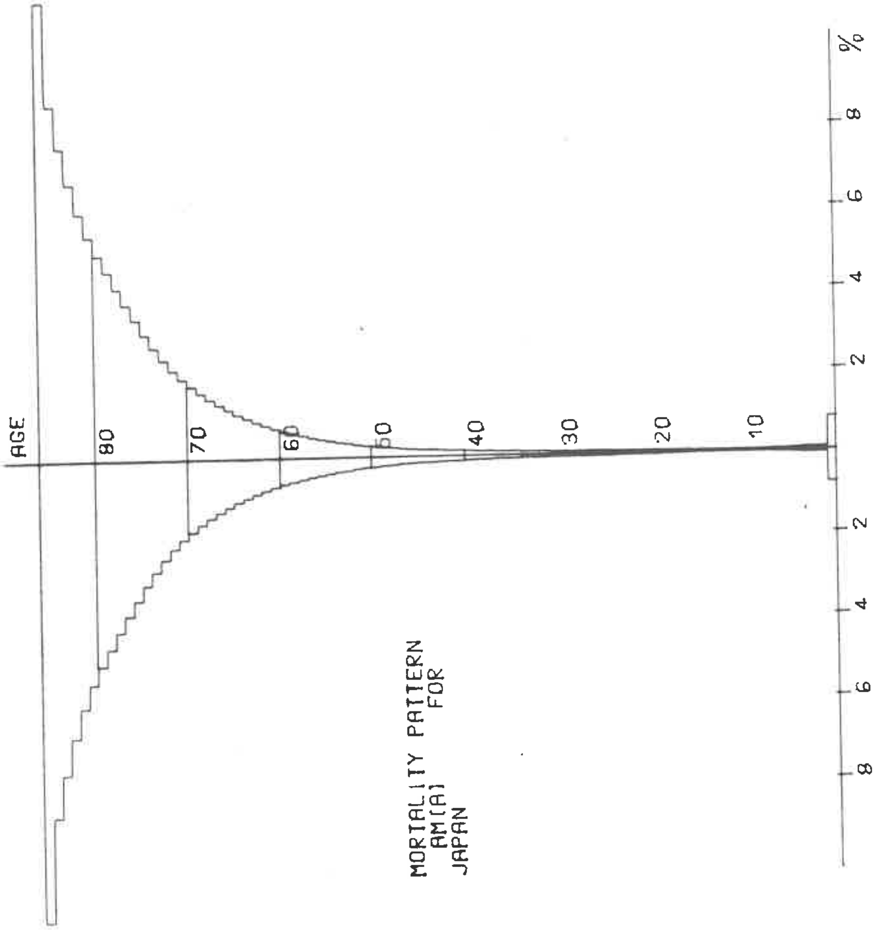

MORTALITY PATTERN
AM(A) FOR
WESTERN EUROPE
AGE
80
70
60
50
40
30
20
10
%
8
6
4
2
2
4
6
8

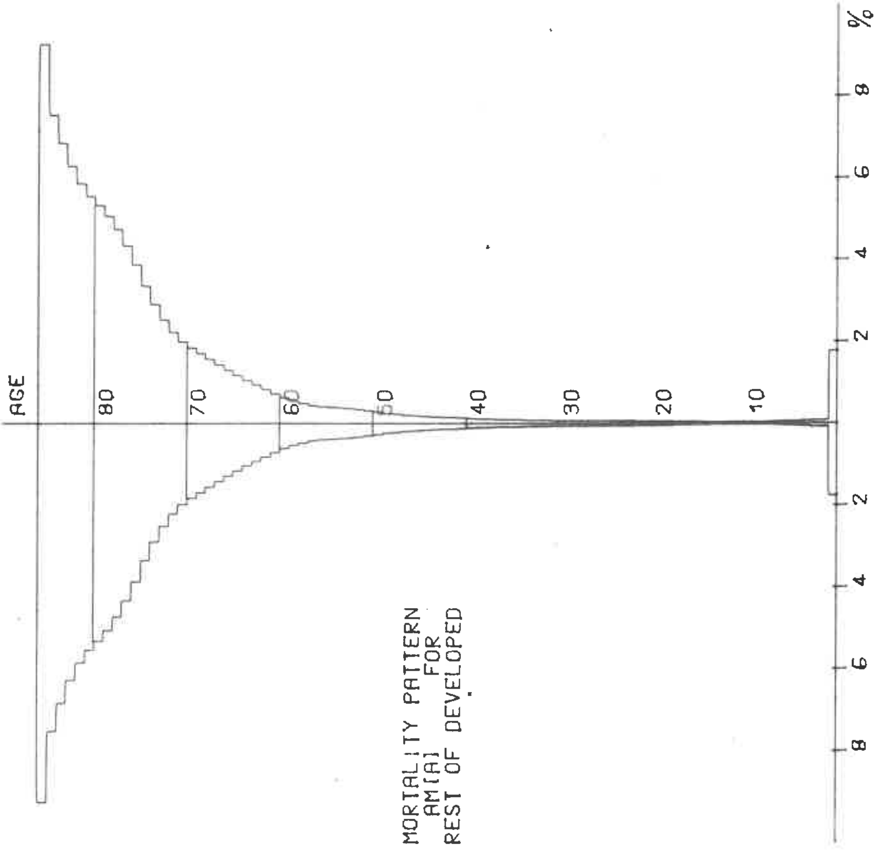
Fig.76

Fig. 77



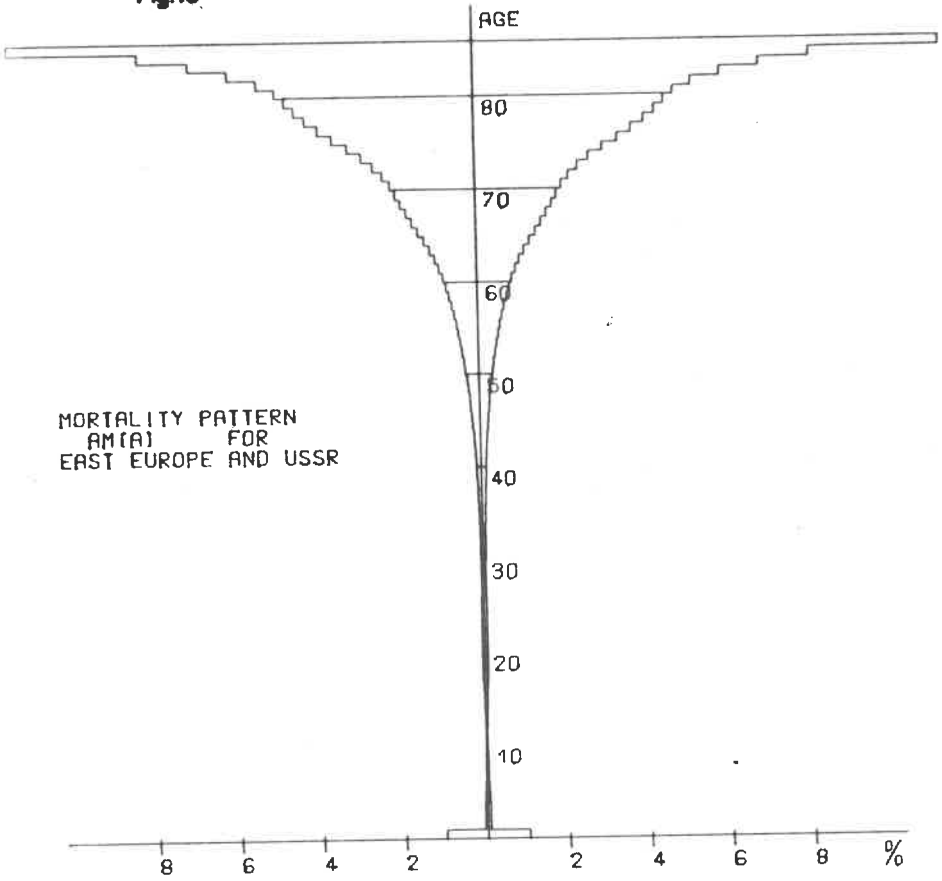
MORTALITY PATTERN FOR
AM(A)
JAPAN

Fig. 78



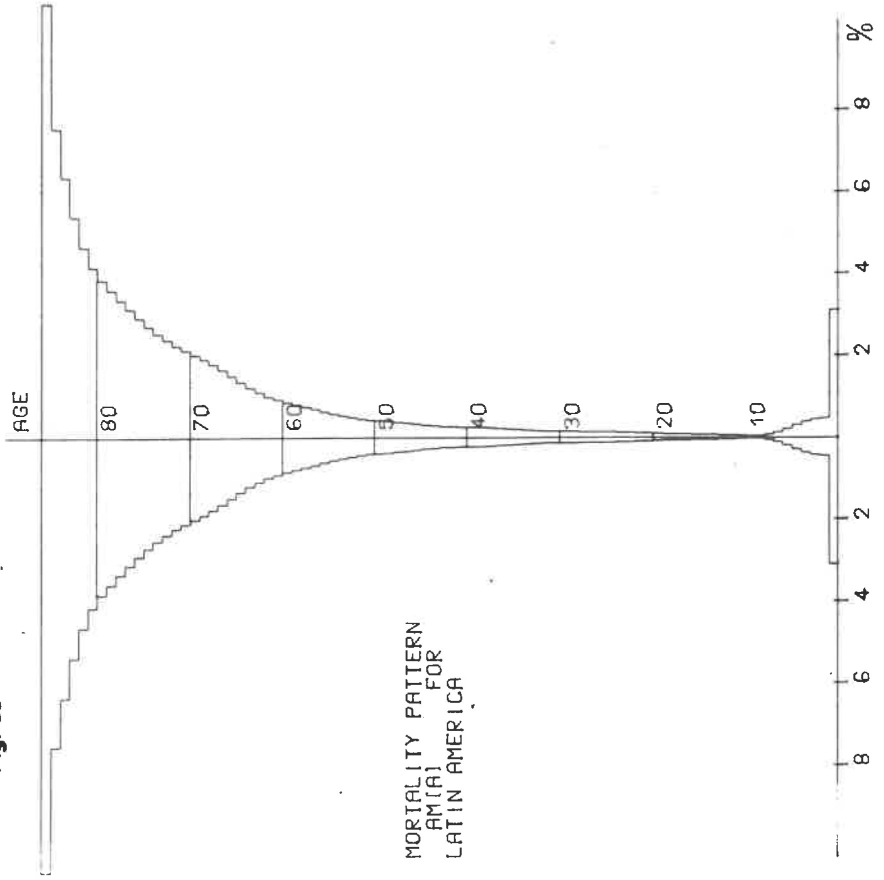
MORTALITY PATTERN
AM(A) FOR
REST OF DEVELOPED

Fig.79



MORTALITY PATTERN
AM(A) FOR
EAST EUROPE AND USSR

Fig. 80



MORTALITY PATTERN
AM(A) FOR
LATIN AMERICA

Fig. 81

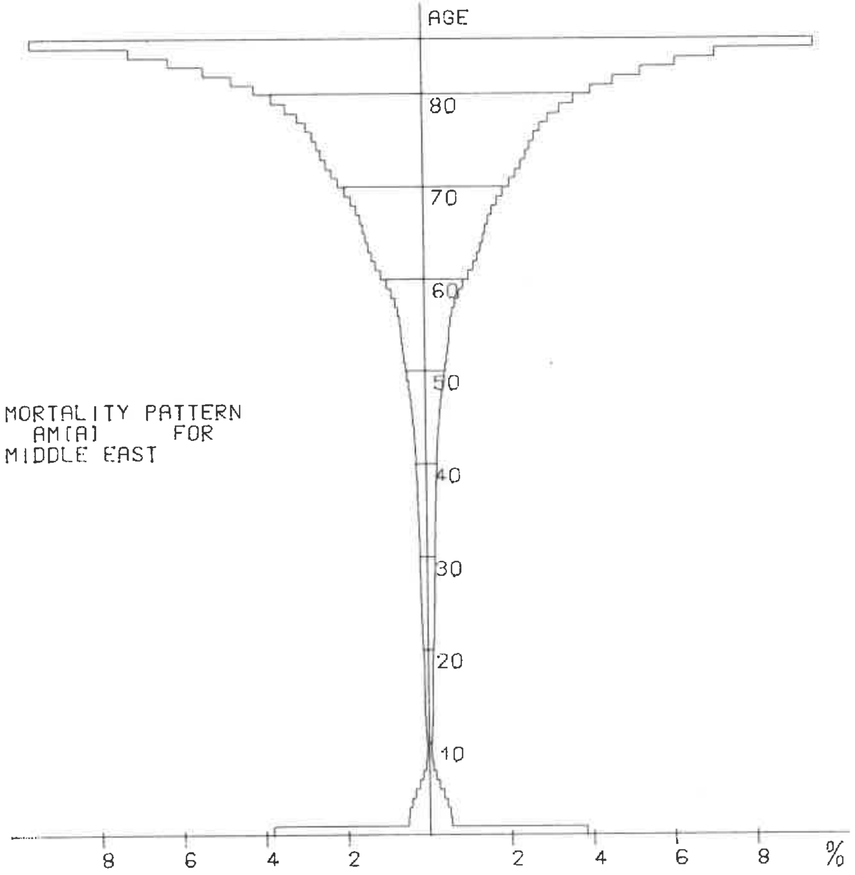

MORTALITY PATTERN
AM(A) FOR
MIDDLE EAST
AGE
80
70
60
50
40
30
20
10
8
6
4
2
2
4
6
8
%

Fig.82

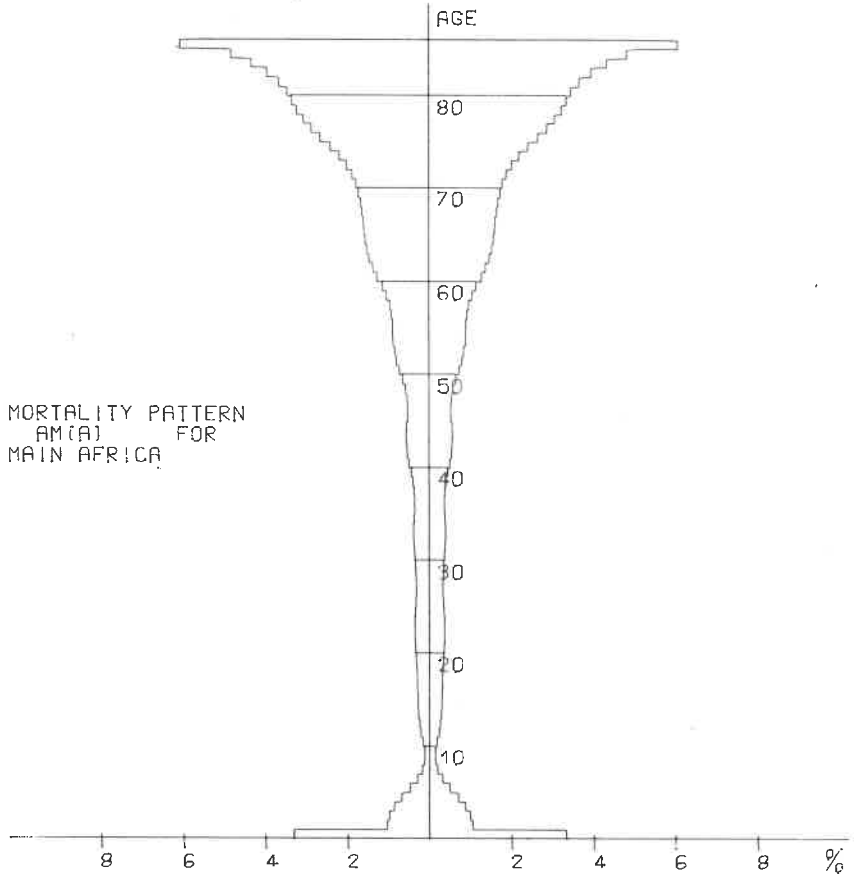
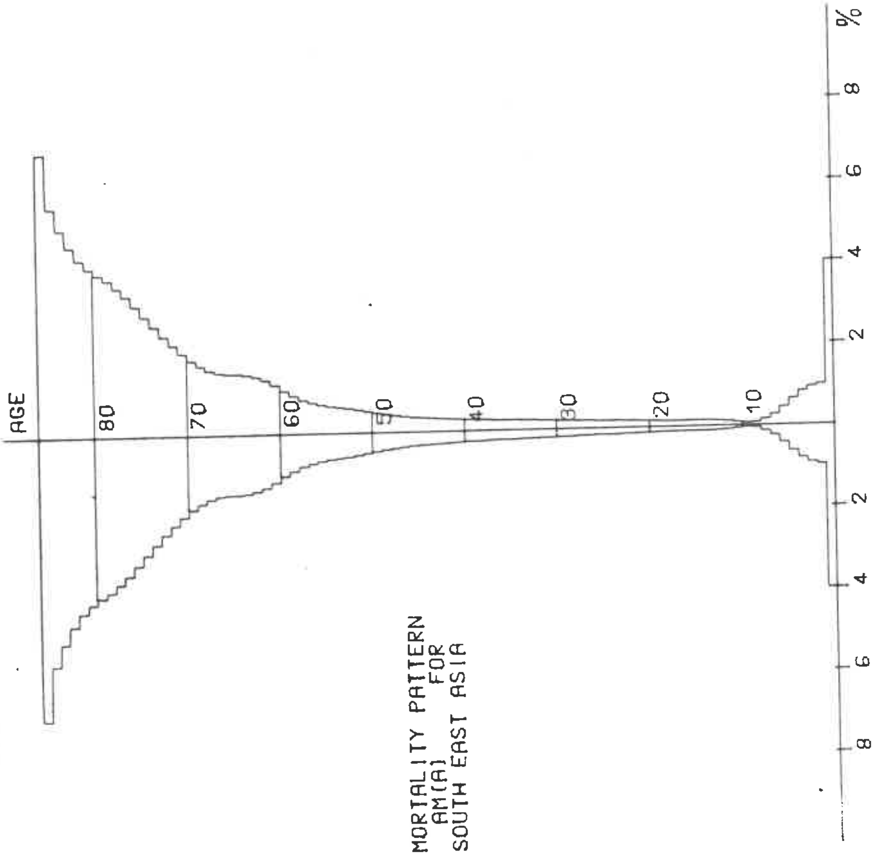
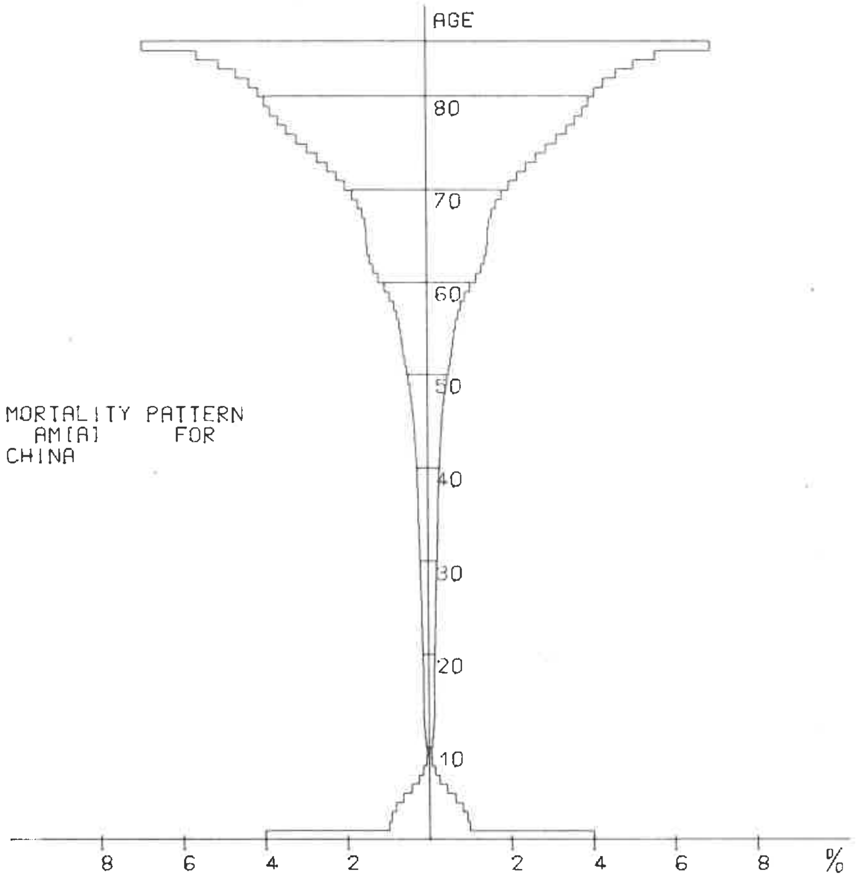

MORTALITY PATTERN
AM(A) FOR
MAIN AFRICA
AGE
80
70
60
50
40
30
20
10
8
6
4
2
2
4
6
8
%

Fig. 83



MORTALITY PATTERN
AM(A) FOR
SOUTH EAST ASIA

Fig. 84


AGE
80
70
60
50
40
30
20
10
MORTALITY PATTERN
AM[A] FOR
CHINA
8
6
4
2
2
4
6
8
%

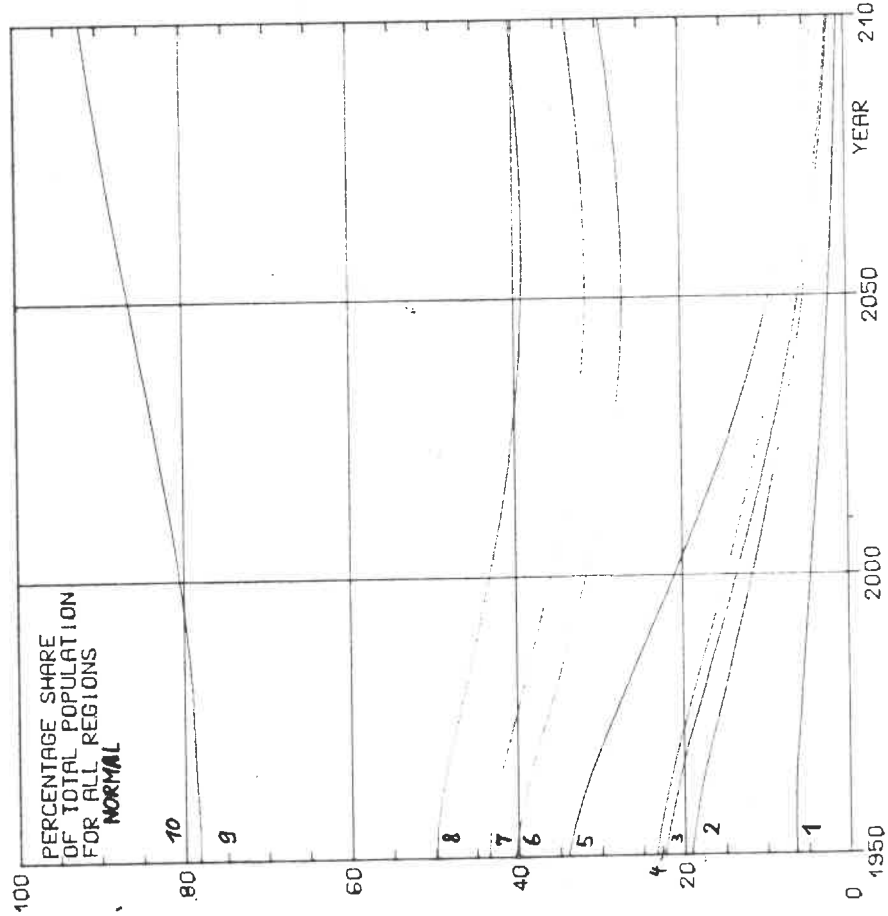

PERCENTAGE SHARE
OF TOTAL POPULATION
FOR ALL REGIONS
NORMAL
100
80
60
40
20
0
1950
2000
2050
2100
YEAR
1
2
3
4
5
6
7
8
9
10

Fig. 108

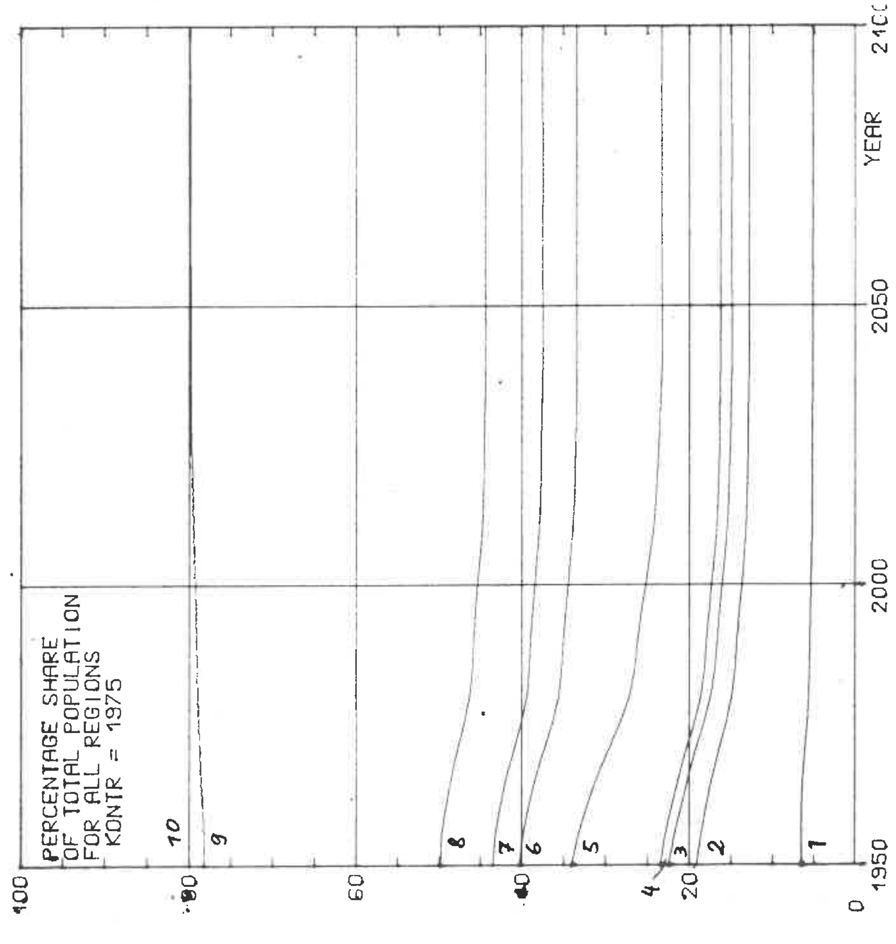

PERCENTAGE SHARE
OF TOTAL POPULATION
FOR ALL REGIONS
KONTR = 1975
100
80
60
40
20
0
1950
2000
2050
2100
YEAR
1
2
3
4
5
6
7
8
9
10

Fig.109

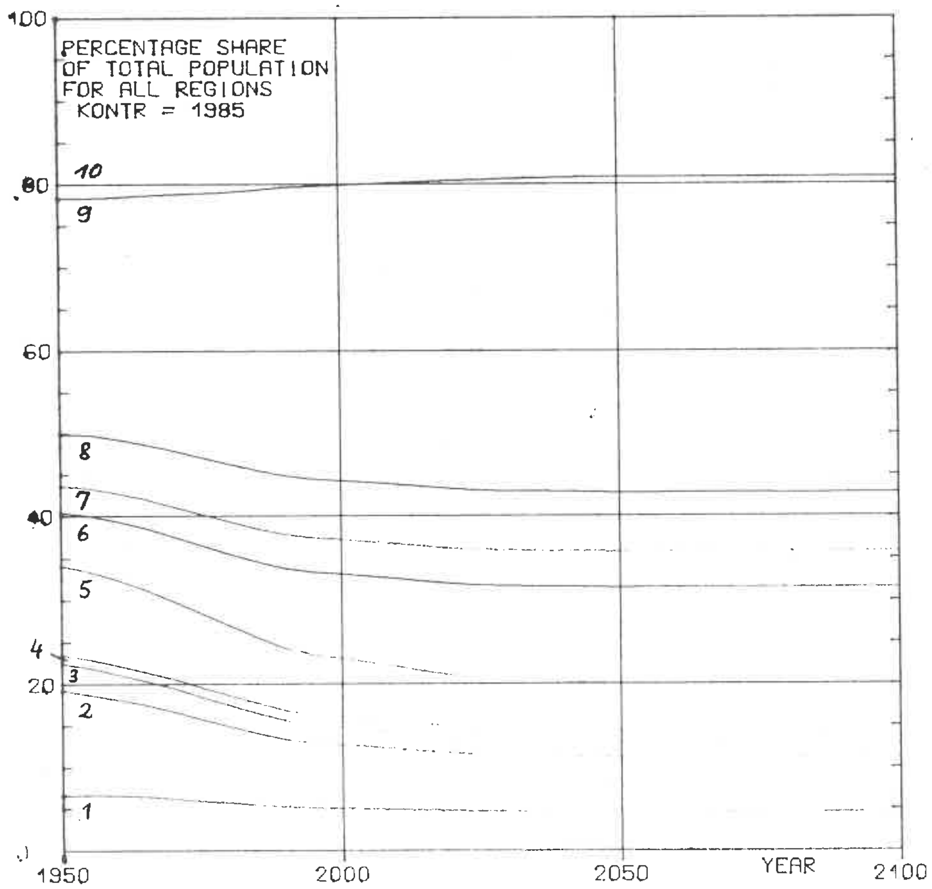

PERCENTAGE SHARE
OF TOTAL POPULATION
FOR ALL REGIONS
KONTR = 1985
100
80
60
40
4
20
0
1950
2000
2050
2100
YEAR
10
9
8
7
6
5
3
2
1

Fig.110

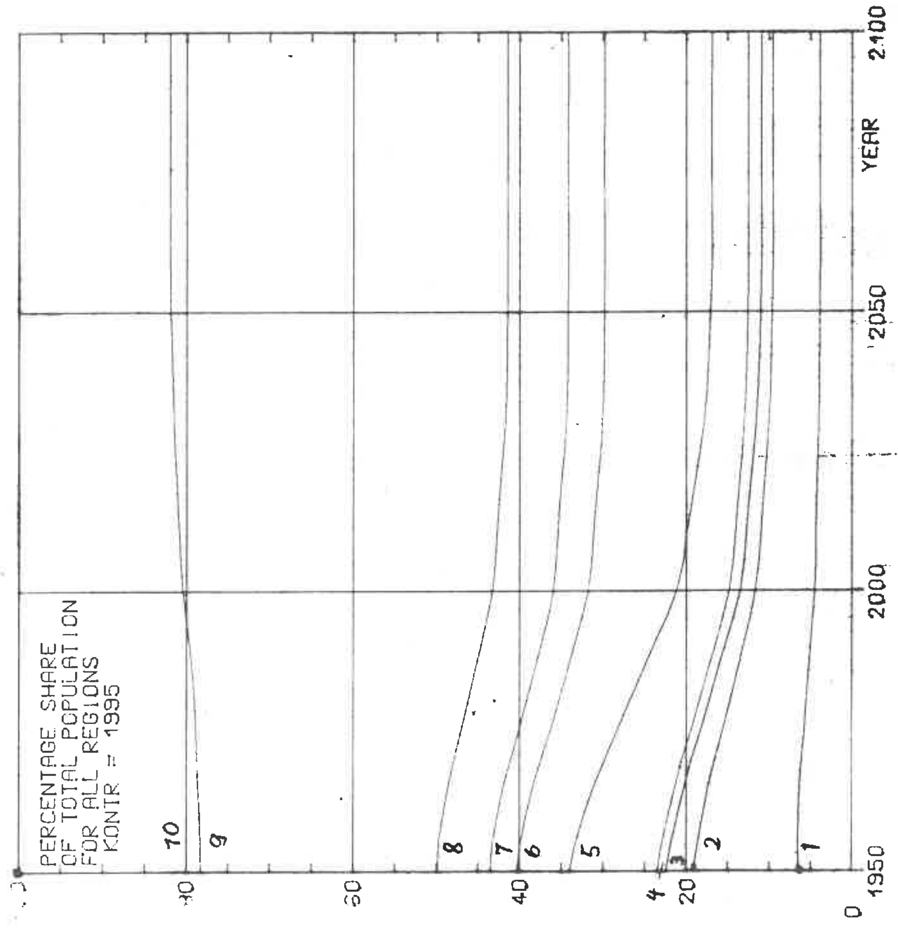
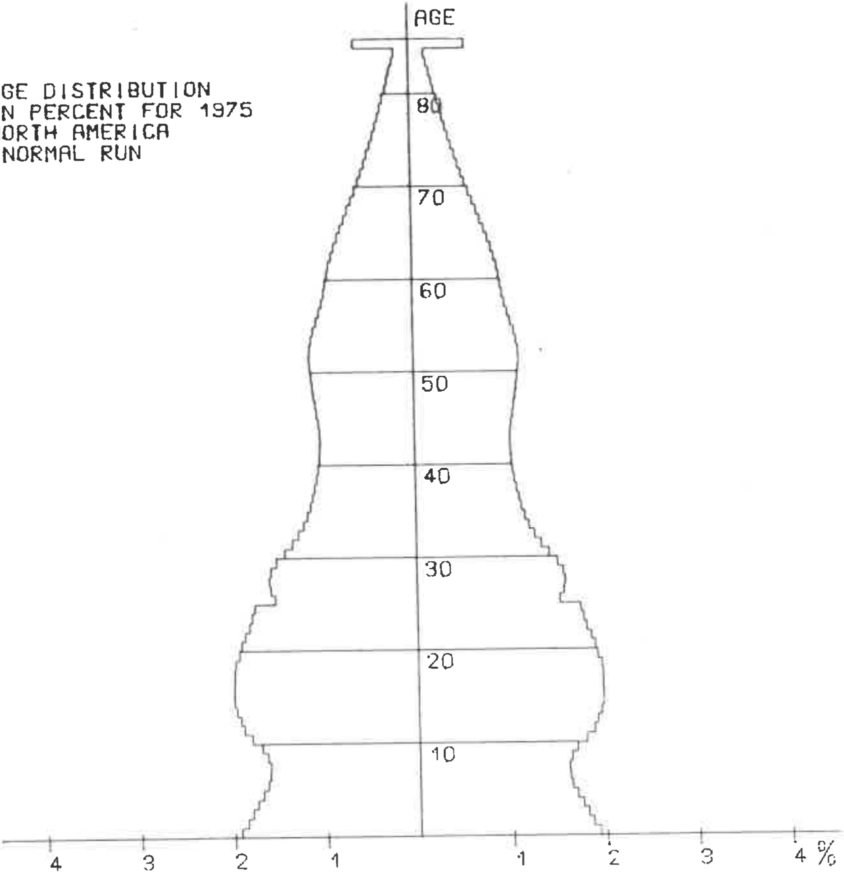

PERCENTAGE SHARE
OF TOTAL POPULATION
FOR ALL REGIONS
KONTR = 1995
0
20
40
60
80
1950
2000
2050
2100
YEAR
1
2
3
4
5
6
7
8
9
10

Fig. 111

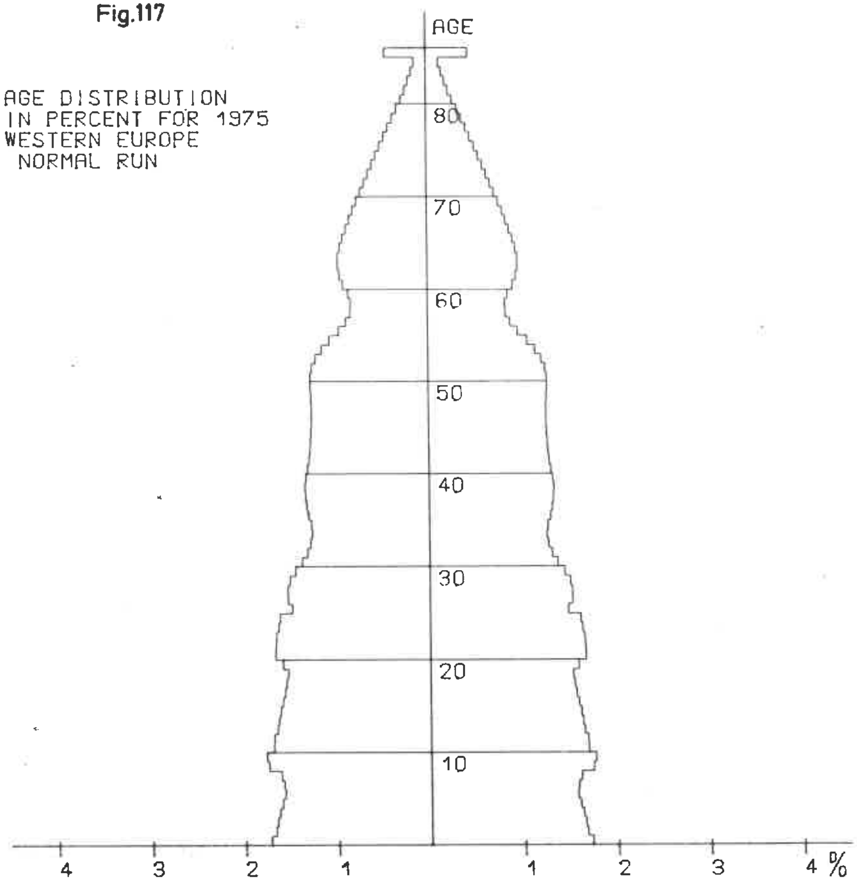
Fig. 113



AGE DISTRIBUTION
IN PERCENT FOR 1975
NORTH AMERICA
NORMAL RUN

Fig.117

AGE DISTRIBUTION
IN PERCENT FOR 1975
WESTERN EUROPE
NORMAL RUN



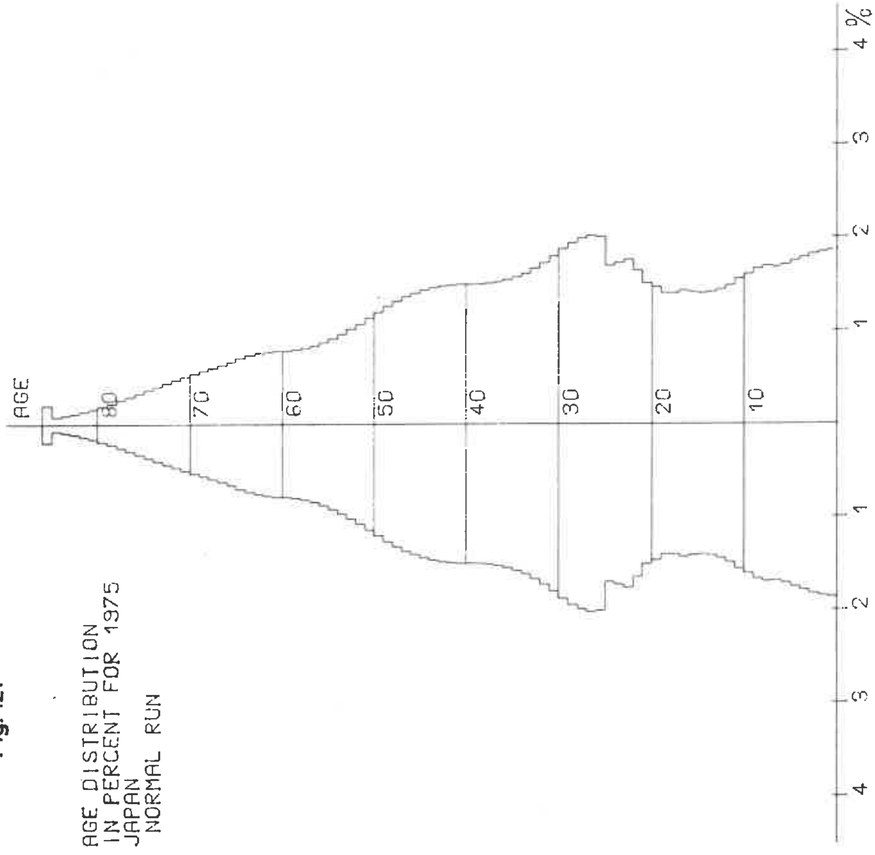
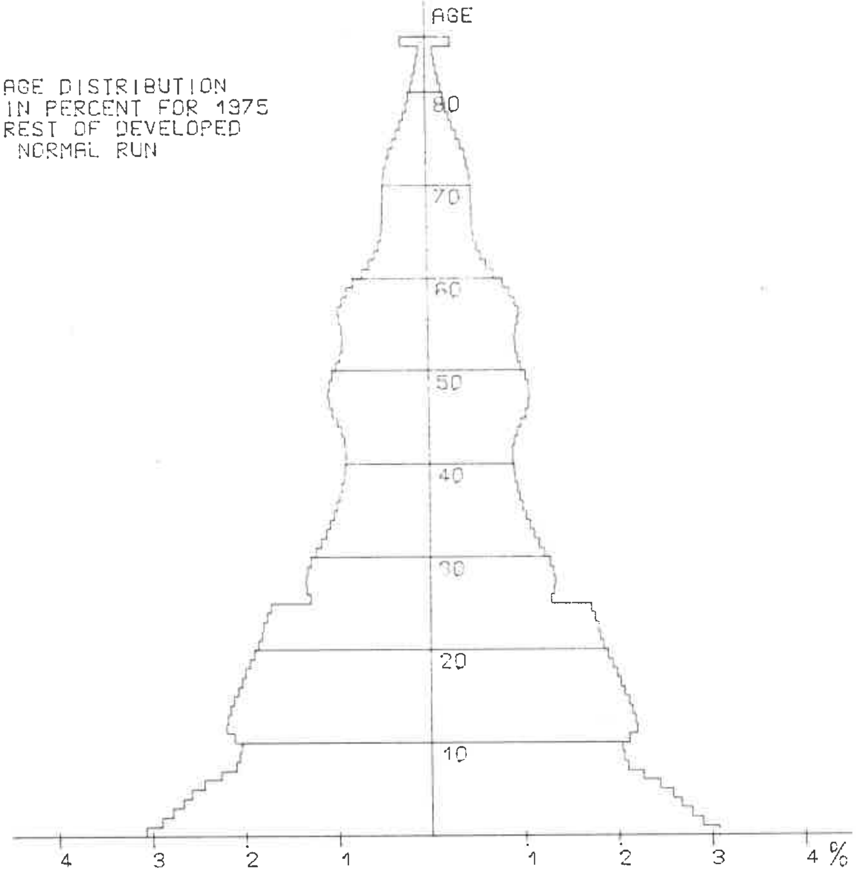


Fig. 121

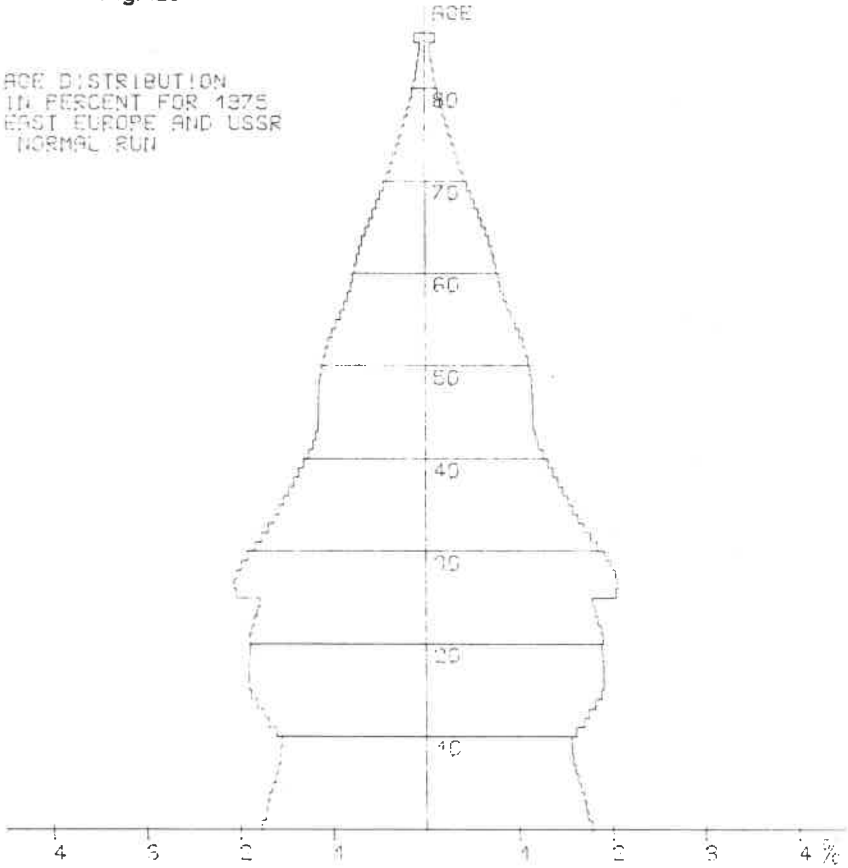
AGE DISTRIBUTION
IN PERCENT FOR 1975
JAPAN
NORMAL RUN

Fig. 125



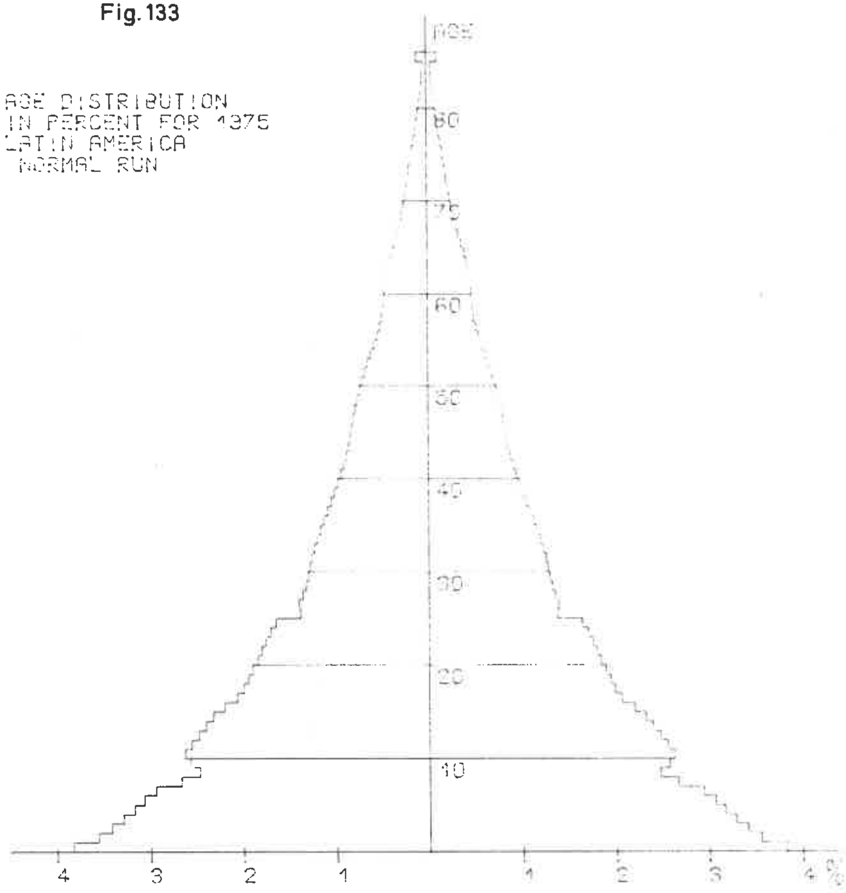
AGE DISTRIBUTION
IN PERCENT FOR 1975
REST OF DEVELOPED
NORMAL RUN

Fig. 129



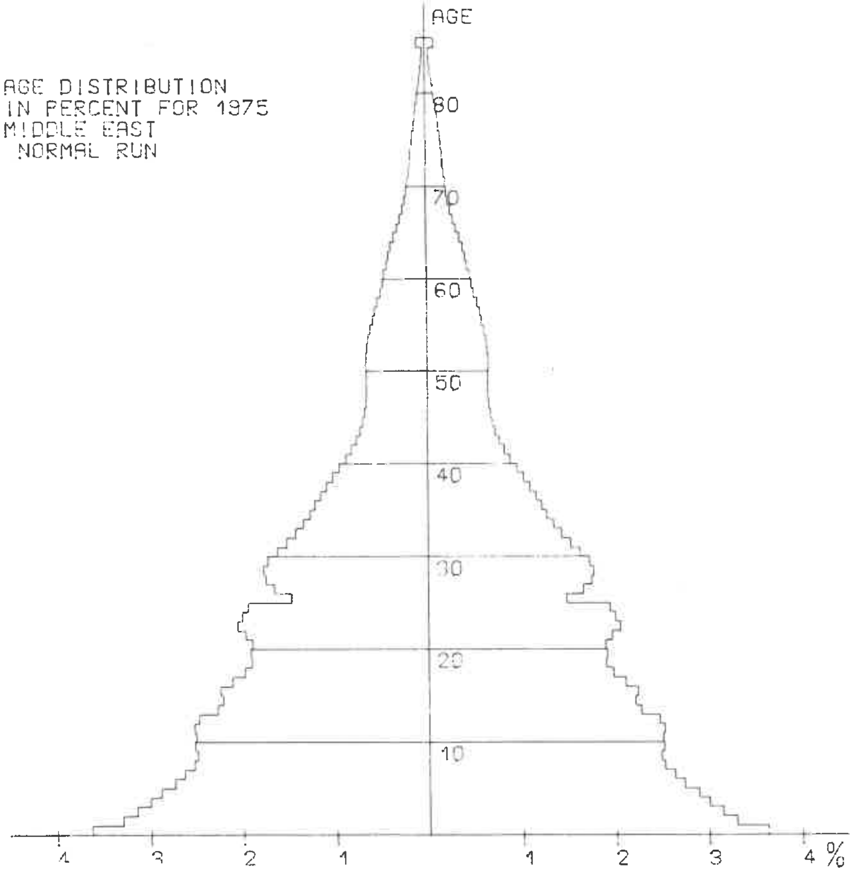
AGE DISTRIBUTION
IN PERCENT FOR 1975
EAST EUROPE AND USSR
NORMAL RUN

Fig. 133



AGE DISTRIBUTION
IN PERCENT FOR 1975
LATIN AMERICA
NORMAL RUN

Fig. 137



AGE DISTRIBUTION
IN PERCENT FOR 1975
MIDDLE EAST
NORMAL RUN

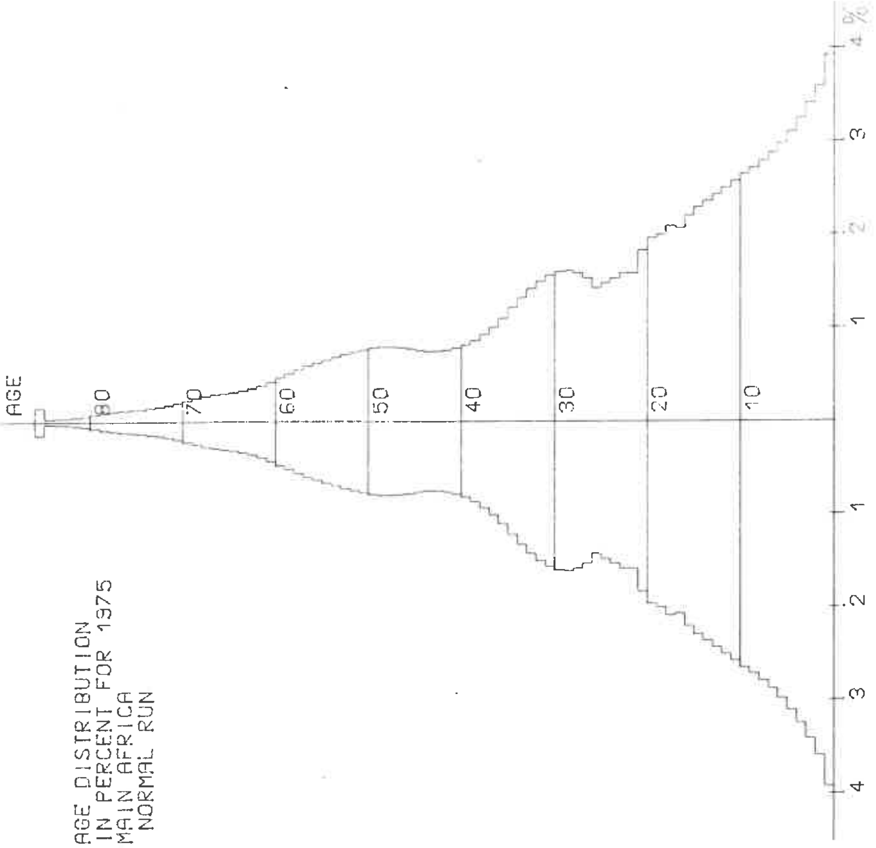
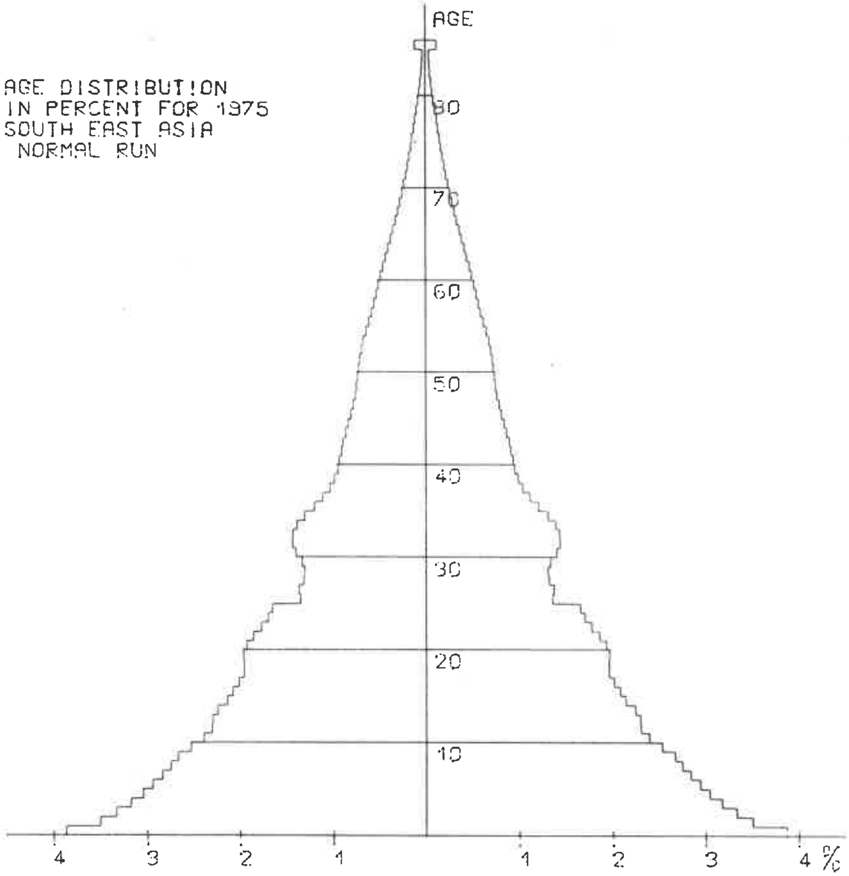


Fig.141

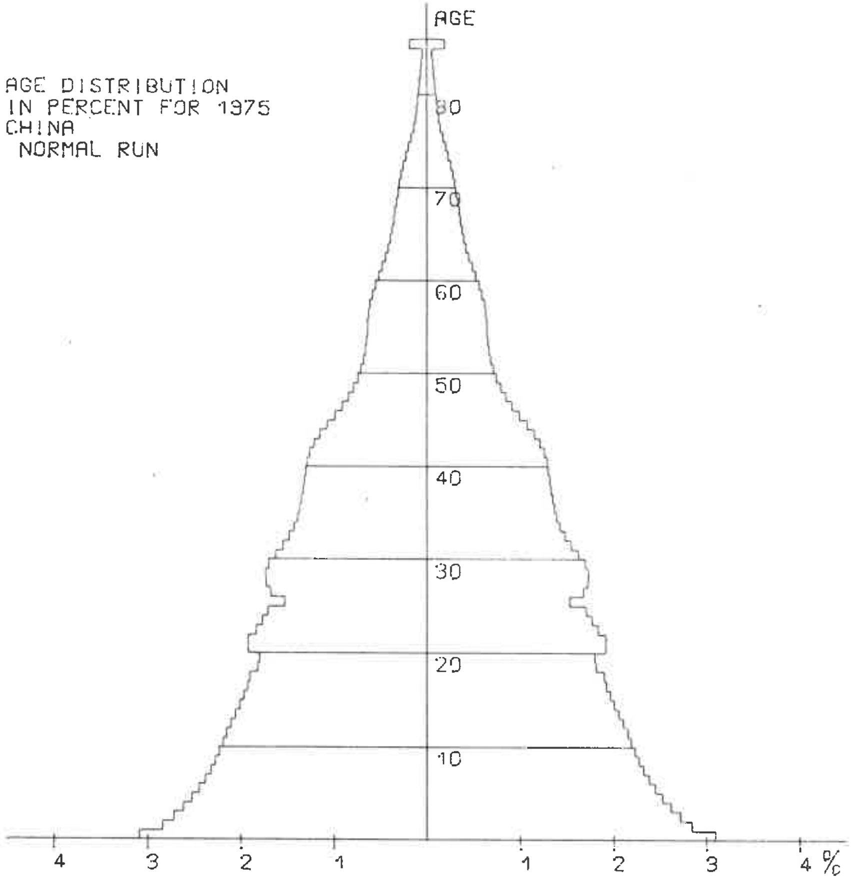
AGE DISTRIBUTION
IN PERCENT FOR 1975
MAIN AFRICA
NORMAL RUN

Fig.145



AGE DISTRIBUTION
IN PERCENT FOR 1975
SOUTH EAST ASIA
NORMAL RUN

Fig.149



AGE DISTRIBUTION
IN PERCENT FOR 1975
CHINA
NORMAL RUN

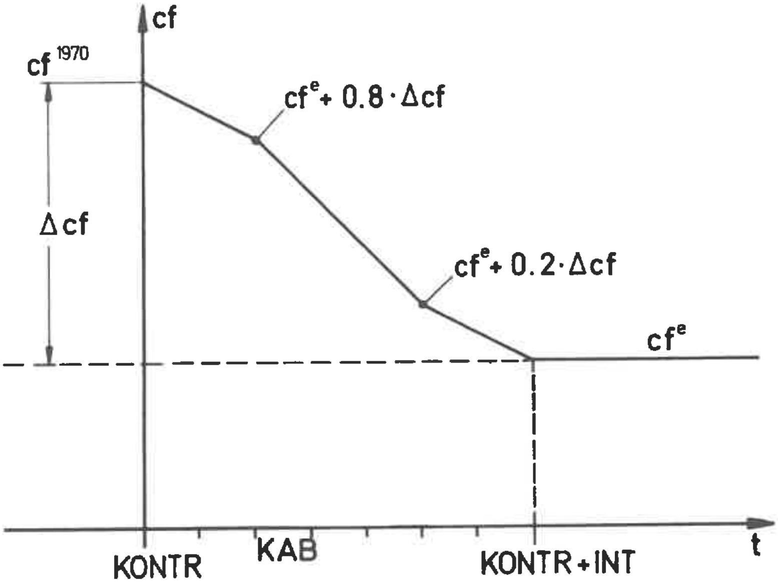


Fig. 192: Scheme for fertility transition period

key numbers for equilibrium runs:

Type 1.1 : INT = 0 ; KONTR = 1975/1985/1995/2200

Type 1.2 : INT = 14 ; KONTR = 1975/1985/1995/2200

Type 1.3 : INT = 35 ; KONTR = 1975/1985/1995/2200

Type 2.1 : KONTR = 1975 ; INT = 0/14/35/∞

Type 2.2 : KONTR = 1985 ; INT = 0/14/35/∞

Type 2.3 : KONTR = 1995 ; INT = 0/14/35/∞

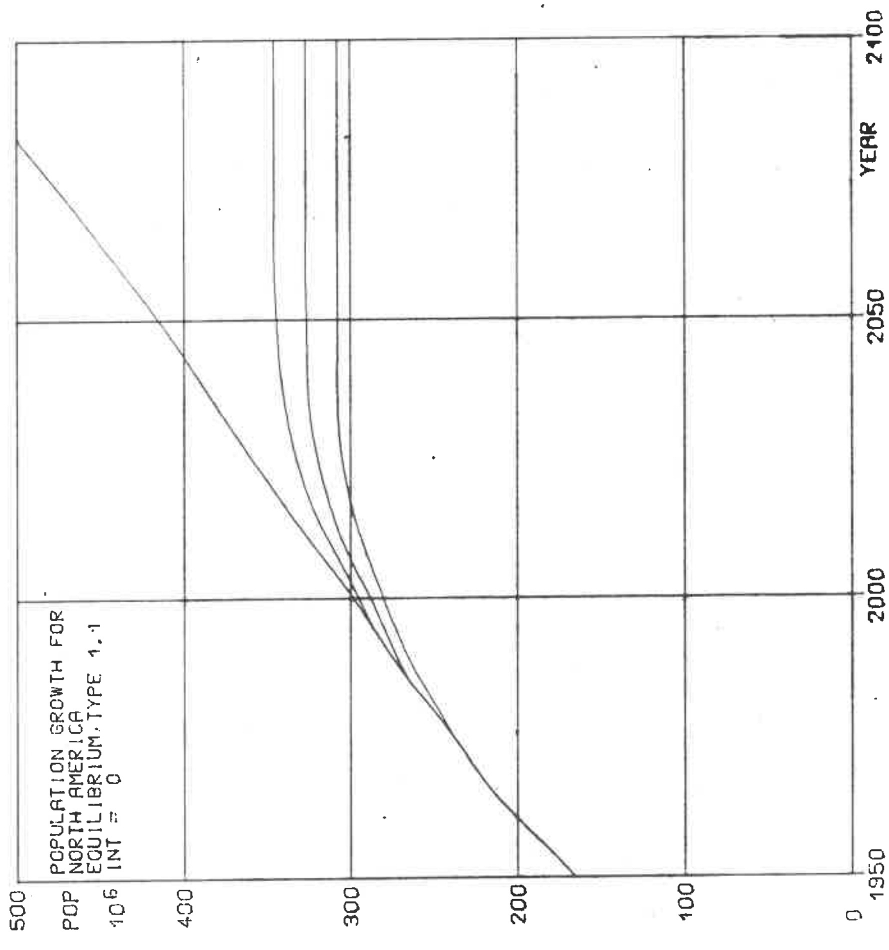

POPULATION GROWTH FOR
NORTH AMERICA
EQUILIBRIUM.TYPE 1.1
INT = 0
POP
10⁶
500
400
300
200
100
0
1950
2000
2050
2100
YEAR

Fig. 193

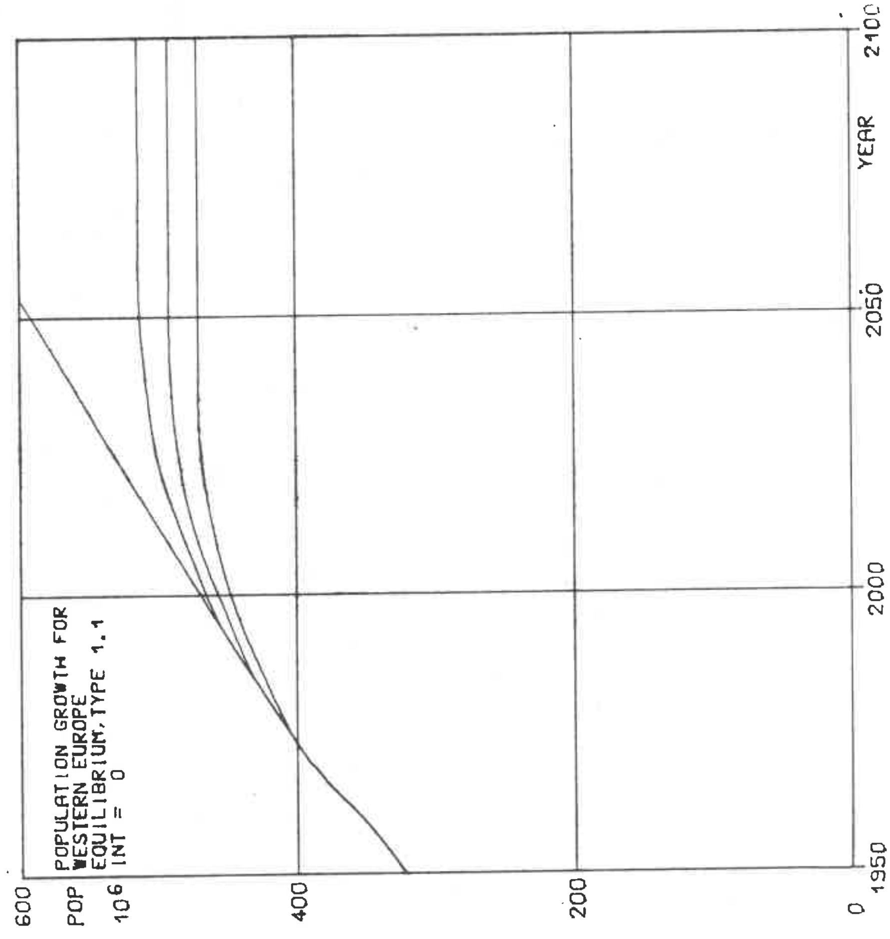

POPULATION GROWTH FOR
WESTERN EUROPE
EQUILIBRIUM, TYPE 1.1
INT = 0
600
POP
10⁶
400
200
0
1950
2000
2050
2100
YEAR

Fig. 194

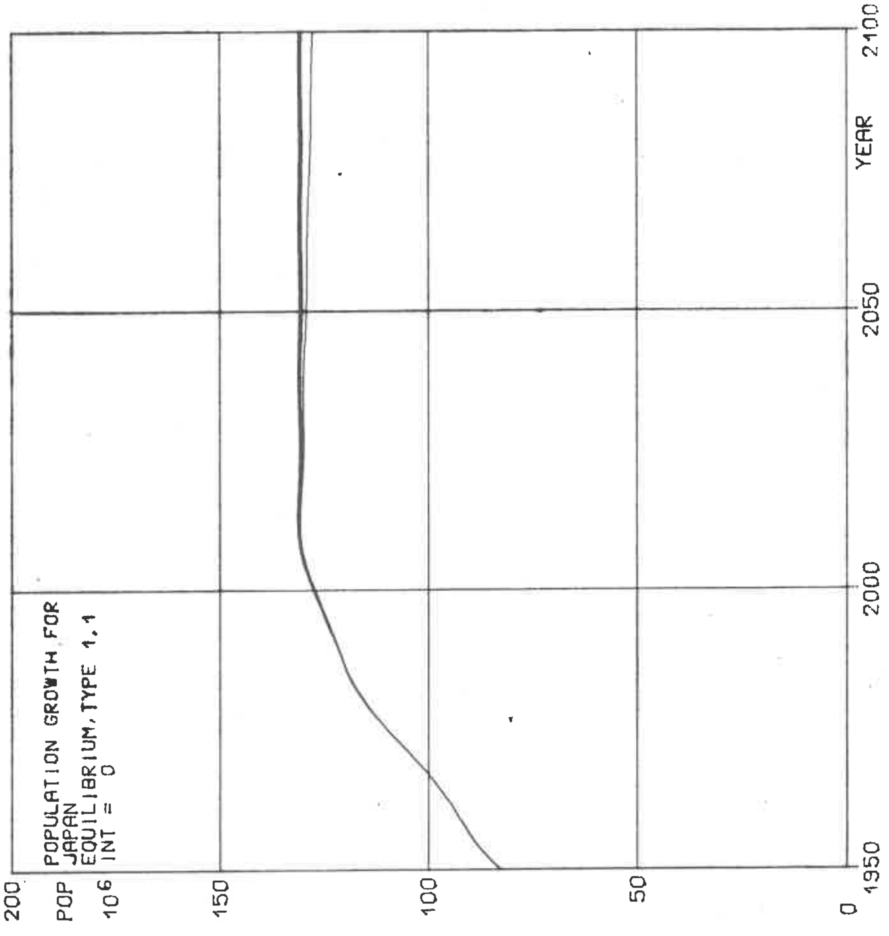

POPULATION GROWTH FOR
JAPAN
EQUILIBRIUM, TYPE 1.1
INT = 0
200
POP
10^6
150
100
50
0
1950
2000
2050
YEAR
2100

Fig. 195

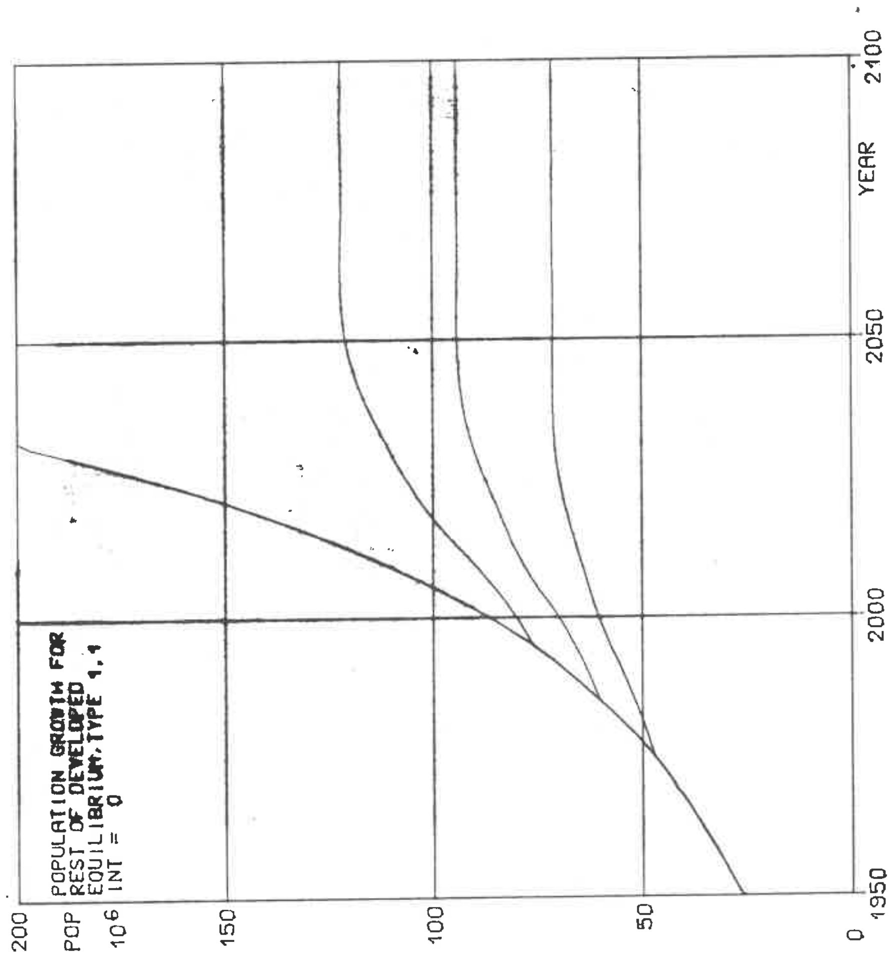

POPULATION GROWTH FOR
REST OF DEVELOPED
EQUILIBRIUM.TYPE 1.4
INT = 0
POP
10^6
200
150
100
50
0
1950
2000
2050
2100
YEAR

Fig.196

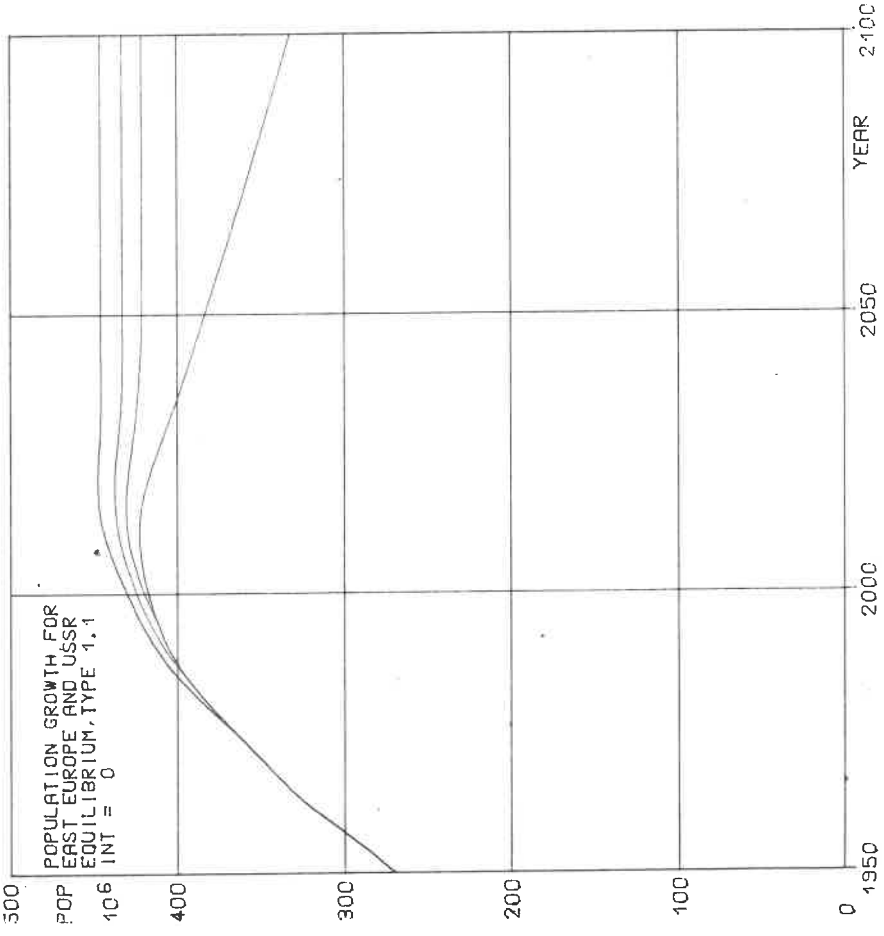

POPULATION GROWTH FOR
EAST EUROPE AND USSR
EQUILIBRIUM, TYPE 1.1
INT = 0
POP
10^6
500
400
300
200
100
0
1950
2000
2050
2100
YEAR

Fig.197

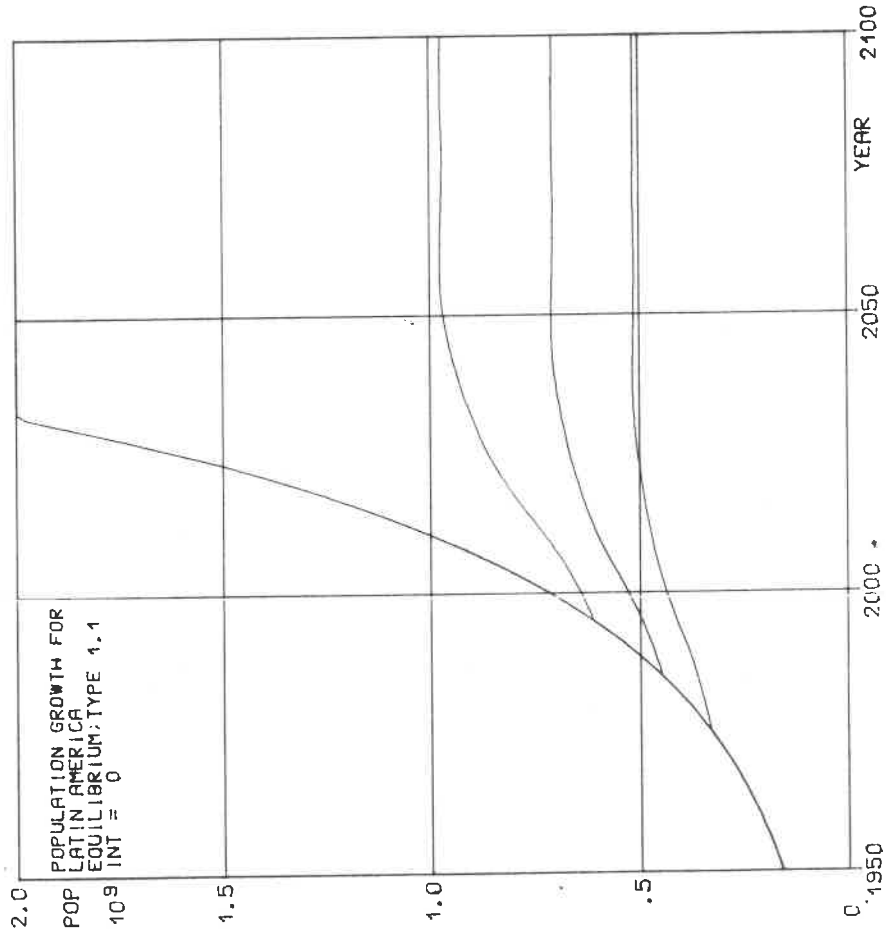

POPULATION GROWTH FOR
LATIN AMERICA
EQUILIBRIUM;TYPE 1.1
INT = 0
2.0
POP
10^9
1.5
1.0
.5
0.
1950
2000
2050
2100
YEAR

Fig. 198

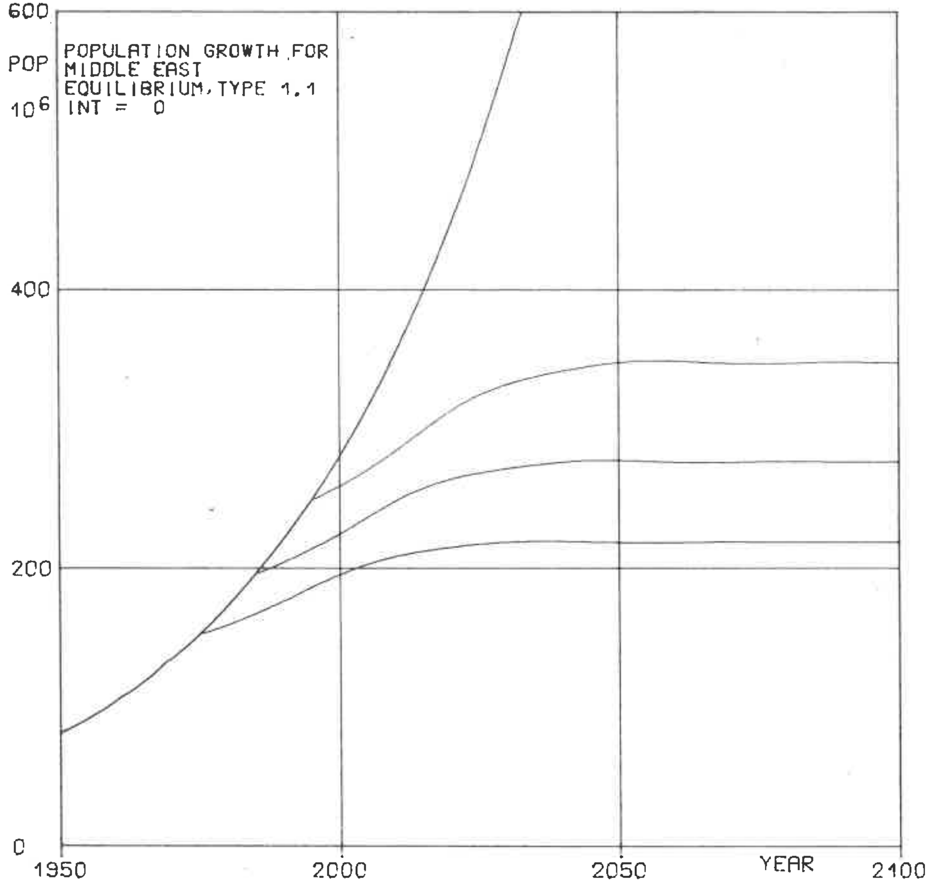

600
POP
10^6
400
200
0
1950
2000
2050
YEAR
2100
POPULATION GROWTH FOR
MIDDLE EAST
EQUILIBRIUM, TYPE 1.1
INT = 0

Fig. 199

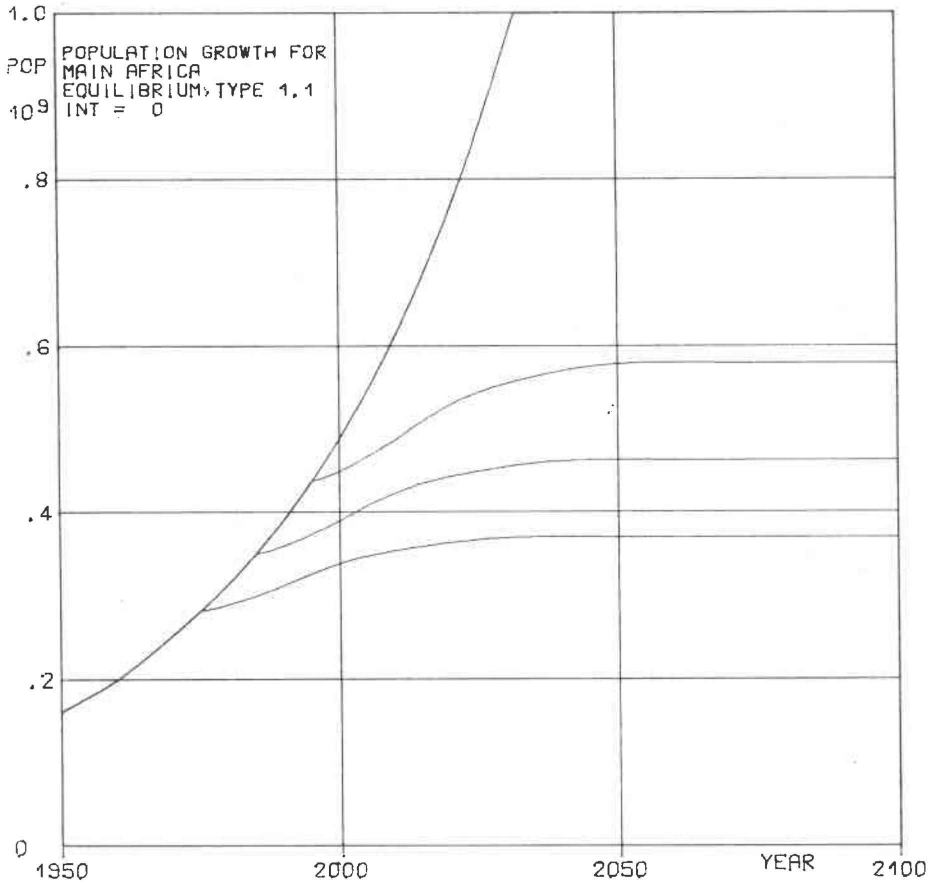

POPULATION GROWTH FOR
MAIN AFRICA
EQUILIBRIUM, TYPE 1.1
INT = 0
POP
10^9
1.0
.8
.6
.4
.2
0
1950
2000
2050
YEAR
2100

Fig. 200

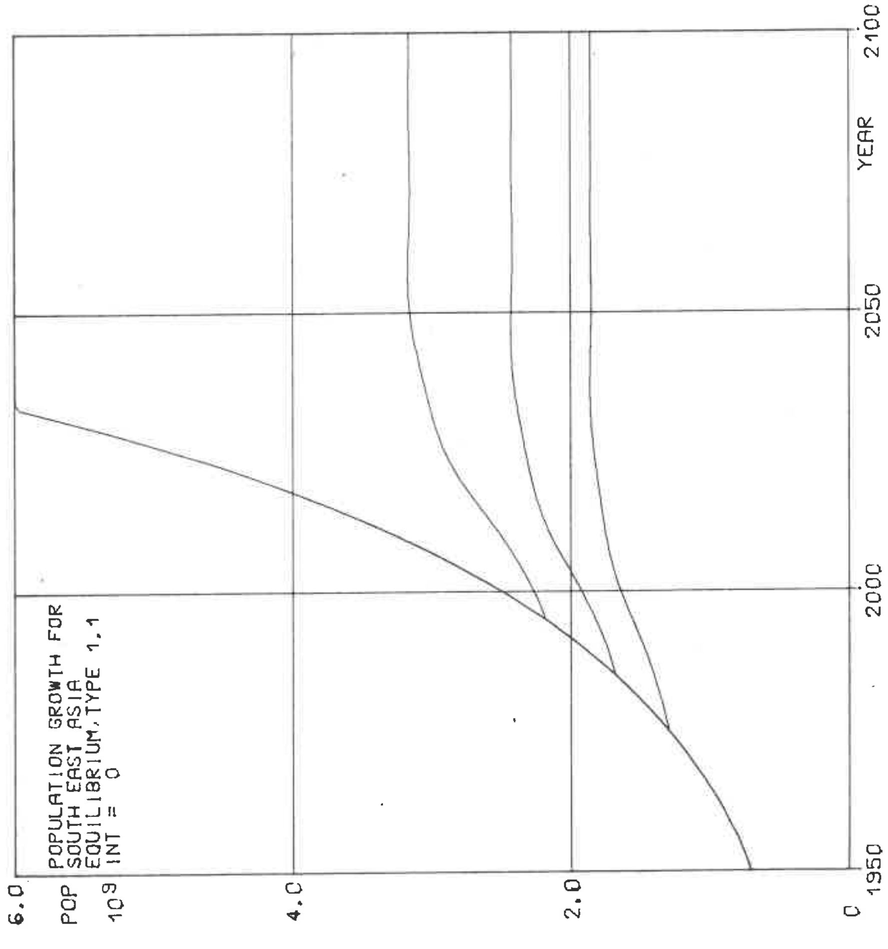

POPULATION GROWTH FOR
SOUTH EAST ASIA
EQUILIBRIUM, TYPE 1.1
INT = 0
6.0
POP
10⁹
4.0
2.0
0
1950
2000
2050
2100
YEAR

Fig. 201

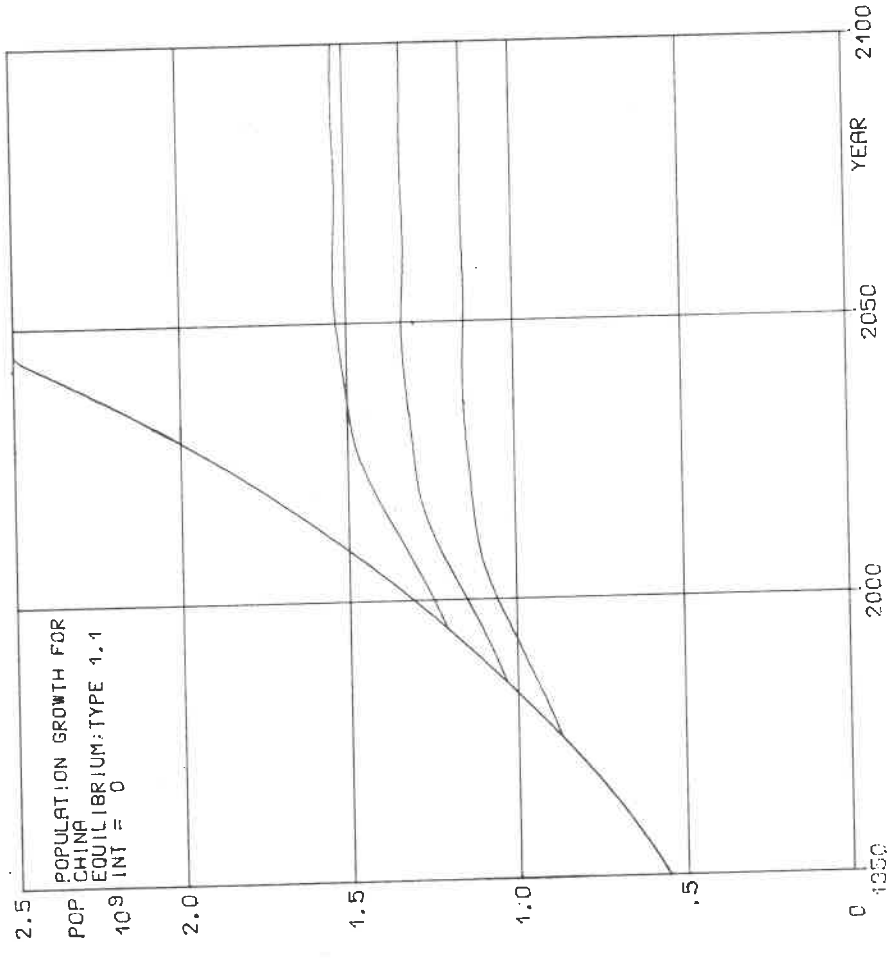

POPULATION GROWTH FOR
CHINA
EQUILIBRIUM:TYPE 1.1
INT = 0
POP
10^9
2.5
2.0
1.5
1.0
.5
0
1950
2000
2050
2100
YEAR

Fig. 202

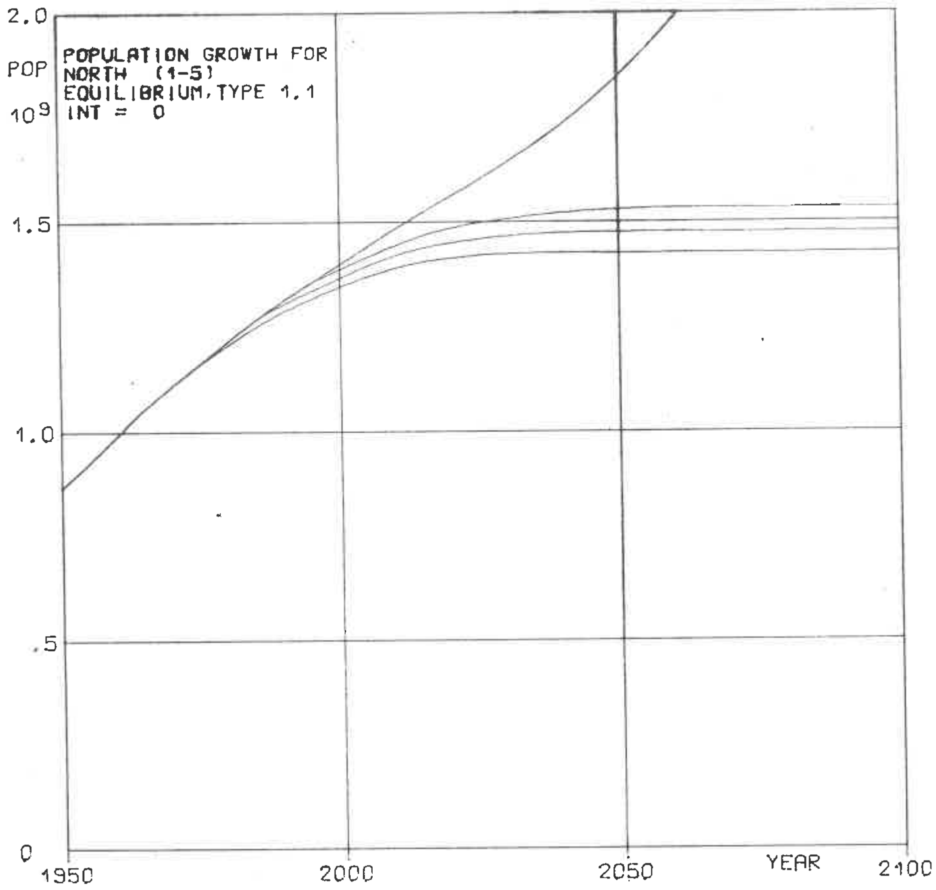

POPULATION GROWTH FOR
NORTH (1-5)
EQUILIBRIUM, TYPE 1.1
INT = 0
POP
10^9
2.0
1.5
1.0
.5
0
1950
2000
2050
YEAR
2100

Fig. 203

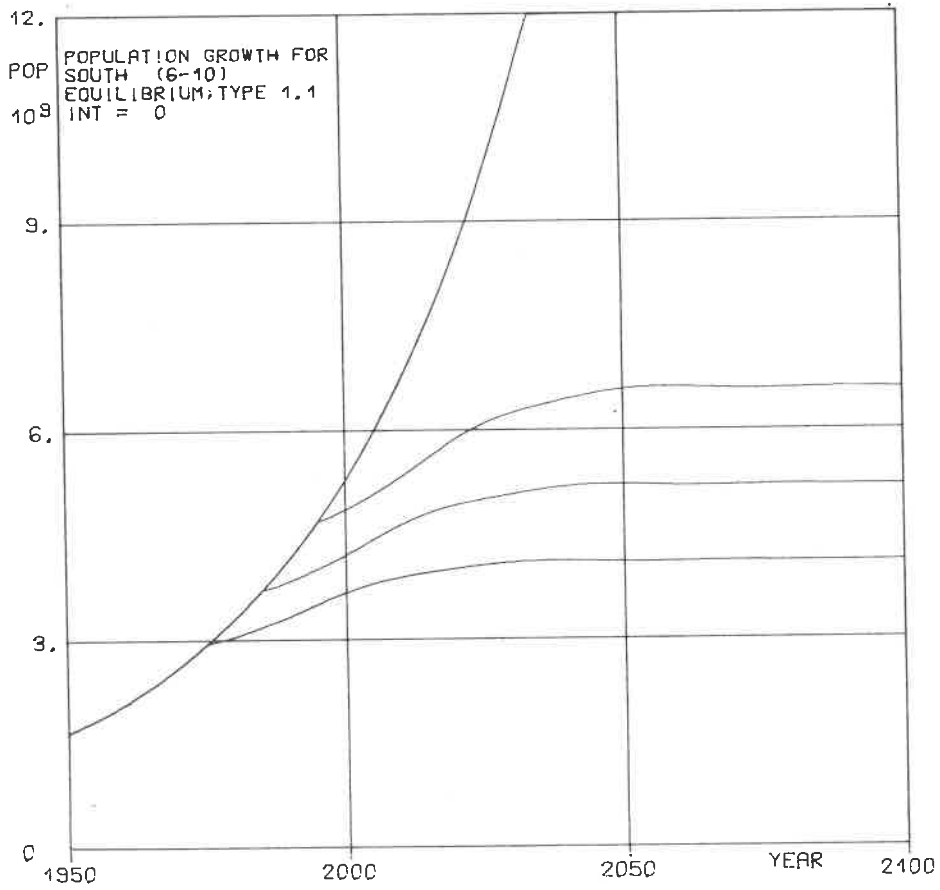

POPULATION GROWTH FOR
SOUTH (6-10)
EQUILIBRIUM;TYPE 1.1
INT = 0
POP
10^9
12.
9.
6.
3.
0
1950
2000
2050
YEAR
2100

Fig. 204

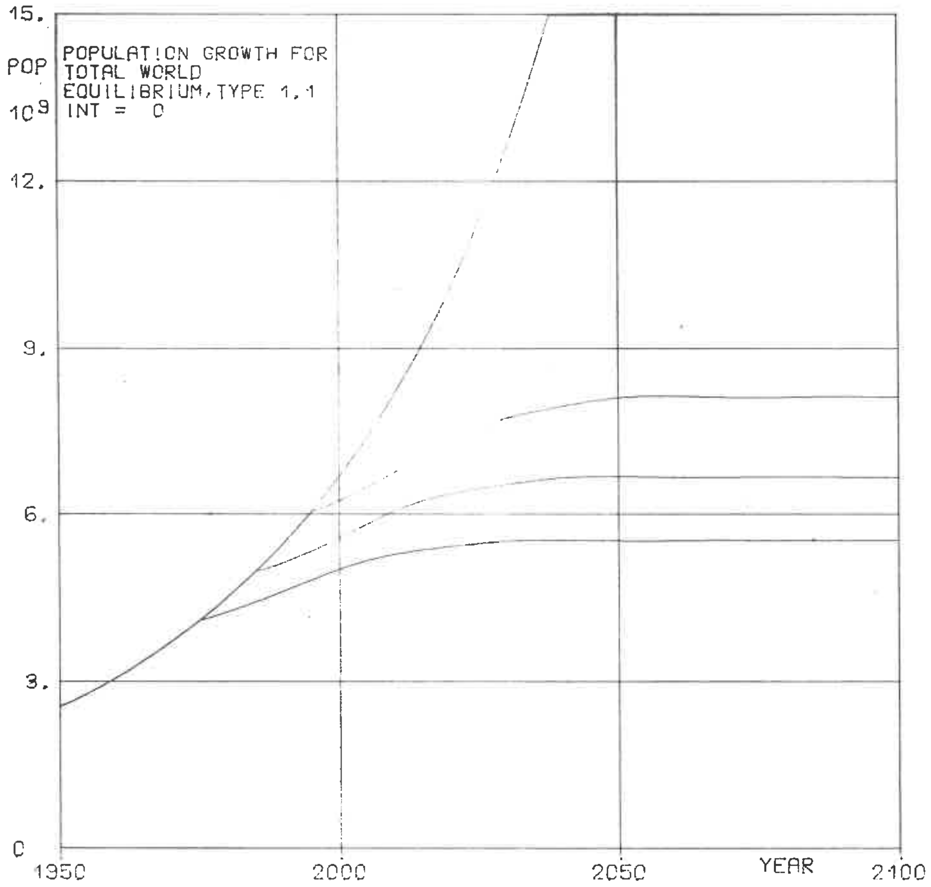

POPULATION GROWTH FOR
TOTAL WORLD
EQUILIBRIUM, TYPE 1, 1
INT = 0
POP
10^9
15.
12.
9.
6.
3.
0
1950
2000
2050
YEAR
2100

Fig. 205

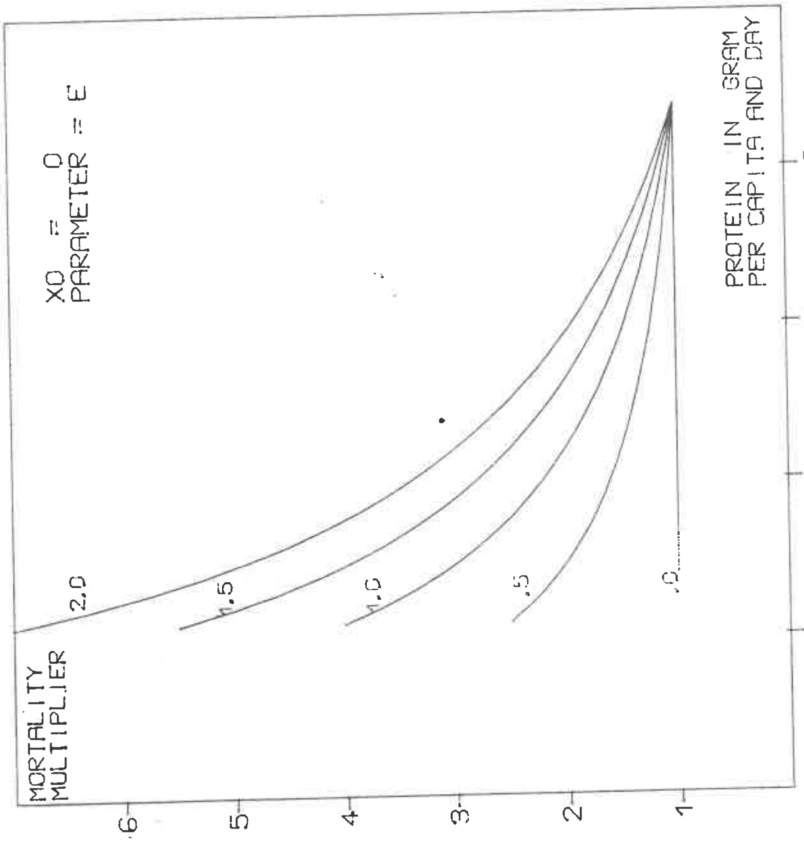

MORTALITY MULTIPLIER
XO = 0
PARAMETER = E
2.0
1.5
1.0
.5
.0
PROTEIN IN GRAM PER CAPITA AND DAY
6
5
4
3
2
1
10
20
30
40

Fig. 271

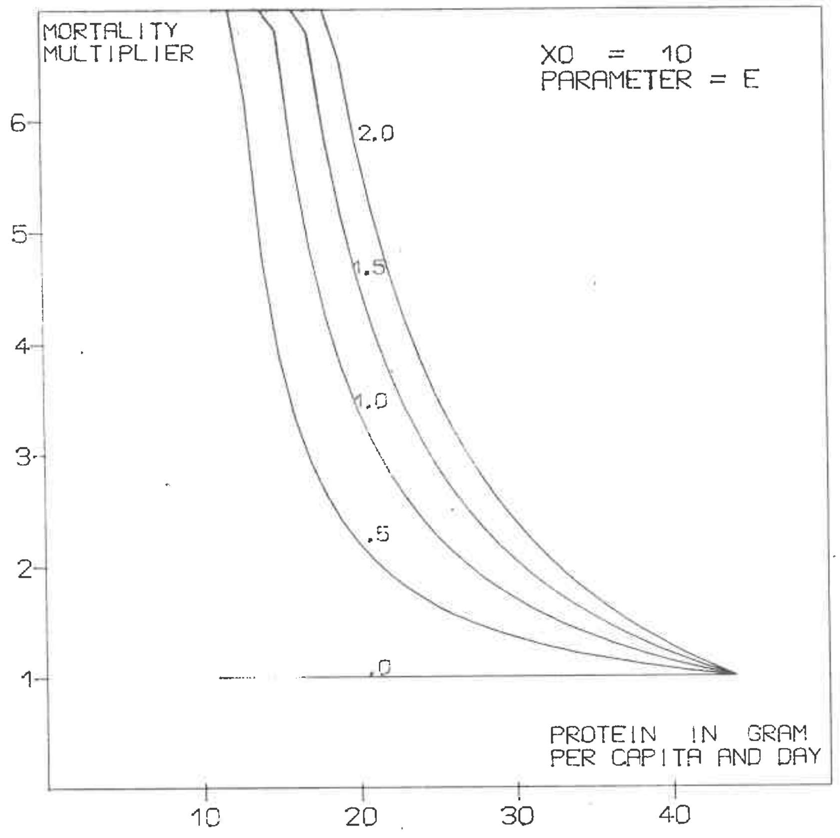

MORTALITY
MULTIPLIER
XO = 10
PARAMETER = E
2.0
1.5
1.0
.5
.0
6
5
4
3
2
1
10
20
30
40
PROTEIN IN GRAM
PER CAPITA AND DAY

Fig. 272

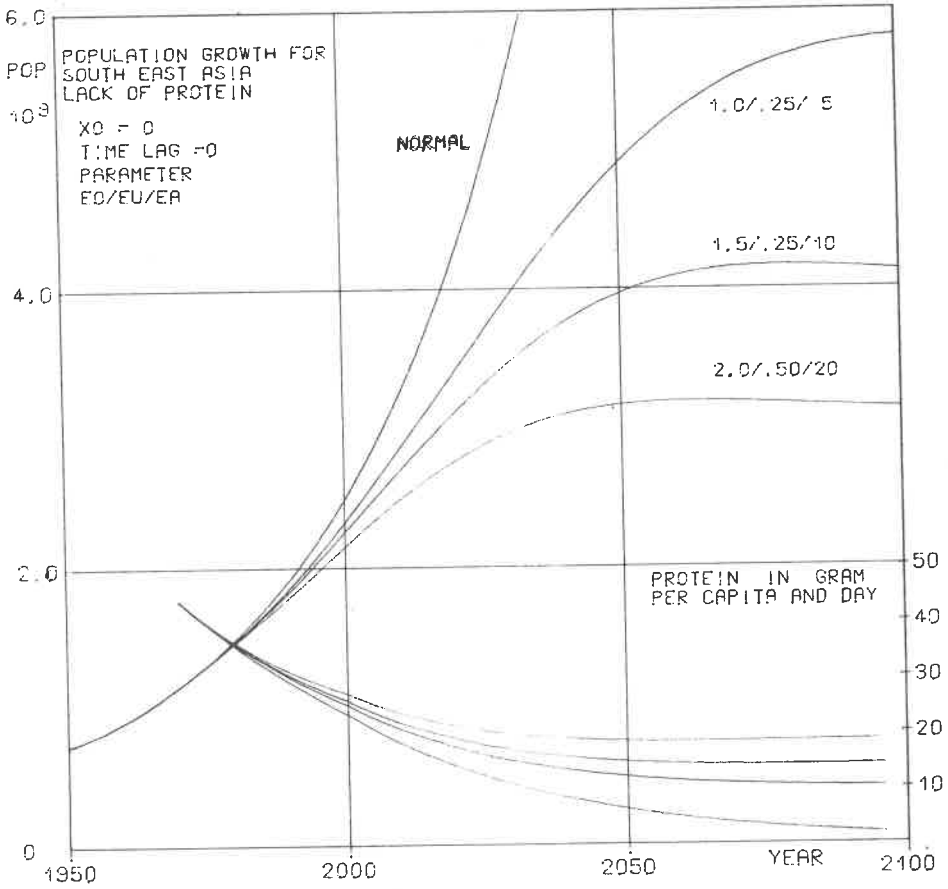

6.0
POP
10⁹
4.0
2.0
0
POPULATION GROWTH FOR
SOUTH EAST ASIA
LACK OF PROTEIN
XO = 0
TIME LAG =0
PARAMETER
EO/EU/EA
NORMAL
1.0/.25/ 5
1.5/.25/10
2.0/.50/20
PROTEIN IN GRAM
PER CAPITA AND DAY
50
40
30
20
10
1950
2000
2050
YEAR
2100

Fig. 273

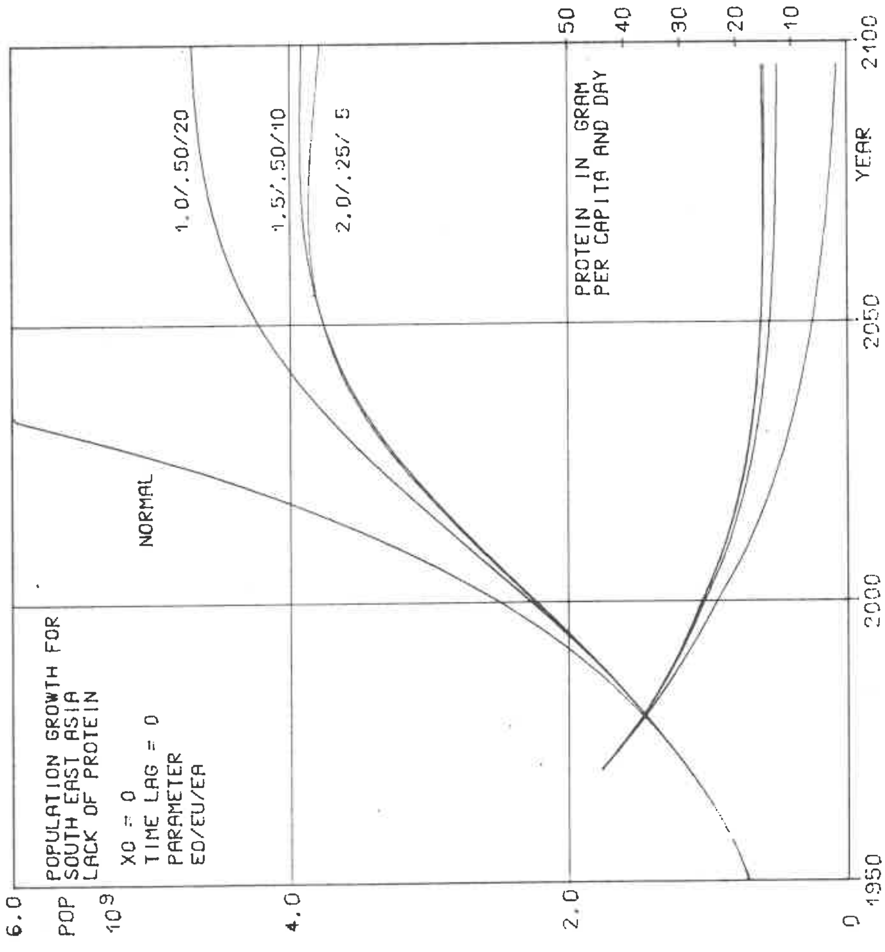

POPULATION GROWTH FOR
SOUTH EAST ASIA
LACK OF PROTEIN
XO = 0
TIME LAG = 0
PARAMETER
ED/EU/EA
NORMAL
1.0/.50/20
1.5/.50/10
2.0/.25/ 5
PROTEIN IN GRAM
PER CAPITA AND DAY
YEAR
6.0
POP
10^9
4.0
2.0
0
1950
2000
2050
2100
50
40
30
20
10

Fig.274

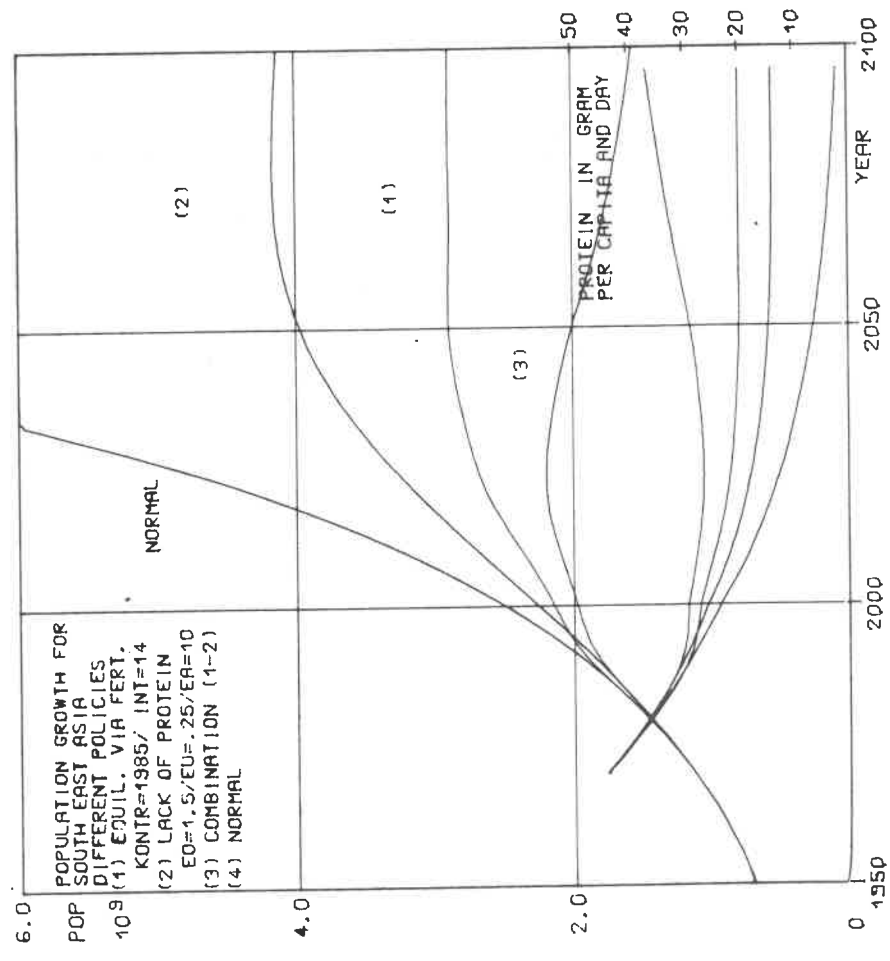

POPULATION GROWTH FOR
SOUTH EAST ASIA
DIFFERENT POLICIES
(1) EQUIL. VIA FERT.
KONTR=1985/ INT=14
(2) LACK OF PROTEIN
EO=1.5/EU=.25/EA=10
(3) COMBINATION (1-2)
(4) NORMAL
6.0
POP
10⁹
4.0
2.0
0
1950
2000
2050
2100
YEAR
NORMAL
(1)
(2)
(3)
PROTEIN IN GRAM
PER CAPITA AND DAY
50
40
30
20
10

Fig. 281

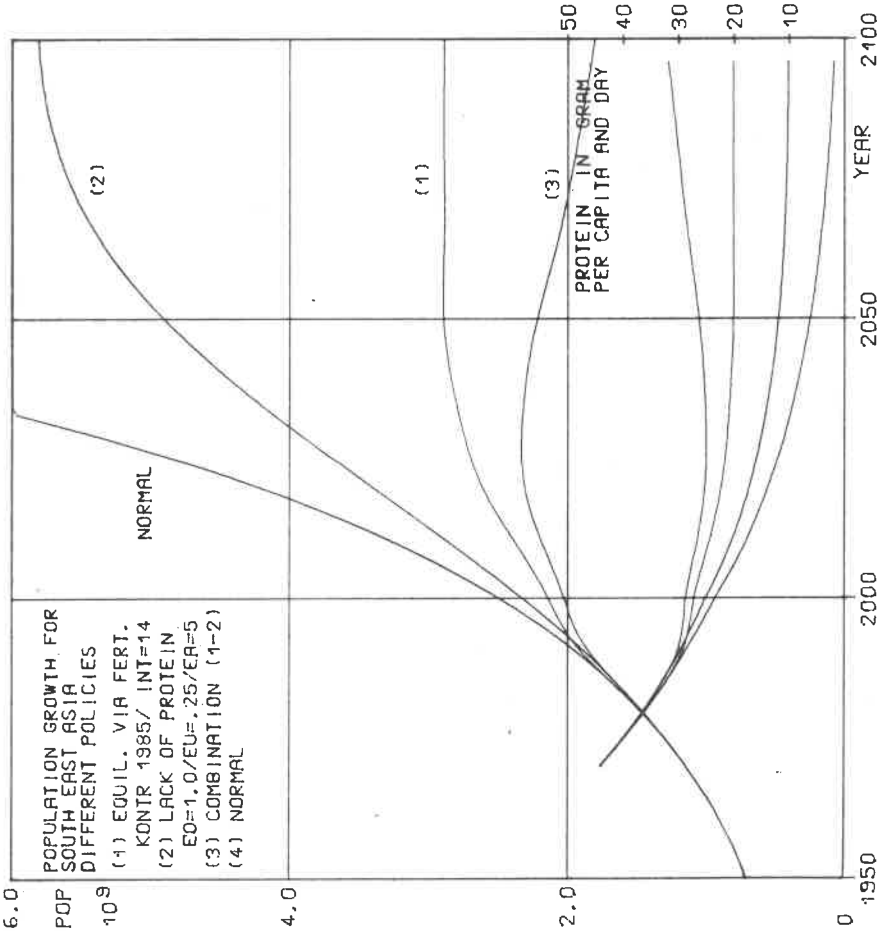

POPULATION GROWTH FOR
SOUTH EAST ASIA
DIFFERENT POLICIES
(1) EQUIL. VIA FERT.
KONTR 1985/ INT=14
(2) LACK OF PROTEIN
EO=1.0/EU=.25/EA=5
(3) COMBINATION (1-2)
(4) NORMAL
NORMAL
(1)
(2)
(3)
PROTEIN IN GRAM
PER CAPITA AND DAY
POP
10⁹
6.0
4.0
2.0
0
1950
2000
2050
2100
YEAR
50
40
30
20
10

Fig. 282

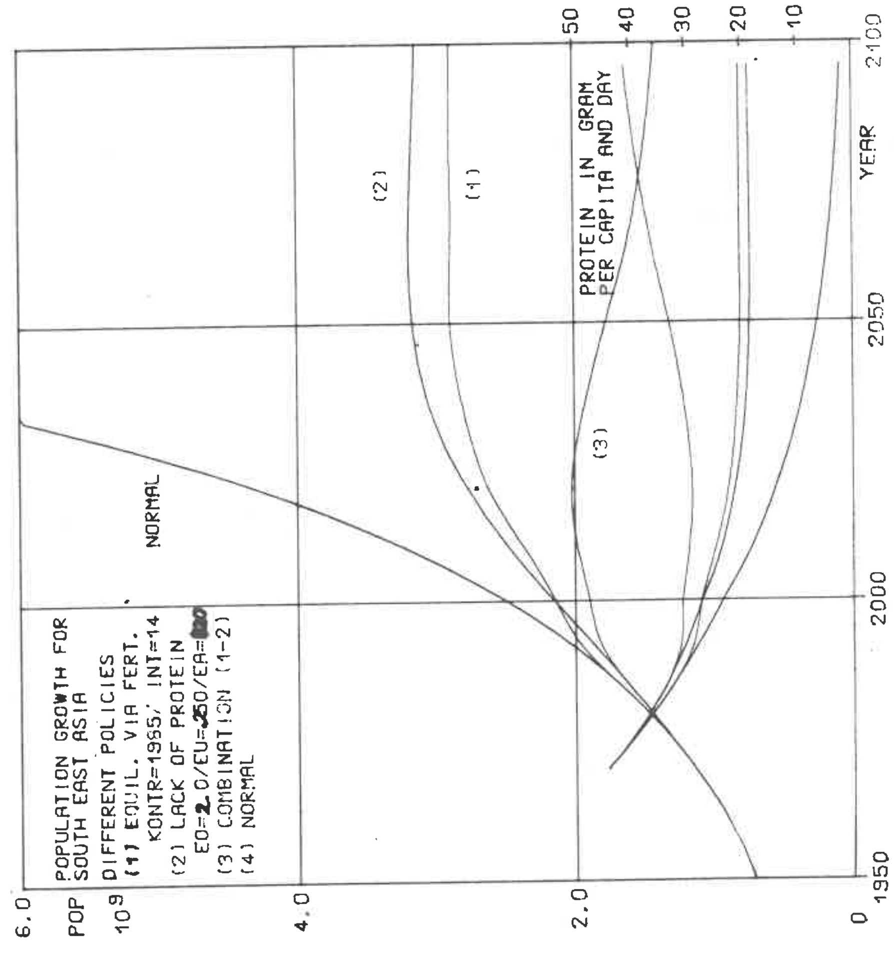

POPULATION GROWTH FOR SOUTH EAST ASIA
DIFFERENT POLICIES
(1) EQUIL. VIA FERT.
KONTR=1965; INT=14
(2) LACK OF PROTEIN
EO=2.0/EU=.350/EA=[illegible]
(3) COMBINATION (1-2)
(4) NORMAL
NORMAL
(1)
(2)
(3)
PROTEIN IN GRAM PER CAPITA AND DAY
POP
10^9
6.0
4.0
2.0
0
1950
2000
2050
2100
YEAR
50
40
30
20
10

Fig. 283

III.2. A SUBMODEL OF THE RELATIONSHIP BETWEEN SELECTED NUTRITIONAL VARIABLES AND EXCESS MORTALITY IN POPULATIONS

T. Weisman

April 1974

Most people agree that there exists some sort of feedback mechanism between the food supply available to a population, and its subsequent growth and change. We are postulating an extrémely simplified model of this feedback relationship, yet one which, as we hope to show, is both realistic and justifiable. The intuitive statement of the relationship is that as less food becomes available to a population, there is a point at which general mortality increases so as to have a dramatic impact on population dynamics. Our task is to both qualify and quantify this relationship.

Human nutrition is complicated subject about which many questions remain unanswered. Certain things, however, are relatively clear. The National Research Council of the Food and Nutrition Board has recommended certain minimum levels of calories (energy), protein, ten vitamins, and five minerals necessary to maintain a healthy state (NAS, 1968). These minimum levels are sometimes very difficult to determine with any degree of confidence, partly because they vary with different individuals in a population as well as with a single individual at different times. Because of these and other factors, there is often disagreement about appropriate nutrient levels. But for our purposes, namely the construction of a model, it is necessary to simplify. To construct a nutrition model with 17 interdependent parameters (with many of the interactions being unknown) is simply not a realistic task. Therefore, we must choose those factors which seem to be the most important indicators of the general nutritional state of a person or population. There is little disagreement that the two most significant indicators are calories (energy) and protein. Sufficient quantities of both are vitally important to health and well-being. Sufficient calories and insufficient protein have been implicated in kwashiorkor, a significant cause of morbidity and mortality in young children around the world. Furthermore, when calories are insufficient, protein is diverted from its maintenance function to energy production, often causing protein deficiency even in the presence of supplementation of the diet with added protein (WHO, 1973) However, the incidence of this latter condition is much rarer than the former.

Because an adequate intake of either energy or protein by itself seems to be a necessary but not sufficient condition for adequate nutrition, and because adequate intakes of both seem to be fairly well correlated with good nutritional status, we will use both factors in constructing our model. Although a previous, more simplified iteration of this model used only protein as an indicator of nutrition, the effect of energy insufficiency was implicitly included. For the reasons given below, it will be seen why including both energy and protein in our model yields a more accurate and defensible representation of reality as well as a more discriminating predictor of future trends.

The human need for energy is based on three basic, interrelated factors:

(1) Body size and composition
(2) Physical activity
(3) Age

All of these factors reflect on the three basic needs for energy, the needs for maintenance, growth, and activity. The maintenance need for energy is the amount of energy which must be consumed to stay alive under conditions of minimal activity. It is basically unaffected by ethnic origin and seems mainly dependent upon the surface area of the body, correlating well with the body weight raised to the power 0.75.

The energy need for growth is basically the amount required for the deposition of new tissue. This value in infants, children and adolescents is approximately 5000 calories per kg of new tissue added.

The obligatory effect of activity on energy requirement is obvious. The WHO categorizes physical activity into four classes: light, moderate, very, and exceptionally, for both men and women. Energy requirements are calculated on the basic weight, sex and moderate activity. Correction factors, which are percentages of total energy requirement of moderate activity are (WHO, 1973):

Light activity	90%
Moderate activity	100%
Very active	117%
Exceptionally active	134%

These factors apply to the various age and sex groups from 13 years onward; however, at this stage of model building we will assume both average weights and moderate activity for all individuals.

Another correction factor is necessary to account for the effects of age. The WHO gives energy requirements for the age 20-39 as a baseline for adults. As people age, for reasons not yet completely determined, their energy requirement diminishes. The following table summarizes the correction factors (WHO, 1973):

20-39 years	100%
40-49 years	95%
50-59 years	90%
60-69 years	80%
70 years and over	70%

We are now in a position to summarize the energy requirements for a population. Because the population model does not break age groups into males and females, we will assume equal numbers of males and females in each age group and use the mean energy requirement for the entire age group. Furthermore, the energy requirements for pregnant and lactating women are implicitly included in the figures for infants less than one year of age. The following table summarizes our age-specific energy requirements (WHO, 1973).

TABLE I

Age-specific energy requirements

Age	Energy per person/day
1	820
1	1180
2	1355
3	1540
4	1695
5	1830
6	1955
7	2075
8	2185
9	2295
10	2400
11	2475
12	2550
13	2625
14	2700
15	2750
16	2735
17	2720
18	2685
19	2610
20-39	2600
40-49	2470
50-59	2340
60-69	2080
70 and over	1820

It now becomes a straight-forward task to calculate both the total and per-capita energy requirements for any population generated in our model. How we will use these figures (in comparison to the figures generated by our Food Model), will be discussed after we consider the human need for protein.

In contrast to the well quantifiable and predictable needs for energy in any given individual, the individual needs for protein seem to vary in a fashion which is only probabilistically predictable. That is, for any group of people of the same age, sex, ethnic background, weight, and activity, individual protein needs will vary in a gaussian distribution, the mean and standard deviation of which can be determined.

It is therefor possible to stipulate a level of protein intake for an age-sex group in a population which would suffice for a vast majority of the individuals in that population. This is precisely the path taken by the WHO.

But before going into the actual numbers involved, it is necessary to discuss the role of protein in diet and metabolism. Protein is the building material of life. Much of the musculo-skeletal and vegetative systems of the body are composed largely of protein, as are all of the enzymes controlling the biochemical processes of metabolism. The protein in the body is never in a static state, but is always being catabolized (broken down) and renewed. This constant turnover, plus the requirements for growth in children, as well as the lack of any specific storage mechanism for protein in the body, necessitates the daily intake of an adequate amount food protein to prevent an actual net loss of body protein (loss of body tissue). Prolonged inadequate protein intake (depending on its severity) in adults causes loss of body substance, increased susceptibility to stress and infection, and ultimately, death. In children, it retards or prevents normal growth and development, decreases resistance to infection, and is ultimately fatal (Cravioto and DeLicardi, 1973; Ramalingaswrmi, 1973).

The WHO committee examined research on daily obligatory nitrogen loss in humans on a protein-free diet. Nitrogen loss is an indicator of protein catabolism (breakdown) in the body. The committee asked the question, what is the minimum amount of protein intake necessary to replace that which is obligatorily catabolized daily? They also examined research on "nitrogen balance". Nitrogen balance studies attempt to determine the minimum amount of daily protein intake which will result in a net nitrogen balance. That is, the amount of protein catabolized (estimated by nitrogen excretion) is balanced exactly by the amount of food protein ingested.

Using the data from all of these studies the committee arrived at a mean protein requirement for adult men and women, adolescents boys and girls, children. They found that the coefficient of variation (standard deviation ÷ mean) for these figures was about 15%, so they estimated that 130% of the mean values would suffice for approximately 97+ % of the population.

The protein specified in these figures is milk or egg protein, both of which are very efficiently utilized by the body. However, most human diets contain proteins which are less efficiently utilized. Therefore, the committee gives "safe" levels adjusted for various quality of proteins. The protein in the average diet in developed countries is approximately 80% as efficient as milk or egg protein. In most developing countries a 70% figure is appropriate (due to lower intake of animal protein). In the very poorest countries where the majority of proteins come from maize or cassava, a 60% figure is used. This is summarized in the following table (WHO, 1973).

TABLE II

Safe level of protein (130% times the mean requirement) in terms of qualities of 80%, 70% and 60% relative to milk or eggs.

Age	Grams egg protein per person per day	Adjusted levels grams/person/day 80	70	60
6-11 months	14	17	20	23
1-3 years	16	20	23	27
4-6 years	20	26	29	34
7-9 years	25	31	35	41
10-12 years	30	37	42	49
13-15 years	34	42	49	57
16-19 years	34	42	49	57
Adults	33	41	47	55
Add for pregnant woman (2nd half of preg.)	add 9	add 11	add 13	add 15
Add for lactating woman (1st six months)	add 17	add 21	add 24	add 28

We are now ready to construct our model. The first step is to look at calories. Using the population distribution of any given region, and our table I, we can calculate the number of calories necessary to satisfy the energy requirements (assuming moderate activity as a general average) for the population of that region. From our food model, we are able to obtain the net total calories available to people in that region. We now compare the figures. If the calories available exceed the calories required, we go on to look at the next step, namely protein. If the calories available are less than the amount needed, we have, depending on the magnitude of the discrepancy, a famine.

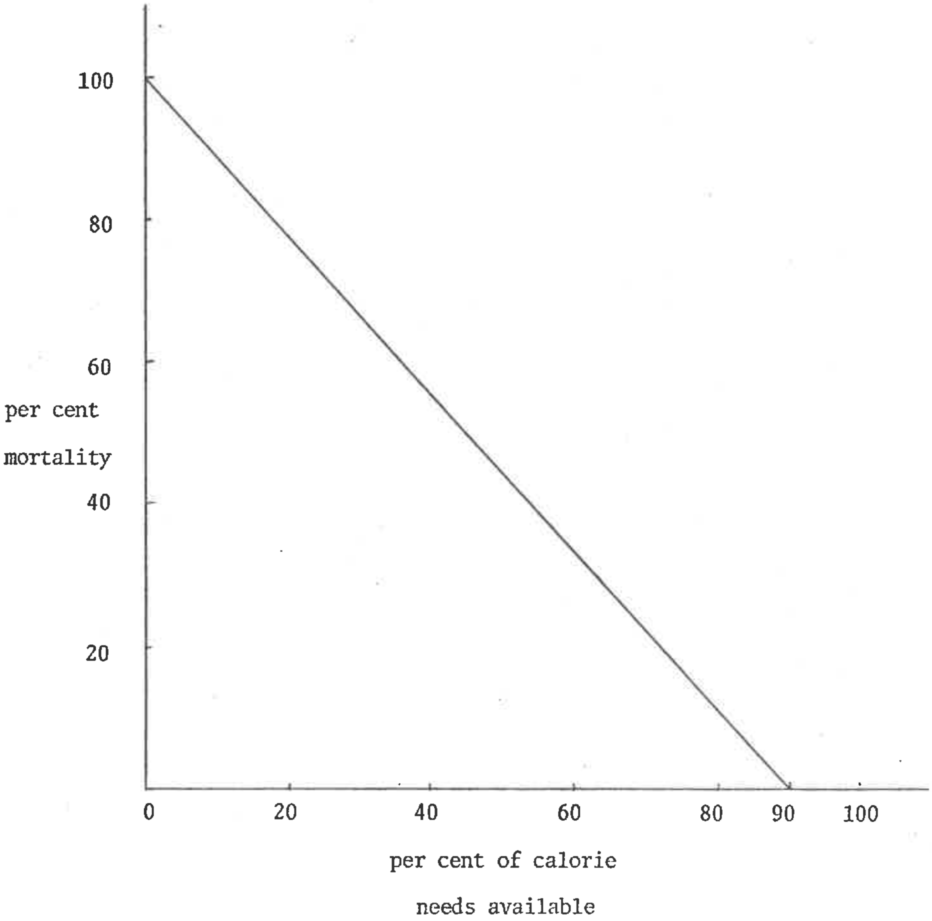
It should be mentioned parenthetically, that certain adverse effects occur when there is a large excess of calories available to a population, namely obesity and its adjuvant effects on mortality from diabetes and cardiovascular diseases. However, these manifest themselves mainly in the elderly, post-reproductive members of a population and have little influence on population dynamics. For this reason, we will, for now, ignore the situation of over-abundance of calories.

The chief question is, how will a lack of calories affect age-specific mortality in a population? The first effects are compensatory in nature. In both children and adults, activity is decreased. In adults, body weight falls, in children growth is retarded. All of these adaptations serve to reduce energy requirements. In situations where the food shortage is acute, following a period of good general nutrition (perhaps an isolated crop failure) these mechanisms are more effective. However, when the food shortage is chronic, individuals have little or no reserve capacity with which to cope. Furthermore, children, because of their energy needs for growth and smaller stored reserves (fat), are particularly vulnerable to not only the direct effects of malnutrition (starvation), but also demonstrate increased susceptibility and mortality due to infectious and parasitic diseases. This is in addition to the fact that during a famine, children are often less able to compete for the scarce supplies of food available.

Because, in a sense, you either eat enough calories to survive or you starve, we can postulate a linear relation between the percentage of needed calories available and the percentage of the population that survives. Essentially this means that if 75% of the necessary calories are available to a chronically deprived population, approximately 75% will survive. This does not directly consider such factors as food distribution or death due to infectious and parasitic disease, but contains them implicitly. But it is a simplification which seems sensible. If you have 100 people to feed but only food for 75, you may try to feed all 100 on a reduced ration. But in real life, in a long-term situation, some will receive adequate food, others will starve. Furthermore, some of those receiving reduced rations will not be able to survive due to increased susceptibility to disease, while others will.

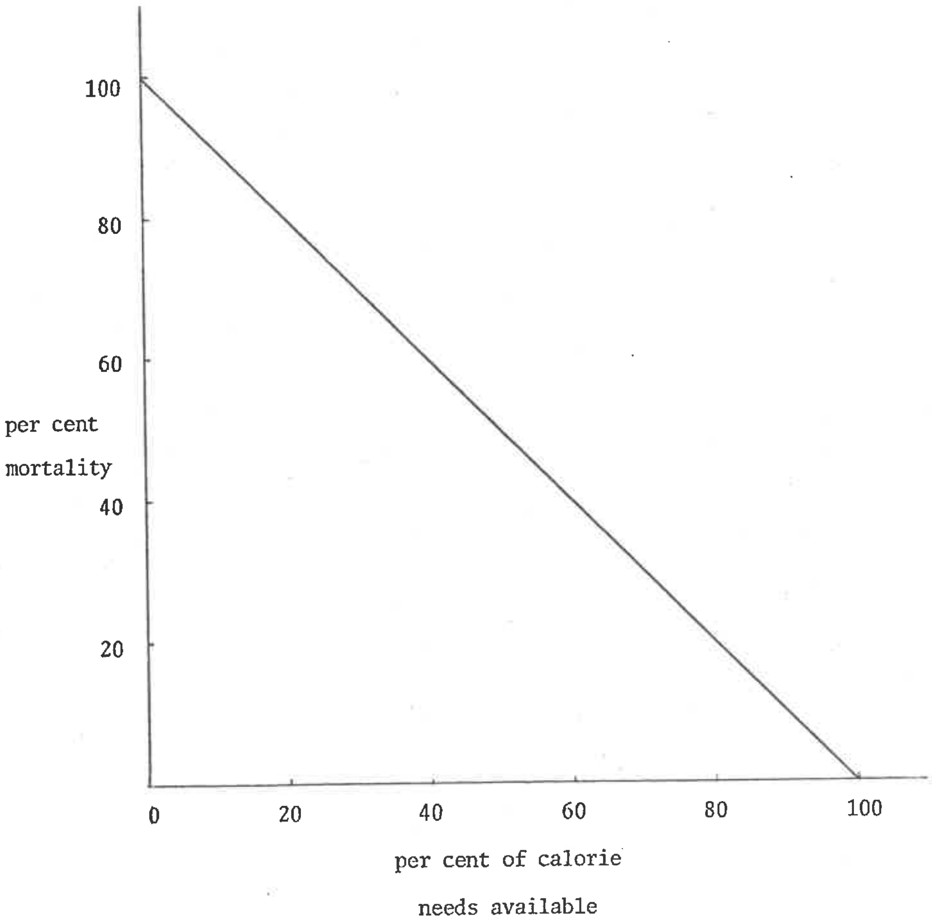
We must postulate two relations. The first concerns situations in regions which, during the preceeding year, had adequate calorie and protein supplies, but for some acute reason (e.g., a local crop failure) in the present year manifested a calorie shortage. Because an individual engaged in light activity requires only 90% of the calories of one engaged in moderate activity (our standard), we are assuming that a well nourished population can withstand a single, acute calorie shortage of as low as 90% of requirements without increased mortality, but that any larger deficit will have a linear effect on mortality as illustrated below: (Relation A)

RELATION A



In a population which during the preceding year had been exposed to either a lack of protein or a lack of calories, any existing reserves would have been used up. Therefore the following relationship is postulated: (Relation B).

RELATION B



We further postualte that there is an increased mortality among the young in situations of food shortage. This is due to such factors as inability to compete with adults for scarce supplies, and retardation of growth, development, and immunological competence. Although we cannot accurately quantify all of these factors, we can determine that the child's specific requirement for energy (calories per kg body weight) is higher than the adult's. It seems reasonable, then, to use this figure as a factor to calculate the increased mortality among younger people to any given food shortage. These figures, based upon the increased energy requirements of children and adolescents, follow in table III (WHO, 1973).

TABLE III

Increased age-specific mortality factors* (calories)

Age	Factor
1	2.6
1-3	2.35
4-6	2.1
7-9	1.8
10-12	1.55
13-15	1.25
16-19	1.05
Adults 20	1.0

* When 39% or more of adults are dying all infants are dying. This is reasonable, for if a famine is this bad, no infants will survive. For computational purposes, mortality in any age group is limited to 100%.

We now come to protein requirements. If a population is not getting adequate calories, protein is usually deficient as well. However, a population may be receiving adequate calories but insufficient protein. This is the case in many areas of the world today.

Using table II and the population distribution of a region, we can calculate "safe" levels of protein intake for the entire region corrected for the average quality of protein available in that region. This total, divided by 1.30, yields a figure we shall call the "mean requirement" for the region. Fifteen percent of this "mean requirement," we shall call the "standard deviation requirement."

We now compare the "mean requirement" for protein in a given region with the net amount of protein actually available to consumers in that region. The difference between the net available protein and the "mean requirement" divided by the "standard deviation requirement" will give us a distance, in σ units from the mean of a standard gaussian distribution. The integral of this distribution at that point yields a per cent survival figure. For example, if the calculated "mean requirement" for a region is one hundred million grams of egg equivalent protein, and the available protein of 70% quality is 178.6 million grams, we perform the following computations:

(1) $(178.6 \times 10^6) \times .7 = 125 \times 10^6$

(2) $125 \times 10^6 - 100 \times 10^6 = 25 \times 10^6$

(3) $(25 \times 10^6) \div (15 \times 10^6) = 1.67$
(standard deviation requirement)

(4) $+ 1.67\ \sigma$ from the mean of a standard gaussian distribution includes 95.25% of the area.

We would then use this resultant figure, 95.25% as the percentage of adults surviving that year, or, in other words, 4.75% of adults would die from causes related to protein deficiency in that year.

As is the case with calories, the specific need of children for protein are higher than for adults. For the same reasons given before, we postulate an age-specific mortality multiplier for protein, based on the specific (per kg body weight) needs for protein of various age groups. These are given in table IV (WHO, 1973).

TABLE IV

Increased age-specific mortality factors* (protein)

Age	Factor
1	3.35
1	2.35
2	2.20
3	2.05
4	1.95
5	1.85
6	1.80
7	1.70
8	1.60
9	1.55
10	1.50
11	1.45
12	1.40
13	1.33
14	1.23
15	1.15
16	1.12
17	1.08
Adult	1.0

* as before, mortality in any age group is limited to 100%, all infants dying when 30% or more adults are dying.

We now have, in cases where both calories and proteins are inadequate, two sets of mortality figures for each age group. Since any sort of weighted summing is harder to justify that a "limiting factor" hypothesis, we will take, as a mortality figure for any given age group, the calculation which gives us the higher mortality. That is, either calories or protein will act as a limiting factor on the number of people in any age group who survive nutritional deficiency.

The final point to mention is how these derived mortality figures will interact with the population model. In order to restrict ourselves to the situation where nutritional status and food supply are the decisive factors, we should first examine mortality patterns in situations where, due to a long history of adequate food supplies, malnutrition has had no effect on mortality patterns. That is to say, even under circumstances of perfectly adequate nutrition a proportion of people in all age groups will nevertheless die in any given year. We shall examine mortality patterns in a number of situations where malnutrition can, for all practical purposes, be ruled out as a cause of, or contributor to, mortality. From these situations we can propose a baseline mortality pattern to use in our calculations. For example, if in our baseline pattern, the expected mortality in an age group is 1.5% and our model generates a nutrition-dependent mortality of 5.0%, 1.5% + 5.0% yields a total mortality of 6.5% in that age group under those nutritional conditions.

A summary of the steps followed in the model is:

(1) Calculate energy requirements of region (Table I)

(2) Compare to total net calories available to region
    (a) if ratio$>$1 go to protein calcualtions
    (b) if ratio$<$1 go to step (3)

(3) (a) If during the previous year no excess mortality was due to nutrition, calculate excess mortality using relation A
   (b) Otherwise use relation B

(4) Use figure obtained in (3) with Table III to obtain age-specific excess mortality with respect to calories

(5) Calculate "mean requirement " and "standard deviation requirement" for protein for the region (Table II)

(6) Compare "mean requirement" to total net protein (consider quality) available to region.

(7) Derive excess mortality factor using standard gaussian distribution.

(8) Use figure derived in step (7) with table IV to obtain age-specific excess mortality with respect to protein.

(9) Compare age-specific mortality rates generated in step (4) and step (8) and use the higher mortality rate for each age.

(10) Add nutrition-dependent mortality rate obtained in (9) to the baseline mortality rate to obtain final mortality rates for each age.

(11) Feed results of step (10) back to the population model.

REFERENCES

1. Cravioto, J., and De Licardie, E.R.: "The Effect of Malnutrition on the Individual," in Nutrition, National Development, and Planning, edited by Berg, A., Scrimshaw, N.S., Call, D.L., Cambridge, Massachusetts, MIT Press, 1973.

2. National Academy of Sciences Publication 1964, Recommended Dietary Allowances, 7th edition. Washington, D.C., 1968.

3. Ramalingaswami, V.: "The Effect of Malnutrition on the Individual: Cellular Growth and Development," in Nutrition, National Development, and Planning, edited by Berg, A., Scrimshaw, N.S., and Call, D.L., Cambridge, Massachusetts, MIT Press, 1973.

4. World Health Organization Technical Report Series No. 522, Energy and Protein Requirements. Geneva, 1973.

III.3. A REGIONALIZED FOOD MODEL FOR THE GLOBAL SYSTEM

W.B. Clapham, T. Shook, M.W. Warshaw

April 1974

Introduction

The most dramatic of the "limits to growth" is food. It has a directness and an absolute quality about it which other potential limits do not have: If a person gets enough food of adequate quality, he can survive and be a productive member of society. If he does not, his productivity will be impaired, and he may not even survive. In many countries, food production is the primary activity, the most important industry, and the prime generator of foreign exchange. It is a complex activity in all areas, representing the confluence of policies governing land use and applied technology, and its spatial complexities stem not only from the historical development of man-land interactions but also the differing ecological potentials of the land itself.

There are no widely accepted estimates of how much food can be produced on the earth today. On one hand, it has been estimated that enough food can be grown to provide a minimum diet for 104 billion people[1]; on the other hand, incipient famines have been predicted for many years[2].

It is implicit in a world whose population is growing that basic subsistence needs (at least) must be met. But food production systems are already being put to an extreme test; and there is some doubt that they can meet the demands being put on them for much longer[3]. There are also severe fallouts of changing the food supply systems on the remainder of the society. The classic paradigm for agricultural change, increasing the intensity of technology, has the by-effect of reducing the man/land ratio and "liberating" thousands of able-bodied workers from the agricultural labor force. But cities cannot always absorb the new workers,[4] so that social turmoil is a common and perhaps necessary result of increasing the capability of food supply systems. The only alternative paradigm that can be observed, agricultural involution as described by Geertz[5], is no more attractive a goal.

In a very simple way, there are only three ways to increase the production of food to meet increasing demands: increasing the area under crop, shifting crop types to those with greater yields, and increasing yields per hectare of a given crop by more intensive farming. All three of these options have been exercised throughout the history of agriculture, but the first has tended to be the first and easiest step; the third has been the most difficult and last. Today, there are parts of the world where virtually all of the potentially arable land is cropped and the mixture of crops is the most productive mixture feasible. The only way that production can be increased is to intensify the farming system to increase yields per hectare production. Even in areas which have much potentially arable land left undeveloped, such as South America and Africa, the land remaining is of poor quality and productivity cannot be increased on these without fairly intensive care[6].

The approach used in this report is predicated on two postulates: first that it is reasonable to view agriculture in an ecosystems framework and secondly that we know enough about agroecosystems to gauge their responses to specific stimuli. These postulates deserve some discussion.

Food-producing ecosystems are of many types, including fields, cultivated fish ponds, pastures, feedlots, marine fisheries, and the like. All have their own methods of exploitation, all are regulated by their own internal feedback devices, and all show considerable variations from place to place. But as ecosystems, they are all governed by the geochemical and biological laws of ecology, and the responses of an ecosystem to some input are controlled by the structure of the ecosystems and the nature of the input much more than by the nature of the society which is making the input. This means that we need not consider political or economic processes in order to describe or simulate the agroecosystems, except as these processes set limits to a society's ability to use a specific input. However, we may need to deal explicitly with ties among agroecosystems.

The possible inputs into the agroecosystems are relatively few: fertilizers containing nutrients from a fairly restricted set, certain methods of soil conditioning, some sort of weed and pest control, and decisions on specific uses of land. But if the responses of agroecosystems to them are functions of the geochemical and biological interactions which occur in the given place, the intensity with which a society uses the inputs at its disposal are controlled by its perceptions of its goals and its own socio-political structure. What this means is that we can simulate agricultural production using a straightforward physical model whose complexity lies only in its ability to consider explicitly the differential productivity of ecosystems, and setting the regulating feedback loops external to the agroecosystems in the socio-economic sphere as they are actually found. For this reason, we have constructed an integrated model including three components: Population growth, an economic model determining investment in various parts of food production, and the physical agroecosystem model. The population and economic models are discussed in detail elsewhere[7]; this report concentrates on the physical agroecosystem model.

The Data Base

The agroecosystem model is based on as much regional data as is available to us. With some exceptions, the data and statistical summaries are from the Food and Agricultural Organization of the United Nations (FAO). The FAO publications used as data sources include the Production Yearbooks of 1970, 1967, 1964, 1961, 1958, 1955, 1953 and 1951, the summary volume of World Crop Statistics 1948-1966, the Fisheries Yearbook, 1970, and the Food Balance Sheets, 1964-1966. Detailed mathematical relationships between variables are based on long time series of up to 22 years. Less intricate relationships are based on the dataof the last few years only. The specific data used to derive the relationships used in each sector of the model are footnoted in the body of the report.

There should be some discussion of the usefulness of the FAO statistical data. Their sources are member governments, and they reflect whatever insufficiencies exist either in data gathering or in political bias. There are a number of missing data points, and the quality of the data varies markedly from region to region and from country to country within a region. All of this means that the data are "noisy" and not as precise as might be desired. In addition, different sets of statistics use different reporting intervals, most commonly either the calendar year or the year ending on 30 June, but other specific years also apply. Despite these problems, we believe that the FAO statistics are a reasonable reflection of at least the commercial phase of world agriculture, and that no better data are available.

Model Structure -- Overview

The food model is designed to be as realistic and complete as possible within the context of a simple dynamic model. To this end, it considers both the production of foodstuffs and allocation of this production to various uses within a given region. Production is considered in three different sectors representing different ways of exploiting available resources and different types of ecosystems. These are field crops, livestock, and fisheries. The land bases for field crops and livestock are calculated by a land use sector, and the model is driven by the economic and population models which have been integrated with the food model. Gross production is expressed in terms of 26 different foodstuffs (Table 1), of which 5 are cereal grains, 8 are non-cereal crops, and the remaining 13 are various meat, fish, and dairy products. The food processing and allocation sector of the model allocates each foodstuff into its use as seedstock, livestock, feed, and food for the human population. Per-capita diet with regard to each foodstuff is calculated, and the results are summed into total calories, total protein, and animal protein. The overall structure of the food model is shown in Figure 1. The main usefulness of this model is that we have considered food in fairly concrete terms. That is, we have considered enough different types of food to allow a feeling for the spectra of food production in different regions of the world, the different uses to which foodstuffs are put in different region, and the nature of the diets that we are predicting for the future.

TABLE 1

Foodstuffs considered in the World Food Model

Cereal Grains

Wheat
Maize
Millets and Sorghum
Rice
Other Cereal Grains

Non-Grain Crops

Sugar Crops
Starchy Root Crops
Vegetables
Pulses
Fruits
Oil Crops
Drinks and Stimulants
Fibers

Meat Products

Beef and Veal
Pork
Lamb, Mutton, and Goat
Horsemeat
Poultry Meat
Edible Offals
Other Meat
Fish

Dairy Products

Honey
Eggs
Milk
Cheese
Butter

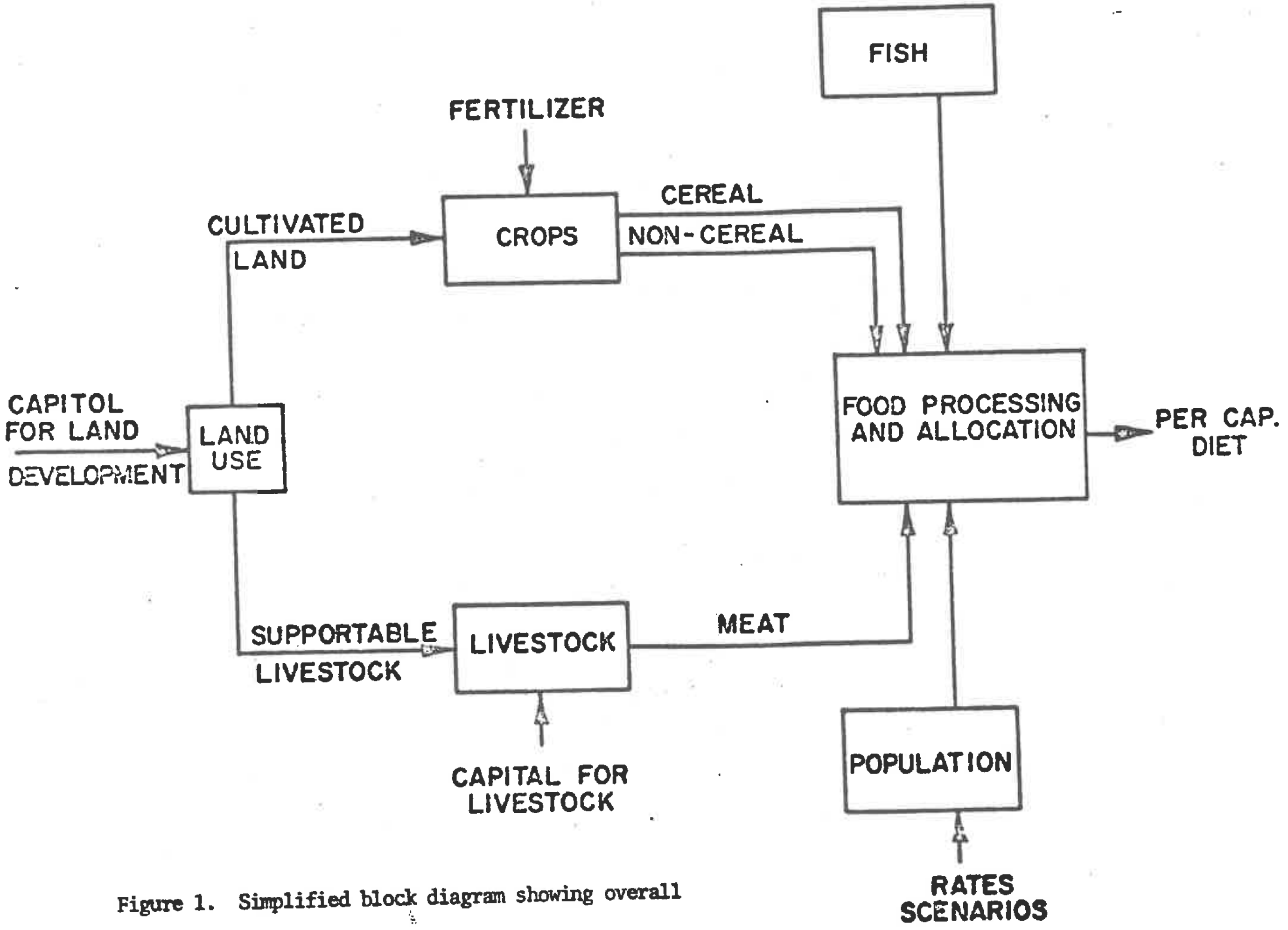


Figure 1. Simplified block diagram showing overall structure of food model

Production of Foodstuffs

The land use sector of the model considers the land which is used for growing crops, that which can potentially be cultivated for crops, land which is potentially grazable but nonarable, and lands which are removed from cultivation or grazing by urbanization or other nonagricultural uses. Land cultivated in cereal grains is the state variable for this section, with maximum arable land a boundary condition and land cultivated in non-cereal crops based on land cultivated in cereals. Rates of development and withdrawal of cereal-cultivated land are calculated by the economic model. We concentrated on cereal grains because these are the most important crops from the viewpoint of calories and gross production; also the basic data on production and area in cereals appears the most reliable.

The field sector of the model relates the land base and technological input to gross crop production (Figure 2). The land base is the total land cultivated in cereal grains as calculated from the land use sector of the model. Technological inputs are expressed in terms of fertilizer usage in kg./ha. The amount of fertilizer used in a region is calculated through the economic model, which determines the amount of money available for purchasing fertilizer in a given year. Obviously, fertilizer is not the only technological input, but it is the most convenient and realistic index of the whole technological package, and data on both its production and consumption are readily available. Indeed most of the advances in agriculture which have been made in the last 25 years have been closely tied in some way with fertilizer use. The main thrust of the Green Revolution, for example, has been to develop new crop lines which would respond better to more intensive

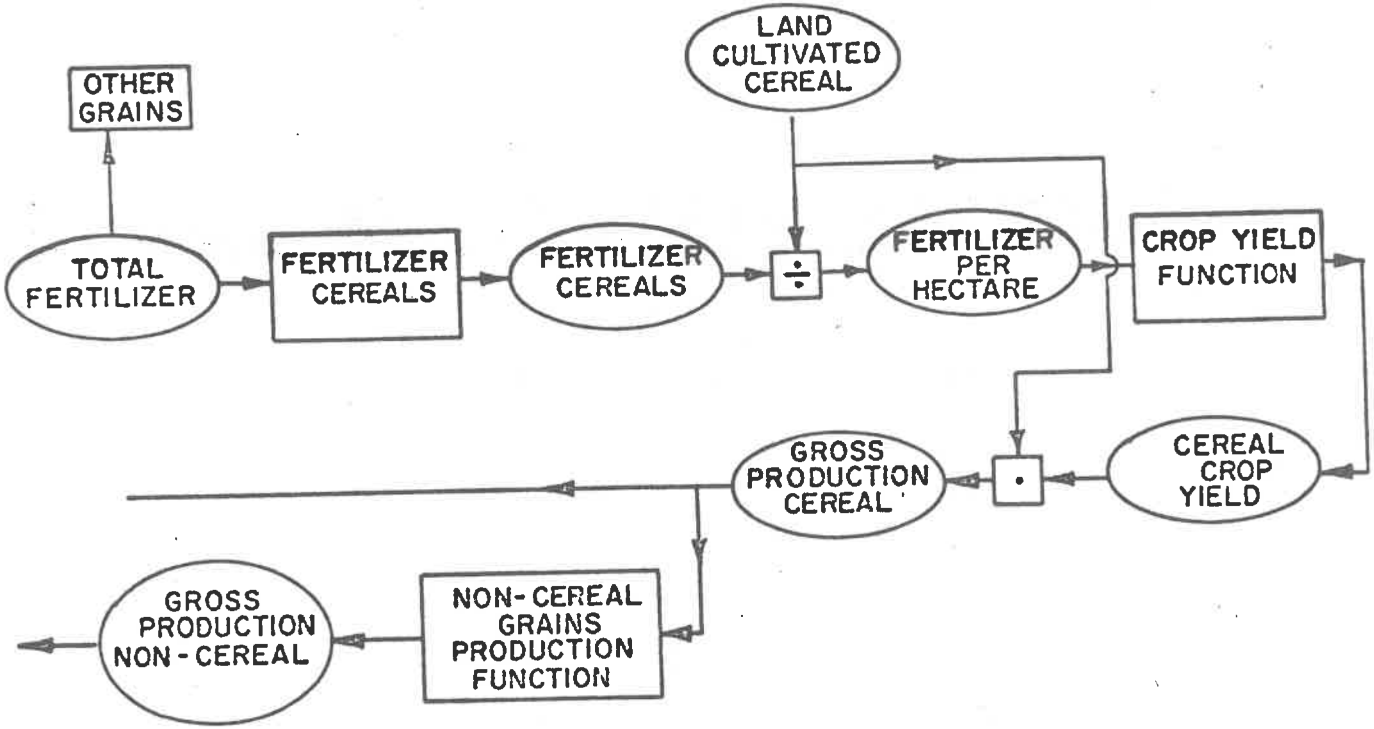


Figure 2. Simplified block diagram showing structure of field sector of food model

fertilizer use.[8] In order to use the new technologies of agriculture, it is necessary for a farmer to purchase them. Thus, technological inputs also imply the flow of a certain amount of capital, so that it is extremely unlikely that anybody would be able to take advantage of any of the other technological options open to him if he did not already use fertilizers. As Lester Brown points out[9], there is no half way in the Green Revolution: one either uses the total package of inputs which is available or one uses none of it. The technological package, including inputs such as irrigation, extension services, pesticides, mechanization, in addition to fertilizers, must be regarded in two ways. In the short run, they are commodities which are purchased and used to increase production; thus they are equivalent to fertilizers and can be included conceptually with them. But in a longer term, the technological infrastructure of agriculture determines not only the yield of crops in any given year, but also the potential ability of the agricultural system to produce. Thus, our model treats the long-term and short-term effects of technology separately. In the short term, fertilizer consumption is a realistic index of the extent of technological input and can be used to calculate annual yield. In the longer term, the nature of the infrastructure and the integration of the whole technological package determines the potential ability of the developed agroecosystems to produce food. We have considered this infrastructure to be a function of long-term capital investment in agricultural technology, and the potential ability of agroecosystems, or maximum possible yield, is computed in the model on the basis of long-term investment.

The land base and fertilizer use are translated into production of grain. Once again, grains were chosen as the group whose production was most meaningfully calculated, as it is the crop with the prime role in the food supply of almost all areas of the world. Production of non-grain crops was calculated from cereal production.

The livestock sector takes advantage of the fact that the relationship between numbers of livestock and meat production is remarkably constant for a given meat type in a given region (Figure 3). Nine different types of livestock and twelve livestock products were considered (Table 2). Additions or subtractions to world livestock herds was calculated from the economic model, constrained by the maximum number of animals that could be supported on natural pasture and by the price of grains for feedlots. This maximum was calculated from the total potentially grazable, but nonarable, land and the average carrying capacity for livestock in the region. It must be noted that although the relationship between livestock numbers and meat production has been quite stable in most regions, it can be altered if a region chooses to invest more or less of its resources in producing livestock for meat purposes. Such a shift in the uses of livestock might, for example, be the result of mechanization in which draft animals are replaced by tractors or other mechanical devices, or if grain now going to feedlots is diverted to the human population.

The fishery sector includes both marine fish and cultivated fish (Figure 4). The "marine" group includes not only marine fish but also fish taken from natural inland waterways. Thus far, we have no figures for cultivated fish production, but we believe that it is far less than natural fish production. However, fish are such a good source of protein that we felt

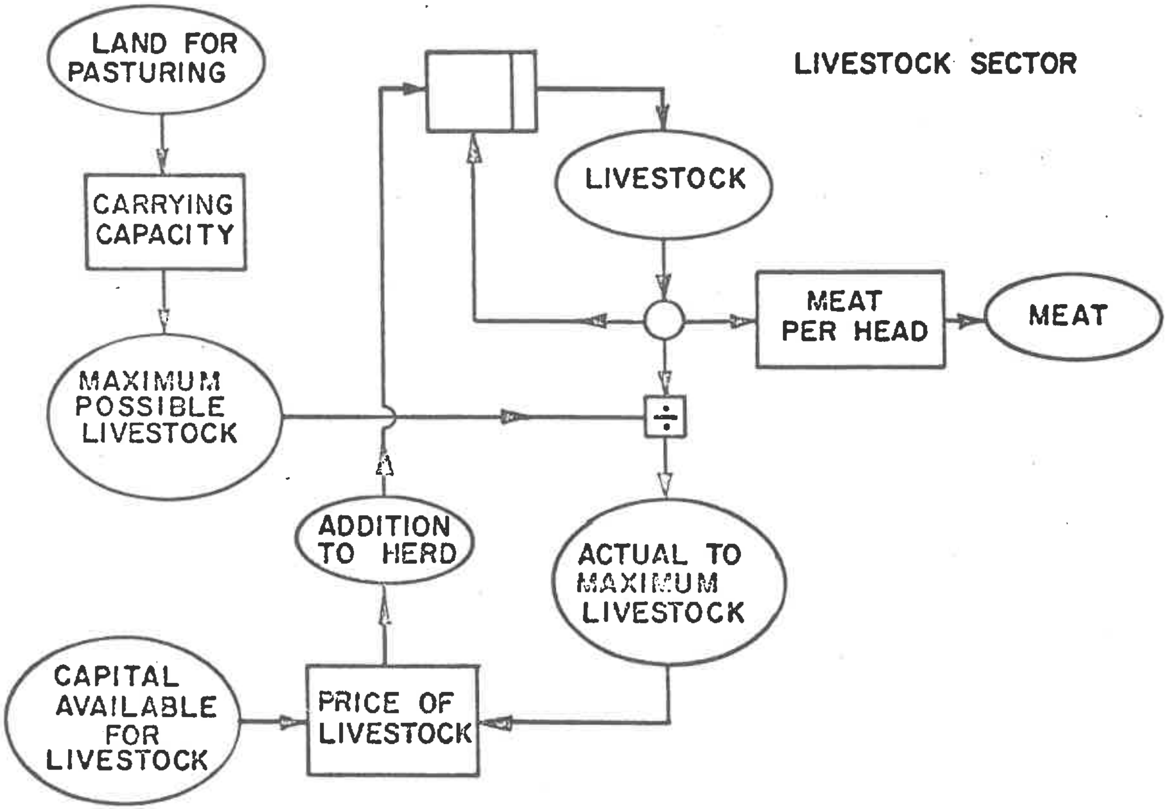


Figure 3. Simplified block diagram of structure of livestock sector of food model

TABLE 2

Livestock Types and Livestock Products Considered

Types of Livestock	Livestock Products
Cattle	Beef and Veal
Pigs	Pork
Sheep and Goats	Lamb, Mutton, and Goat
Horses	Horsemeat
All Poultry	Poultry Meat
Chickens and Miscellaneous Poultry	Eggs
Honey	Honey
Mules, Asses, Buffaloes, Camels	Other Meat
Cattle, Buffaloes, Sheep, and Goats	Edible Offals
Cattle, Buffaloes, Sheep, and Goats	Milk
Cattle, Buffaloes, Sheep, and Goats	Cheese
Cattle, Buffaloes, Sheep, and Goats	Butter

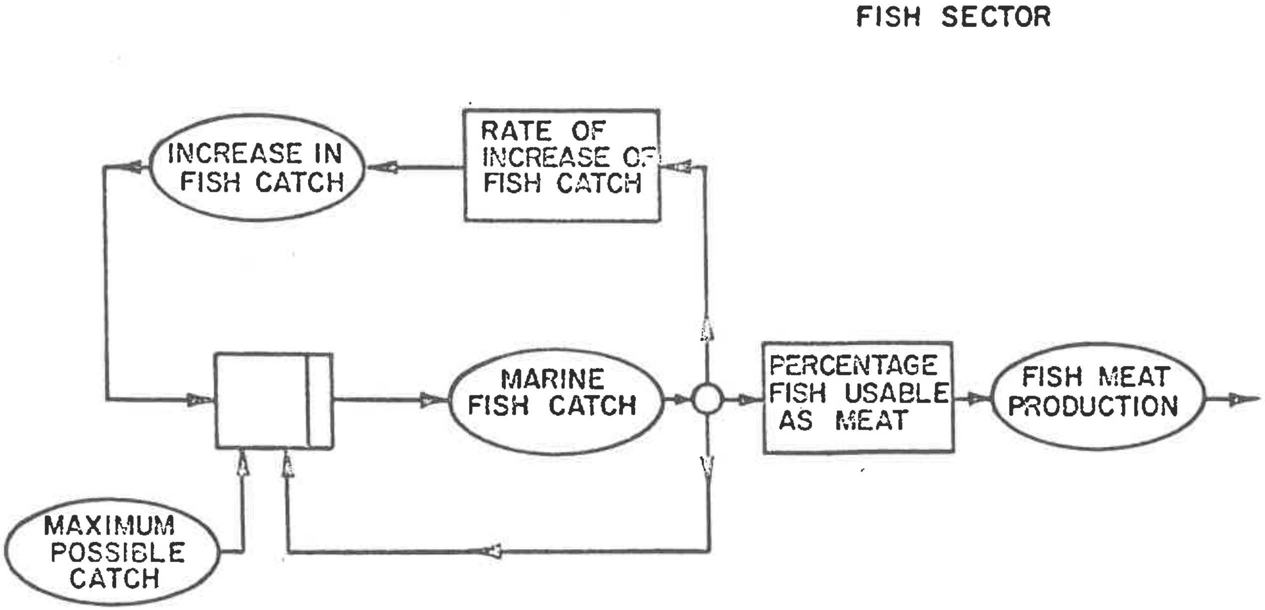


Figure 4. Simplified block diagram showing structure of marine fishery sector of food model

that an explicit consideration of aquaculture would be an important requisite for scenario development in an accurate model of the world food supply. Marine fish catches, of course, are well known, as are the animal growth rates of those catches. But the maximum possible catch is not well known. Several estimates have been made[11], and the specific estimates used can be considered a scenario variable. For aquaculture, many sources of information are available[12]. They strongly suggest that the best basis to determine the yield of cultural fish is the area of the fish-pond, and that the relationship between pond area and fish yield is fairly constant within a region but will vary considerably from region to region. Let us now examine the basis for the equations used in each module in greater detail.

Land Use

The land use sector of the model functions mainly to calculate the land base for the field sector given the current area in grains, the rates of development and withdrawal of arable land, and the maximum developable arable land (Figure 5). This land base is that which is actually harvested annually, and it may be considerably less than the land actually planted in a given crop or involved in a long-term cropping cycle. Development of arable land is driven by the economic model through the investment available to develop land and a land-price function depending on the proportion of potentially arable land remaining to be developed. Permanent withdrawal of cultivated land for purposes such as roads, urbanization, and the like, is treated as a function of population growth.

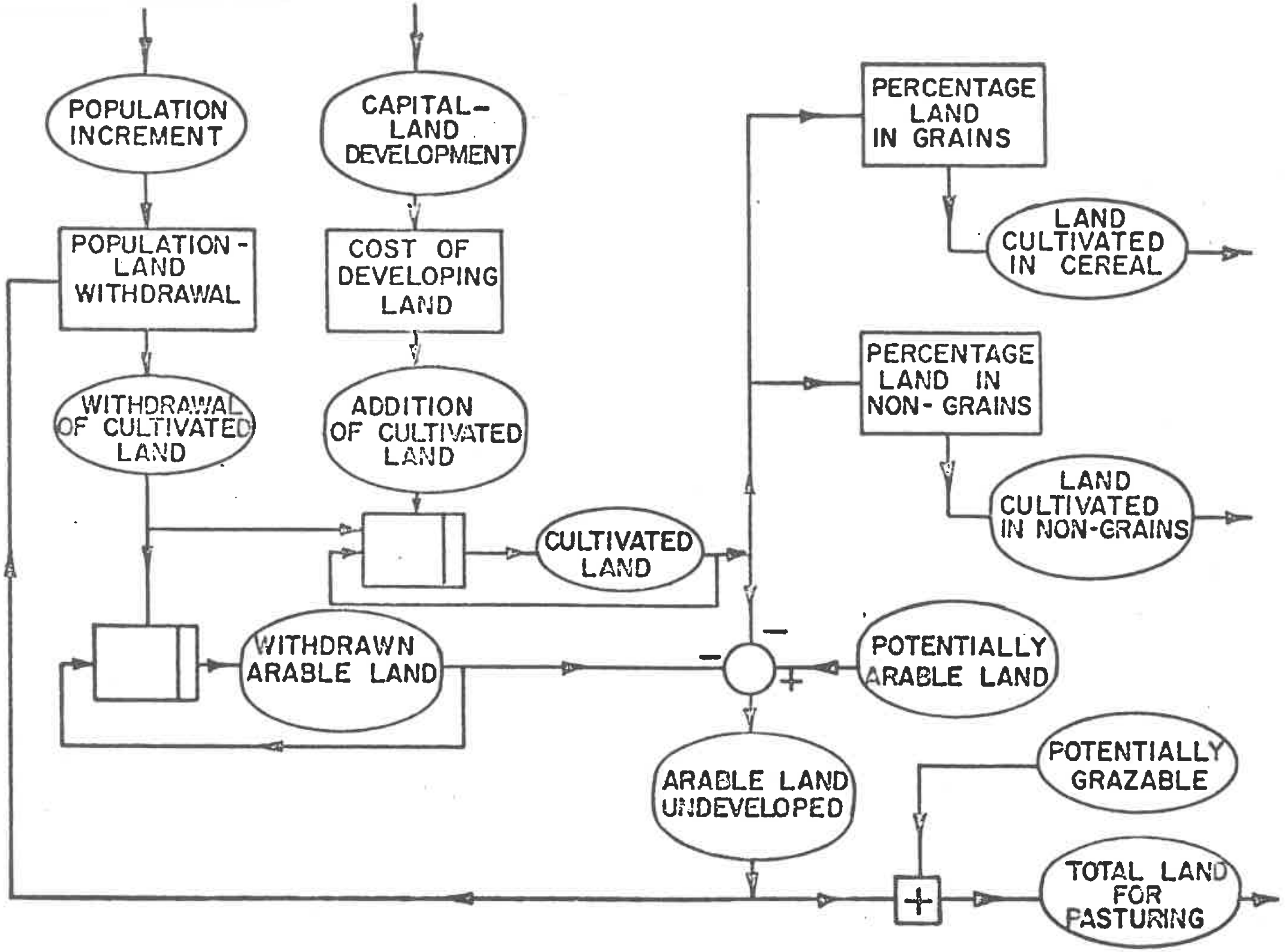


Figure 5. Simplified block diagram showing structure of land-use sector of food model

The land use model concentrates on land cropped in grain. The reason for this is that the data base for croplands in grain is much better than that for lands in non-grain crops[13]. Lands in non-grain crops are assumed to have a linear relationship to those in grain crops. As shown in Figure 6, this relationship is rather noisy due to the inadequacies of the data base for non-grain crops, but the role of non-grain land in the rest of the model is relatively minor, as that the effect of this inadequacy on the model's prediction ability is minimized. The total amount of land in production is the sum of the land cultivated in grains and that cultivated in non-grains.

It is clear that land development can continue until there is no more land suitable for cultivation. But how much land is suitable for cultivation in a region is an open question. In principle, any land can be made arable given sufficient capital, energy, and other resources. But some land is suitable for utilization as it exists naturally and some is not. It is possible that when the food crisis is much worse than it is now, land which is currently non-arable will be reengineered to make it arable, but we shall ignore this possibility for two reasons. First, the Malthusian repercussions of the global food crisis will hit first in the third world, which does not have the capital to rebuild currently non-arable land. Secondly, the estimates of arable land, especially in the tropics, may be unreasonably large. An excellent discussion of the criterion for the different uses of land are given by Revelle et. al.[14] There are two main ways in which the maximum amounts of potentially arable land have been estimated. First, land is arable if it has ever entered the cultivation cycle. This is the basis of the FAO definition of arable land[15], and it gives minimum estimates for lands which can enter the cultivation cycle. But there is no way to gauge the relationship between this estimate and the maximum acreage that can actually be harvested in a given year. As shown in Table 3, this acreage is only a fraction of the FAO estimates of arable land for most regions, and it is the area that is cultivated and harvested each year which is the land base for production. Especially in tropical areas, arable land may be usable only in a relatively long-term cycle of shifting cultivation, and efforts to shorten the fallow period may do permanent damage to the land[16]. We in the temperate zone are used to thinking in terms of continuous cultivation, but even here the need for crop rotation effectively lowers the actual acreage which can be cultivated and harvested annually. We cannot say at this time what must be done in the tropics to bring land now in long-fallow cultivation schemes under continuous cropping. On the other side of the question, some lands can be effectively double or triple-cropped. This, of course, effectively raises the maximum arable land over what would otherwise be the case. In short, there is no easy way to estimate meaningful values for maximum cultivable land from the FAO arable land figures.

A second way to estimate maximum potential arable land is to use the approach of Revelle _et_. _al_.[17]. This approach does not consider whether or not land has actually been cultivated, but rather what percentage of a given soil type is potentially arable on the average. This approach avoids the subjective aspect of determining whether land has or has not been used, concentrating on the most important factor in the system, the soil. The amounts of the various major soil types in each region is fairly well known.

Table 3

	(a) Ultimate Maximum Arable Land	(b) Land in the Cultivation Cycle	(c) (b) as percent of (a)	(d) Land Harvested per Year	(e) (d) as percent of (b)	(f) Average Growth Rate Harvested Land
1. N. America	392,000	219,844	56.1	111,499	50.7	-1.51
2. W. Europe	155,000	127,318	82.1	88,707	69.7	0.53
3. Japan	8,000	5,603	70.0	5,858	104.6	-1.57
4. Rest of Developed	150,000	57,779	38.5	19,474	33.7	2.82
5. E. Europe	382,000	279,894	73.3	193,260	69.0	0.98
6. Latin America	429,000	128,206	29.9	76,587	59.7	2.83
7. Mideast	86,000	52,606	61.2	28,676	54.5	1.14
8. Africa	423,000	166,997	39.5	73,080	43.8	1.77
9. S. SE Asia	278,000	267,798	96.3	235,156	87.8	1.54
10. China	122,000	117,774	96.5	(100,000)	(84.9)	----
World	2,425,000	1,423,819	58.7	1,000,390	70.3	1.08

All land figures are in thousands of hectares.

Figures in parentheses are our estimates

Sources:

(a) Revelle: Will the earth's land and water resources be sufficient for future populations? Paper delivered at Stockholm Conference

(b) F.A.O.: Production Yearbook, 1970

(d) F.A.O.: Production Yearbook, 1967 (data are for 1965)

(f) F.A.O.: Production Yearbooks (data are for years 1948-1969).

But many of the objections to the use of the FAO estimates also apply to the Revelle et. al. estimates -- perhaps more so, since the latter are larger. In this report, we shall use the estimates of Revelle et. al. for maximum potentially arable land.

In any case, the choice of the maximum potentially arable land in a region is important, since the rate of development of cultivated land is related to the potentially cultivated land remaining uncultivated. This variable determines the price of developing additional land, and thus forms the basis of the land development portion of the model.

Field

The field module takes inputs of fertilizer and land and calculates field crop production. The key to this module is the relationship between the use of fertilizer on grain crops and the production of grain. This is a very complex relationship based on the mixture of crops (not only the species involved but also the local varieties), the other factors which accompany fertilizer use (irrigation, mechanization, pesticide usage, use of new crop strains, and the like), and the quality of the land on which the crops are being grown. Clearly, one can determine the relations between yield and any one variable, holding all other constant, in a simple graph[18]. Or two variables can form a 3-dimensional equation which will relate fertilizer use to yield when all of the variables are varying and none are held constant. We can make some reasonable simplifying assumptions, however, which will allow us to do this. First, we shall assume that there is little change in the relative abundance of crop species grown in a region.

In fact there has been some, but it is quite small. Second we shall assume that it is reasonable to speak of the average land in a region and to assume that the average response of the crop mixture to technological inputs (such as fertilizer) is very similar to the actual response of crops on the actual mix of arable land, of which some is better than average and some is worse. This is an important assumption, because realistic public food-production policy must be based on the average land being used for crops. Also, it points out why crop yield-response data from agriculture experiment stations cannot be incorporated directly in a regional model, since such stations may not be located on "average" land and they will not be running experiments in which all of the possible inputs will vary simultaneously. Nor will they be subject to the infrastructural deficiencies and bottlenecks of the average farm. It is likely, of course, that technological inputs are likely to be used on better than average land before they are used on poorer-than-average land, simply because they tend to be capital-intensive, and owners of better land are more likely to accumulate capital faster than owners of poorer land. As more intensive farming spreads, it will spread from better land to poorer land. But the error stemming from this source will be counterbalanced, at least in part, by our first assumption, since if there is a change in crop species, it will likely be from relatively less productive to relatively more productive sorts. Thus the most important factor in determining crop yield is the extent of the technological input.

As mentioned above, the technological input involves significantly more than just fertilizer: it includes mechanization, pesticides, genetic hybridization, irrigation, and a lot of other factors. For a number of reasons, the use of fertilizer is the most useful index for these factors, but we cannot disregard the others. That is, when fields get fertilized to the optimum degree, holding the rest of the technological inputs constant, it is likely that some other technological devices will be available to raise crop yields still further. The most common interpretation of the relationship between crop yields and fertilizer usage is a parabolic curve, in which the yield drops off above the optimum application rate[18]. But in practice, fertilizer usage is so closely integrated with the others inputs that it would not be increased were there no corresponding changes in the rest of the technological packages. But to say (as we will) that the application rate of fertilizer is not limited by some maximum on the same order as the present optimum rate is to make the optimistic assumption that new technological tools will be available as they are needed.

Let us discuss some of the reasons that fertilizer usage is the best index of technological input in the field. Like pesticides, irrigation, mechanization, and crop hybridization, fertilizers are purchased commodities[19] and they cannot be used at all until farmers have a minimum of capital made available to them from some source. Once agriculture is part of the commercial economy, we can assume that the disposition of the available funds among the various types of input (fertilizer, hybrid seeds, water, etc.) will be so as to maximize, at least approximately, the returns on the investment (i.e., salable produce). Thus fertilizer is a basic aspect of commercialization. But it is more than that. Many, if not most, of the steps in crop hybridization have been involved in making crops more responsive to the use of fertilizer. Many, if not most, of the irrigation projects in the third world today were built because farmers, now that they had the opportunity to get a sufficient yield to sell a substantial part of it, could afford to buy water to supplement that crop's new ability to respond to fertilizers. In short, fertilizers are the basis upon which the Green Revolution is based. Not only is it a useful index of the degree of commercialism in agriculture, a better index of the actual technological input into agriculture could not be imagined. If it is somewhat oversimplified, other indexes have this fault as well, and it makes up for it by being simple and having a sound data base.

There is no obvious way to extrapolate the fertilizer/yield curve beyond its current levels. It is likely that it is a diminishing - marginal - returns curve of some kind; most relationships of this general sort are. But the precise sort of curve is anybody's guess. As the most useful general curve, we have chosen the saturating exponential function:

$$\mathrm{GRPH} = \mathrm{FA}[1.0 - (\mathrm{FA} - \mathrm{FB}) * \mathrm{EXPF}\ (-\mathrm{FC}*\mathrm{ZPHG}/(\mathrm{FA}-\mathrm{FB}))]$$

where GRPH is the grain yield per hectare, ZPHG is the fertilizer usage per hectare of grain, FA is the maximum grain yield, FB is the grain yield when fertilization is nil, and FC is the initial slope of the curve. FB and FC were determined by fitting the equation above to 22 years worth of data for all regions of the world[20]. ZPHG is the annual fertilizer application ratio on the land, and hence represents the short-term effects of technological input discussed above. FA represents the long-term effects of the investment of capital in the agricultural sector of the economy to define the maximum regional production possible. Without an adequate infrastructure to integrate the technological aspects of food production, all the fertilizer use in the world will not be able to raise regional yield per hectare; with adequate integration, a limited amount of fertilizer (or other imputs) will go relatively further[21]. Both ZPHG and FA are calculated through the economic model. The family of curves involved in the 10 regions considered, as well as the data upon which they are based, are shown in Figure 7.

The gross regional production of grains is calculated by multiplying the grain yield per hectare times the area of land cultivated in grain:

Thus far we have considered only grain in our discussion. Non-grain crops are also of some importance as cash and/or food crops and must be considered. Aggregate production of non-grain crops is calculated assuming a linear relationship between total production of grain and non-grain crops: The curves fitting the data and the data upon which they are based are shown in Figure 8[22].

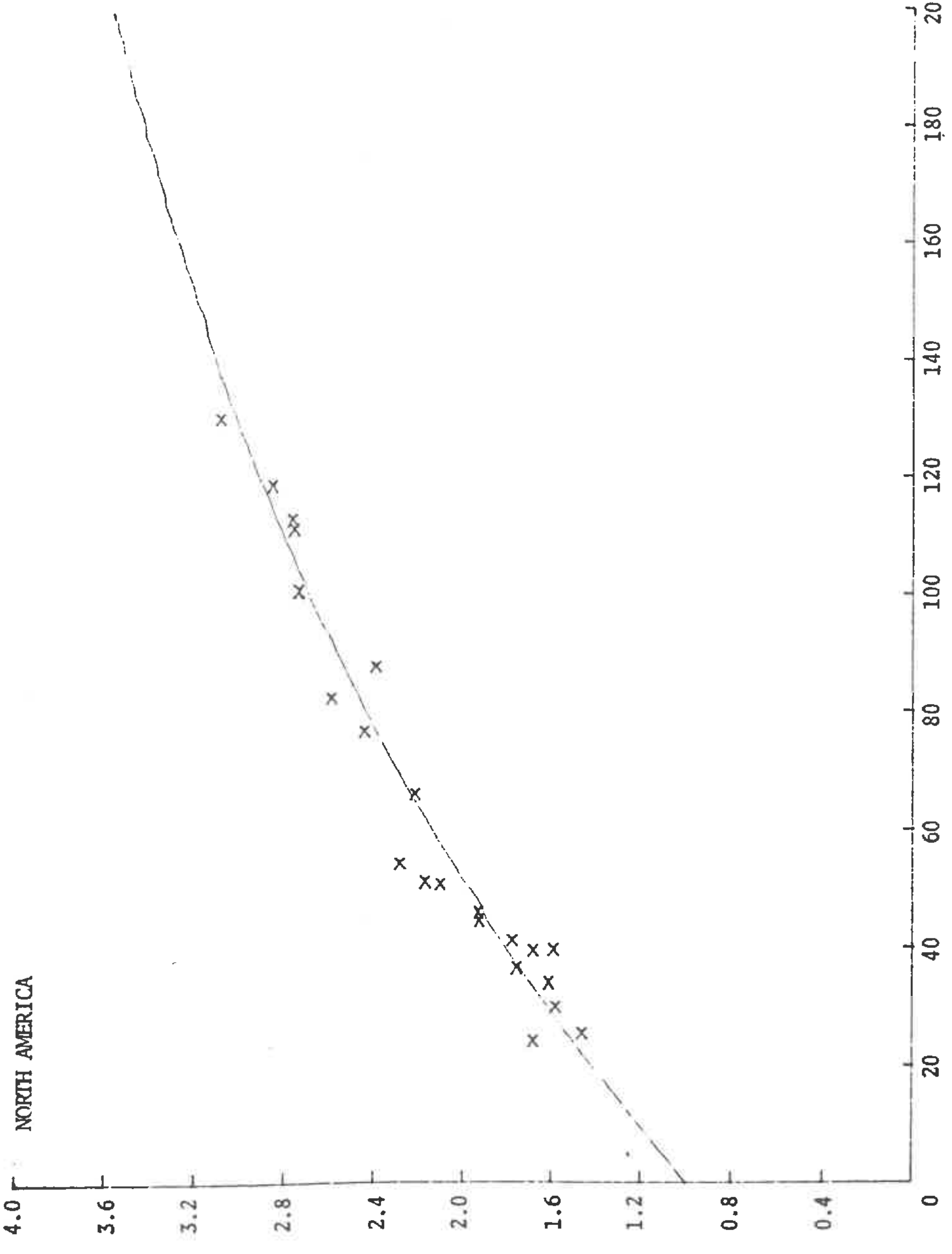
Livestock

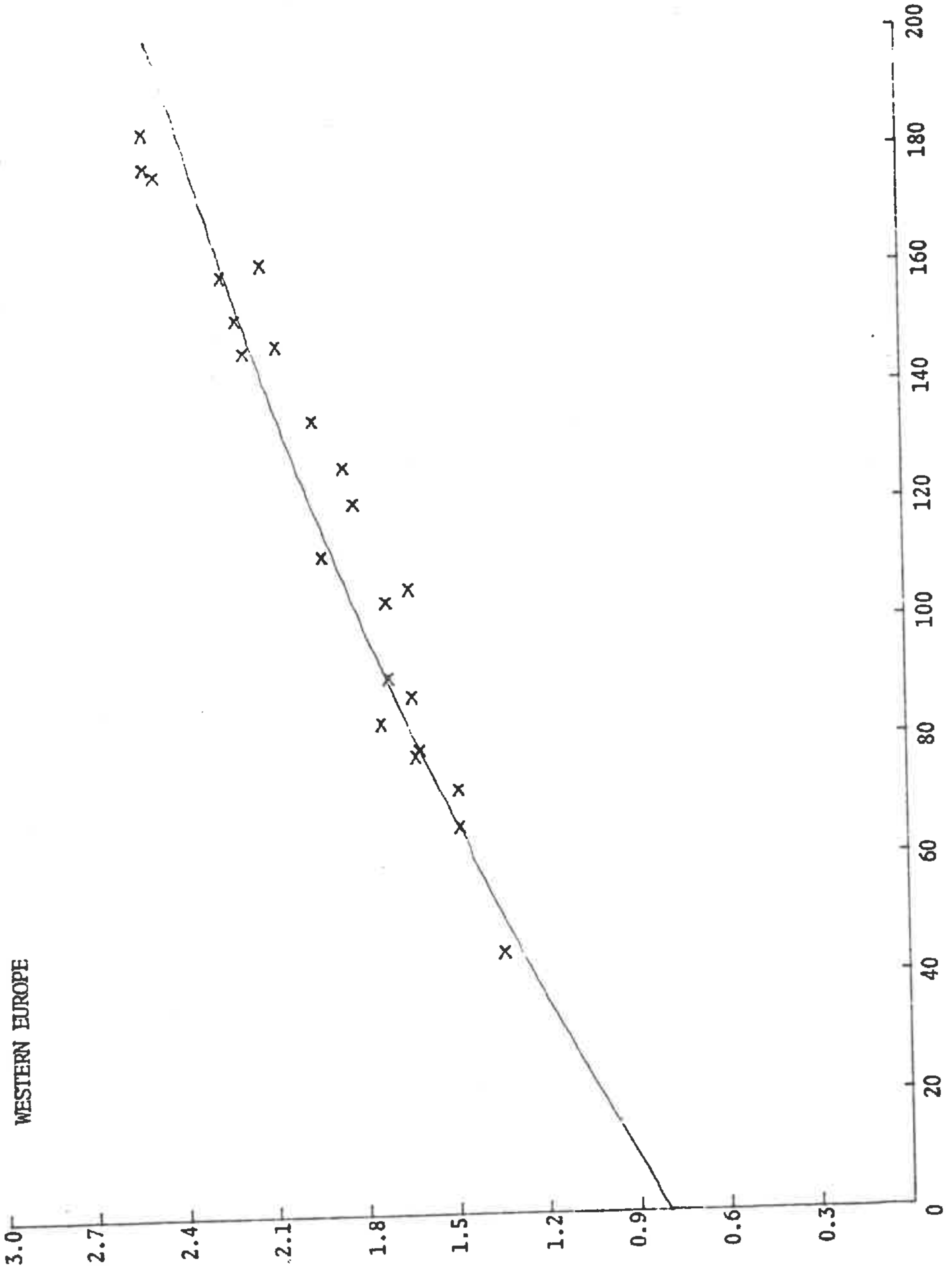
The livestock sector of the world food model is the simplest sector, but it is not a trivial sector. Other world models have ignored meat as being both a prodigal use of fixed energy and a food source which will not be feasible for the third world[23]. However, livestock must be considered explicitly for several reasons. First, while they may not be as good a source of calories as plant crops, they are a much better source of proteins,

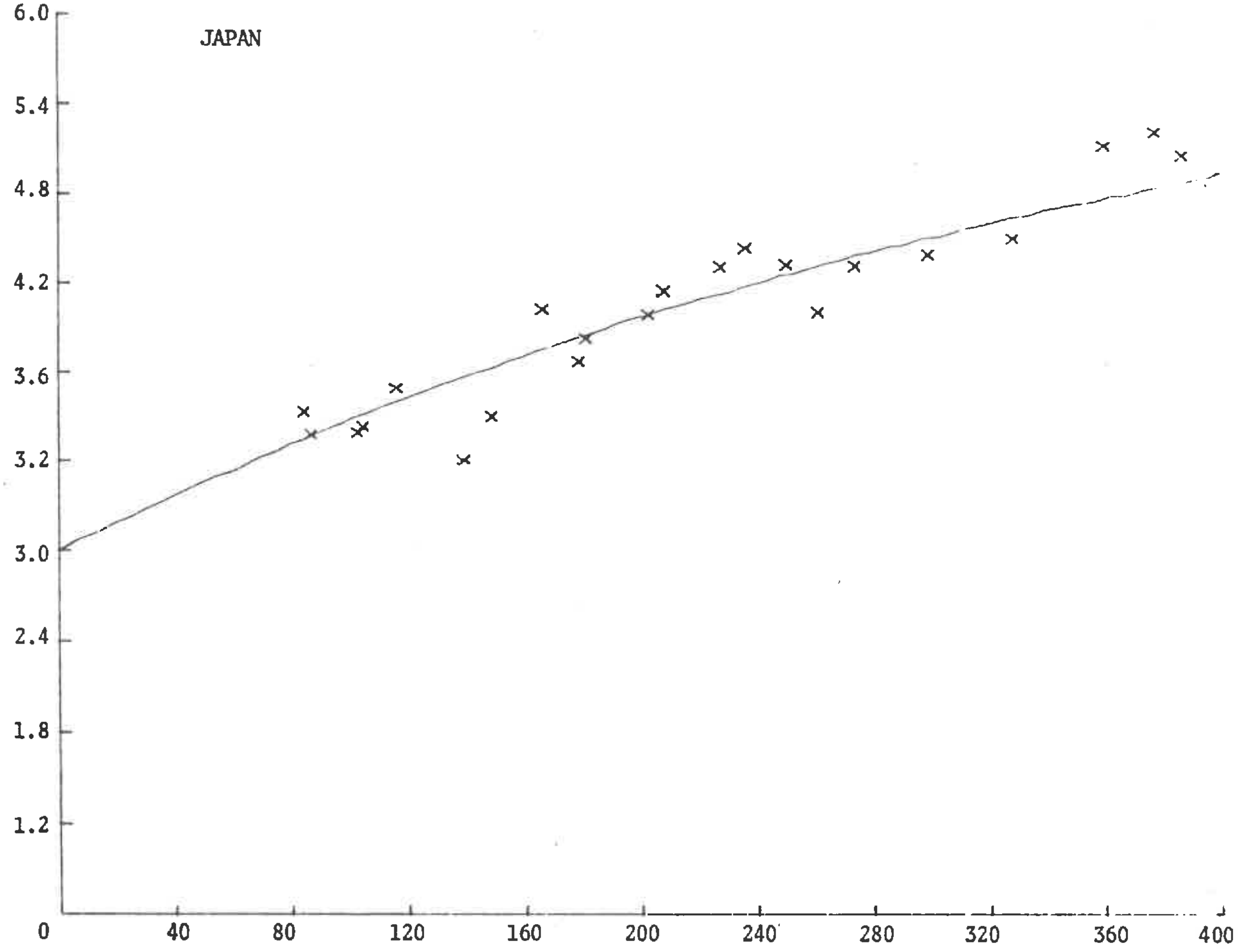
Figure 7

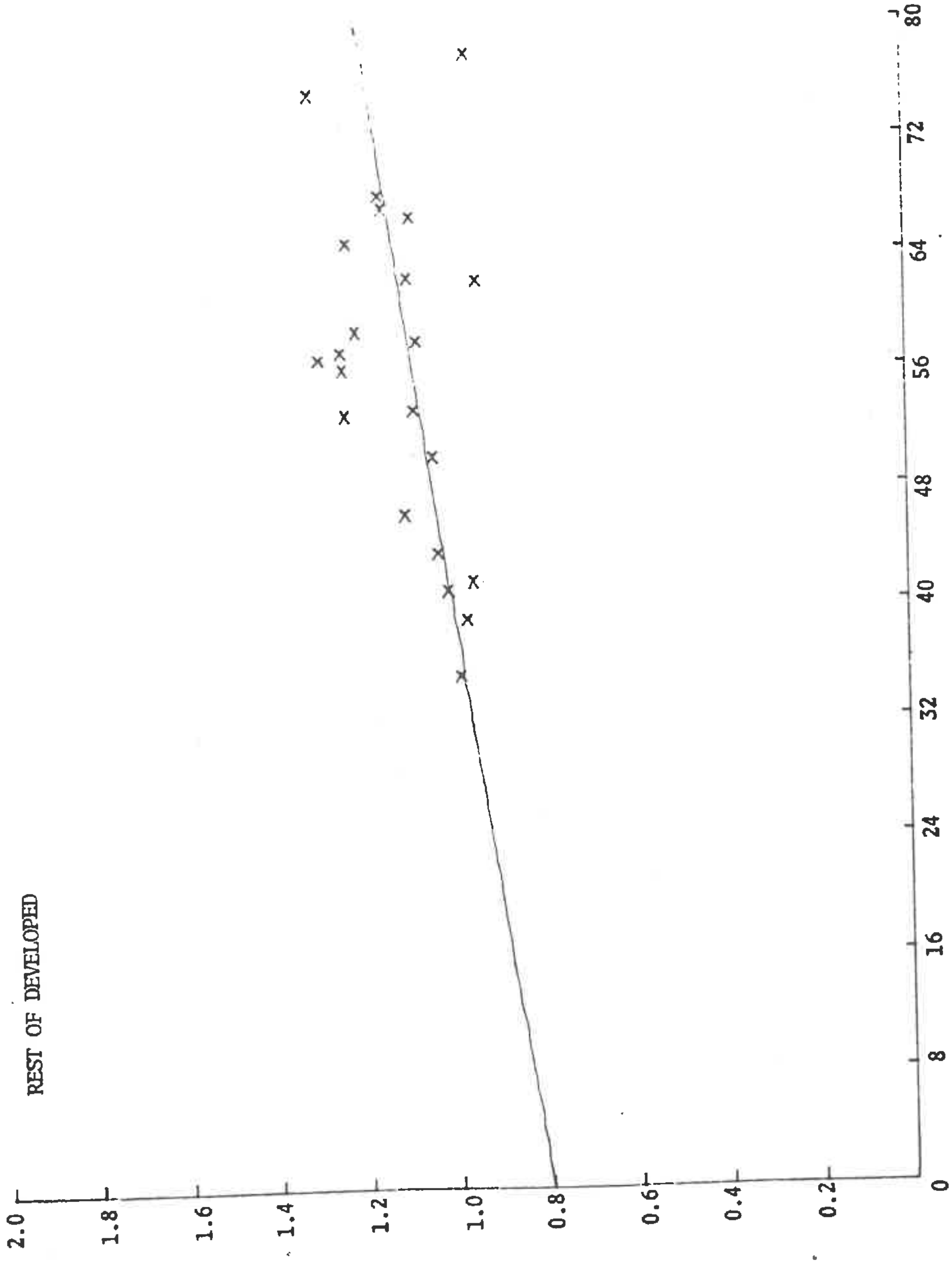
Relationships between fertilizer per hectare and grain yield, by region. Ordinate: Yield of grain in metric tons per hectare; Abscissa: Fertilizer application in kg. per hectare.

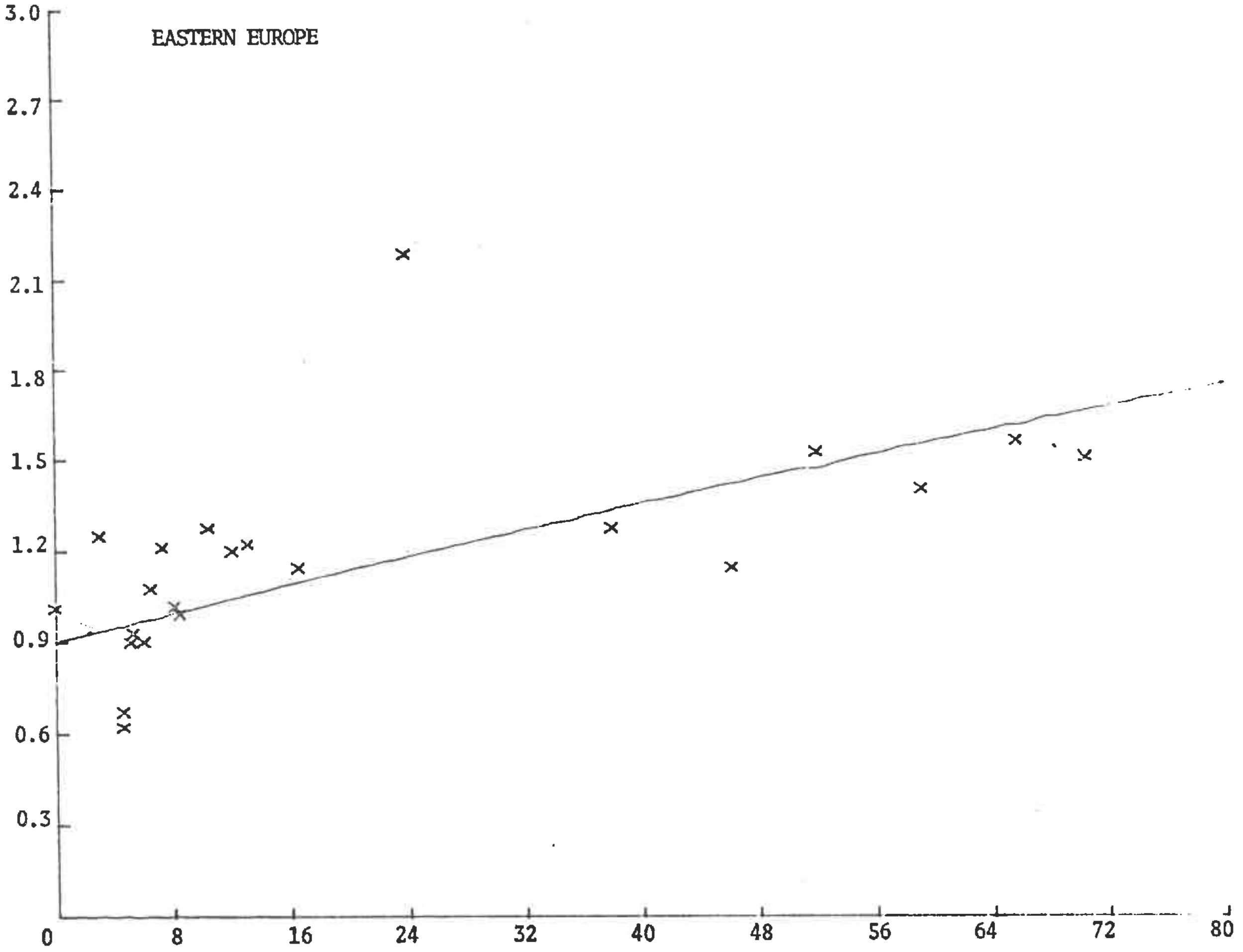
B 525

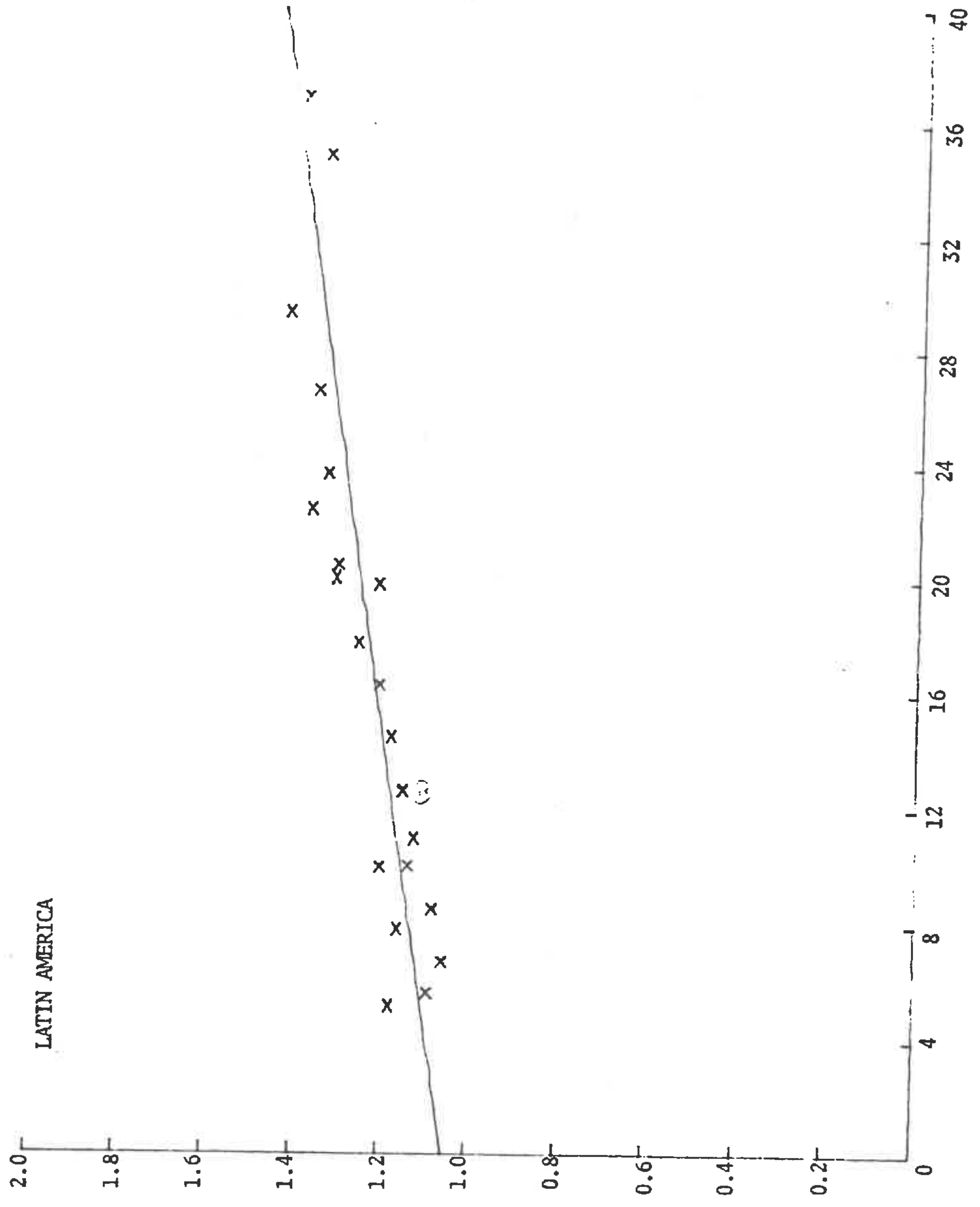

NORTH AMERICA
4.0
3.6
3.2
2.8
2.4
2.0
1.6
1.2
0.8
0.4
0
20
40
60
80
100
120
140
160
180
200

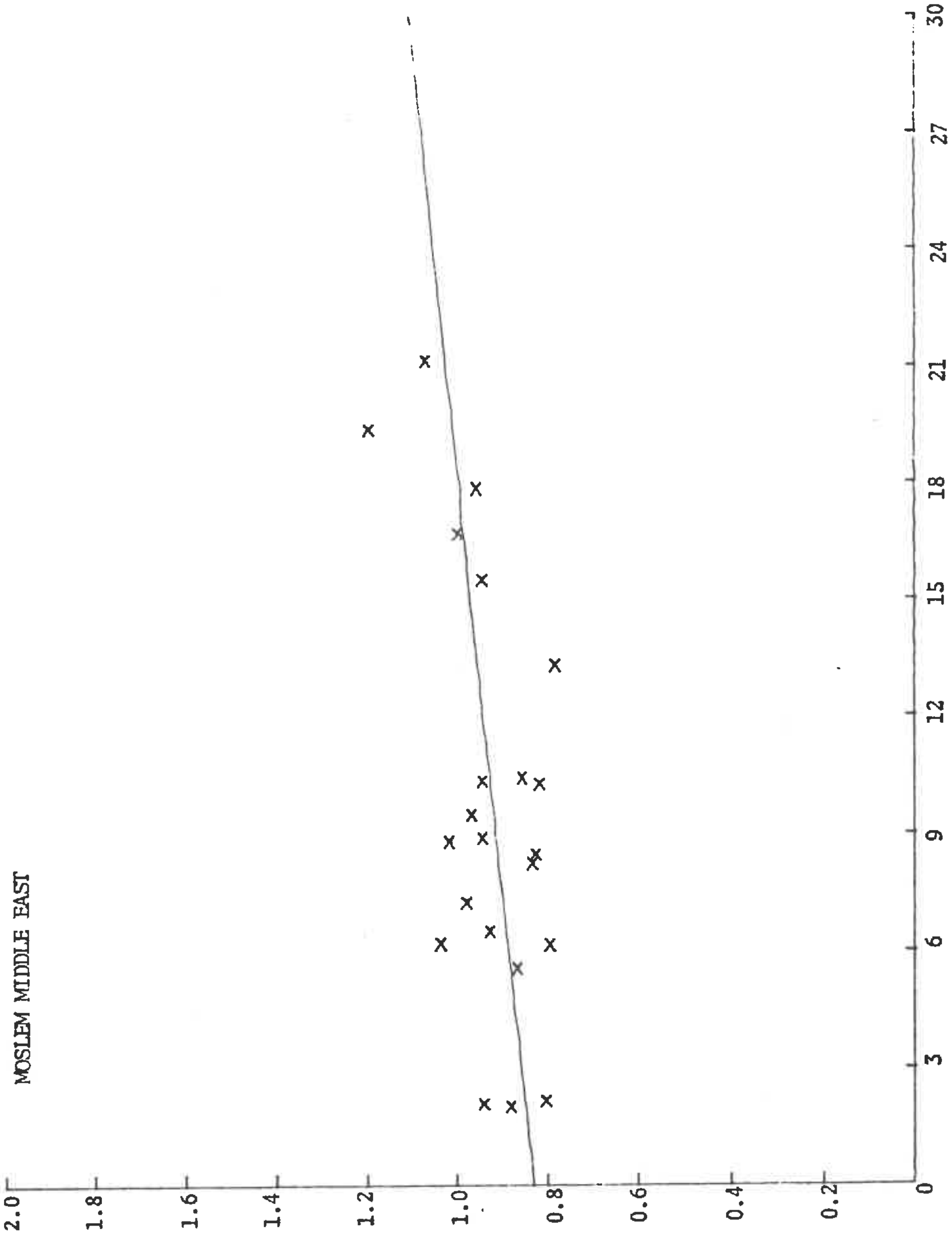

WESTERN EUROPE
3.0
2.7
2.4
2.1
1.8
1.5
1.2
0.9
0.6
0.3
0
20
40
60
80
100
120
140
160
180
200


JAPAN
6.0
5.4
4.8
4.2
3.6
3.2
3.0
2.4
1.8
1.2
0
40
80
120
160
200
240
280
320
360
400

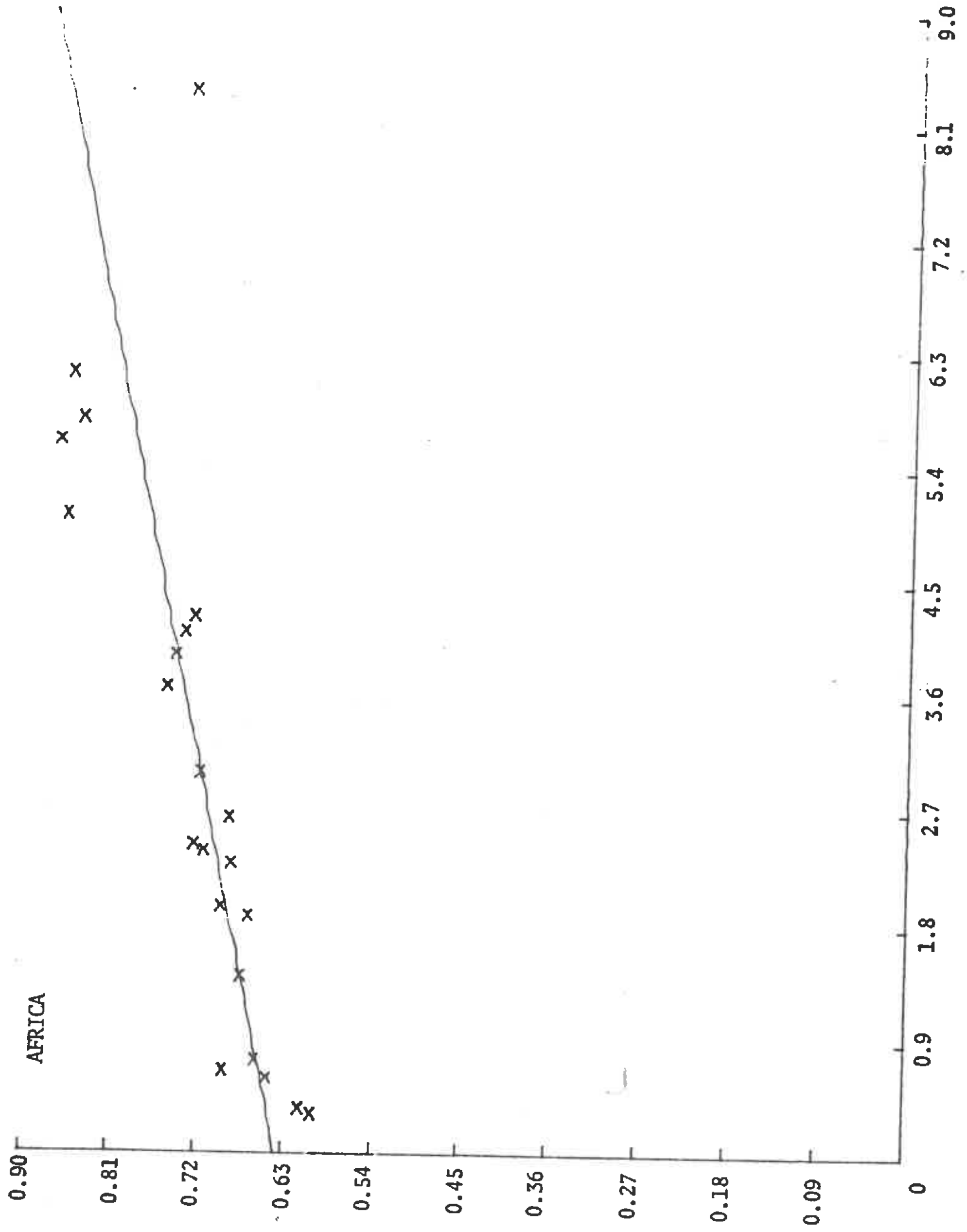

REST OF DEVELOPED
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
8
16
24
32
40
48
56
64
72
80

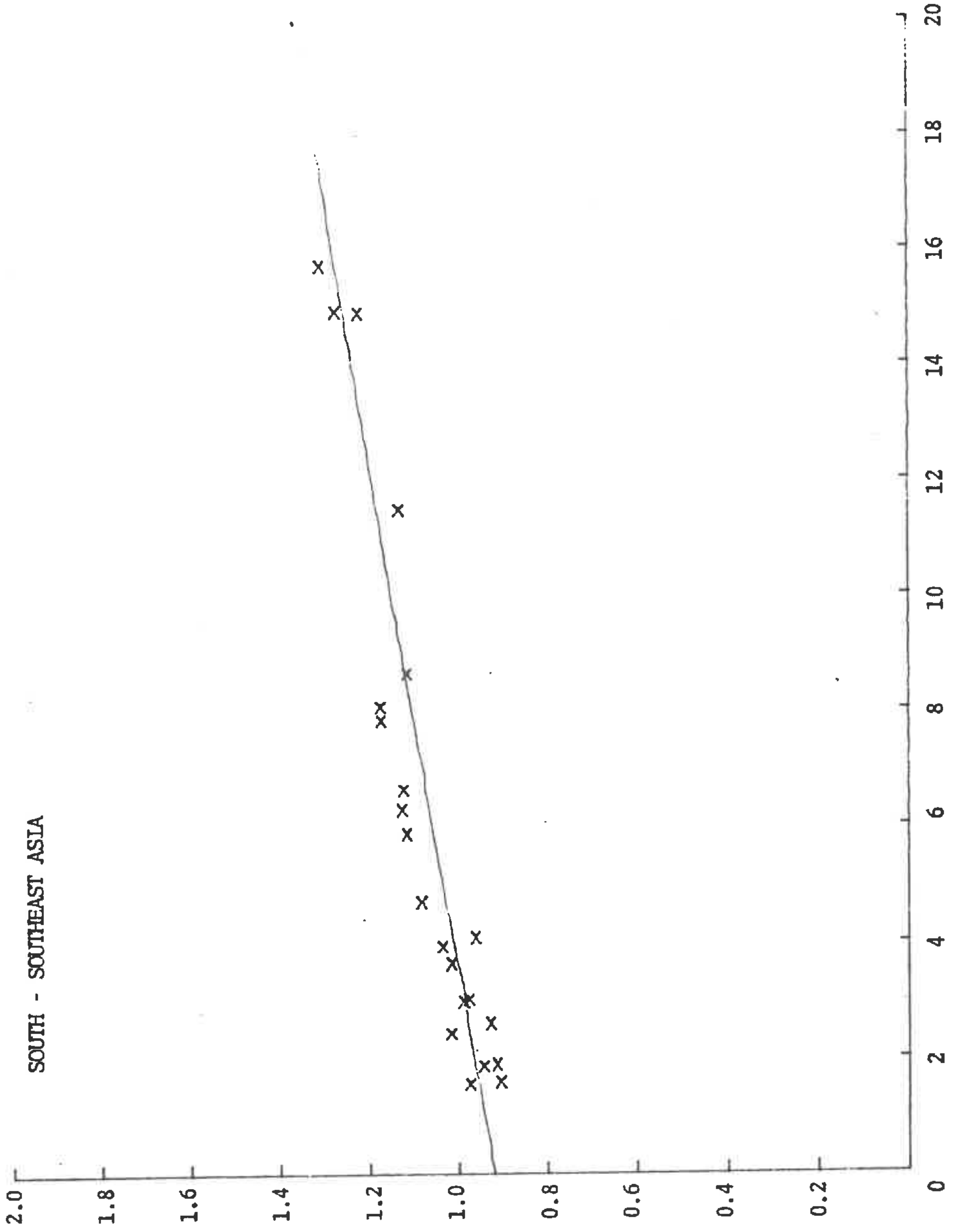

EASTERN EUROPE
3.0
2.7
2.4
2.1
1.8
1.5
1.2
0.9
0.6
0.3
0
8
16
24
32
40
48
56
64
72
80


LATIN AMERICA
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
4
8
12
16
20
24
28
32
36
40

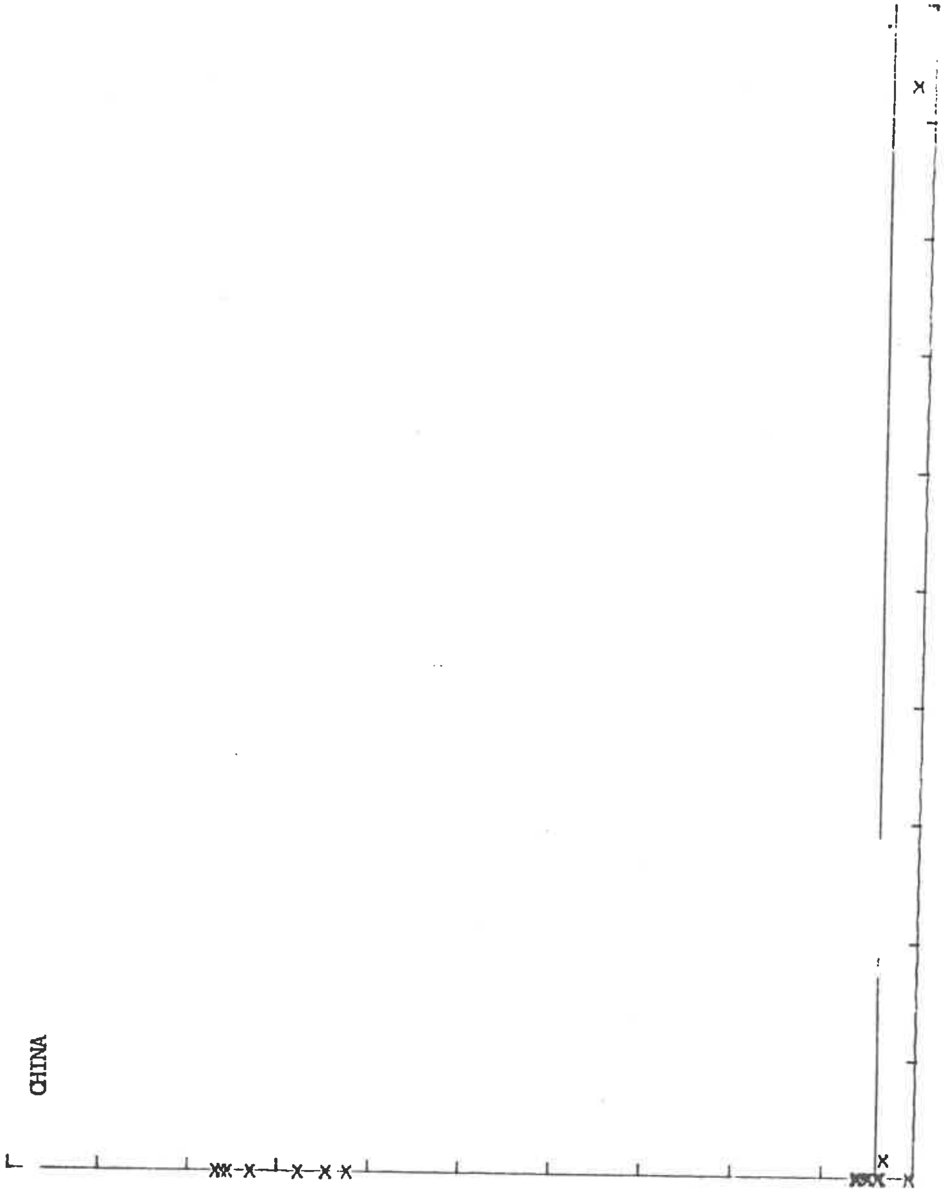

MOSLEM MIDDLE EAST
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
3
6
9
12
15
18
21
24
27
30

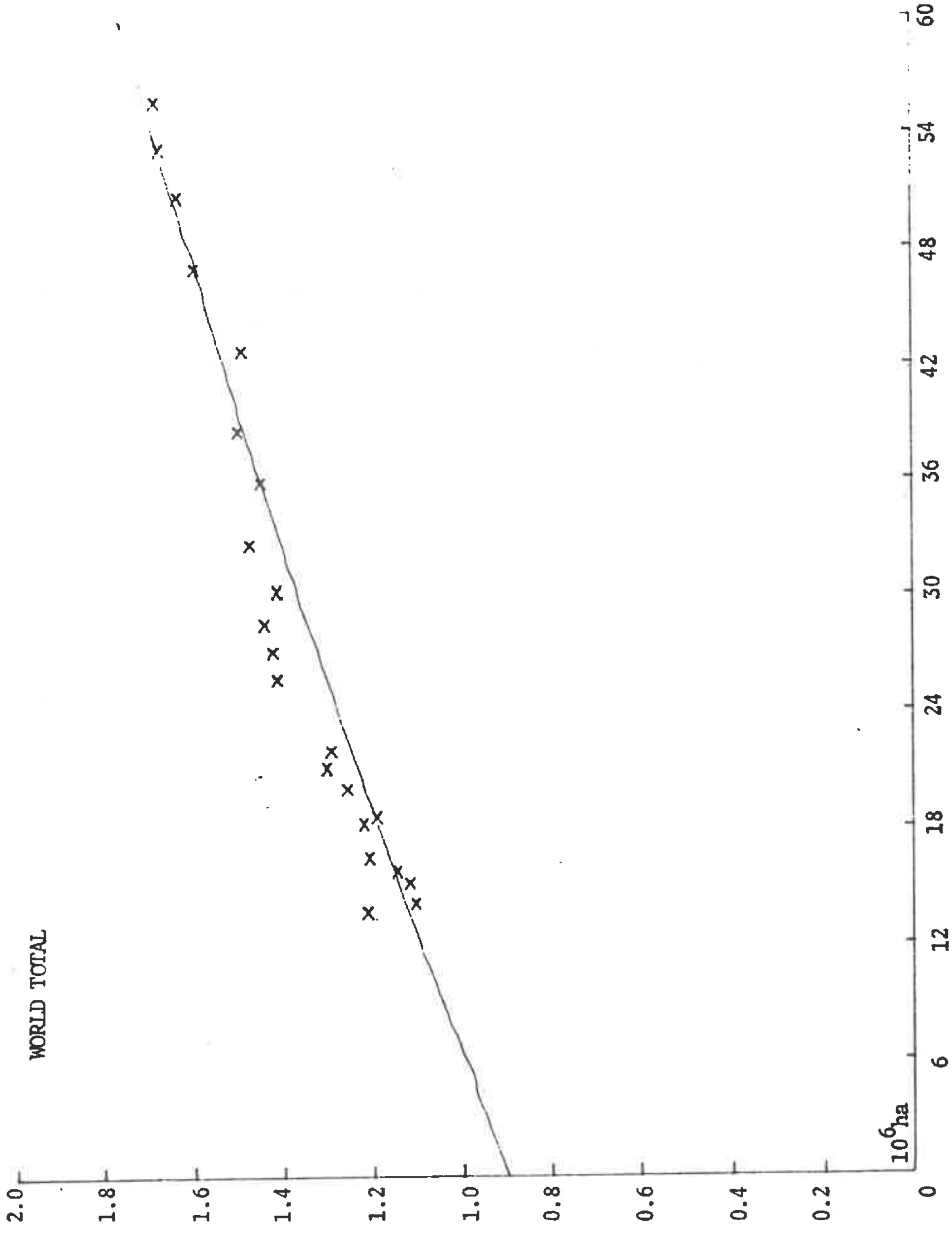
B 532


AFRICA
0.90
0.81
0.72
0.63
0.54
0.45
0.36
0.27
0.18
0.09
0
0.9
1.8
2.7
3.6
4.5
5.4
6.3
7.2
8.1
9.0


SOUTH - SOUTHEAST ASIA
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
2
4
6
8
10
12
14
16
18
20

B 534




WORLD TOTAL
10^6ha
0
6
12
18
24
30
36
42
48
54
60
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0

especially high-quality proteins. A diet that contains even a small amount of meat is likely to be much better than one containing none at all. Second, livestock feed is a significant use of foodstuffs in all regions, and we cannot model the tradeoff between plant food and animal food without explicitly considering this particular use of plant food. Third, a major use of livestock in much of the world is as draft animals. As mechanization becomes increasingly the fact, animals which were previously needed for power will become available for protein supplements in the diet.

The state variable for this sector is the number of animals, which grows according to new livestock purchased as calculated by the economic model. There is a maximum number of animals which can be maintained in a region. This is due to the facts that natural pastures have carrying capacities and that the numbers of livestock that can be maintained in feedlots is limited by the amount of feed. At this level of aggregation, however, we shall calculate the maximum only with regard to the maximum carrying capacity of natural pastures[24].

Eight different types of livestock are considered in each region: cattle, pigs, sheep and goats, horses, other large animals (mules, asses, buffalos, and camels) chickens, all poultry, and dairy animals (cattle, buffalos, sheep, and goats).[25] Eleven kinds of animal foods are derived from these livestock types: beef and veal, pork, lamb and mutton, horsemeat, other meat, eggs, poultry meat, milk, cheese, butter and edible offals. Production of honey is also included in this section. The relationship between livestock number and meat production have been determined as an average of the year 1966-1969 from FAO figures[26]. These are quite consistent, as shown in Table 4. Thus as livestock numbers are allowed to change through time, the production of various livestock products follows.

Fisheries

Fishery resources can be divided into those of natural waters and cultivated fish ponds. The catch of fish by the nations of the world is well known[27], as are the growth rates of that catch. But the maximum sustainable yield for the world ocean fishery is not at all well understood, and estimates have ranged from 55 to over 1,000 million metric tons per year[28]. Present problems in fish production, including major declines in the Peruvian Anchoveta fisheries, suggest that the lower estimates are more realistic, and we have used Ryther's estimate of 100 million metric tons as the world maximum sustainable catch.

In this model we have assumed that regional marine fish catch would continue to grow at its current rate until the world maximum substantial yield was reached, at which point the catch would level off.

Fish constitute, in many respects, an ideal food supplement since they are very high in protein but rather low in calories. Furthermore, they can be rendered into fish meals and fish protein concentrate flour which can provide high quality animal protein with low bulk and excellent storage capability. Thus, if as seems now to be the case, the primary food problem in an area is a deficiency of protein, expansion of fish in the diet would

TABLE 4

Relationship between production of livestock products and the average number of animals in herds in all 10 regions

	REGION									
	1	2	3	4	5	6	7	8	9	10
No. Cattle	120.6	117.5	3.0	39.1	120.0	230.4	15.6	124.5	253.8	66.5
Beef-Veal Prod.	10756.4	6553.8	168.2	1607.1	6132.0	6505.0	560.0	1665.6	1100.9	2216.8
Production Factor	89.177	55.800	56.286	41.108	51.082	28.23	35.815	13.373	4.337	33.351
No Pigs	60.1	95.7	5.7	4.2	89.9	93.8	0.1	4.8	32.1	216.9
Pork Prod.	6004.8	7553.7	517.1	288.5	6662.8	1652.8	10.2	133.7	1143.8	8099.7
Production Factor	99.926	78.936	90.871	69.469	74.122	17.616	94.886	27.933	35.658	37.338
No Sheep & Goats	28.3	168.3	0.4	267.0	176.1	174.2	123.4	168.1	180.6	143.0
Lamb-Mutton Prod.	299.0	933.5	1.2	1382.8	994.3	472.2	651.7	560.8	632.1	699.1
Production Factor	10.572	5.546	3.218	5.179	5.647	2.711	5.281	3.337	3.500	4.888
No Horses	6.9	6.1	0.2	1.1	12.1	24.1	1.3	2.6	3.3	9.916
Horsemeat Prod.	3.7	172.7	14.2	-	14.0	19.2	3.0	2.3	1.1	-
Production Factor	0.531	28.137	58.819	-	1.158	0.797	2.332	0.877	0.337	-
No Other Animals	0.007	5.7	-	1.3	1.8	14.2	9.9	17.6	91.5	40.447
Other Meat Prod.	-	409.6	-	171.7	212.9	2.8	56.0	333.5	18.3	-
Production Factor	-	72.45	-	130.31	117.04	0.20	5.64	18.53	0.20	-
Prod. Honey	137.20	41.23	6.66	26.01	245.47	79.85	5.97	10.73	1.50	-
No Poultry	510.7	474.9	134.2	53.7	871.2	552.8	127.4	286.0	535.6	1083.2
Poultry Meat Prod.	5997.8	2199.0	225.2	238.3	1047.1	511.3	183.9	24.08	468.7	2421.9
Production Factor	11.745	4.630	1.679	4.435	1.615	0.925	1.443	0.842	0.875	2.236
No Chickens	491.9	468.5	133.8	50.4	843.8	537.7	120.9	282.8	469.3	1083.2
Egg Prod.	4258.4	4247.0	1262.9	396.8	2967.6	1206.6	230.7	274.3	732.1	3117.3
Production Factor	8.657	9.066	9.440	7.869	3.517	2.244	1.909	0.970	1.560	2.878

	REGION									
	1	2	3	4	5	6	7	8	9	10
No Dairy Animal	99.3	112.2	2.4	59.0	114.3	201.9	27.0	116.4	307.5	98.0
Edible Offal Prod.	1108.5	1108.2	57.7	266.6	253.7	399.7	103.8	359.8	193.7	-
Production Factor	11.16	9.88	23.77	4.52	2.22	1.98	3.85	3.09	0.63	-
Milk Prod.	61431.9	118335.1	3788.9	16745.0	114977.1	22788.9	6054.3	5148.2	35997.4	3184.6
Production Factor	618.5	1055.0	1560.5	283.9	1006.1	112.9	224.5	52.8	117.1	32.5
Cheese Prod.	1271.3	2277.0	31.1	224.1	1428.5	323.0	366.8	-	-	-
Production Factor	12.8	20.3	12.8	3.8	12.5	1.6	13.6	-	-	-
Butter Prod.	685.3	1469.4	2.9	524.9	1702.8	100.9	13.3	116.4	461.3	-
Production Factor	6.9	13.1	1.21	8.9	14.9	0.5	0.5	0.4	1.5	

All livestock numbers are in million individuals

All production figures are in thousand metric tons

Production Factors are in kg/animal

Dash indicates lack of data

be a useful means of meeting this deficiency. So we have included aquaculture as an explicit means of improving protein production in the area. The literature on fish pond culture is adequate, but not terribly large[12]. It suggests several things. First, the relationship between the land area in fish ponds is essentially uniform within an area (Table 5), but it may vary over several orders of magnitude from region to region. This is due to several factors, mainly the fish species being raised and the intensity of the fish culture. The reason for this latter phenomenon is not clear; it may be cultural or it may have some other basis, but it does seem to hold. Because of this relationship, however, it becomes possible to estimate the potential for fish production in cultivated fish ponds by setting the growth rate of land in fish ponds as a scenario variable.

The catch of fish from natural watercourses and cultivated fish ponds is added and converted to meat by a uniform factor of 45%.

Allocation of Food

The outputs from the food-producing sectors of the model (field, livestock, and fisheries) calculate production in terms of useful foodstuffs (edible portions, meat, etc.). These foodstuffs are then equivalenced to a single vector including all of the important foodstuffs, plant and animals. To make the destination of the food more realistic, several different categories of plant foods are calculated from the aggregated categories of "grains" and "non-grains". Cereal grains are subdivided into wheat, maize, mutton and sorghum, rice, and other cereals; non-grains are subdivided into sugars, starches, root crops, vegetables, pulses, fruits, oil crops, drinks and stimulants, and fibers. The percentage distributions of the food types are considered constant for each region. A complete

TABLE 5

Relationshp of fish production in cultivated ponds to fish pond area, by region.

Region	Production of finfish in fish ponds mean(kg/ha)	Std. deviation	Number of Observations
1	963.	1697.	46
2	797.	466.	12
3	3778.	6159.	9
4	1441.	1725.	28
5	854.	451.	3
8	2713.	3804.	5
9	2074.	479.	74
10	2832.	1967.	5
World	1712.	1988.	184

Data are from sources listed in footnote 12 listing of the crops included in each category is given in Table 6; the percentages of the various crop types in each region is given in Table 7. This disaggregation serves two purposes: first it will enable us to get a feel for the makeup of the complete diet of an average person in each of the regions; secondly it separates out crops which are important in international trade, and which can thus be used as indicators of interregional capital in agriculture.

The next step in the model is to calculate the use of the food supply within a region (Figure 9)[29]. Defining food supply as the sum of gross regional production plus import, less export, we have considered 5 uses: livestock feed, seed, human food, industrial uses, and wastage inherent in extraction. The disposition of foodstuffs into these uses is shown in Table 8. Retention as seed means that a percentage of the crop is held back as the seedstock for the next year's crop. As more efficient seed-producing schemes are adopted throughout the world, these percentages may fall, but they can never be eliminated. Industrial uses are manyfold. Some are for heavy industry (as in the case of some of the vegetable oils), while others are for specialized uses within the food industry (either human food or pet food). Insofar as was possible, seed, imports, and exports were considered in terms of raw agricultural products; feed, industrial uses, and food were considered in actual weight of the commodity.

Livestock feed included the materials fed to livestock. This is a significant use of grains in all regions, and in some regions may account for the majority of grain use. In some cases, materials are fed to livestock to fatten them to increase meat quality and quantity. In others

TABLE 6

Specific Crops included in each of the categories considered in the world food model.

CATEGORY	CROPS INCLUDED
Wheat	Wheat
Maize	Maize
Millets & Sorghum	Millet and Sorghum
Rice	Rice
Other Cereals	Rye, Barley, Oats, Mixed Grains, Buckwheat, Miscellaneous Cereals.
Sugar Crops	Sugar Cane, Sugar Beets
Starchy Root Crops	Potatoes, Sweet Potatoes and Yams, Cassava
Vegetables	Onions, Tomatoes, Cabbages, Cauliflowers
Pulses	Greenbeans, Green peas, Dry beans, Dry peas, Dry broad beans, Chick peas, Lentils, Pigeon peas, Cow peas, Vetch, Lupins, Other pulses.
Fruits	Apples, Pears, Plums and Prunes, Cherries, Peaches, Apricots, Grapes, Oranges and Tangerines, Grapefruit, Lemons and Limes, Dates, Figs, Bananas, Pineapples,
Oil Crops	Olives, Palm Kernels, Soybeans, Peanuts, Cottonseed, Linseed, Hempseed, Rapeseed, Sesame Seed, Sunflower Seed, Castor Beans, Copra, Tung oil.
Drinks and Stimulants	Coffee, Cocoa, Tea, Hops, Tobacco
Fibers	Cotton Lint, Flax fiber, Hempfiber, Jute, Abaca, Agaves, Other hard fibers, Natural Rubber

TABLE 7

Percentages of individual crop types in aggregate crops.

REGION

Crop Type	1	2	3	4	5	6	7	8	9	10	World Average
Wheat	25.25	42.40	7.01	50.68	46.08	22.90	46.26	2.08	10.00	20.79	25.85
Maize	47.32	11.68	0.41	29.51	13.51	50.13	11.29	26.39	6.38	1.51	21.22
Millets & Sorghum	5.58	0.19	0.46	4.05	1.38	3.93	4.96	56.38	10.89	0.00	7.27
Rice	1.44	1.44	81.51	0.91	0.29	15.59	11.98	12.17	69.96	71.10	24.69
Other Cereals	20.41	44.29	10.61	14.85	38.74	7.45	25.51	2.98	2.77	6.54	20.97
Cereal Grains	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Sugar Crops	31.98	26.44	6.54	75.88	28.77	73.60	28.29	16.28	64.36	28.88	41.46
Starchy Root Crops	14.57	36.30	54.22	5.32	60.15	12.02	5.55	68.22	13.88	2.20	35.43
Vegetables	7.51	7.14	18.78	2.48	1.79	0.83	12.63	0.28	0.64	0.00	2.36
Pulses	3.06	2.44	2.30	0.97	1.60	1.27	5.44	3.48	6.30	15.69	3.03
Fruits	16.48	23.88	13.14	12.66	3.02	8.09	33.66	1.52	3.53	2.75	9.17
Oil Crops	22.36	3.30	3.77	2.36	3.63	2.27	10.90	7.15	7.01	38.22	6.48
Drinks & Stimulants	1.04	0.22	1.20	0.20	0.16	1.24	0.34	1.95	0.75	9.24	0.70
Fibers	2.99	0.27	0.05	0.12	0.88	0.68	3.18	1.10	3.51	3.03	1.36
Non-Grain Crops	99.99	99.99	100.00	99.99	100.00	100.00	99.99	99.98	99.98	100.01	99.99

Data refer to percentages of total cereal grain and non-grain Production by weight. From FAO sources
(footnote 13)

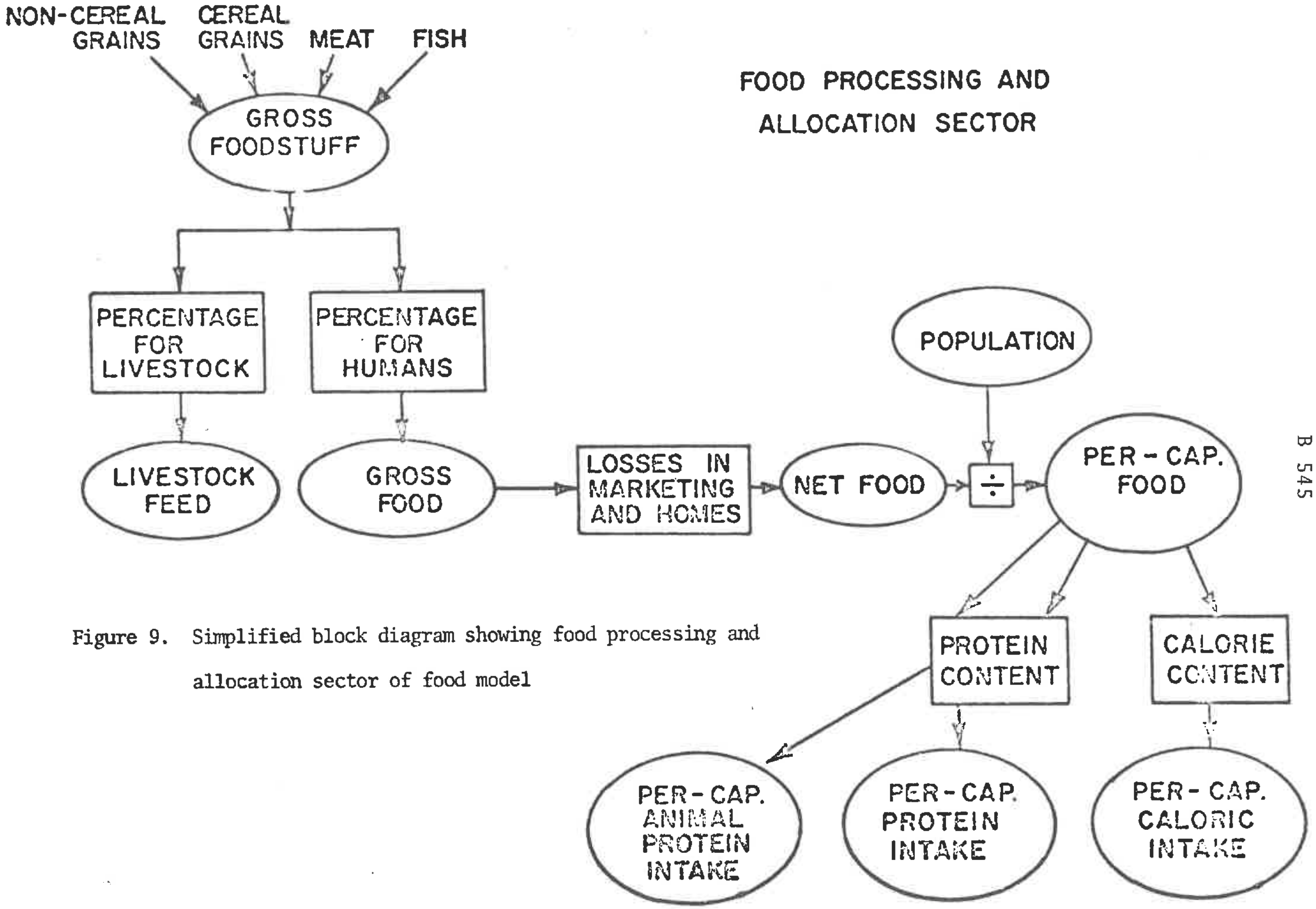


Figure 9. Simplified block diagram showing food processing and allocation sector of food model

these are fed to increase the usefulness of livestock as draft animals. This usage of foodstuffs is a complex one: In principle it can be reduced, thus freeing additional food to go to people. But these parameters cannot be involved in scenarios unless its impact on the energy supply and the protein intake of the regions concerned are considered. Finally, some of the foodstuffs is actually consumed by humans as food. For some foodstuffs, this may be an astonishingly low proportion. But it gives us the basis for the actual diet of a region. It will be noted in Table 8 that not all of the uses add up to 100%. The reason for this is that there is always waste. Some of this is in the form of actual waste of raw foodstuffs, while much of it is due to the fact that the extraction rate of refined products may be rather low[30].

The amount of food calculated by the model at this point is essentially that which appears for human consumption at the wholesale level. Between this stage and its conversion into human biomass, another adjustment is needed to describe the losses in the marketing process and in the home. In an industrialized country, these losses average around 10%; in other regions with poorer storage facilities they may be much higher. The regional net food supply is calculated and then divided by the population to give the average per capita intake of each foodstuff.

The protein and calorie content of each foodstuff is known (table 9) so that the average regional per capita intake of each foodstuff can be expressed in proteins and calories. These can then be added to give the total intake of calories, of all proteins, and of animal (high quality) proteins.

TABLE 9

Energy and Protein Content of Foodstuffs Considered

Foodstuff	Calories Cal/gm.	Proteins Percent
Cereal Grains		
Wheat	3.500	12.2
Maize	3.600	9.5
Millets & Sorghum	3.480	9.7
Rice	3.600	6.7
Other Cereals	3.490	11.8
Non-Cereal Crops		
Sugars	3.870	-
Roots	0.920	1.8
Vegetables	0.220	1.7
Pulses	3.450	23.1
Fruits	0.590	0.7
Oils	2.750	19.0
Drinks	-	-
Fibers	-	-
Meat and Dairy Products		
Beef	2.500	17.7
Pork	4.380	11.9
Lamb	2.880	15.6
Horsemeat	0.940	20.0
Other Meat	1.650	15.2
Honey	2.900	-
Poultry	1.300	20.0
Eggs	1.630	12.4
Offals	1.430	16.0
Milk	0.650	3.5
Cheese	3.000	18.0
Butter	7.160	0.6
Fish	1.320	18.8

Application of the food model

Because the food model is a simple feed-through model, it must be driven by some external parameters. It was originally driven by the observed rates of growth of the state variables, but the world is in such a rapid state of flux now that we felt that these rates could not be maintained for long and that the results obtained thereby were not meaningful. Thus, the food model was integrated with the economic and population models developed by Richardson and by Oehmen and Paul[7], to form a single model of the world food production system. Several scenarios have been run for regions 1 and 9 and the results are very meaningful. These are described in detail in the accompanying report by Richardson et al.

1. Revelle, R. 1972, Will the Earth's Land and Water Resources be Sufficient for Future Populations? Paper delivered at the United Nations Conference on the Human Environment, Stockholm. Multilithed: 39 pp.

2. For example, Malthus, T.R. An Essay on the Principle of Populations; Paddock, W. and Paddock, P., Famine-1975; America's Decision: Who Will Survive. Boston: Little Brown & Co.: X + 276 pp. Books, Inc.: 223 pp.; Borgstrom, G. 1967. The Hungry Planet. New York: The Macmillan Co.: XX + 507 pp. Dumont, R. and Rosier, B., 1969. The Hungry Future, Translated by R. Linell and R. B. Sutcliffe, New York: Praeger Publishers: 271 pp.

3. Pimentel, D., Hurd, L.E., Bellotti, A.C., Forster, M.J., Oka, L.A., Sholes, O.D., and Whitman, R.J. 1973. Food Production and the Energy Crisis. Science 182:443-449; Guernier, M. 1973. Perspectives Alimentaires de l'An 2000. Technical Report (Mimeographed).

4. For example, Thiessenhusen, W.C. 1971 Latin America's Employment Problem. Science 171: 868-874.

5. Geertz, C. 1963. Agricultural Involution: The Process of Ecological Change in Indonesia. Association of Asian Studies, Monographs and Papers, 11. Berkeley: University of California Press: XX + 176 pp.

6. e.g. Watters, R. F. 1971. Shifting Cultivation in Latin America. FAO Forestry Development Paper No. 17: xi + 305; Gourou. P. 1956. The Quality of Land Use of Tropical Cultivators, in Thomas, W.L. Jr. (ed). Man's Role in Changing the Face of the Earth. Chicago: University of Chicago Press: 336-349; Miracle, M.S. 1967. Agriculture in the Congo Basin: Tradition and Change in African Rural Economics. Madison: University of Wisconsin Press: xv + 355. Janzen, D.H., 1973. Tropical Agroecosystems. Science 182:1212-1219. In addition most descriptive treatments of cultural ecology in tropical areas give some feeling for the care that has to be given to poor tropical soils. The book by Marvin Miracle is a useful entry into this literature for central Africa.

7. Oehmen, K.H. and Paul, W. 1974. World Population Model Report for the multilevel regionalized world Medeling Project. 3 vol. and Richardson, J.M. 1974. Scenario Analysis of the World Food Problem. Report for the multilevel regionalized world modeling project. 32 pp.

8. Brown, L.R., 1970. Seeds of Change: The Green Revolution and Development in the 1970's. New York: Praeger Publishers: xv + 205; Anon, 1970. Provisional Indicative World Plan for Agricultural Development: Rome: FAO: 2 vol., 672 pp.

9. Brown, L.R., 1970. Seeds of Change. The Green Revolution and Development in the 1970's New York: Praeger Publishers, esp. ch. 5-7.

10. This pricing mechanism is discussed by Richardson in The Integrated Food Policy Analyses Model.

11. Graham, H.W. and Edwards, R. L. 1962. The world biomass of marine fishes. Fish in Nutrition. Fishing News (Books) Ltd: 3-8; Pike, S.F. and Spilhaus, A., 1962. Marine Resources. A report to the Committee on natural resources of the National Academy of Acience - National Research Council. NAS-NRC pub. 1000-E; Chapman, W.M. 1965. Potential Resources of the Ocean. Long Beach, Calif.: Van Camp Seafood Company, 43 pp; Meseck, G. 1962. Importance of fisheries production and utilization in the food economy. Fish in Nutrition. Fishing News (Books), Ltd. 23-27. Shaefer, M.B., 1965. The potential harvest of the sea. Trans. Am Fish. Soc. 94: 123-128, Rythers, J.H., 1969. Photosynthesis and Fish production in the sea. Science 166: 72-76; Ricker, W.E., 1969. Food from the sea ch. 5 in Resources and Man: A study and Recommendations by the committee on Resources and Man, National Academy of Sciences - National Research Council: San Francisco: W.H. Freeman and Co., 65-86.

12. Hora, SL 1951. Pond Culture of Warm Water Fishes " UNSC on the conservation & Utilization of Resources" VII; 120-4;

Lin SY 1951. Pond Culture of Warm Water Fishes "UNSC on the Conservation & Utilization of Resources" VII; 131-135;

Rabanol, HR 1951. Pond Culture of Warm Water Fishes "UNSC on the Conservation & Utilization of Resourses" VII 142-45;

Evaluation of Balance between fishes & available fish foods on multipecies Fish Culture Ponds in Taiwan. Transactions of the American Fisheries Society. 99: 708 ff;

Fourteen years of management & Fishery Success on Alabama State owned Fishing lakes. Trans. Am. Fish Soc. 99: 124ff;

Increasing Fish Production in Ponds . Trans. Am. Fisheries Sc. 92: 292ff;

Comparative Evaluation of 2 Tilapias as Pondfish in Alabama. Trans Am Fish Soc. 89; 142ff;

Fish Production on Terrace Water Ponds on Alabama. Trans Am Fish Society 69: 101ff;

Aquaculture Science. 161; 1098-1106;

Variation in Carp Production on Replicate Ponds. Trans. Am Fish Soc. 99: p 74-79;

Dynamics of fishes on an Alabama Pond Subjected to intensive angling. Trans. Am Fish Soc. 100; 757-68;

Standing Crops of Fish in Oregon Farm Ponds. Trans. Am Fish Soc. 92: 25-29;

Hiyama, Yoshio 1951. Rice Paddy Carp Culture in Japan. "UNSC on the Conservation & Utilization of Resources" VII: 124-6;

Hofstede, AE 1951. Pond Culture of Warm Water Fishes in Indonesia UNSC on the Conservation and Utilization of Resourses" VII 133-6;

Meehan, Lloyd O. 1951. Pond Culture of Warm Water Fishes as Related to Soil Conservation. "UNSC on the Conservation & Utilization of Resourses" VII: 138-142;

Jelacin, Ivan 1951. Fresh Water Fishery - Artificial Insemination of Carp "UNSC on the Conservation & Utilization of Resourses" VII; 158-60:

Fish Farming & Inland Fishery Management on Rural Economy FAO Fisheries Study No. 3. July 1954;

Idyll, CP. 1970. The Sea Against Hunger. New York: Thomas Y. Cromwell Co. 70-71;

Bennell, GW. 1971. Management of Lakes & Ponds New York: Van Nostrand Reinhold Co.;

Kuk, RG. 1972. A review of recent developments in Tilopia Culture, with special reference to Fish Farming in the heated effluents of power stations. Aquaculture 1: 45-60;

Opaszymski, Karol 1972. Use of Phytophagous Fish to control Aquatic plants. Aquaculture 1: 61-74;

Shang, Yung 1973. Comparison of the economic potential of Aquaculture, Land Animal Husbandry, & Oceanic Fisheries: The Case of Taiwan. Aquaculture 2: 187-195;

McLarney, William O. 1971. The Farm Pond Revisited. Organic Gardening & Farming 18: 88-92;

McLarney, William O. 1971. Aquaculture on the organic farm & homestead. Organic Gardening & Farming. 18: 71-77

13. Data are from the World Crop Statistics 1948-1964 and the Production Yearbooks of 1967 and 1970. National figures for production, area under crop, and yields are given for over 10 cereal grains and 58 non-cereal crops. All 3 types are given for the cereals and most of the other crops; however area and yield are (unfortunately) omitted for perennials and some other minor crops. Production and area (where available) data were aggregated into the regions for the period of 1948-1970. The relationship between land cultivated in grains and that cultivated in non-grains was determined by linear regression.

14. Revelle, R., Brody, N.C., Brown, A.L., Hayan, R.M., Orvedal, A.C., Peterson, D.F., Russell, M.B., Thorne, W. Schilfgaarde, J. van. and Horne, G.F. 1967. Water and Land. Chap. 7 in the World Food Problems A Report of the President's Scientific Advisory Committee. Washington: US Government Printing Office: 405-470.

15. FAO defines arable land in the notes to Table 1 of the Production Yearbook. It should be noted that this statistic is probably the most subjective in the entire compendium, since it is based entirely on the judgement of various national ministries of agriculture, and each ministry assesses its own land base by a different yardstick.

16. For example Watters, R.F., 1971. Shifting Cultivation in Latin America. FAO Forestry Development Paper No. 17: x + 305; Horsfall, J.G. Brady, N.C., Cline, M.G., Drosdoff, M., Cuilken, P.C., Kellogg, C.E., Odum, H.T., Overbeck, J. van, 1967. Tropical Soils and Climates. Chap. 8 in The World Food Problem, A Report of the President's Scientific Advisory Committee. Washington: U.S. Government Printing Office: 471-500.

17. Revelle, R.., Brady, N.C., Brown, A.L., Haspen, R.M., Orvedul, A.C., Peterson, D.F., Russell, M.S. Thorne, W., Schilfgaarde, J.Van., and Horne, G.F., 1967. Water and Land. Chaper 7 in The World Food Problem: A Report of the President's Scientific Advisory Committee. Washington, 405-470. Revelle, R. 1972. Will the Earth's Land and Water Resources be sufficient for future populations? Paper given at the United Nations Conference on The Human Environment, Stockholm.

18. Experimental Yield-response data are a major tool of agricultural experiment and development stations throughout the world. Few types of relationships are more common than the 2-dimensional graph (or equation) relating fertilizer applications to yield. For discussion of these relationships in areas identified with the world food crisis, see Narain, C.D. 1968. Methods of Estimating National Fertilizer Requirements, in Fertilizer Production, Technology, and Use. New York: FAO: 370-382; De Geus, J G. 1967. Fertilizer Guide for Tropical and Subtropical Farming. Zurich: Centre d'Etude de l'Azote: 727 pp.: Malavolta, E. Haug, H.P., Mello, FAF, and Brasil Sobr, M.O.C., 1962. On the Mineral Nutrition of Some Tropical Crops: Berne: International Potash Institute: 155 pp.; Cooke, G.W. 1972. Fertilizer for Maximum Yield. New York: Hafner Publishing Co.: XXIV + 296 pp.; Anon, 1966. Statistics of Crop Responses to Fertilizers. Rome: FAO, 112 pp. Some discussion of 3-dimensional surfaces is provided by the article by R.D. Narain.

19. Lester Brown Discusses the interrelationship between these factors in a particularly lucid way in Seeds of Change.

20. Data for grain production and area are from World Crop Statistics 1948-1966 and the Production Yearbooks of 1967 and 1970. National figure are aggregated into data on total cereal production and total area in cereals for all regions. Regional grain yield per hectare (GRPH) was calculated by dividing total production by total area. The fertilizer consumption data are from the Production Yearbooks of 1951, 1953, 1955, 1958, 1961, 1964, 1967, and 1970. Total consumption of fertilizer was aggregated to regional totals using the same product as that of grain production. As a rule of thumb, we assumed that 2/3 of the fertilizer consumption was on cereal grains; this was a suggestion from Dr. Raymond Ewell. Professor of Chemical Engineering at SUNY-Buffalo, a widely respected expert on fertilizer usage. Thus, the average regional fertilizer application rate was calculated by dividing two-thirds of the regional fertilizer consumption by the area cultivated in grains.

21. See. Richardson, J.M. 1974. Scenario Analysis of the World Food Problem Report for the Multilevel Regionalized World Modeling Project. 32 pp.

22. The data for this relationship are from World Crop Statistics 1948-1966 and the Production Yearbooks of 1967 and 1970. Aggregation of production data for 10 cereal grains and 58 non-cereal crops into regional totals is by the same protocal as that used in footnotes 11 and 19. The relationships between gross production of cereal grains and that of non-cereal crop was determined by a linear regression using the aggregated data for the period 1948-1969.

23. This is implicit in the reliance on arable land as the prime level determining food production in Meadows, D.H., Meadows, D.L., Randers, J., and Behrens, W.W., III, 1972. The Limits to Growth. New York: Universe Books: 205 pp., and it is explicit in the technical report on the agricultural sector of that study (xerox copy, privately circulated. Appendix to Chapter 1).

24. Data are from Revelle, R., Brady, NC., Brown, A.L., Hagan, RM., Orvedal, A.C., Peterson, D.F., Russell, M.G., Thorne W., and Schilfgards, Ivan., Water and Land. Ch. 7 in The World Food Problem. Washington: Govt. Printing Office: 405-470. Land is apportioned into the 10 regions in proporation to the amount of arable land from each continent in each region.

25. The numbers of animals in each region are taken from the FAO production yearbook for 1970, with national totals being aggregated to regional totals in the same manner as the crop data described earlier. Only the years 1966-1969 or 1966-1970 (depending on the extent of the data in the 1970 Production Yearbook) were considered, because the relationships being considered are much simpler. The average annual ratio of change in livestock numbers were calculated as the average percentage change in regional livestock population during the interval.

26. The production of meat in each region is listed in the FAO Production Yearbooks for 1967 and 1970, with national totals aggregated to regional totals as done before. The relationship between livestock number and meat production was obtained by dividing regional meat production by regional lovestock population.

27. These data were obtained in the FAO Fisheries Yearbook for 1970. The average annual growth rate of the regional catches were calculated by aggregating national catch into regional catch and determining the average percentage change in the regional catch during the interval 1964 to 1970.

28. The low estimate is from Graham, H.W., and R.L. Edwards, 1962. The World Biomass of marine fishes. Fish in Nutrition. Fishing News (Books) Ltd; 3-8. The high come from Pike, S.T. and Spilhaus, A., 1962. Marine Resources: A report to the committee on Natural Resources of the National Academy of Sciences. National Research Council. NAS-NRC. Pub. 1000-E, and Chapman, W.M., 1965. Potential Resources of the Ocean Long Beach, Calif., Van Camp Seafood Company; 43 pp. (Available on loan from Living Marine Resources, Inc., San Diego).

29. The allocation of food to the various uses are based on the FAO Food Balance Sheets 1964-1966, which list production, import, exports, animal feed, seed, manufacturing, waste, and net food for all major foodstuffs. We have taken the food balance sheets for the largest countries in each region, Canada and the United States in region 1. France, The Federal Republic of Germany, Greece, Italy, The Netherlands, Spain, Sweden, Turkey and the United Kingdom in Region 2; Japan in region 3; Australia, New Zealand, and the Republic of South Africa in region 4; Bulgaria, Czechoslovakia, The Democratic Republic of Germany, Hungary, Poland, Romania and the USSR in region 5; Argentina, Brazil, Chile, Colombia, Cuba, Ecuador, Mexico, Peru, and Venezula in region 6; Algeria, Iran, Irag, Morocco, Syria, and the United Arab Republic in region 7; Ethiopia, Ghana, Kenya, Madagascar, Nigeria, Rhodesia, Sudan, Tanzania, Uganda, Upper Volta Zaire in Region 8; and Burma, India, Indonesia, Pakistan, the Philippines, Taiwan, and Thailand in region 9; and the Peoples' Republic of China, North Korea, and North Vietnam in region 10), and calculated coefficients of retention as seed, use as livestock feed, and use as a human food for all regions and all foodstuffs except for fibers. The seed coefficient is the total amount reserved for seed divided by total production. The livestock feed coefficient is the total feed going to livestock divided by the total local production plus net import. The food coefficient is the total food going to the human populations divided by the total local production plus net import.

    It should be noted that these data are also provided to FAO by member governments, and thus show the same biases as the other FAO data. Also, two different ways of reporting certain data are used in the volume of Food Balance Sheets, one of which obscures the relationship between gross production of foodstuff and the form in which it is imported or exported. Even so, these data are as good as indication of the disposition of food within regions as can be asked at this point, and errors are probably no greater than in other portions of the model.

30 For example, sugar cane - raw sugar, 10%; sugar beets - raw sugar, 13.5%, soybeans - soybean oil, 19%; coconuts - coconut oil, 15% sunflower seeds - sunflower oil, 35%., etc.

III.4. THE STRUCTURAL DESCRIPTION AND SENSITIVITY ANALYSIS OF THE FOOD SUBMODEL

M.D. Mesarovic, J.M. Richardson Jr., T. Shook,
M.W. Warshaw

April 1974

Table of Contents

1. Overall Structure

The principal structure of the model of interest for the analysis of the food situation are the population and economics, land use and food on the technology stratum and the individuals stratum on which the response on the individuals to food and diet deficiency or surplus is assessed. In the report we study the structure of the submodels of interest for the food analysis,the linkages and data base. The land use food production submodel (Clapham and Warshaw,1974) and the population submodel (Oehmen and Paul,1974) have been already described. In the case of the economic stratum, a two sector (food and non-food) aggregation of the nine sector regionalized micro-economic model (Hickman, Klein and Mesarovic, 1974) is of interest of the food analysis presented in this report and we shall describe how this aggregation is made.

A simplified diagram of the connections within the world system model of interest to the food analysis are identified in Fig. 1-1. The reader will note that, in addition to the four submodels, a pricing mechanism, import sector, export sector and mechanism for comparing regional food supply with population needs, are identified as important components.

1.1 Components of the Integrated Model

1.1.1 The Population and Economic Submodels

The overview of the main aspects of the population submodel of interest for our purpose is given in Fig. 1-2. To permit coupling with the land use and food production strata, while retaining maximum siplicity, a model on the microeconomic level of resolution, comprising of an agricultural and non-agricultural sector has been used.

Parameters, inputs, outputs and scenario variables of the econimic submodel are identified in Figure 1-3. Coefficients for consumption, investment, government expenditure, imports and exports in the demand equations are defined exogenously. Input-output matrix coefficients,

B 558

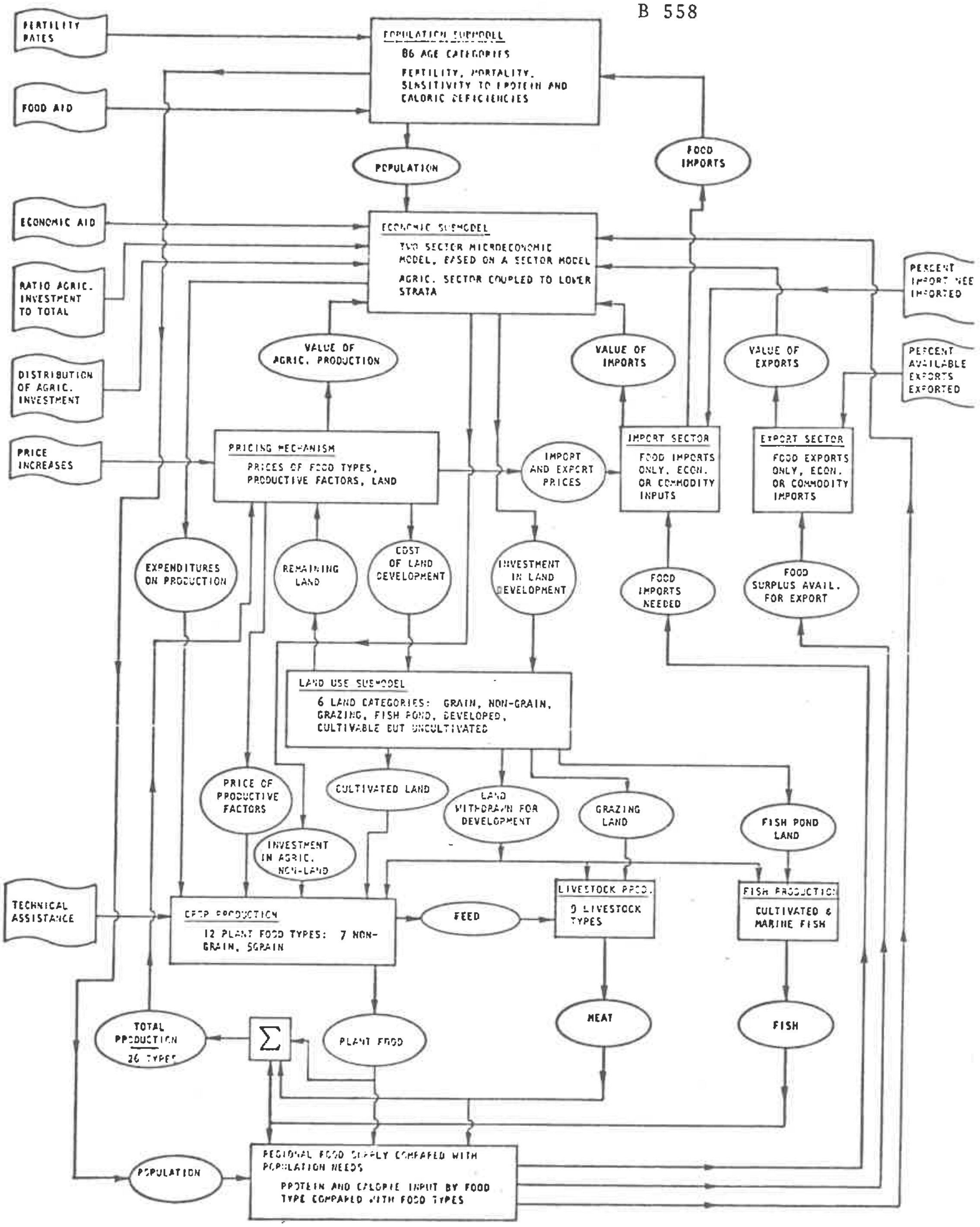


Figure I-4. Integrated Food Policy Analysis Model: Structure and Principal Interrelationships Between Strata and Sectors

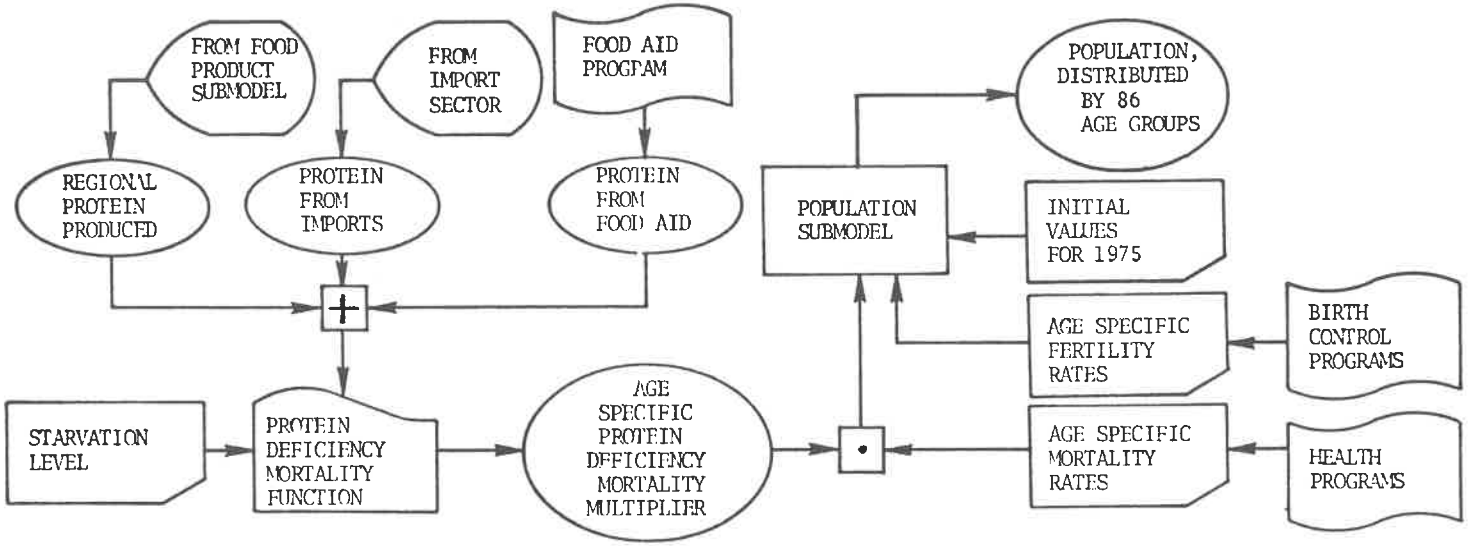


Figure 1-2. Population Submodel: Simplified Representation of Parameters, Inputs and Outputs

B 560

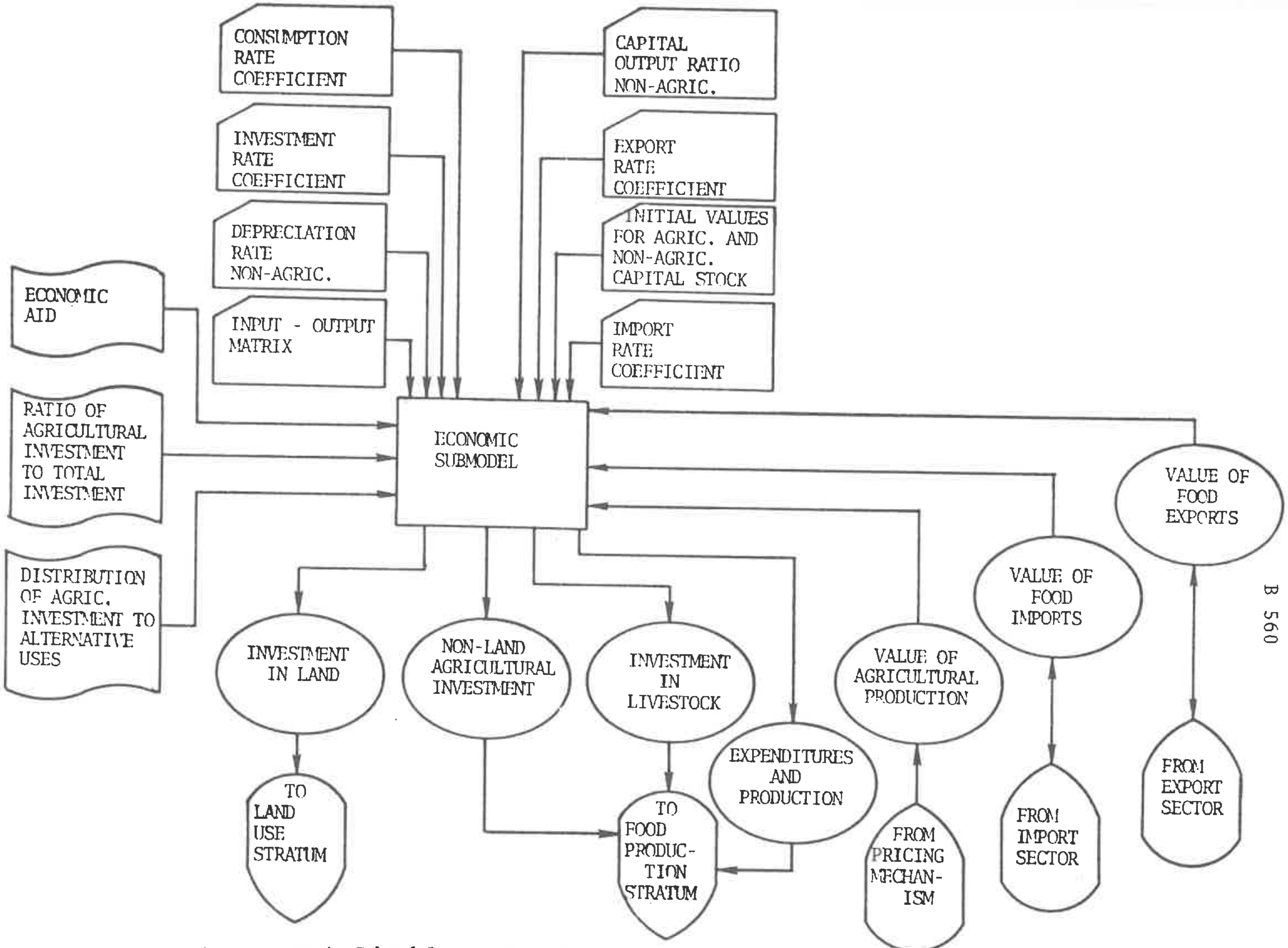


Figure 1-3. Economic Submodel: Simplified Representation of Parameters, Inputs and Outputs

the non-agricultural sector capital output ratio and the non-agricultural sector depreciation rate are also defined as exogenous coefficients.*

The scenario variables identified for the economic stratum reflect a concern with the problems of investment development of aid, and with the distribution of investments. Both the ratio of agricultural investment to total investment and the distribution of agricultural investment to fertilizer production and technological improvement, land and livestock can be manipulated.**

The outputs from the economic stratum which affect the level of food production are <u>investment in land</u>, <u>investment in livestock</u>, <u>non-land agricultural investment</u> and <u>expenditures in production</u>. The latter is expended on fertilizer and other non-capital factors of production.*** A fraction of agricultural investment may also be allocated to a fertilizer production use subsidy program. The value of imports may also be

---

* A comprehensive economic data base [Erdilek et. al., 1974] has been used to estimate parameters and validate the micro-economic model for which these coefficients are derived. See, for example, McCarthy and Shuttic [1974].

** We have considered the possibility of implementing a mechanism which would maximize the marginal productivity of investments with respect to the three categories; however, it has not been implemented at this time. Such a mechanism might prove to be of some value for modeling relatively "free market" agricultural systems such as that of North America. (Even in North America, however, the level of government involvement has been relatively high.) For centrally planned systems, treating the distribution of investment as a scenario variable is probably most appropriate.

*** Following the practice of FAO and others in aggregate productivity and yield-value analysis, fertilizer consumption is used as an indication for a mix of non-capital inputs to the food production process.

specified as an input to the import sector from the food production sector. When this is done, the value of food imports, an input to the population sector, is determined by the funds allocated to imports and current market prices. The value of food exports may be specified in a similar manner.

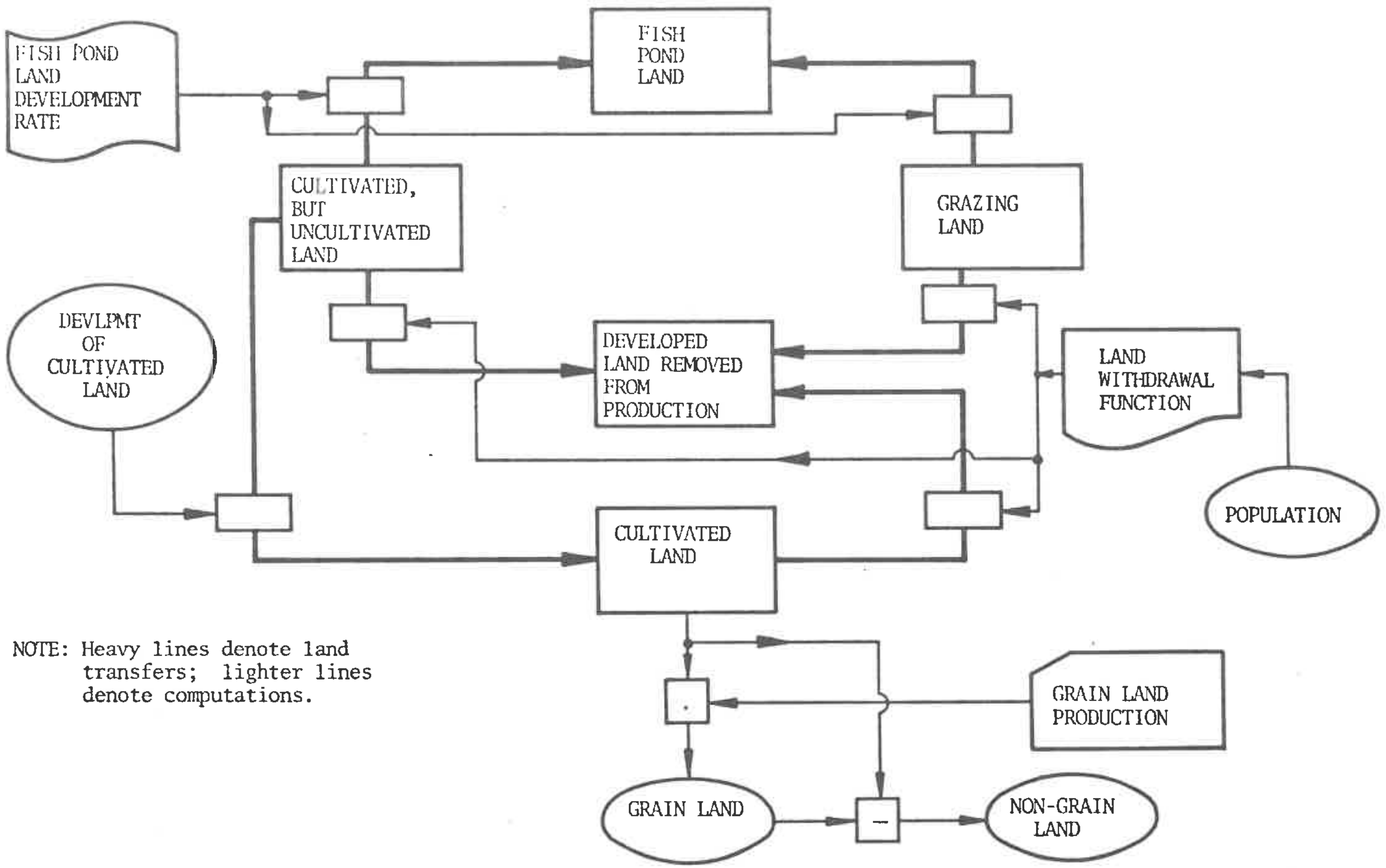
Alternatively, the volume of exports and of imports (measured in food or edible protein) may be specified by scenario variable inputs to the import sector. When the model is used in this way, the value of food imports and the value of food exports are inputs to the demand equations of the economic submodel. The value of agricultural production is a function of the amount and price of products produced in the other input to the economic submodel. As noted above, this input replaces the value of agricultural production calculated from a production function in the one stratum microeconomic model.

1.1.2 The Land Use Submodel

The basic structure of the land use submodel pictured in Figure 1-4. For categories of land - cultivable but uncultivated, grazing, developed, cultivated and fish pond are defined as state variables.* The rate of increase in cultivated land is determined by the amount of investment in

---

* For reasons which are discussed in the technical report describing the land use and food models [Clapham and Warshaw, 1974], grain land rather than cultivated land is defined as a state variable in the actual model computations. This difference has no effect on the overall results. The structure depicted in Figure 1-6 conveys, in the judgment of the author, a clearer understanding of the model.



NOTE: Heavy lines denote land transfers; lighter lines denote computations.

Figure I-4. Simplified Structure of the Land Use Model land development and land development costs (which include the price of land). Development costs increase as the amount of cultivable but uncultivated land decreases. As population increases, land is withdrawn from agricultural uses for urban and economic development.

Parameters, inputs, outputs and scenario variables of the land use submodel are identified in Figure 1-5. Since the price of land is sensitive to the amount of uncultivated agricultural land available for development, both the input and output couple the land use model to the pricing mechanism. Outputs to the food production sector - grain land, non -grain land, total land for livestock support and fish pond land - are significant factors in determining the amount of food produced. Because of inadequate data, components of the model dealing with the production of cultivated fish have not been coupled to the economic sector in the present version of the model. Hence, scenarios which examine this type of food must be directly implemented in the land use sector, rather than through shifts in patterns of investment in the economic sector. This also means, of course, that the economic implications of such scenarios can not fully be taken into account.

1.1.3 The Food Production Submodel

Because the food model computes information on twenty-six food types, it appears to be quite complex.* The fairly high level of disaggregation

---

* Both the land use and food submodels were developed by Clapham and Warshaw. It should not be assumed that the brief discussion here is, in any sense, an adequately substitute for the detailed elaboration found in their technical report [Clapham and Warshaw, 1974].

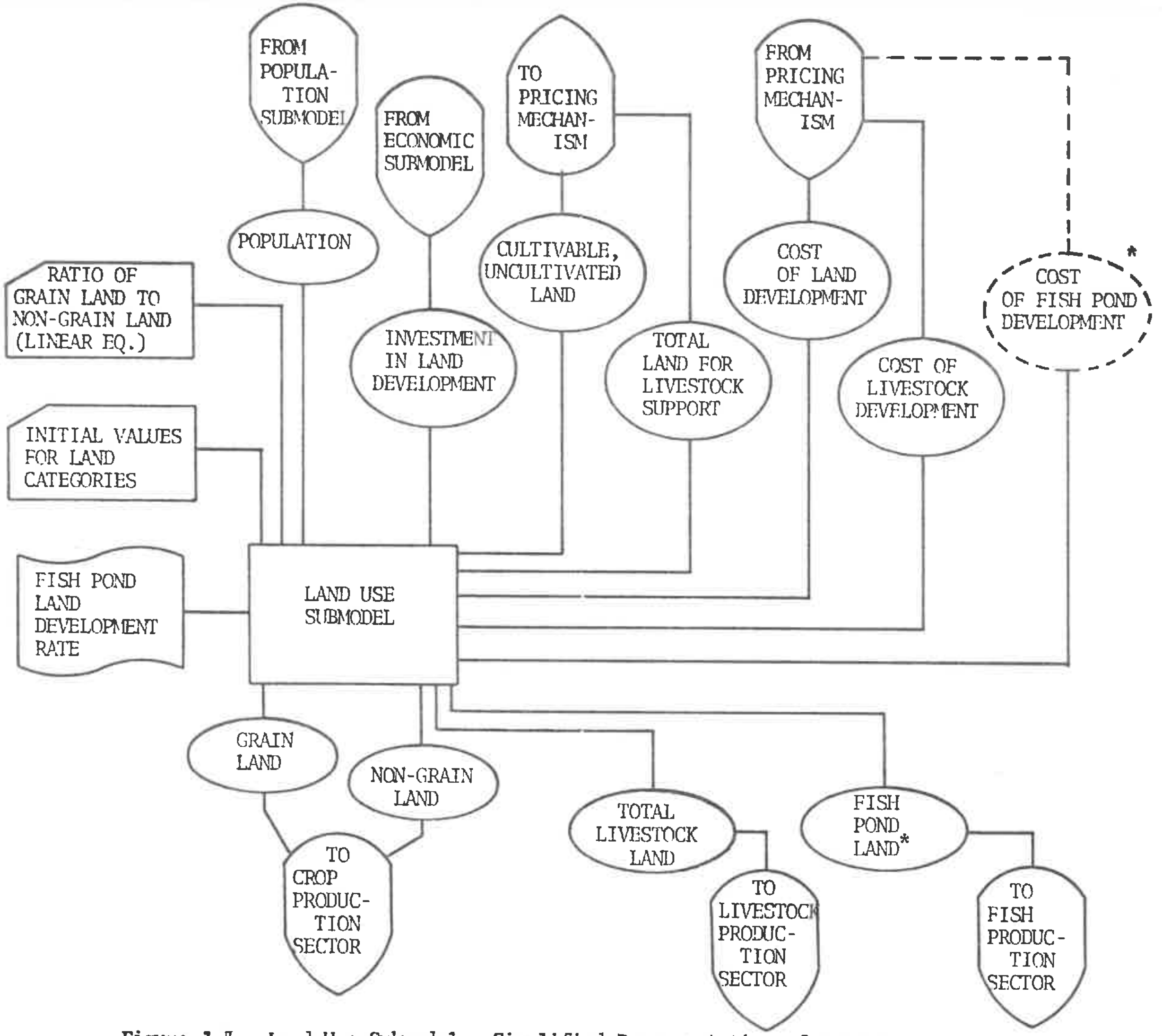


Figure I-3. Land Use Submodel: Simplified Representation of Parameters, Inputs and Outputs permits an examination of different uses to which foodstuffs are put in different regions and allows for costs of future dietary patterns to be made in concrete terms. But the underlying rationale of the model is straightforward (Figure 1-6). Gross production levels in the three sectors - plants, livestock and fish - are determined by the input levels of land, capital and other factors of production.* Production levels for the various food types are determined by gross production levels with adjustments made to take into account the utilization of some portion of the output for seed and livestock. In calculating the net food production level from which regional production of calories and protein is computed, household, marketing and food processing losses are also taken into account.

For many policy analysis problems, the food model can simply be viewed as a "black box" with inputs of land, capital and other factors of production and outputs of protein and calories. But for other problems the availability of data in the different food types will be quite significant.

The inputs to and outputs from the food model and their significance should be clear from Figure 1-6 and the above discussion. There are no scenario variables presently defined. Because of the complex disaggregation and reaggregation scheme, this submodel has by far the largest

---

* As indicated by the dotted lines in Figure 1-6, this scheme is fully implemented only for the plant production sector. In Region 9, on which our attention has first been focused, failure to take production costs directly into account in the fish and livestock sectors is probably not of great significance. In the Region 1 scenarios, livestock production costs are taken into account indirectly.

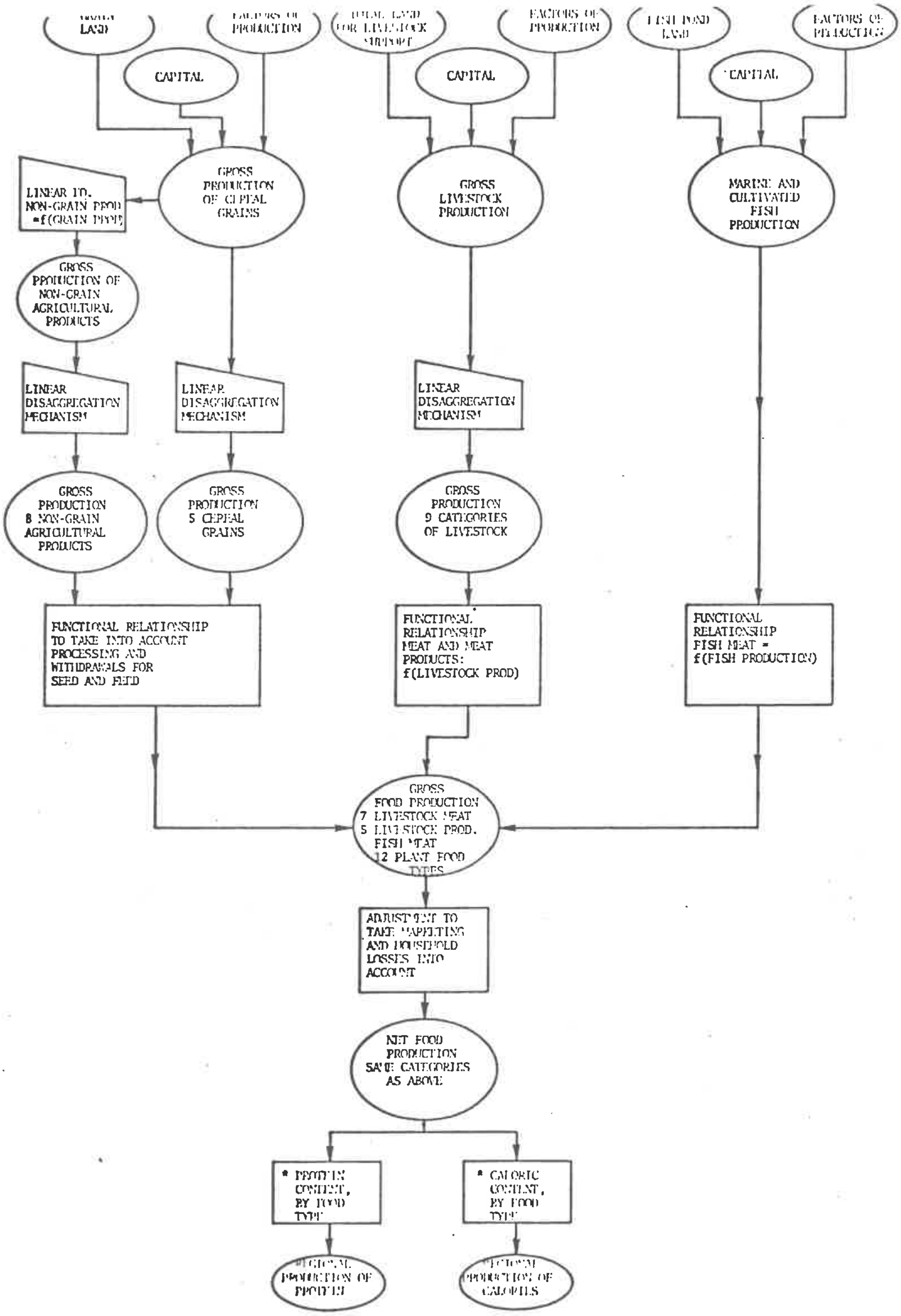


Figure 1-6 Basic Structure of the Food Production Submodel

number of parameters. It is interesting to note that regional differences between parameter values are, in a surprising number of instances, quite significant*.

1.2 Couplings within the World Model of Interest for the Food Analysis

Many of the couplings between submodels are described in more details elsewhere and require no elaboration other than that presented above. The population-economic, papulation-land use and land use submodel couplings fall into this category. But the pricing mechanism while couples economic-sector variables, measured in dollar values, with land use and food production variables, measured in physical quantities, does merit further discussion. The mechanism which compares regional food supply with population needs will also be briefly considered.

1.2.1 The Pricing Mechanism

The pricing mechanism is composed of four distinct components which are not directly coupled (Figure 1-7). Three of the components compute per-unit costs for land, livestock and productive factors related to crops. The fourth assingns monetary values to the various categories of agricultural production, thus computing the agricultural component of GRP, an input to the economic sector. In two of the components - valuation of

---

*For examples, see the specification of parameter values for Region 1 and Region 9 in Part 5, below.

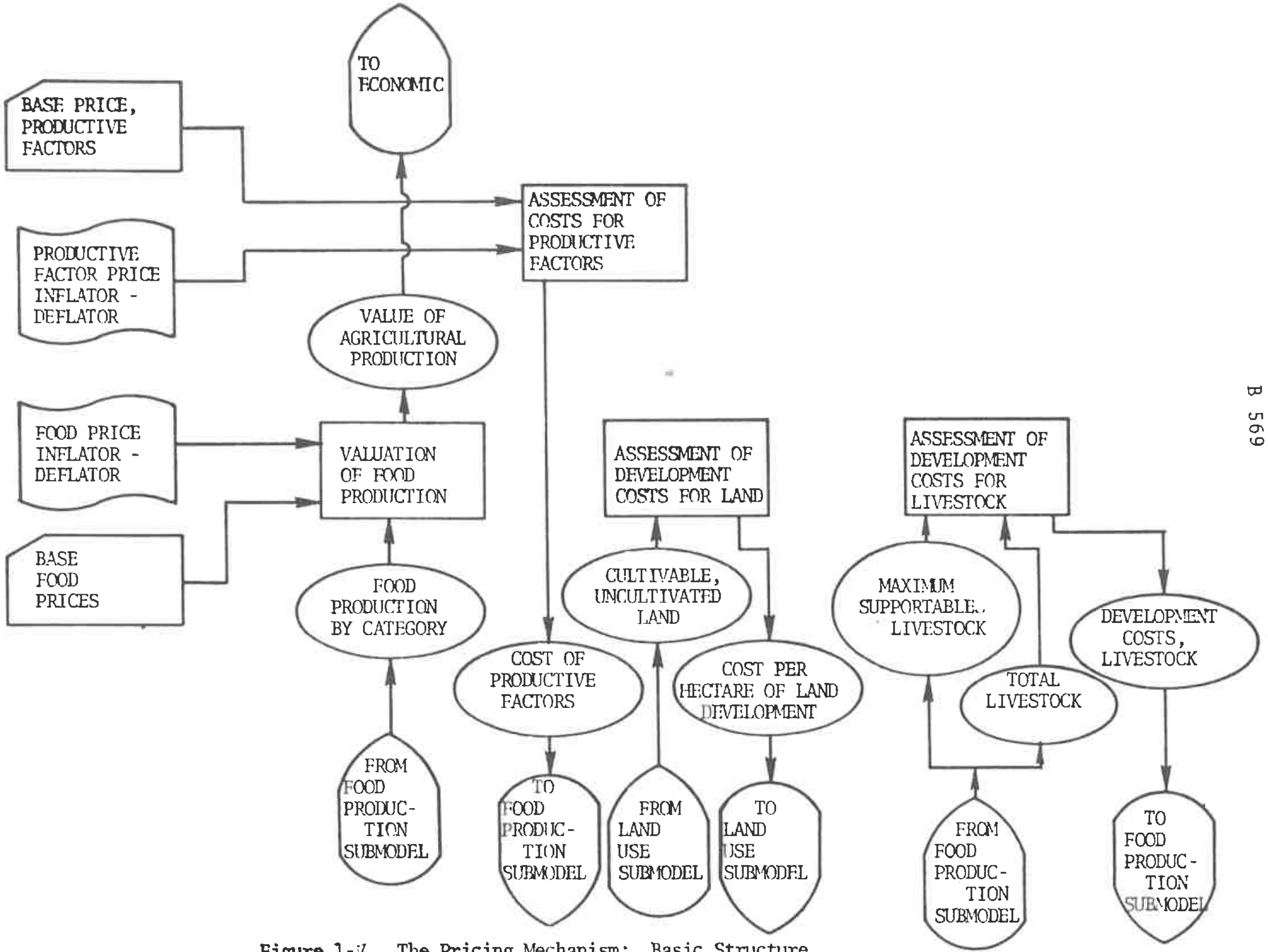


Figure 1-7. The Pricing Mechanism: Basic Structure, Inputs and Outputs

food production and assessment of costs for productive factors. The respective values and costs of physical commodities ard determined by parameters and scenario variables. The scenario variables are used to inflate or deflate food and/or productive factor prices relative to those of other commodities.*

In the two other components, the amount of available land is a constraint which affects prices. Costs of land development are directly related to the available land remaining for cultivation. In land deficient regions, such as fertile Asia, costs rise steeply as remaining land diminishes. Eventually they may reach prohibitive levels. Costs associated with increasing the number of livestock may be indirectly affected by the amount of land available for livestock support through variables which measure the maximum number of grazing livestock that can be supported. It is possible to increase herds beyond that "maximum," but the capital and production costs involved increase significantly.

1.2.2 Regional Food Supply Compared With Population Needs

Because food protein and calories are direct inputs to the population stratum where the occurrance of starvation, if any, is computed, this sector does not have any significant effect on the overall model dynamics.

---

*The reader will recall that all monetary values are in 1963 constraint dollars.

However, the relationship between food needs and supply determines import needs or the availability of surplus for export. The existence of surpluses or deficits are of importence when examining scenarios involving interregional food aid programs.

"Food Needs" are defined as the amount of food which will result in an adequate level of nutrition*. This is substantually above the starvation level. In establishing base needs, we have been guided by the work of WHO in this area. Food needs are also sensitive to increases in GNP/ per capita thus, particularly in the developed regions, food demand might be a more appropriate label for this variable. The inputs to and outputs four this mechanism are pictured in Figure 1-8.

---

*For a more detailed discussion of this and other specific parameter values, see Section 5, below.

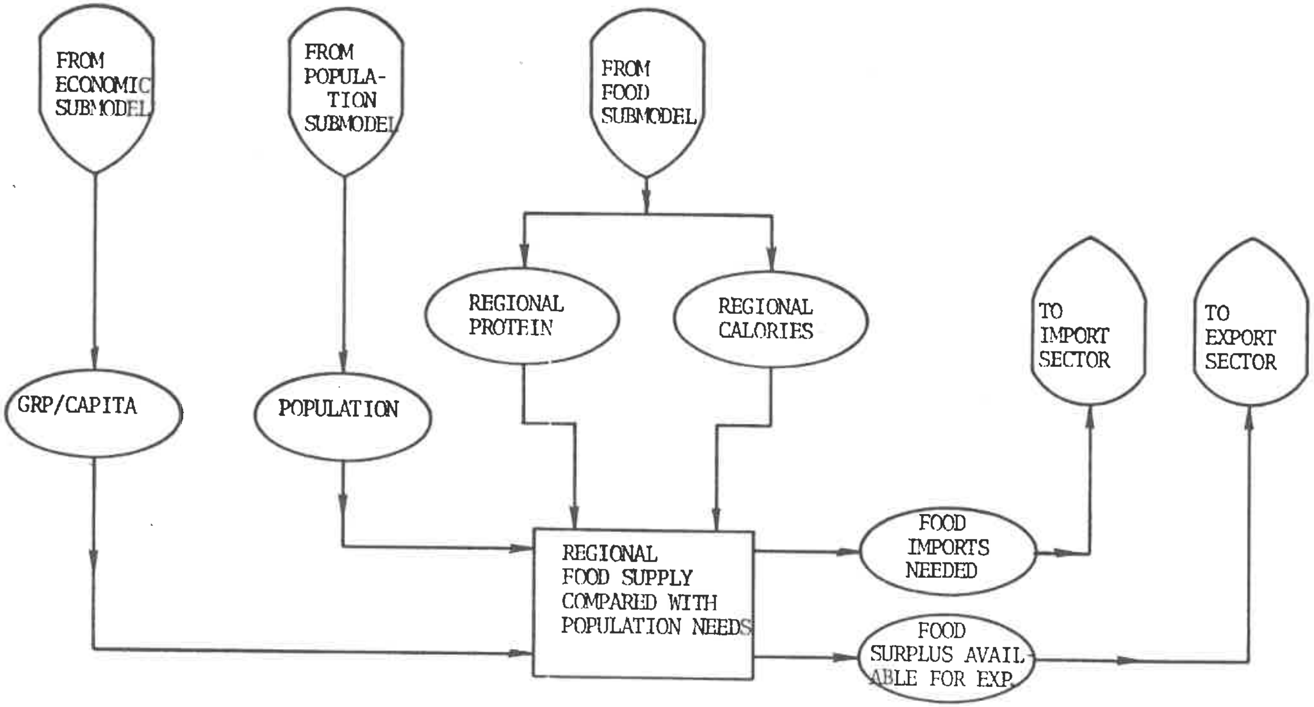


Figure 1-8 . Regional Food Supply Compared with Population Needs: Inputs and Outputs

2. Model Equations

In this section, the complete set of equations from the world model of interest for the food assessment is presented. As noted in the introduction, this is done so that this report could be, essentially, self contained for the readers who are not interested in details of the world model as a whole. However, it should be emphasized again that this discussion cannot be regarded as an adequate substitute for the more fully elaborated discussions of individual submodels or the overall structure by Mesarovic et al., Clapham, Oehmen and Paul, Clapham and Warshaw. Its intent is to present a clear and detailed picture of the way in which these relationships affect the world food situation*.

2.1. The Population Submodel

(1) Total Population

$$POP = \sum_{I=0}^{86} AP(I)^{**} \tag{1.1}$$

$$AP(0) = BABIES - DN(0) \tag{1.2}$$

---

*When discussing the equations of a computer model, selection of an appropriate notation always posses a problem. Use of strict mathematical notation may make if difficult to understand the computer program. On the other hand, discussion of a FORTRAN program, in all its detail will necessarily include items which may confuse, rather than clarify understanding of the model structure. In the presentation below, a notations scheme somewhere in between these two alternatives has been chosen. In the technical papers describing the individual submodels, more traditional mathematical notation has been used.

**Since all of the model computations are annual, time subscripts have been omitted.

$$AP(I) = AP(I) - DN(I) \qquad I = 1,85 \tag{1.3}$$

$$AP(86) = AP(86) - DN(86) + AP(85) \tag{1.4}$$

Computed Values:	POP	Total Population
	AP(0)	People aged 0 - .5 years, after infant mortality has been taken into account
	BABIES	Number of Live Births
	DN(0)	Infant Mortality
	AP(I)	Population, by age category
	DN(I)	Number of Deaths, by age category

(2) Births

$$BABIES = FERT * \sum_{I=1}^{86} (AP(I) * AF(I)) \tag{2.1}$$

Parameters:	FERT	Fertility Coefficient
	AF(I)	Normalized age specific probability that a person in the age group between $I-\frac{1}{2}$ and $I+\frac{1}{2}$ will produce a child between July 1 of year t and July 1 of year t-1.*
Computed Values:	BABIES	Number of Live Births

---

[*] The product of FERT and AF(I) is the actual age specific fertility. For further discussion, see Oehmen and Paul [1974, p. 3, ff].

(3) Deaths

$$DN(0) = BABIES * AMPF(0) * AM(0) * .5 * MORT \tag{3.1}$$

$$DN(I) = AP(I) * AMPF(I) * AM(I) * MORT \tag{3.2}$$

$$DN(86) = AP(86) * AMPF(86) * AM(86) * MORT \tag{3.3}$$

Parameters:	MORT	Mortality Coefficient
	AM(I)	Normalized age specific probability that a person in the age group between I-½ and I+½ will die between July 1 of year t and July 1 of year t-1.*
Computed Values:	DN(0)	Infant Mortality
	BABIES	Number of Live Births

It is envisioned that MORT will be used as a scenario variable in scenarios which examine the effects of improving health care. However, no such scenarios have, as yet, been implemented.

(4) Effects of Protein Starvation on Mortality

$$PROPCI = PTPCR * PRODST * 1000/365 \tag{4.1}$$

$$I = TIMLAG + .5 \tag{4.2}$$

$$PPCSAV(I) = PROPCI \tag{4.3}$$

$$PROPCN = PPCSAV(1) \tag{4.4}$$

$$PROFAC = (PRONOR - PROO)/(PROPCN - PROO) - 1.0 \tag{4.5}$$

---

*The rationale for MORT and AM(I) is similar to that for FERT and AF(I).

$$E(I) = (EO - EU) * EXPF(-I/EA) + EU \qquad (4.6)$$

$$AMPF(I) = PROFAC * E + 1 \qquad (4.7)$$

$$AMPF(0) = PROFAC * EO + 1 \qquad (4.8)$$

$$AMPF(86) = PROFAC * EU + 1 \qquad (4.9)$$

Parameters:	PRODST	Protein distribution factor (Scenario Variable)
	TIMLAG	The time interval between a decrease in protein per capita and its impact on mortality
	PRONOR	Level of daily protein per capita below which starvation occurs
	PROO	Level of protein per capita below which there is no survival
	EO	Multiplier denoting sensitivity of babies to protein starvation
	EU	Multiplier denoting sensitivity of older people to protein deficiency
	EA	Time constant denoting the number of years that pass until E, the age speicifc sensitivity minus EU drops to 37% of EO - EU (in eqn. 4.6)
Computed Values:	PROPCI	Daily per capita protein consumption
	PTPCR	Annual protein per capita produced regionally
	PPCSAV	Intermediate value used in computing lagged daily per capita protein consumption
	PROPCN	Multiplier denoting the amount by which age specific mortality is increased due to protein deficiencies
	E	Multiplier denoting sensitivity, by age group, to protein deficiency
	AMPF(I)	Effects of protein starvation on mortality

Coupling between the food production submodel and the population submodel occurs in Equation 4.1, through the variable PTPCR. The scaling factor, 1000/365, converts the dimensionality of the food production submodel (kilograms per capita per year) to that of the population model (grams protein per capita per day). The protein distribution factor, PRODIST, takes into account inadequacies and inequities in the distribution system which can occur in less developed regions of the world. Because of this uneven distribution, the actual amount of food needed to provide adequate nutrition (or prevent starvation) is greater than one would predict by simply computing PROPCI from regional aggregate food production. Equations 4.2 - 4.4 take into account the time delay between changes in food supply and their impact on the population.

Computation of the effects of protein starvation on mortality is broken down into two components. In equation 4.5, a multiplier is computed which denotes the age specific sensitivity of the population to protein deficiency. Values of this variable are related in plots of the "starvation factor" in scenario results. Values of E(I) are highest for babies and fall off rapidly during the period specified by EA. (A typical distribution of E(I) is pictured in Figure 4-1.) The variable PROFAC is sensitive to the amount of protein deficiency, relative to the threshold starvation levels specified by the values of PRONOR (level below which starvation occurs) and PROO (level below which there is no survival). Over the range of E(I), equation 4.7 generates a hyperbolic with its verticle asymptote at PROO (Figure 4-2). Since EO and EU are, respectively, the upper and lower bounds of E(I), the equations for AMPF(0) and AMPF(86) are defined separately from equation 4.7.

B 578

Figure 2-1

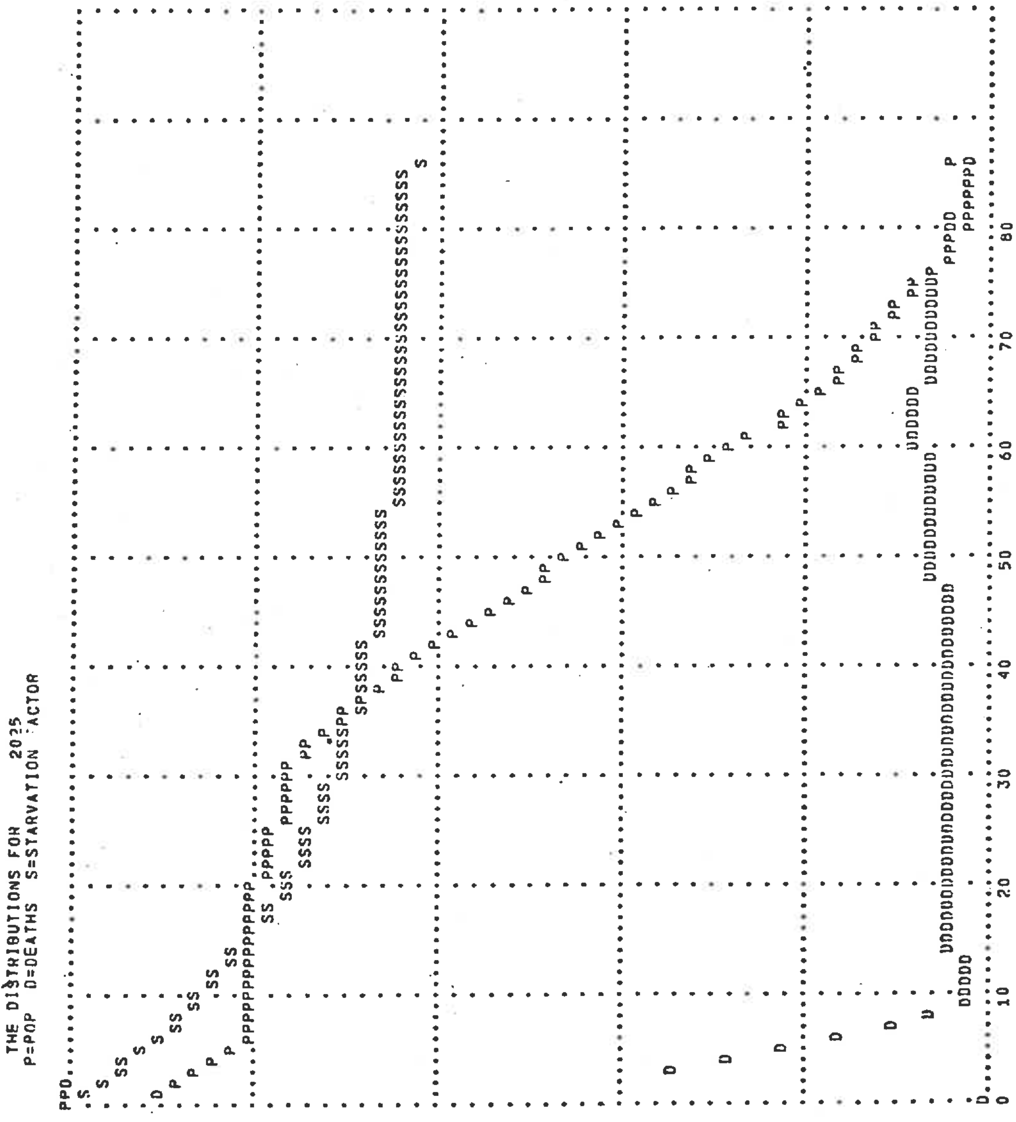
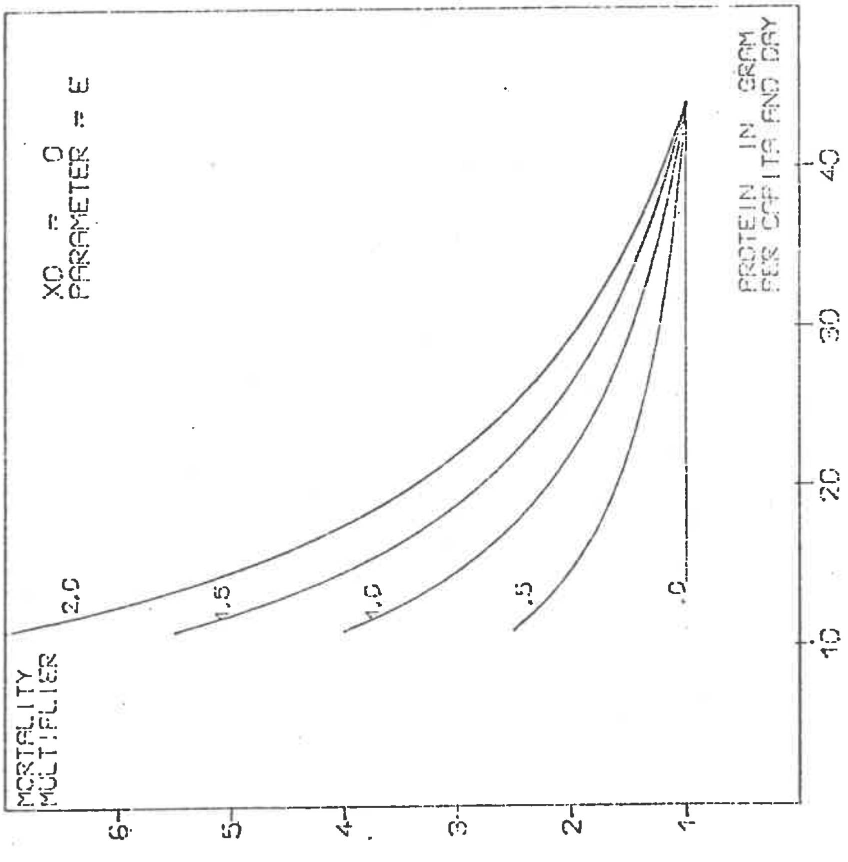


Figure 2-2.


MORTALITY MULTIPLIER
XO = 0
PARAMETER = E
2.0
1.5
1.0
.5
.0
PROTEIN IN GRAM PER CAPITA AND DAY
1
2
3
4
5
6
10
20
30
40

(5) Indicators

$$DCHLD = \sum_{I=0}^{15} DN(I) \qquad (5.1)$$

$$CBR = BABIES/POP \qquad (5.2)$$

$$CDR = DEATHS/POP \qquad (5.3)$$

$$POPGR = (BABIES - DEATHS)/POP \qquad (5.4)$$

Computed Values:		
	DCHLD	Total child deaths, ages 0 - 15
	DN(I)	Mortality, by age category
	CBR	Crude birth rate
	CDR	Crude death rate
	POPGR	Population growth rate

Equations 5.1 - 5.4 have no effects on the dynamics of the model. Their prupose is to calculate some of the more commonly used demographic indicators for use in scenario analysis.

2.2. The Economic Submodel

(1) Production

$$KA_t = KA_{t-1} * (1 - DA) + IA \qquad (1.1)$$

$$YAX = KA * QA \qquad (1.2)$$

$$KDA = KA * DA \qquad (1.3)$$

$$KNA_t = KNA_{t-1} * (1 - DNA) + INA \qquad (1.4)$$

$$YNA = KNA * QNA \tag{1.5}$$

$$KDNA = KNA * DNA \tag{1.6}$$

$$Y = YNA + YA \tag{1.7}$$

Parameters:	DA	Depreciation rate, agricultural sector*
	QA	Capital per output ratio, agricultural sector
	DNA	Depreciation rate, non-agricultural sector
	QNA	Capital per output ratio, non-agricultural sector
Computed Values:	KA	Capital stock, agricultural sector
	IA	Investment, agriculture sector
	YAX	Agricultural output, computed within the economic stratum
	KDA	Amount of depreciation, agricultural sector
	KNA	Capital stock, non-agricultural sector
	INA	Investment, non-agricultural sector
	KDNA	Amount of depreciation, non-agricultural sector
	Y	Gross regional product

Equations 1.1 and 1.2, from the decoupled economic model have been retained so that YAX can be compared with YA, which is calculated by the food production model and pricing mechanism. Since the effects of depreciation on capital stock are computed directly in equations 1.1 and 1.4, KDA and KDNA are only included so that their values may be available as indicators.

---

*As noted in Part 1 above, the "agricultural sector" of the economic sub-model aggregates both the agriculture and food sectors of the nine sector micro economic model.

(2) Gross Outputs and Intermediate Demand

$$Z(1) = A1I(1,1) * YA + A1I(2,1) * YNA \tag{2.1}$$

$$Z(2) = A1I(1,2) * YA + A1I(2,2) * YNA \tag{2.2}$$

$$U(1) = A(1,1) * Z(1) + A(2,1) * Z(2) \tag{2.3}$$

$$U(2) = A(1,2) * Z(2) + A(2,2) * Z(2) \tag{2.4}$$

$$UA = A(2,1) * Z(2) \tag{2.5}$$

$$UAF = UA * UAFK \tag{2.6}$$

Parameters for this section are the "A" input-output matrix and its inverse. The matrices have the following structure:

$$\begin{array}{l|cc|} & \text{Agriculture} & \text{Industry} \\ \hline \text{Agriculture} & A_{11} & A_{12} \\ \text{Industry} & A_{21} & A_{22} \\ \hline \end{array}$$

In the equations, numbers in parentheses denote the cells of the matrix. "I" denotes the inverse of the matrix.[*]

---

[*] Where a variable has been defined in an immediately preceeding section, the definition will not always be repeated.

Computed Values:	Z(1)	Gross output, agricultural sector
	Z(2)	Gross output, non-agricultural sector
	U(1)	Intermediate demand, agricultural sector
	U(2)	Intermediate demand, non-agricultural sector
	UA	Intermediate demand, from agriculture
	UAF	Total expenditures on fertilizer and related productive factors
	UAFK	Coefficient, expenditures on fertilizer and related productive factors

(3) Investment

$$I = GI * YNA * SYSYNA \tag{3.1}$$

$$SYSYNA = Y/YNA \tag{3.2}$$

$$IAS = (IAKS - IAK) * I \tag{3.3}$$

$$IAS = (IAS, 0.0) \tag{3.4}$$

$$IA = IAK * I + K1 * IAS \tag{3.5}$$

$$SUAF = UAS + (1 - K1) * IAS \tag{3.6}$$

$$INA = I - IA \tag{3.7}$$

$$IR = I * IRK \tag{3.8}$$

$$IMN = I - IR \tag{3.9}$$

$$IAP = IAPK * IA \tag{3.10}$$

$$IALV = IAVK * IA \tag{3.11}$$

$$IALD = IA - IAP - IALV \tag{3.12}$$

Parameters:	GI	Total investment, coefficient
	IAKS	Shift of Investment of agricultural sector (Scenario Variable)

	IAK	Investment in agricultural sector, coefficient
	K1	Fraction of investment to agricultural capital stock (Scenario Variable)
	IRK	Investment, regional, coefficient
	IAPK	Investment in agricultural production, coefficient (Scenario Variable)
	IALVK	Investment in livestock, coefficient (Scenario Variable)
Computed Values:	I	Total investment
	YNA	Regional product, non-agricultural sector
	SYSYNA	Ratio of GRP to regional product, non-argicultural sector
	IAS	Amount of investment shifted from agricultural sector to non-agricultural sector
	IA	Investment, agricultural sector
	SUAF	Total expenditures on fertilizer and related productive factors (equivalent to UAF)
	INA	Investment, non-agricultural sector
	IR	Regional investment
	IMN	Imports of investment capital needed
	IAP	Investment in non-land agricultural capital stock
	IALV	Investment in livestock development
	IALD	Investment in land development

Four important scenario variables appear in the equations of this section, IAKS, K1, IAPK and IALVK. Through the mechanism defined in equations 3.3 - 3.6, IAKS will override the historically based value for the fraction of investment in agriculture, IAK, and shift additional investment from non-agricultural to agricultural uses. The value of K1 divides the additional resources made available between capital development and a subsidy program to promote greater use of fertilizer and related inputs. IAPK and IALVK allocate agricultural capital development funds to alternative uses.

The investment allocation IALD is an input to the land use submodel. IAP and IALV are inputs to the food production submodel. The equations for regional investment and investment needs (3.7 and 3.8) define indicators which do not presently affect the model dynamics.

(4) Consumption, Governmental Expenditure, Imports

$$C = GC * Y \tag{4.1}$$

$$G = GG * Y \tag{4.2}$$

$$M = GM * Y \tag{4.3}$$

$$MA = MAK * M \tag{4.4}$$

```
      IF (IMN - M * MA)   10,10,11*
10    MI = M - MA
      GO TO 12
11    MI = IMN
      CONTINUE
12    MC = M - MA - MI
      MC = MAX (MC,0,0)
```

---

[*] Here we have made a rare exception in our notation and used the FORTRAN "IF" statement to depict the model structure.

Parameters:	GC	Consumption, coefficient
	GG	Government expenditures, coefficient
	GM	Imports, coefficient
	MAK	Agricultural imports, coefficient
Computed Values:	C	Consumption
	G	Governmental expenditures
	M	Imports
	MA	Imports, agriculture
	IMN	Imports needed
	MC	Imports for consumption
	MI	Imports, investment

The reader will note that only imports, consumption, government expenditure and investment - not exports - have been considered in the demand equations. Exports are considered, but in a way which does not affect the dynamics of the economic submodel. For further discussion, see the section below dealing with the export sector.

2.3. The Land Use Submodel

(1) Cultivated Land

$$CLGR_t = CLGR_{t-1} + CLDGR - CLWGR \tag{1.1}$$

$$CLNG = TA + TB * CLGR \tag{1.2}$$

$$CL = CLGR + CLNG \tag{1.3}$$

Parameters:	TA	Subscript of linear equation relating grain land to non-grain land
	TB	Slope of linear equation relating grain land to non-grain land
Computed Values:	CLGR	Cultivated land, grain
	CLDGR	Cultivated land development, grain
	CLWGR	Cultivated land withdrawal, grain
	CLNG	Cultivated land, non-grain
	CL	Cultivated land

(2) Livestock Land

$$GL = GLM - GLW \tag{2.1}$$

$$TLLS = GL + CLR \tag{2.2}$$

$$CLR = TLM * (CLM/TLM) - CL - CLW \tag{2.3}$$

Parameters:	GLM	Maximum grazing land
	TLM	Maximum total land (includes grazing land and cultivable land)
	CLM	Maximum cultivable land
Computed Values:	GL	Grazing land
	GLW	Grazing land withdrawn for urbanization and economic development
	TLLS	Total land for livestock support
	CLR	Cultivable land remaining

(3) Withdrawal of Land for Urban and Economic Development

$$\mathrm{TLWR} = \mathrm{TLW}/\mathrm{TLM} \tag{3.1}$$

$$\mathrm{TLWM} = \mathrm{TLWMF}\ (\mathrm{TLWR}) \tag{3.2}$$

$$\mathrm{TLAW} = (\mathrm{BABIES} - \mathrm{DN}(0)) \tag{3.3}$$

$$\mathrm{CLAW} = \mathrm{TLAW} * (\mathrm{CLM}/\mathrm{TLM}) \tag{3.4}$$

$$\mathrm{CLW} = \mathrm{TLW} * (\mathrm{CLM}/\mathrm{TLM}) \tag{3.5}$$

$$\mathrm{GLW} = \mathrm{TLW} - \mathrm{CLW} \tag{3.6}$$

$$\mathrm{TLW}_t = \mathrm{TLW}_{t-1} + \mathrm{TLAW} \tag{3.7}$$

$$\mathrm{FCLR} = \mathrm{CL}/(\mathrm{TLM} * (\mathrm{CLM}/\mathrm{TLM}) - \mathrm{CLW}) \tag{3.8}$$

Parameters:	TLM	Maximum total land (includes grazing land and culivable land
	TLWPCB	Per capita land withdrawal, base value
	CLM	Maximum cultivable land
Computed Values:	TLWR	Ratio of land withdrawn to maximum total land
	TLW	Total land withdrawn for urbanization and economic development
	TLWM	Land withdrawal multiplier
	TLAW	Annual withdrawal of land for urbanization and economic development
	BABIES	Number of live births
	DN(0)	Infant mortality
	CLAW	Annual withdrawal of cultivated land
	CLW	Total cultivable land withdrawn
	GLW	Grazing land withdrawn
	FCLR	Fraction of cultivated land remaining

Through a coupling with the population model (equation 2.3), the equations in this section take into account the urbanization of land due to population growth. TLWPCB is the withdrawal rate per capita for the initial year of the run. This value is adjusted by the multiplier TLWM to allow for increasing population density as the amount of available land decreases (equation 2.3). The shape of the nonlinear function TLWMF will vary somewhat from region to region.

It is assumed that much of the land withdrawn for urbanization will be cultivable or grazing land. A second assumption is that friction of TLAW withdrawn, respectively, from cultivated and grazing land will be determined by the ratio CLM/TLM.

(4) Development of Cultivated Land

$$\mathrm{CLD} = \mathrm{IALD}/\mathrm{KCLDH} \tag{4.1}$$

$$\mathrm{CLDNG} = \mathrm{CLD} * \mathrm{CLNG}/\mathrm{CL} \tag{4.2}$$

$$\mathrm{CLDGR} = \mathrm{CLD} * \mathrm{CLGR}/\mathrm{CL} \tag{4.3}$$

Computed Values:	CLD	Cultivated Land developed
	IALD	Investment in land development
	KCLDH	Capital cost of land development per hectare
	CLDNG	Cultivated land developed, non-grain
	CL	Cultivated land
	CLDGR	Cultivated land developed, grain

Coupling between tha land use and economic submodels occurs through IALD in equation 4.1. KCLDH is computed in the pricing mechanism as a non-linear function of FCLR.

2.4. The Food Production Submodel

(1) Crop Production

$$\mathrm{PMCI = PMCIF\ (YNAPC)} \tag{1.1}$$

$$\mathrm{KAPH = KA/CL} \tag{1.2}$$

$$\mathrm{PTFC = PTFCF\ (KAPH)} \tag{1.3}$$

$$\mathrm{FA = PMCI + PTFC} \tag{1.4}$$

$$\mathrm{ZPHG = TPF * GZPHK/CLGR} \tag{1.5}$$

$$\mathrm{TPF = UAF/PXPF} \tag{1.6}$$

$$\mathrm{TEMP = FA - FB} \tag{1.7}$$

$$\mathrm{GRPH = FA - TEMP * EXPF\ (-FC/TEMP * ZPHG)} \tag{1.8}$$

$$\mathrm{GRGP = CLGR * GRPH} \tag{1.9}$$

$$\mathrm{NGGP = FD + FE * GRGP} \tag{1.10}$$

Parameters:	FB	Minimum level for grain productivity, constant
	FC	Slope of grain productivity curve at minimum level, constant
	FD	Intercept of linear equation in which production of non-grain crops per hectare is calculated as a function of the production of grain crops
	FE	Slope of linera equation in which non-grain production is calculated as a function of the production of grain crops
Computed Values:	PMCI	Productivity coefficient from infrastructure
	YNAPC	Regional product, non-agricultural, per capita
	KAPH	Agricultural capital, per hectare

KA	Agricultural capital
CL	Cultivated land
PTFC	Productivity coefficient from capital investment
ZPHG	Use, per hectare, of fertilizer and related productive factors
TPF	Total use of fertilizer and related productive factors
GZPHK	Coefficient, fraction of fertilizer and other productive factors devoted to grain production
CLGR	Cultivated land, grain
UAF	Expenditures for fertilizer and related productive factors
PXPF	Price of fertilizer and related productive factors
TEMP	Intermediate value used in computation of productivity
GRPH	Grain production per hectare
FA	Saturation level for grain production
GRGP	Gross production, grain crops
NGGP	Gross production, non-grain crops

The crop production sector is obviously one of the most important in the entire model, especially when the capability of potentially food-deficient regions (such as South Asia) to meet future needs is being considered. Five variables - CLGR, YNAPC, KAPH, UAF and PXPC - link the food production model to other strata. They are also the principal determinants of productivity.

Productivity per hectare (equation 1.8) is calculated as a saturating exponential function of fertilizer and other factor inputs.[*] FB and FC are

---

[*] Fertilizer is viewed as an index of other technological inputs contributing to productivity. See Clapham and Warshaw [1974].

regionally specific parameters denoting, respectively, the yield if no inputs are provided, and the initial slope of the curve defined by equation 1.8.

For computing forecasts based on an extrapolation of present trends, it might be adequate to let fertilizer use serve as an index for all relevant inputs. However, designing an integrated model to be used for scenario analysis requires that sensitivity to different mixes of productive inputs be incorporated. This approach, moreover, is quite consistent with recent experience gained in foreign aid and technical assistance programs. Both aid giving and recipient nations have discovered, to their sorrow, that a miz of inputs which is inappropriate to a particular region will produce far less than the anticipated results.

The approach used here is not presented as a complete solution to the problem - obviously it is only a beginning. ZPHG is used an indicator of consumerable productive inputs. We have in mind, primarily, fertilizer, seed and pesticides. This variable is a direct input to equation 1.8 and determines productivity per hectare given the constraints defined by the values of FA, FB and FC. The two other productive factors taken into account are, first, capitalization and capital infrastructure of the agricultural sector and second, the overall regional level of economic

---

[*] Robert Evenson's recent work on factor productivity in India [Evenson, 1972; Mohan and Evenson, 1973; Evenson and Kislev, 1973] is an example of the more detailed work at the national and subnational level which must be undertaken to fully elaborate this component of the model.

development. The first variable, KAPH, agricultural capital stock per hectare,[*] is used as an indicator which is intended to take into account concrete factors such as tools, machinery and irrigation systems, and more intangible ones such as research and extension.[**] Clearly these factors at, at least to some degree, independent of the level of consumerable inputs. (Compare, for instance, the agricultural systems of Japan and the United States.)

The second variable- PCMI, takes into account more diffuse characteristics of the social and economic infrastructure, such as transportation systems, communication systems, the overall level of education, etc. The assumption is made that these factors, aggregated additively, affect the threshold of maximum productivity, FA, in equation 1.8. The specific functional relationships , PMCIF and PTFCF, defined for Regions 1 and 9, will be discussed in Section 5, below.

(2) Livestock Production

(2.1) Livestock "On the Hoof"

$$SLVMA = RLLVS * TLLS \qquad (2.1.1)$$

$$SLVA = SLV(2) * SLVK(2) + SLV(4) + SLV(5) + SLV(9) \qquad (2.1.2)$$

---

[*] Ideally, only that portion of agricultural capital stock devoted to productive factors other than livestock and land should be used. Eventually KAPH will be broken down in this way to compute PTFC. At the present stage of our work, however, we feel that this approach would reflect a level of detail not justified by the available data.

[**] For an analysis of the contribution of research and extension to productivity, see Evenson and Kislev [1973].

$$SLVAR = SLVA/SLVMA \tag{2.1.3}$$

$$LVPLM = XLVPLMF\ (SLVAR) \tag{2.1.4}$$

$$UALV(J) = IALV * SLV(J) * SLVK(J)/SLVA \qquad J=1,\ \ldots,\ 9 \tag{2.1.5}$$

$$ALVI(J) = UALV(J)/LVPL(J) \qquad J = 1,\ \ldots\ ,\ 9 \tag{2.1.6}$$

$$SLV(J)_t = SLV(J)_{t-1} + ALXI(J) \qquad J = 1,\ \ldots\ ,\ 9 \tag{2.1.7}$$

(2.2) <u>Production of Meat and Livestock Products</u>

$$SLVP(J) = SLV(J) * SLVMK(J)/1000.0 \qquad J = 1,\ldots,\ 9 \tag{2.2.1}$$

$$SLVP(J) = SLV(9) * SLVMK(J)/1000.0 \qquad J = 1,\ldots,\ 9 \tag{2.2.2}$$

Parameters:*	SLVK(J)	Coefficient to correct individual categories of livestock for purposes of aggregating to a single base unit
	RLLVS	Land livestock support rate
	SLVMK(J)	Meat from livestock coefficient**
Computed Values:	SLVMA	Total livestock supportable on available grazing land
	TLLS	Total land for livestock support
	SLVA	Total livestock in animal units
	SLVAR	Total livestock, animal use ratio
	LVPLM	Livestock, price-land multiplier

---

[*] The types of livestock considered are cattle, pigs, sheep and goats, horses, other large animals (mules, asses, buffalos, camels), chickens, all poultry and dairy animals.

[**] The types of animal food considered in the model are beef and veal, pork, lamb and mutton, horsemeat, other meat, eggs, poultry ,eat, milk, cheese and butter. Production of honey is also included.

UALV(J)	Investment in additional livestock, by type
IALV(J)	Investment in livestock, by livestock categories
LVPL(J)	Development capital cost per livestock unit
SLV(J)	Total livestock, by type
SLVMK(J)	Meat from livestock, coefficient, by type

TLLS, TALV and LVPL are the variables by which the livestock sector is coupled to other parts of the model. The calculation of TLLS in the land use submodel and IALV in the economic submodel have already been discussed. The value of LVPL os computed in the price sector and is dependent on whether or not the carrying capacity of the available livestock land, TLLS, has been exceeded. So long as the total number of animals is below the carrying capacity, development coasts are low. But when the capacity is exceeded, necessitating a more capital intensive system of livestock production, development costs escalate rapidly.

(3) Fish Production

$$\mathrm{AWFM} = \mathrm{FWCM} * \mathrm{AWFMK} \tag{3.1}$$

$$\mathrm{AUFWP} = \mathrm{UFWP} * \mathrm{WB} \tag{3.2}$$

$$\mathrm{FWCP} = \mathrm{UFWP} * \mathrm{UFWPK} \tag{3.3}$$

$$\mathrm{FWCT} = \mathrm{FWCM} + \mathrm{FWCP} \tag{3.4}$$

$$\mathrm{FWT} = \mathrm{FWCT} * \mathrm{FWCNTK} \tag{3.5}$$

$$\mathrm{SFWCM} = \mathrm{MIN1F}\ (\mathrm{FWCM} + \mathrm{AFWM},\ \mathrm{FWMM}) \tag{3.6}$$

$$\mathrm{SUFWP} = \mathrm{MIN1F}\ (\mathrm{UFWP} + \mathrm{AUFWP},\ \mathrm{UFWPM}) \tag{3.7}$$

Parameters:	AWFMK	Growth rate of marine fish production
	WB	Fish pond growth rate
	UFWPK	Relationship between land use and pond fish
	FWCM	Catch of marine fish
	FWCNTK	Meat from fish, coefficient
	UFWP	Land in pond culture

The fish production model has bot been fully coupled to the economic model on the input side. Instead, fish production is sensitive to the within stratum scenario variables, AWFMK and UFWPK.

(4) Production of Crop Food Types and Distribution of Food to Alternative Uses

$$PLGP(J) = NGGP * NGGPK(J) \qquad J = 14, \ldots, 21 \qquad (4.1)$$

$$PLGP(J) = GRGP * GRGPK(J) \qquad J = 22, \ldots, 26 \qquad (4.2)^{*}$$

$$SFT(J) = FGP(J) * SPFTK(J) \qquad (4.3)$$

$$FTS(J) = FGP(J) \qquad (4.4)$$

$$LSFT(J) = LSFTK(J) * FTS(J) \qquad (4.5)$$

$$FTG(J) = FFTK(J) * FTS(J) \qquad (4.6)$$

$$FTN(J) = FTG(J) * (1.0 - HMLF(J)) \qquad (4.7)^{**}$$

---

[*] Equation 4.1 computes production of non-grain crops, while equation 4.2 computes production of grain crops. Categories of non-grain crops taken into account in the model are sugars, starches, root crops, vegetables, pulses, fruits, oil crops, drinks and stimulants and fibres. Grain crop categories are wheat, maize, sorghum, rice and other cereals.

[**] In equations 4.3-4.7, J = 1, ... , 26.

Parameters:	NGGPK(J)	Coefficient which disaggregates non-grain crop production into 7 categories
	GRGPK(J)	Coefficient which disaggregates grain crop production into 5 categories
	SPFTK(J)	Withdrawals for seed, by category
	LSFTK(J)	Withdrawals for livestock food, by category
	FFTK(J)	Total human food supply, coefficient by type
	HMLF(J)	Household and market losses, by type
Computed Values:	SFT(J)	Seed food total, by category
	FGP(J)	Gross regional food production, by category
	FTS(J)	Gross food supply, by type
	LSFT(J)	Livestock food total, by type
	FTG(J)	Gross human food supply, by type
	FTN(J)	Net human food supply, by type

2.5. Regional Food Supply Compared with Population Needs

(1) Supply*

$$FJRPC(J) = FTN(J)/POP * 1000 \qquad J = 1, \ldots 26 \tag{1.1}$$

$$VCLPCR(J) = FSRPC(J) * CLK(J) \qquad J = 1, \ldots 26 \tag{1.2}$$

$$VPTPCR(J) = FSRPC(J) * PTK(J) \qquad J = 1, \ldots 26 \tag{1.3}$$

$$CLPCR = \sum_{J=1}^{26} VCLPCR(J) \tag{1.4}$$

$$PTPCR = \sum_{J=1}^{26} VPTPCR(J) \tag{1.5}$$

---

*Where it appears in this section, the 1000 is simply a scaling factor.

$$\mathrm{PTAPCR} = \sum_{J=1}^{13} \mathrm{VCLPCR}(J) \tag{1.6}$$

$$\mathrm{PTAR} = \mathrm{PTAPCR} * \mathrm{POP}/1000.0 \tag{1.7}$$

Parameters:	CLK(J)	Calorie content coefficient, by category
	PTK(J)	Protein content, coefficient
Computed Values:	FSRPC(J)	Regionally produced food, by category
	POP	Population
	VCLPCR(J)	Calories per capita, regional, by category
	VPTPCR(J)	Protein per capita, regional, by category
	CLPCR	Calories, per capita, regional
	PTPCR	Protein per capita, regional
	PTAPCR	Annual protein per capita, regional

(2) Comparison with Needs

$$\mathrm{PTNM} = \mathrm{PTKF}\ (\mathrm{YPC}) \tag{2.1}$$

$$\mathrm{PTPCN} = \mathrm{FTPCB} * \mathrm{PTNM} \tag{2.2}$$

$$\mathrm{SPTPC} = \mathrm{MAX}\ (\mathrm{PTPCR} - \mathrm{PCPCN}, 0.0) \tag{2.3}$$

$$\mathrm{DPTPC} = \mathrm{MAX}\ (\mathrm{PTPCN} - \mathrm{PTPCR}, 0.0) \tag{2.4}$$

$$\mathrm{PTPCSN} = \mathrm{PTPCR}/\mathrm{PTPCN} \tag{2.5}$$

$$\mathrm{PTN} = \mathrm{PTPCN} * \mathrm{POP}/1000.0 \tag{2.6}$$

$$\mathrm{PTR} = \mathrm{PTPCR} * \mathrm{POP}/1000.0 \tag{2.7}$$

$$\mathrm{DPT} = \mathrm{DPTPC} * \mathrm{POP}/1000.0 \tag{2.8}$$

$$\mathrm{PTPCDR} = \mathrm{PTPCR}/365.0 \tag{2.9}$$

Computed Values:	PTNM	Protein needs multiplier
	PTPCB	Protein per capita base
	YPC	Gross regional product, per capita
	PTPCN	Protein per captia needed
	SPTPC	Per capita protein surplus
	DPTPC	Per capita protein deficit
	PTPCN	Protein per capita, ratio of supply to needs
	PTN	Total protein needs
	PTR	Regional protein
	DPT	Regional protein deficit
	PTPCDR	Regional daily protein per capita

As noted in Section 1.2.2. above, PTPCN is defined independently of the starvation level, PRONCR, in the population model. Equations in this section are used to compute import needs and export surplusses, but otherwise have no effect on the overall model dynamics. The principal function of this section is to provide indicators for scenario analysis.

1.6. The Pricing Mechanism

(1) Prices

$$PXLVP = PXLV * PXLVK * PXK \qquad (1.1)$$

$$GRV = GRGP * PXGR * PXK \qquad (1.2)$$

$$NGV = NGGP * PXNG * PXK \qquad (1.3)$$

$$SLVV = \sum_{J=1}^{5} SLVP(J) \qquad (1.4)$$

$$\mathrm{LVV} = \mathrm{SLVV} * \mathrm{PXLVP} \tag{1.5}$$

$$\mathrm{FSV} = \mathrm{FWT} * \mathrm{PXFS} * \mathrm{PXK} \tag{1.6}$$

$$\mathrm{YA} = \mathrm{GRV} + \mathrm{NGV} + \mathrm{LVV} + \mathrm{FSV} \tag{1.7}$$

$$\mathrm{YAPC} = \mathrm{YA}/\mathrm{POP} \tag{1.8}$$

$$\mathrm{PXPTM}_t = \mathrm{PXPTM}_{t-1} * (1.0 + \mathrm{RPXPTM}) \tag{1.9}$$

Parameters:	PXLV	Base price of meat
	PXLVK	Meat price coefficient
	PXK	Price coefficient
	PXGR	Price of grain
	PXNG	Price of non-grain crops
	PXFS	Price of fish
	RPXPTM	Rate of change, protein imports
Computed Values:	PXLVP	Adjusted price of meat
	GRV	Dollar value, grain production
	GRGP	Gross grain production
	NGV	Dollar value, non-grain production
	NGGP	Gross production, non-grain crops
	SLVV	Total livestock meat production
	SLVP	Meat production from livestock, by category
	LVV	Dollar value, livestock production
	FSV	Dollar value, fish production
	FWT	Total fish meat production
	YA	Gross regional product, agriculture
	YAPC	Gross regional product, per capita
	PXPTM	Price of protein imports

The structure of this section is straightforward and requires little elaboration. Prices are defined for each category. The value of production is the product of prices and production. The price coefficients PXK and PXLVK have been added to allow experimentation with the model.

(2) <u>Cases</u>

$$\mathrm{PXPF}_t = \mathrm{PXPF}_{t-1} * (1.0 + \mathrm{RPXPF}) \tag{2.1}$$

$$\mathrm{TPF} = \mathrm{UAF}/\mathrm{PXPF} \tag{2.2}$$

$$\mathrm{LVPL(J)} = \mathrm{PXLVB(J)} * \mathrm{LVPLM} \qquad J = 1, \ldots, 9 \tag{2.3}$$

$$\mathrm{KCLDH} = \mathrm{XKLDF\ (FCLR)} \tag{2.4}$$

Parameters:	RPXPF	Rate of price increase, productive factors
	PXLVB(J)	Livestock price, base value, by category
Computed Values:	PXPF	Price of productive factors
	TPF	Total productive factors
	UAF	Expenditures on productive factors
	LVPL(J)	Development costs, livestock, by category
	LVPLM	Livestock price land multiplier
	KCLDH	Capital cost, land develop per hectare
	FCLR	Fraction of cultivated land remaining

In this section, the rate of price increase for productive factors is a scenario variable (equation 2.1). Since all monetary values are in 1963 constant dollars, inflation is not taken into account. But scenarios involving <u>relative</u> price increases (or decreases) can be examined.

As noted in the discussion above, both the price of land and livestock development costs are sensitive to hortages of land.

2.7. Energy Consumption

$$ENZ = TPF * ENZPLK \tag{1}$$

$$ENFZR = CLPCR * POP/ENZ/1000.0 \tag{2}$$

Parameters	ENZPLK	Energy requirements, coefficient
Computed Values:	ENZ	Energy required for plant food production
	CLPCR	Calories per capita, regional
	ENFZR	Ratio of energy in food produced to that required for plant food production

This section will assume increased importance when the integrated food model is coupled with the energy model which has been developed for the Multilevels Regionalized World Modeling Project.

2.8. The Import Sector

$$FDMV = DPT * PXPTM \tag{1}$$

$$FDMAR = FDMV/YA \tag{2}$$

$$FDMYR = FDMV/Y \tag{3}$$

$$FDMMR = FDMV/M \tag{4}$$

Computed Values:	FDMV	Dollar value of food imports
	FDMAR	Ratio of food imports to agricultural production
	FDMYR	Ratio of food imports to total GRP
	FDMMR	Ratio of food imports to total imports

2.9. The Export Sector

$$FDXV = YA * (SPT/PTR) \tag{1}$$

$$FDXAR = FDXV/YA \tag{2}$$

$$FDXYR = FDXV/Y \tag{3}$$

$$FDXXR = FDXV/X \tag{4}$$

$$FDX9YR = FDXV9/Y \tag{5}$$

$$FDX9AR = FDXV9/YA \tag{6}$$

$$PTX9RR = PTX9/PTR \tag{7}$$

$$PTX9SR = PTX9/SPT \tag{8}$$

Parameters:	FDXV9	Value of food exported from Region 1 to Region 9
Computed Values:	FDXV	Value of exports
	SPT	Surplus protein
	PTR	Regionally produced protein

This sector couples Region 1 and Region 9. It has been used in the "foreign aid" scenario discussed below. FDXV9 may be coupled on line (under the assumption that all Region 9 food needs are met by Region 1, or it may be implemented as a scenario variable).

The variables calculated in equations 3 - 8 are indicators. Since they are all ratios, their definition should be evident from the equations. Hence, written definitions have not been provided.

3. Parameters and Functional Relationships

Because many of the parameters and functional relationships in the model are region specific, discussion of this component of the model has been separated from the equations. The parameters presented are "base run" parameters for Regions 9 and 1, which have been the focus of our scenario analysis. Results from sensitivity analysis in which many of these parameter values have been varied reported in section 4, below.

Some of the parameters in the population and food models (such as the coefficients for individual food types) which are discussed in other reports, have not been reported here. Omission reflected the author's belief that inclusion would not be of any particular value in aiding the reader to understand the structure of the world model of importance for food policy analysis.

The division of equations and parameters into two sections has not been made for convenience alone. It reflects our judgment as to the relative importance of the two components of the model. We are quite confident about the overall model structure. On the other hand, while we have exercised care and used the best available data to estimate parameters and functional relationships, it is probable that further investigation will reveal the need for some changes. Whether such changes will significantly affect the model's behavior can, of course, only be determined by sensitivity analysis similar to that discussed in Section 6.

3.1 The Population Submodel

Region 9	Region 1
(Births)	
FERT = TIME SERIES:	*
(Deaths)	
MORT = 28/1000 Pop.	*
(Effects of protein starvation on mortality)	
PRODST = .7	*
TIMLAG = 1.0	*
PRONOL = 44.0 GM/DAY	*
PROD = 25.0 GM/DAY	*
EO = 1.0	*
EL = .25	*
EA = 10.0	*

Since detailed results on Region 1 population were not of interest, a simple growth modwl was substituted for the population model. A population growth rate of .01 per year was assumed.

If the data source or justification for a particular parameter value is not presented here, it will be found in the technical report describing the submodel in which the parameter appears.

3.2 The Economic Submodel

(1) Production

	Region 9	Region 1	
KA_{1975}	39.5	186.0	(Billion $)
KNA_{1975}	225.5	2219.0	
DA	.055	.055	
DNA	.0285	.0285	
QNA	2.49	2.858	

(2) Gross Outputs and Intermediate Demand

A MATRIX - Region 9

	Agriculture	Industry
Agriculture	.2024	.055
Industry	.069	.2898

A MATRIX - Region 9

	Agriculture	Industry
Agriculture	.4379	.0091
Industry	.2121	.4166

(3) Investment

	Region 9	Region 1
GI	.1286	.1703
IAKS	0.0	0.0
IAK	.15	.042
IRK	.30	.90
IAPK	.50	.50
IALVK	.05	.08

(4) Consumption, Government Expenditure, Imports

	Region 9	Region 1
GC	.7599	.6436
GG	.10	.10
GM	.1249	.0664
MAK	.1736	0.0

3.3 The Land Use Submodel

3.3.1 Parameters

(1) Cultivated Land

	Region 9	Region 1
$CLGR_{1975}$	171.844	68.5156
TA	-48.6982	29.1987
TB	.7969	.0204

(2) Livestock Land

	Region 9	Region 1
GLM	287.813	444.445
TLM	565.0	836.0
CLM	278.0	391.5

(3) Withdrawal of Land For Urban and Economic Development

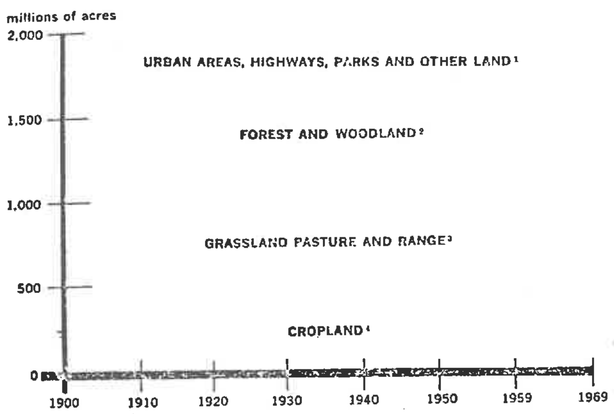
	Region 9	Region 1
TLM	565.0	836.0
CLM	278.0	391.5
TLWPCB	.5	.001

3.3.2 Functions

(1) TLWM = TLWMF(TLWR)

The land withdrawal multiplier in conjunction with the parameter, per capita land withdrawal, base value (TLWFCB) takes into account the effects of population growth and, indirectly, economic growth or land use. Data is not at all satisfactory for either region; however, agricultural output is not particularly sensitive to variations in TLWBCP within reasonable limits in either region.

A recent survey by the Council on Environmental Quality (Fig. 3-1), based on data compiled by the Economic Research Service of the U.S. Department of Agriculture (1972), shows little change in broad land use patterns. Even when unreasonable assumptions about land development are made, availability of land is not a constraint on agricultural production



Land Utilization, 48 States, 1900-1969

1. Urban and other built areas, highways, railroads, airports, parks and other land.
2. Excludes forested areas reserved for parks and other special uses.
3. Includes grassland pasture and range, private and public.
4. Cropland planted, cropland in summer fallow, soil improvement crops, and land being prepared for crops and idle.

Cropland acreages prior to 1954 are for the year preceding the date of the inventory.

Source: U.S. Department of Agriculture, Economic Research Service

Figure 3-1

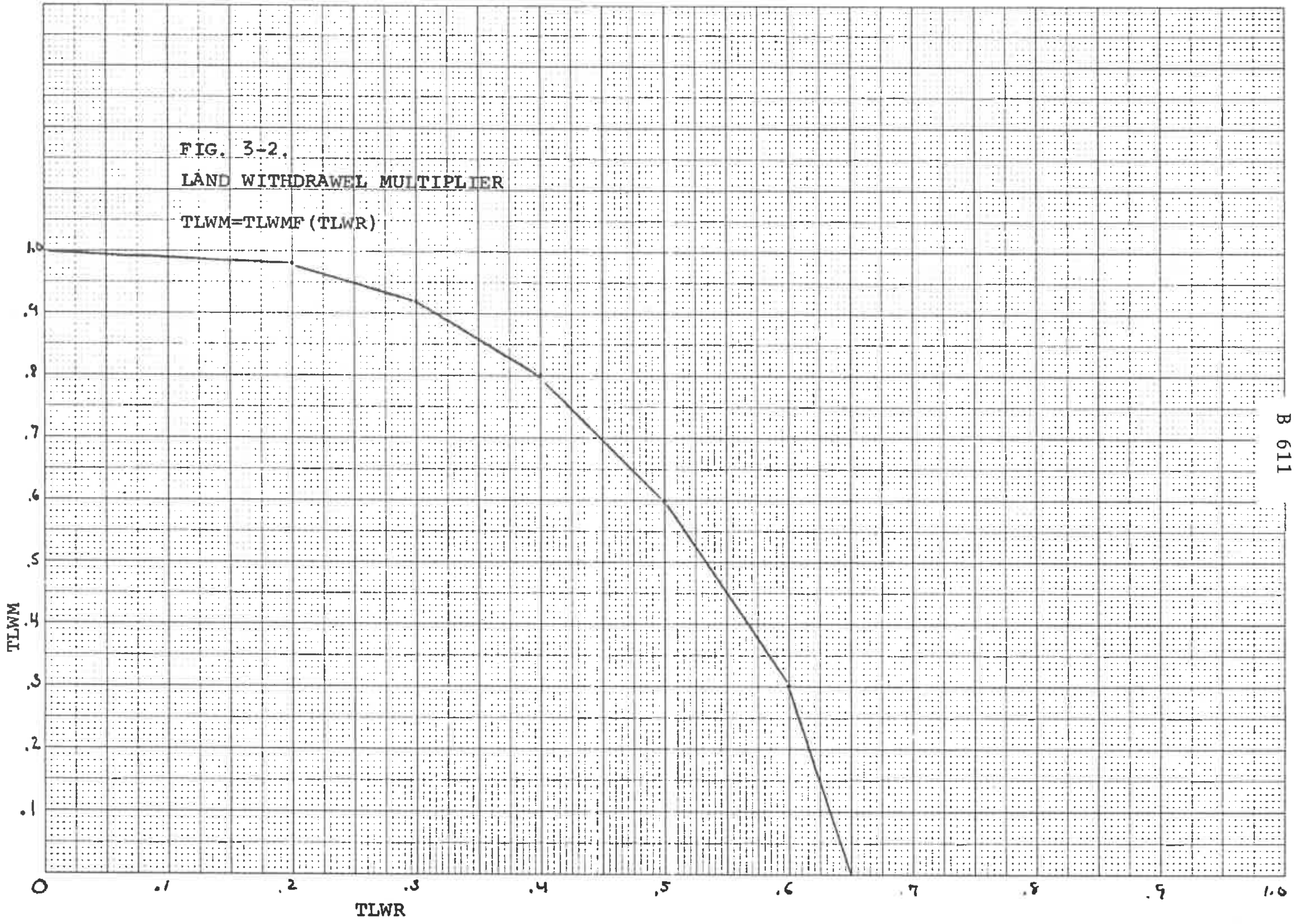


FIG. 3-2.

LAND WITHDRAWEL MULTIPLIER

TLWM=TLWMF(TLWR)

in North America. TLWMF is defined in Figure 5-2. It is a rough, but reasonable, estimate according to theland use information in our data base. Because of the relative unimportance of the withdrawal phenomena during the period of our scenario, we have not tried to define it further.

In Region 9, we have assumed that, despite the high levels of population growth, withdrawal would be very low. Of course, land availability is a severe constraint on agricultural productivity, and if an estimate is over-optimistic, forecasts of productivity in South Asia would have to be revised downward.

3.4 The Food Production Submodel

3.4.1 Crop Production

(1) Parameters

	Region 9	Region 1
FB	.919983	1.0
FC	.0238991	.0229
FD	-66.1973	-15.0
FE	1.71991	.615

(2) Functions

PMCI = PMCIF (YNAPC)

PTFC = PTFCF(KAPH)

Recall that PMCI and PTFC combine additively and define a coefficient, FA, which is the productivity saturation level in the equation

$$GRPH=FA-TEMP*EXPF(-FC/TEMP*ZPHG) \quad (1)$$

where:

FB is the intercept,

FC is the slope at the intercept, and

TEMP = FA-FB.

It was assumed, for reasons discussed above, that the two factors would affect FA, the cumulative effects of direct investment in the agricultural sector (agricultural capital stock, KNA) and the overall level of economic development (measured by YNAPC).

While this was consistent with the relevant literature, we did not feel that it would be appropriate to attempt development of a precise estimation procedure at this time. Rather, we decided to treat the components of FA as scenario variables, but in a special way - by imputing the development characteristics of more developed regions, for which data was available, to Region 9. The version of the function used for the scenario and sensitivity runs presented here uses the United States as the prototype. Log-linear was selected as the appropriate functional form and the slope of the function was determined by the following values (based on 1970 values). The functions are graphed in

$KAPH_1$ = \$463

GRAIN $PROD_1$ = 2.939

$KAPH_9$ = \$56.70

GRAIN $PROD_9$ = 1.35

The assumption was made that the effects of the overall level of economic development was about one-third that of the capital stock in the agricultural sector.

We are aware that there is wide diversity in agricultural productivity in South Asia. As much as seven tons per hectare of rice has been produced on some experimental plots in the Philippines. But we feel that, if anything, our projection of potential productivity for the region is optimistic. Possibly productivity may be much less.

It should, perhaps, be emphasized again that the actual level of productivity is not determined by FA, but by the inputs of productive factors. In no instance during our scenario runs does this threshold act as a direct constraint. But it does affect productivity indirectly.

Clapham and Warshaw [1974] have fitted the curve described in equation 1 to data from 1948 to 1970 for all ten regions of the world. Examination of their results is most helpful in gaining a more complete understanding of the assumptions presented here.

Region 1

In Region 1, it is assumed that the overall level of economic development is so high that it would have no further effects. Hence, values for PMCI are not defined. A graph of PTFC is found in Figure 5-5. In "fits" for historical data by Clapham and Warshaw for the region, FA was defined at a level of about 8. The assumption that ten times present capitalization would produce that threshold was a very rough estimate. However, it should be noted that in our scenario analyses, it is land, rather than increased capitalization, which produces increased productivity. For the result reported thus far, values of this function never fall within what we would regard as the dubious range.

3.4.2 Livestock Production

(1) Parameters

	Region 9	Region 1
RLLVS	87.7129	1.16675

(2) Functions

LVPLM = XLVPLMF(SLVAR)

Wheat

SLVAR = SLVA/SLVMA

SLVMA = RLLVS * TLLS

There are two critical parameters in this mechanism, RLLVS, the carrying capacity of land and PXLVB the development cost for livestock. RLLVS is a region specific parameter from the food model. PXLVB was computed by dividing the capital stock in livestock in 1970 by the number of livestock. Comparisons with market prices indicated that the figure obtained in this way was reasonable.

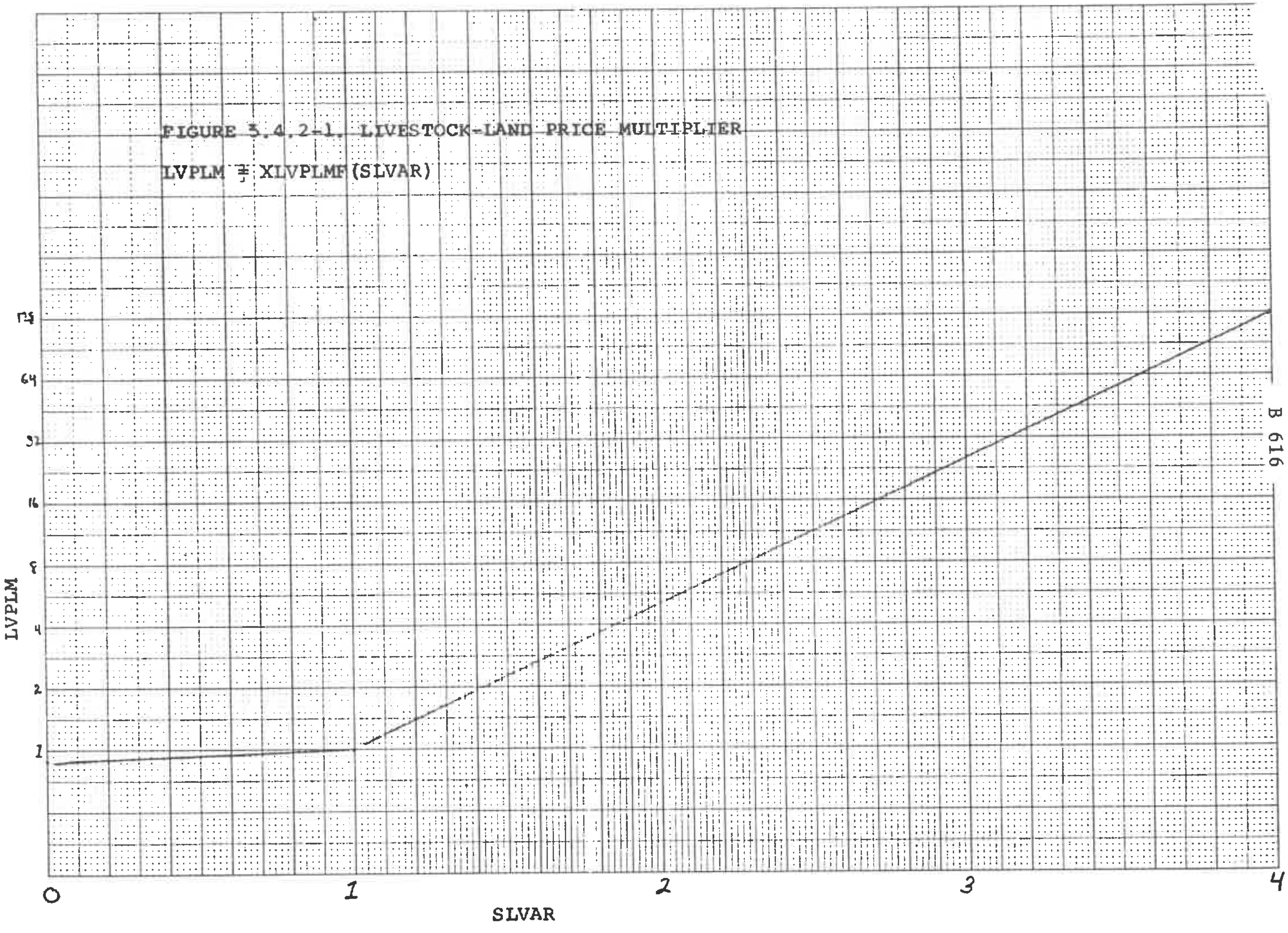


FIGURE 3.4.2-1. LIVESTOCK-LAND PRICE MULTIPLIER

LVPLM = XLVPLMF(SLVAR)

The function, which is assumed to be applicable to both regions 1 and 9 (remember that the base prices and carrying capacities differ has little effect so long as livestock numbers are below the maximum. But as the value of SLVAR exceeds 1, development costs increase rapidly. (Fig. 3.4.2-1).

This function does not have any significant effect on food production during the period examined. In Region 1 the livestock numbers are far below carrying capacity. In Region 9 livestock is an insignificant component of total food.

3.4.3 Fish Production

(1) Parameters

	Region 9	Region 1
AFWMK	.0710	.0119
WB	.0010	0.0
UFWPK	2.074	.9632
FWCM	13.09	3.8731
FWCNTK	.4499	.4499
UFWP	.0011	.0011

3.4.4 Production of Crop Food Types and Distribution of Food to Alternative Uses

Parameters in this section are reported in Clapham and Warshaw (1974).

3.5 Regional Food Supply Compared with Population Needs

Parameters in this section are reported in Clapham and Warshaw (1974).

3.6 The Pricing Mechanism

(1) Parameters[*]

	Region 9	Region 1
PXLV	1.50	1.50
PXLVK	1.0	1.0
PXK	1.0	1.0
PXGR	.114	.114
PXNG	.089	.089
PXFS	.89	.89
RPXPTM	0.0	0.0
$PXPF_{1975}$	.149	.149

(2) Functions

KCLDH = XKLDF(FCLR)

KCLDH = KCLDF(SCLR

---

[*] Prices are in thousands of dollars.

where

FCLR=CLR/CLM

Region 9:

This function computes the costs of developing land, taking into account the decreasing amount of land available for development. It is based on the following assumptions.

(1) Agricultural capital formation = total capital formation * .145. (Based on historical data).

(2) Investment to non-land productive factors = .5 (based on inferences from historical data and some sketchy data).

(3) Investment to livestock = .05.

(4) Investment to land = .45 * IA.

From these assumptions it was possible to estimate annual investments in land and compare them with annual data on total increase in cultivated land from the food data bank. (Fig. 3.4.6-1). From this the curve was smoothed and the remainder was estimated to ensure that prices would increase rapidly as the amount of land diminished. (Fig. 3.4.6-2).

Region 1:

In this region, the shape of the function takes into account that a substantial amount has been removed from production as a result of U.S. government agricultural policies and can be brought back into production at relatively little cost. After that, there is a steady, linear increase in costs as the amount of land diminishes. (Fig. 3.4.6-3).

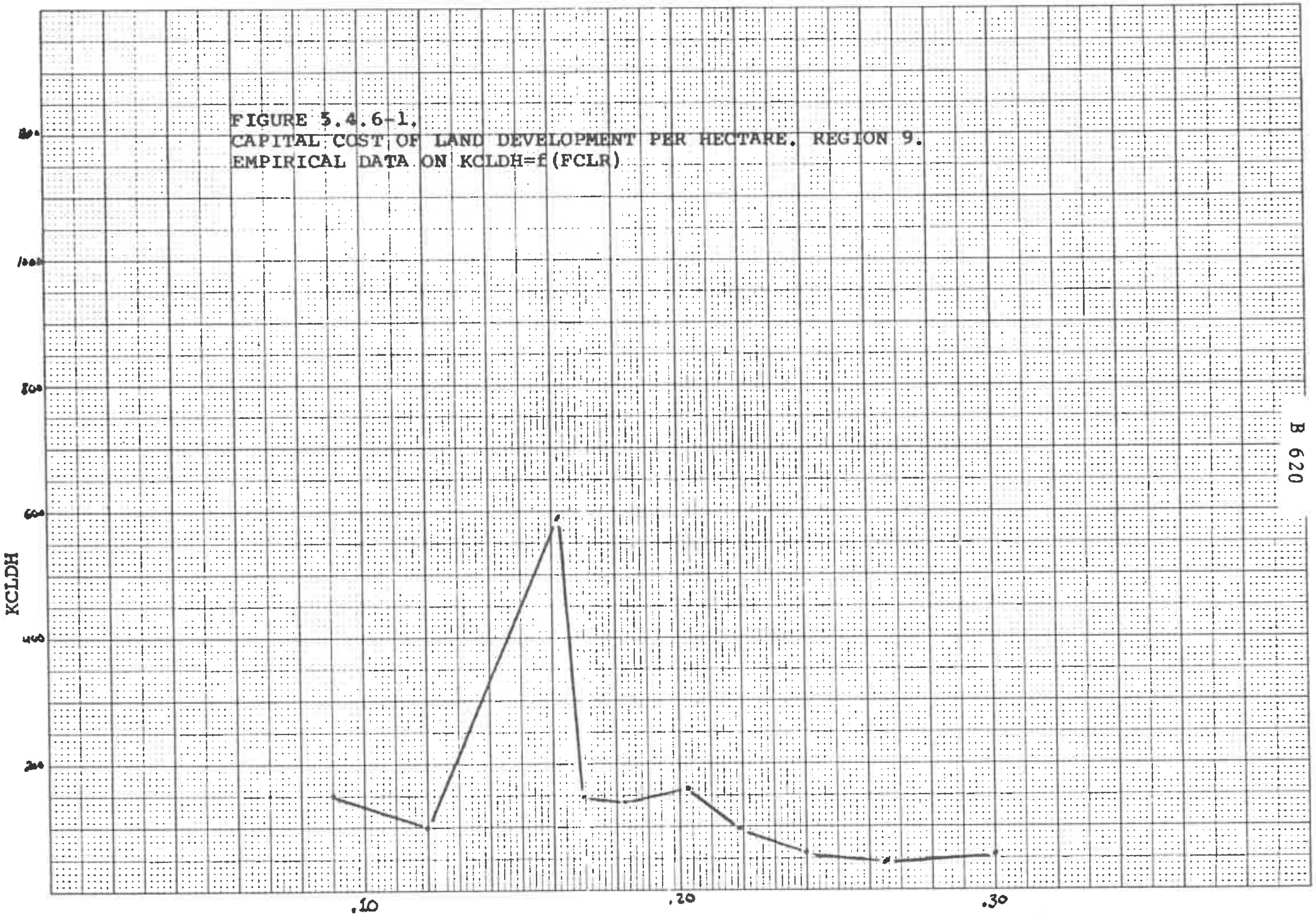


FIGURE 5.4.6-1.
CAPITAL COST OF LAND DEVELOPMENT PER HECTARE. REGION 9.
EMPIRICAL DATA ON KCLDH=f(FCLR)

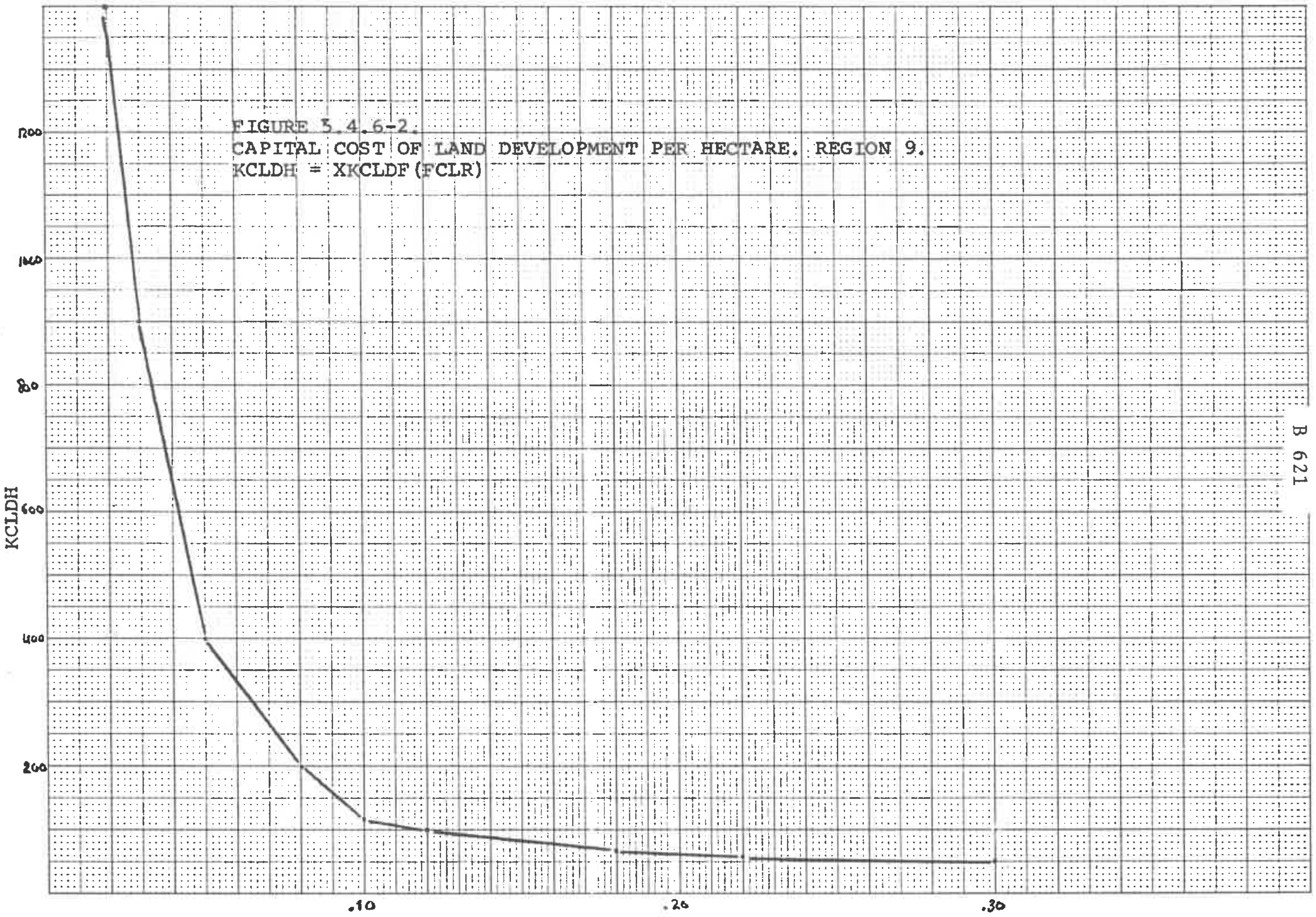


FIGURE 3.4.6-2.
CAPITAL COST OF LAND DEVELOPMENT PER HECTARE. REGION 9.
KCLDH = XKCLDF(FCLR)

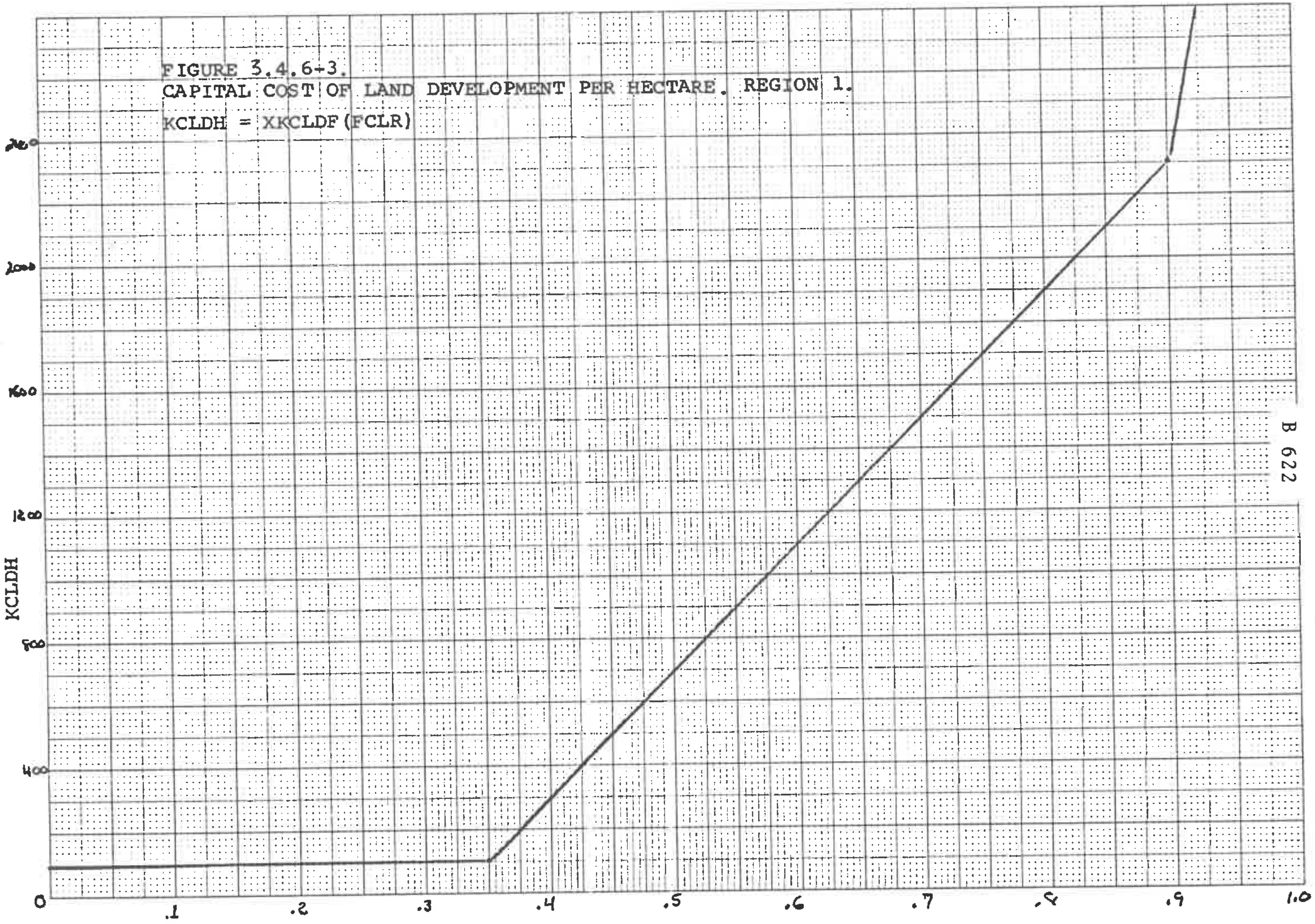


FIGURE 3.4.6-3.
CAPITAL COST OF LAND DEVELOPMENT PER HECTARE. REGION 1.
KCLDH = XKCLDF(FCLR)

4. Sensitivity Analysis

In order to determine the errors which might be introduced by the inevitable inaccuracy in the parameters a most detailed sensitivity analysis is performed. The results of eighteen sensitivity analysis runs are reported in the full IIASA report. The complete listing of the runs is summarized in figures 4-1 and 4-2. The runs for South Asia focus on demographic variables. The runs for North America focus on economic and agricultural output.

Comparative data on five sets of runs for South Asia and six sets of runs for North America are reported there.

FIGURE 4-1

Region 9. Sensitivity Analysis

	BASE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
PRODIST	.70	1.0	.8	.6															
PXPF	.15				.100	.200													
RPXPF	.02						.015	.040											
RPXK	.015								.015	.040									
UAFK	.30										.10	.50							
PXGR	0.115												.100	.130					
FAK	.0														-1.0	1.0	5.0		
IAPK	.50																	.3	.7

18. IAPK from .5 to 1.0 During Period FM 1975 to 2000.

FIGURE 4-2.

Region 1. Sensitivity Analysis

	BASE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
IAK	.05	.10	.025																
IAPK				.025	.10	.50													
TLWPCB							.1	1.0											
FAK									-1.0	1.0	5.0								
PXPF												.100	.200						
RPXPF														.025	.040				
RPXK																.015	.040		
PXGR																		.100	.130

B 626

III.5. SCENARIO ANALYSIS OF THE WORLD FOOD SITUATION 1975 - 2o25

W.B. Clapham Jr., M.S. Mesarovic, J.M. Richardson Jr.,
T. Shook, M.W. Warshaw

April 1974

Table of Contents

1. Introduction

This paper examines alternative policies which might be implemented in the food deficient and food sufficient regions of the world to prevent the occurrence of deaths from starvation during the next fifty years. In addition, it examines, using scenario analysis, the possibilities for self-sufficiency in regions of the world where serious deficiencies are presently being forecast.

Potentially severe food deficiencies exist in two of the ten regions of the world, South Asia (Region 9) and Africa (Region 8). Parts of Latin America may also face deficiencies, if present trends continue. However, in our judgment, there is no comparison between the severity of the problems which are likely to be encountered in South Asia and those of other regions. Accordingly, it is to this region that we have devoted primary attention in preparing for this presentation.

There are four principal reasons why the problems of South Asia will, in our judgment, require particularly urgent attention during the next decade.

(1) First, the absolute number of additional people who will have to be fed, as a result of population growth, is relatively much greater.

Our model forecasts a population of more than 1.3 billion in 1975 (1.3075). By 1985, if present trends continue, an additional 380 million will be added. If sufficient food were available, another 497 million persons would be added to the population of South Asia during the next decade.

(2) Second is the shortage of land, complicating the problem of increasing agricultural productivity.

There are about 278 million hectares of potentially arable land in South Asia. In 1965, 47 1/2 million remained uncultivated. According to our assessment, the comparable figure for 1975 will be about 16.7 million. By 1980, the amount of potentially arable, uncultivated land remaining in South Asia will be insignificant.

(3) A third reason for focusing on the problems of South Asia is that, paradoxically, it is in this region that a technologically intensive system of agricultural production is most needed, but it is also in this region that obstacles to the implementation of such a system are, perhaps, the most severe of anywhere in the world.

The total amount of agricultural capital stock, divided by the amount of cultivated land, provides a very rough indicator of the gap which separates the technologically intensive agriculture of North America and that of South Asia. For South Asia the figure is about $150/hectare. For North America it is 12 times as great.

To capitalize agriculture in South Asia at a level equivalent to that of North America would require an investment of more than 400 billion dollars (in 1963 prices).

Moreover, this kind of aggregate comparison wholly ignores the problem of creating the social, educational and economic infrastructure necessary to support technologically intensive agriculture.

(4) A Final reason for focusing on South Asia is the need for balanced economic development in the region. We do not believe that it is possible for a technologically intensive system of agriculture to exist, except as part of a balanced economy. Our analysis suggests that substantial shifts of investment to meet short term food needs would, in the long run, significantly reduce the prospects for balanced economic growth. Moreover, it is our conclusion that without balanced economic growth in South Asia, agricultural self-sufficiency is impossible.

There are a number of problems and issues which can be examined using the integrated food policy analysis model. For this presentation we have focused on three issues which, in our judgment, are most pressing and crucial for South Asia and for the more affluent regions of the world which are potential sources of assistance.

(1) First, we have examined the possibilities that self-sufficiency can be achieved without significant outside aid, during the period from 1975 through 2020.

Our conclusion is that self-sufficiency is technically possible if a program of birth control can be implemented which would gradually reduce crude birth rates from the present 42/1000 per year to 24/1000 by the year 2010. We doubt that any less than thirty five years will be necessary to achieve this objective; possibly this estimate is optimistic. Thirty more years will elapse before an equilibrium is reached.

Without outside assistance, however, the cost of this policy will be a severe increase in starvation, due to protein deficiency, during the period from 1987 to 2025.

Moreover, if policies are implemented within the region to relieve this starvation, by importing food or shifting investment to the agricultural sector, the resultant general economic decline will lead to starvation after 2020 with no real hope of attaining self-sufficiency.

(2) The second issue we have examined is the contribution which could be made by a program of foreign aid to the attainment of self-sufficiency.

From the perspective of potential aid-giving nations of the world, perhaps the most important conclusion to emerge from this analysis is that the period of aid could be finite in duration, if combined with the population control program discussed above.

(3) The third issue we have examined is the capabilities of a single developed region, comprising the United States and Canada, to provide the needed aid, assuming that no additional demands from the rest of the world were made.

2. Summary of Significant Results Based on Scenario Analysis

Our presentation of scenarios has been divided into two sections. In this section a summary of results from eight scenarios which appear to be of particular significance. The purpose of this is to define the magnitude of the problem and the scope of possible solutions without overwhelming the reader with the mass of detail which this type of analysis can generate. In Section 4, a complete set of detailed results from fifteen runs will be found. These will be helpful for analyzing the performance in particular strata or answering questions raised by the summary.

The first four scenarios summarized in this section assess the extent of the food supply prolem in South Asia and the capabilities of the region to help itself, without outside intervention.(Figure 3-1).

First, we have projected historical trends in the region, to explore the extent of the potential starvation problem;

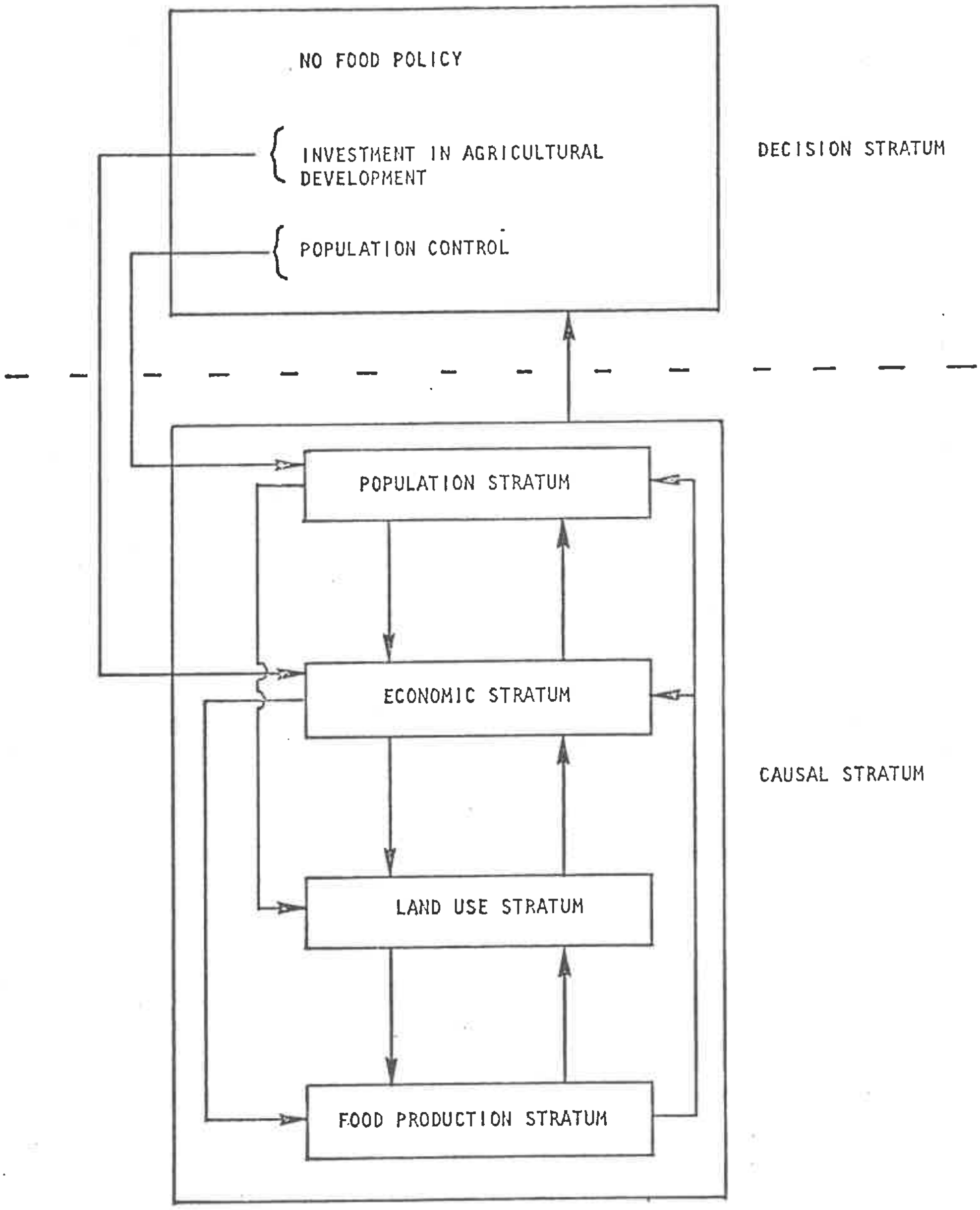
second, we have implemented a policy of agrarian development by shifting investment to the agricultural sector;

third, a population policy has been implemented to gradually limit births and achieve a state of equilibrium and

finally, the population and agrarian development policies have been cominged.

In the second four scenarios, the capabilities of one region, North America to provide needed assistance to South Asia are assessed.(Figure 3-2).

B 634



Integrated Food Policy Analysis Model: Regional Policies

Figure 3-1.

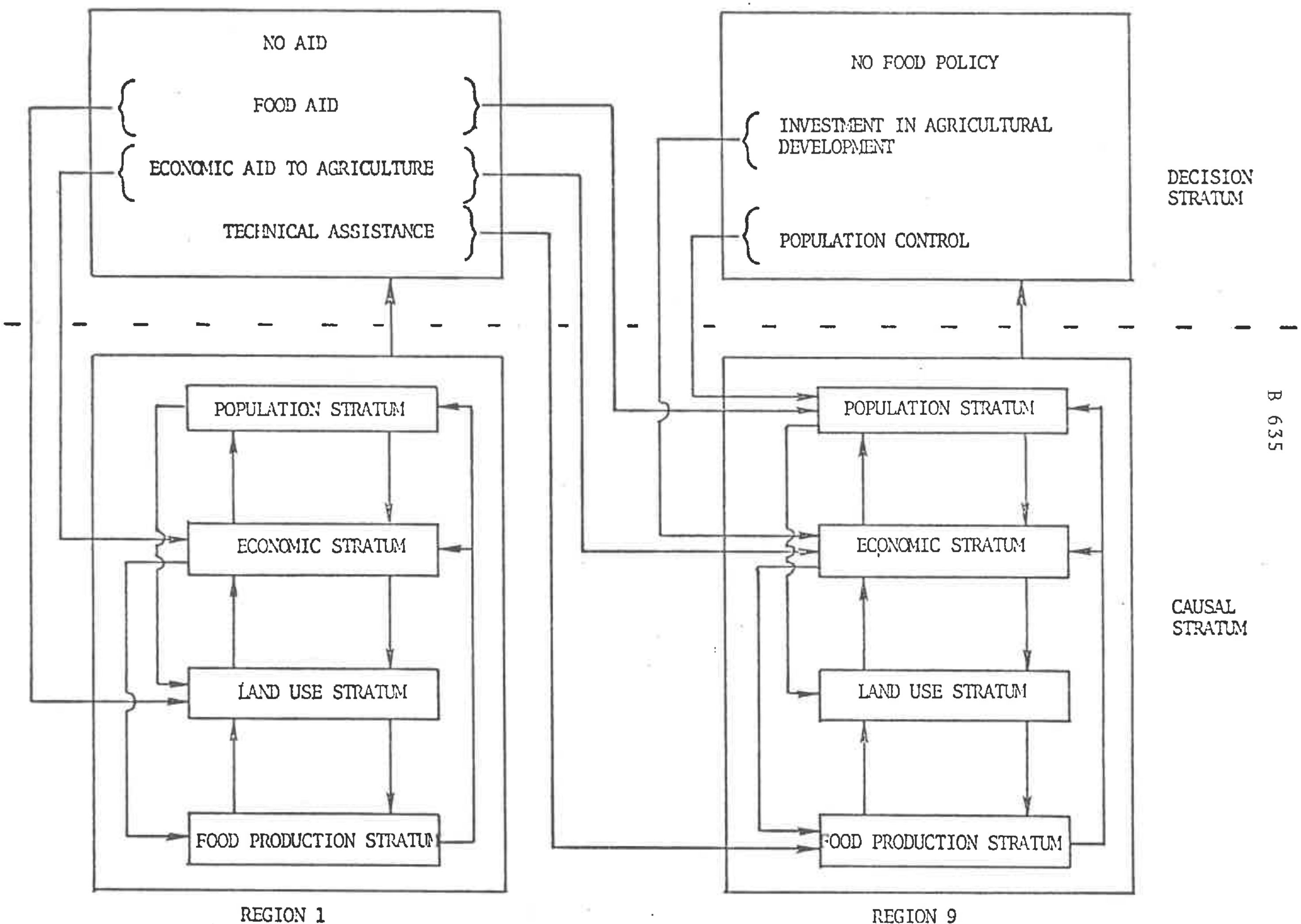


Figure 3-2. Integrated Food Policy Analysis Model - Inter-Regional Cooperation

First, an historical trend for the region has been projected.

Second, we have assumed that no population policy is implemented in South Asia and examined the capabilities of North America to meet the resultant food needs.

Third, we have assumed that South Asia does implement a population policy and made an assessment of the capabilities of North America to meet the resultant food needs.

Finally, we have assessed the effects on the North American economy of building agricultural self-sufficiency in South Asia through an investment development assistance program.

Our conclusion is that such a program of aid is technically and economically feasible, but could not be effected without some reduction in the level of economic development, relative to the level which could be attained if such a program were not implemented.

We recognize, of course that there would be severe political problems involved in gaining support for such a program. Our analysis provides no basis at this time for determining whether or not <u>those</u> problems are soluble. However, our judgment is that the necessary program can only be implemented on a global basis, with the cooperation of all the developed food-sufficient nations of the world.

Scenario 1. Historical Trends

In this scenario, we have assumed that the economic priorities of the last twenty years would prevail. Population control is not given major priority, but a modest policy is implemented over a fifty year period.

In figure 3.3, the results of this scenario have been projected with the additional assumption that the food needed to meet the growing deficit is available from somewhere and, consequently that no starvation occurs. This allows a realistic picture of the total deficit to be presented. Over a fifty year period, with continued population growth, it would amount to more than 700,000,000 tons of protein. About ten times as much food would be needed to make up that deficit.

A more realistic picture of what would happen, since 70 trillion tons of food aid will not be forthcoming, is presented in figure 3.2. Regional daily per-capita protein supply is insufficient at the outset and falls sharply thereafter. When the supply falls below

the starvation level of 54 kg./day, in about 1985, starvation deaths, especially among children begin to occur with increasing frequency. We estimate that the additional starvation deaths would number about 500,000,000.

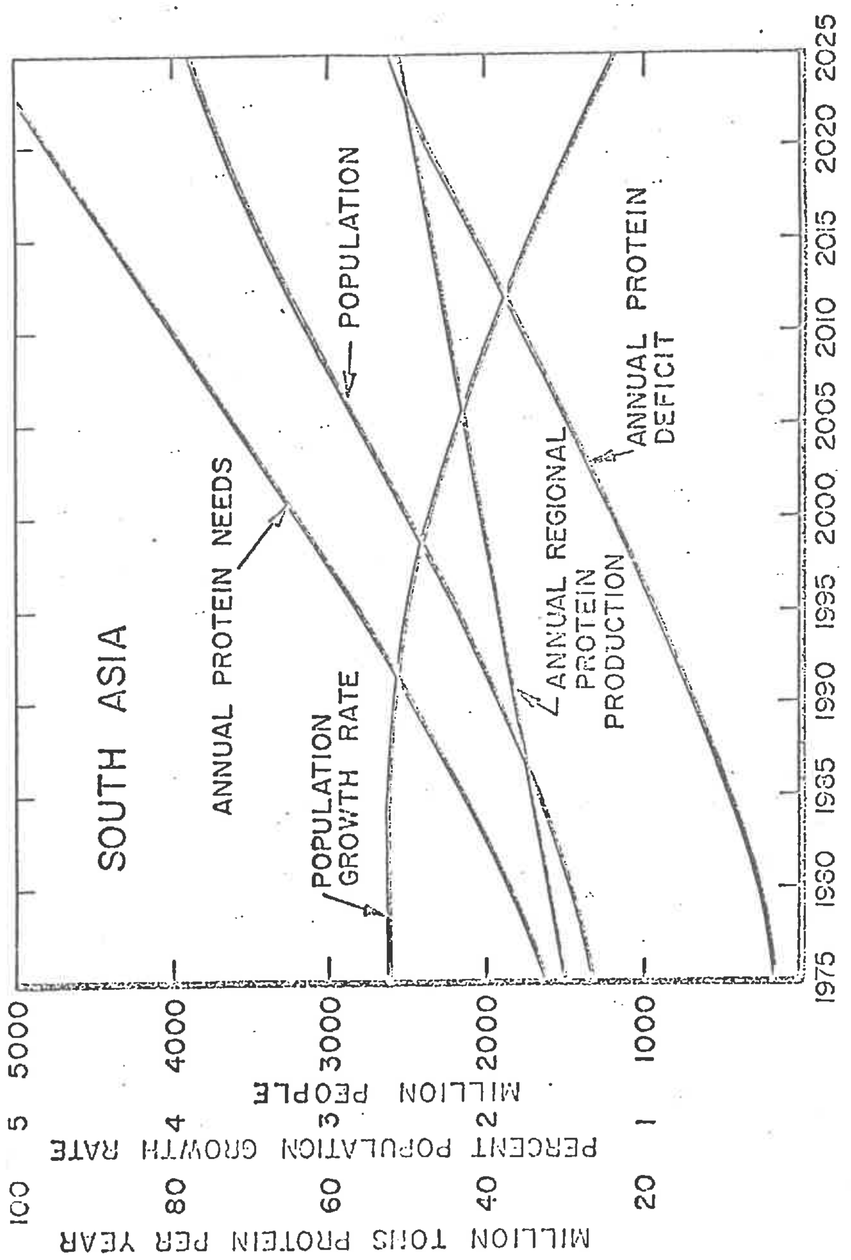

SOUTH ASIA
ANNUAL PROTEIN NEEDS
POPULATION
POPULATION GROWTH RATE
ANNUAL REGIONAL PROTEIN PRODUCTION
ANNUAL PROTEIN DEFICIT
MILLION PEOPLE
5000
4000
3000
2000
1000
PERCENT POPULATION GROWTH RATE
5
4
3
2
1
MILLION TONS PROTEIN PER YEAR
100
80
60
40
20
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025

Figure 3-3.

Scenario 2. Regional Investment in Agricultural Development

In this scenario we have examined the consequences of attempting to make South Asia self-sufficient in food by making it, essentially, an agricultural region. This has been done by shifting investment to the agricultural sector during the period from 1975 to 2005.

Figure 3-6 shows the economic consequences of this policy. Gross regional product drops from about 11 hundred billion dollars to about 5 hundred billion dollars. The principal reason for this is the failure of the industrial sector to develop. During the period from about 1980 to 2025 agricultural output is higher, but the gap is gradually narrowing by the end of the period.

Our indicators of food supply and population show that this policy will postpone the starvation problem but not eliminate it (Figures 3-7, 3-8). Regional supply can keep up with needs until about 1990. After that period there is rapid deterioration with little hope of attaining self-sufficiency.

Scenario 3. Population Policy

The results from our first two scenarios clearly indicate that starvation will be a long term problem and that some sort of population policy must be an essential component of any food policy. But it is unrealistic to assume that birth rates can quickly be reduced. Even

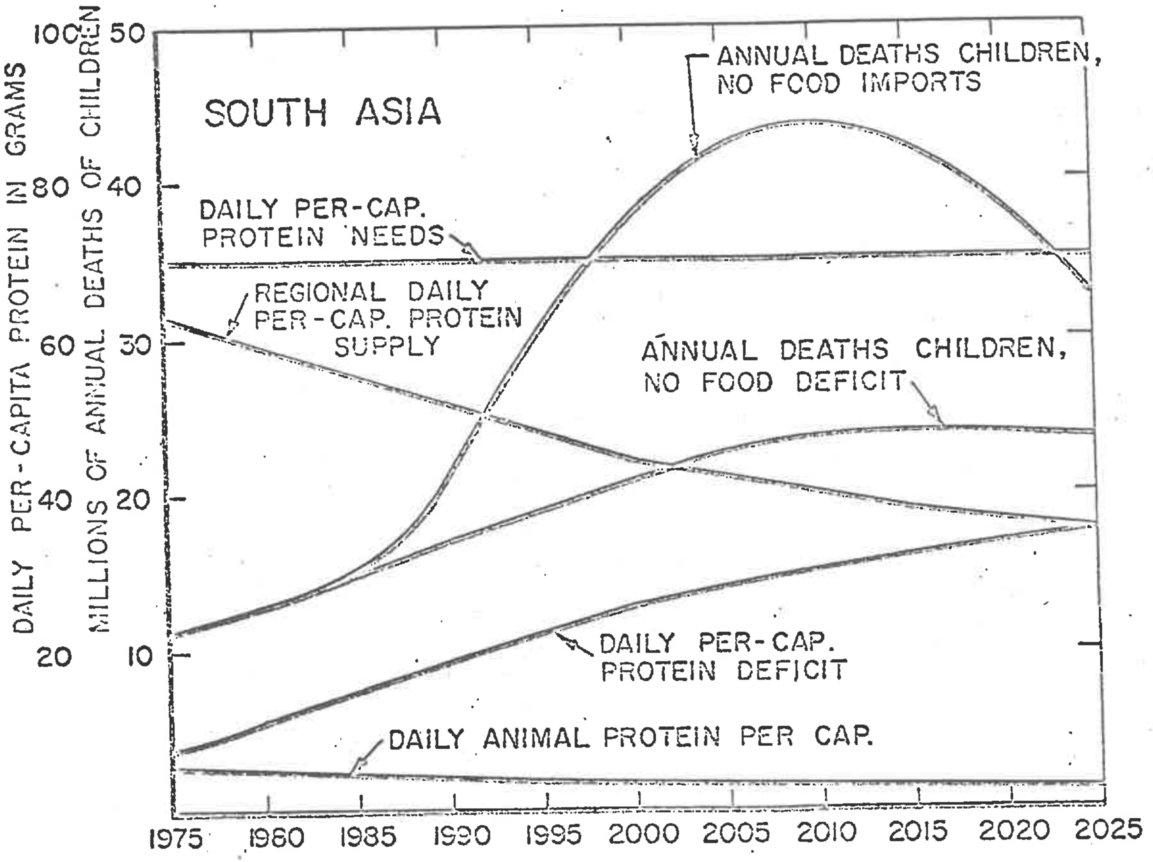

SOUTH ASIA
DAILY PER-CAPITA PROTEIN IN GRAMS
100
80
60
40
20
MILLIONS OF ANNUAL DEATHS OF CHILDREN
50
40
30
20
10
ANNUAL DEATHS CHILDREN, NO FOOD IMPORTS
DAILY PER-CAP. PROTEIN NEEDS
REGIONAL DAILY PER-CAP. PROTEIN SUPPLY
ANNUAL DEATHS CHILDREN, NO FOOD DEFICIT
DAILY PER-CAP. PROTEIN DEFICIT
DAILY ANIMAL PROTEIN PER CAP.
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025

Figure 3-4.

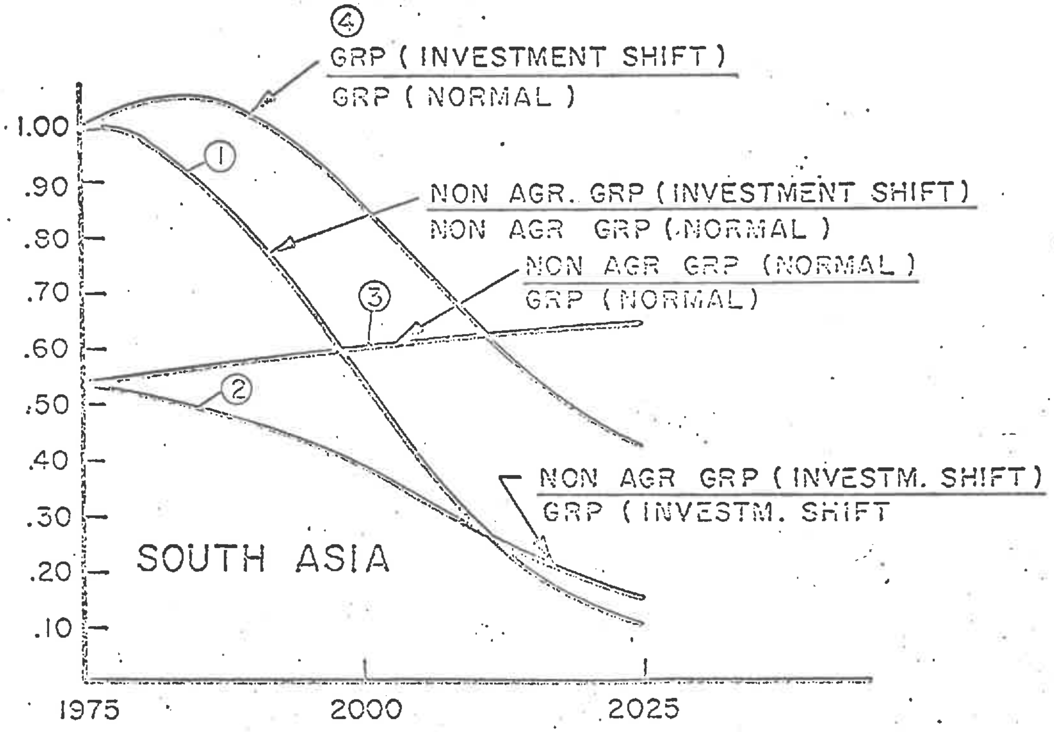

④
GRP (INVESTMENT SHIFT) / GRP (NORMAL)
①
NON AGR. GRP (INVESTMENT SHIFT) / NON AGR GRP (NORMAL)
③
NON AGR GRP (NORMAL) / GRP (NORMAL)
②
NON AGR GRP (INVESTM. SHIFT) / GRP (INVESTM. SHIFT
SOUTH ASIA
1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
1975
2000
2025

Figure 3-3

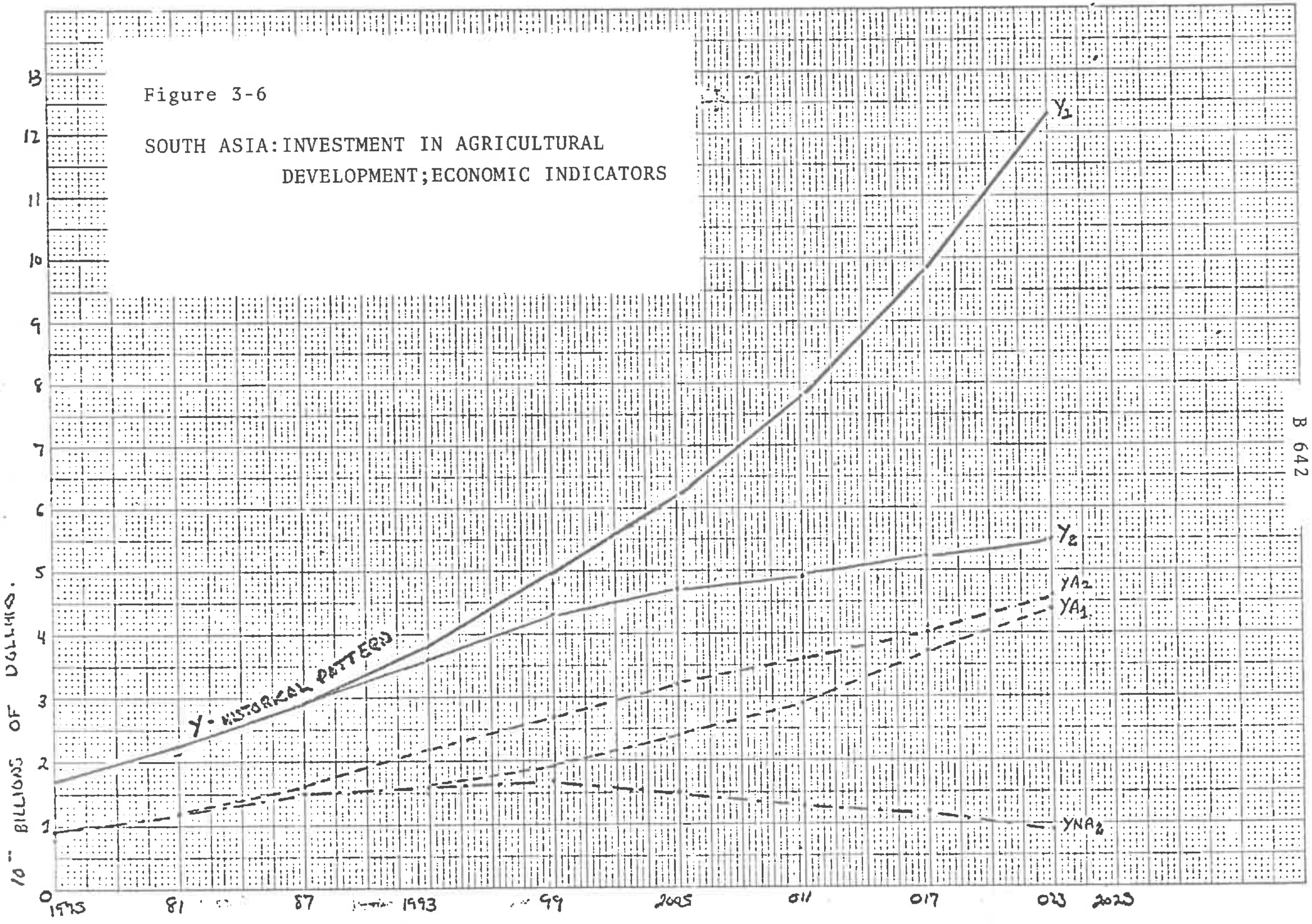
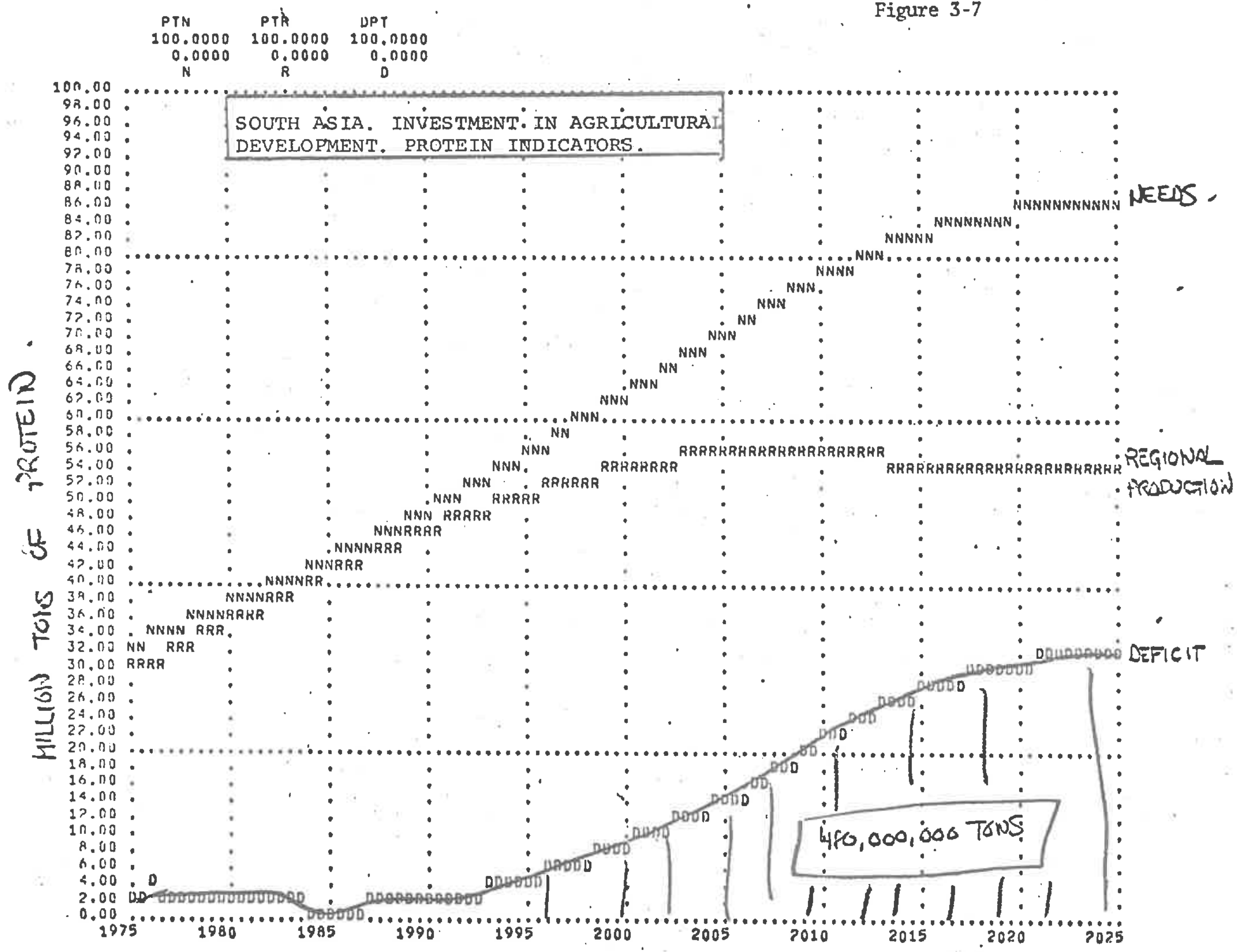


Figure 3-6

SOUTH ASIA: INVESTMENT IN AGRICULTURAL DEVELOPMENT; ECONOMIC INDICATORS

PAGE 23 04/04/74 03:12 PROTEIN INDICATORS

Figure 3-7



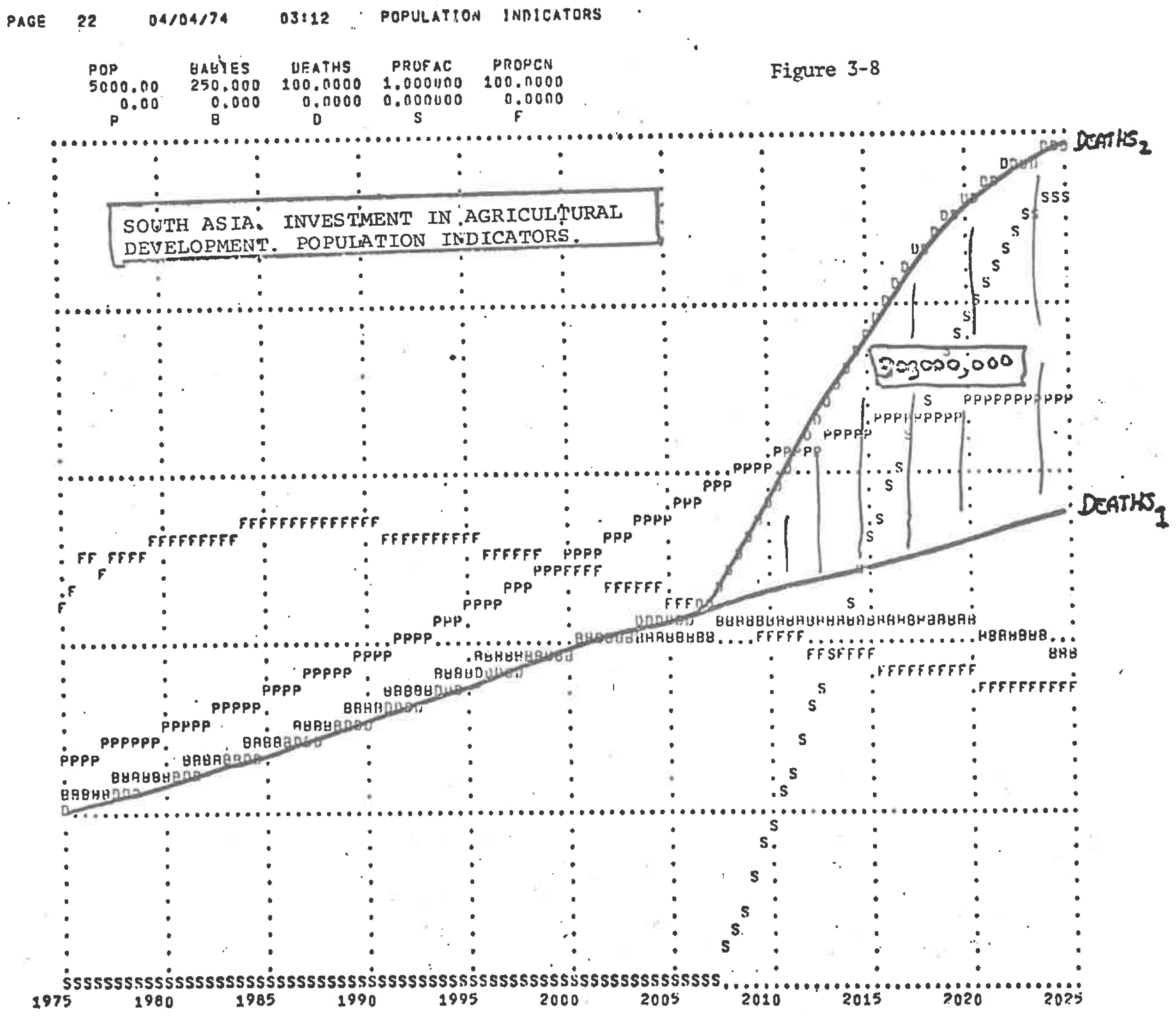

PAGE 22 04/04/74 03:12 POPULATION INDICATORS
POP 5000.00 0.00 P
BABIES 250.000 0.000 B
DEATHS 100.0000 0.0000 D
PROFAC 1.000000 0.000000 S
PROPCN 100.0000 0.0000 F
SOUTH ASIA. INVESTMENT IN AGRICULTURAL DEVELOPMENT. POPULATION INDICATORS.
DEATHS₂
DEATHS₁
23000,000
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025

Figure 3-8

after reduction is achieved, a substantial amount of time - about 30 years - will elapse before we can reasonably expect the population to stabilize.

In the population policy scenario we have implemented a program which gradually reduces crude birth rates from 42 per-thousand to 22 per thousand during a 35 year period from 1975 to 2010. We calculate that this policy would stabilize the population of South Asia at slightly less than 3 billion in about 2040.

Figure 3-9 shows the effects of the policy on several population indicators.

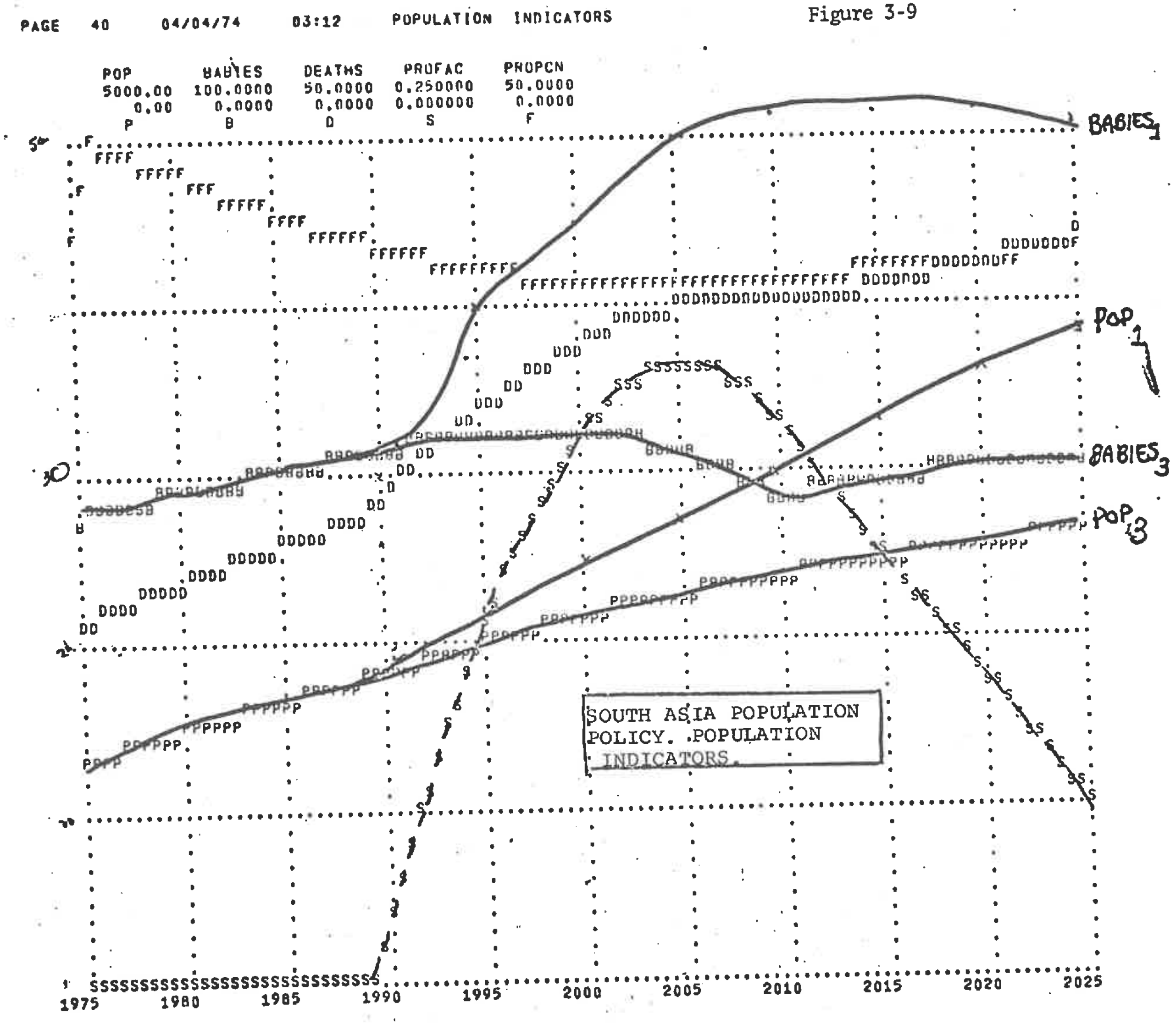
In Figure 3-10 protein supply and needs per-capita are presented. Protein supplies continue to fall below needs, but the trend is toward self-sufficiency.

Scenario 4. Population Policy Combined with Agricultural Development

It is unlikely, however, that a society could continue a program of balanced development in the face of starvation. Instead, it is likely that investment shifts to agriculture would be made. This would alleviate the protein deficit in the short run, but with unfortunate long term consequences, especially increasing protein deficits after 2005 (Figure 3-11). Self-sufficiency could not be attained. The effects on population provide additional evidence that balanced development is essential.

In the second set of scenarios we shift attention to North America and explore the capabilities of that region to meet the needs of South Asia.

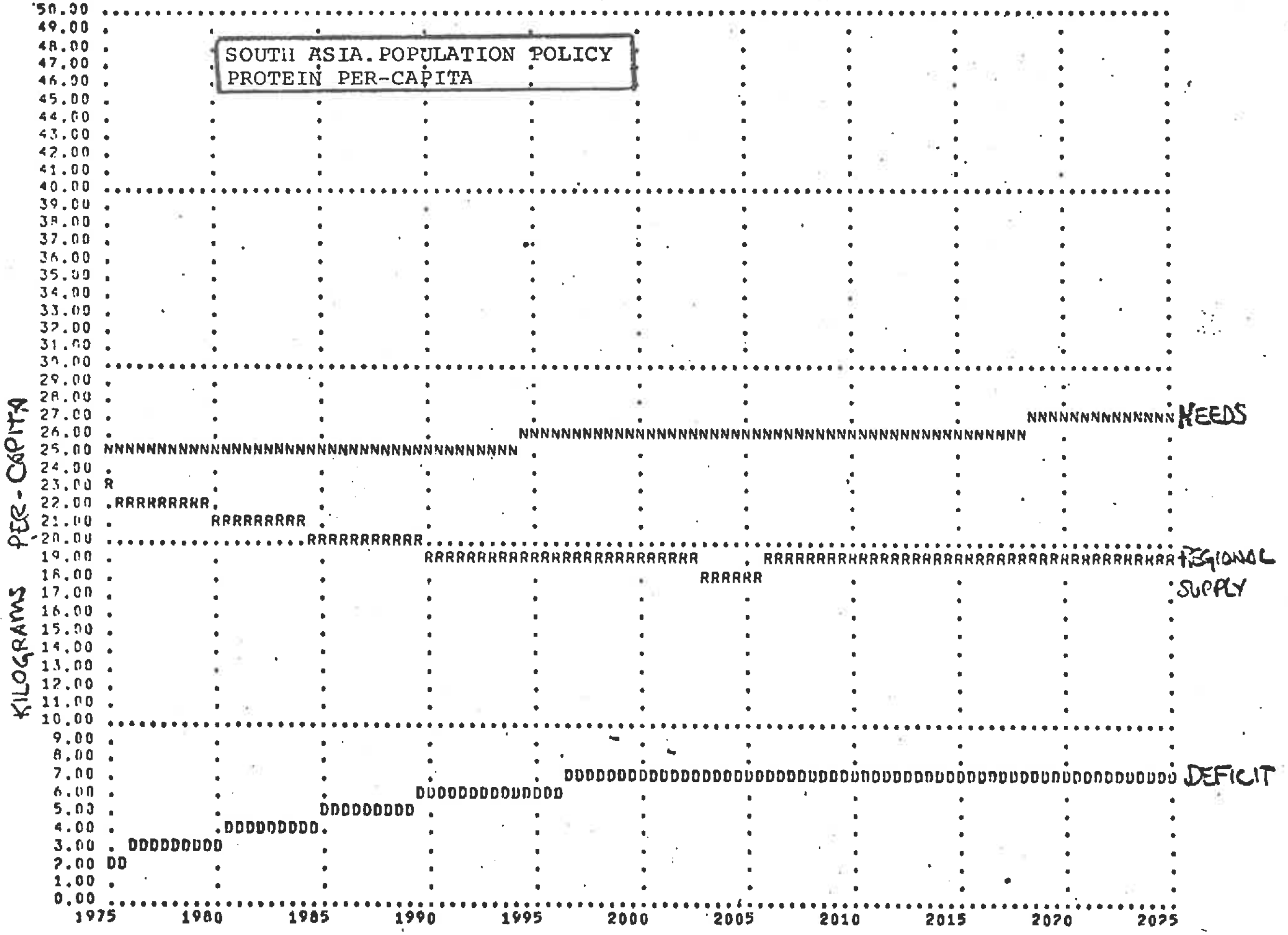
Figure 3-9



B 646

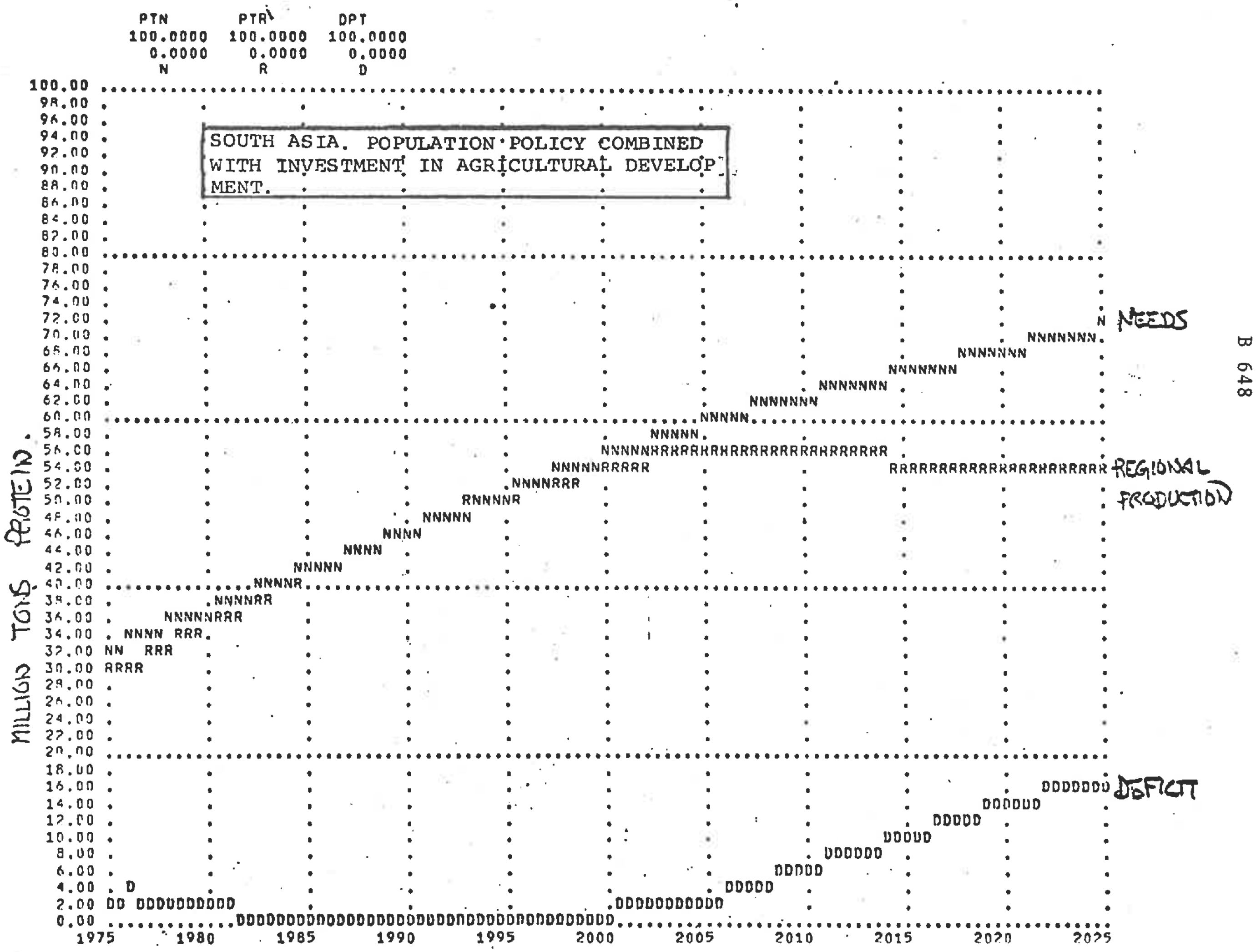
```
PAGE   42      04/04/74      03:12      PROTEIN INDICATORS

         PTPCN        PTPCR        DPTPC
         50.0000      50.0000      50.0000
          0.0000       0.0000       0.0000
           N            R            D
```

Figure 3-10



PAGE 58 04/04/74 03:12 PROTEIN INDICATORS

Figure 3-11


SOUTH ASIA. POPULATION POLICY COMBINED WITH INVESTMENT IN AGRICULTURAL DEVELOPMENT.

B 648

Scenario 5. Historical Trend. Food Production Capabilities

In the first scenario, we have examined the capability of North America to produce increased food without seriously affecting the structure of its economy. This has been done by projecting the historical pattern of investment in agriculture, relative to investment in the rest of the economy. The results show that substantial surplus capacity exists (Figure 3-12).

In fact, after 2000 more than double the regional needs could be produced. We recognize that this would not occur in the absence of demand for agricultural products. The more likely pattern would be a continued decrease in the agricultural sector relative to the total economy.

Scenario 6. No Population Control in Southeast Asia, North America Attempts to Meet The Needs by Reducing Consumption

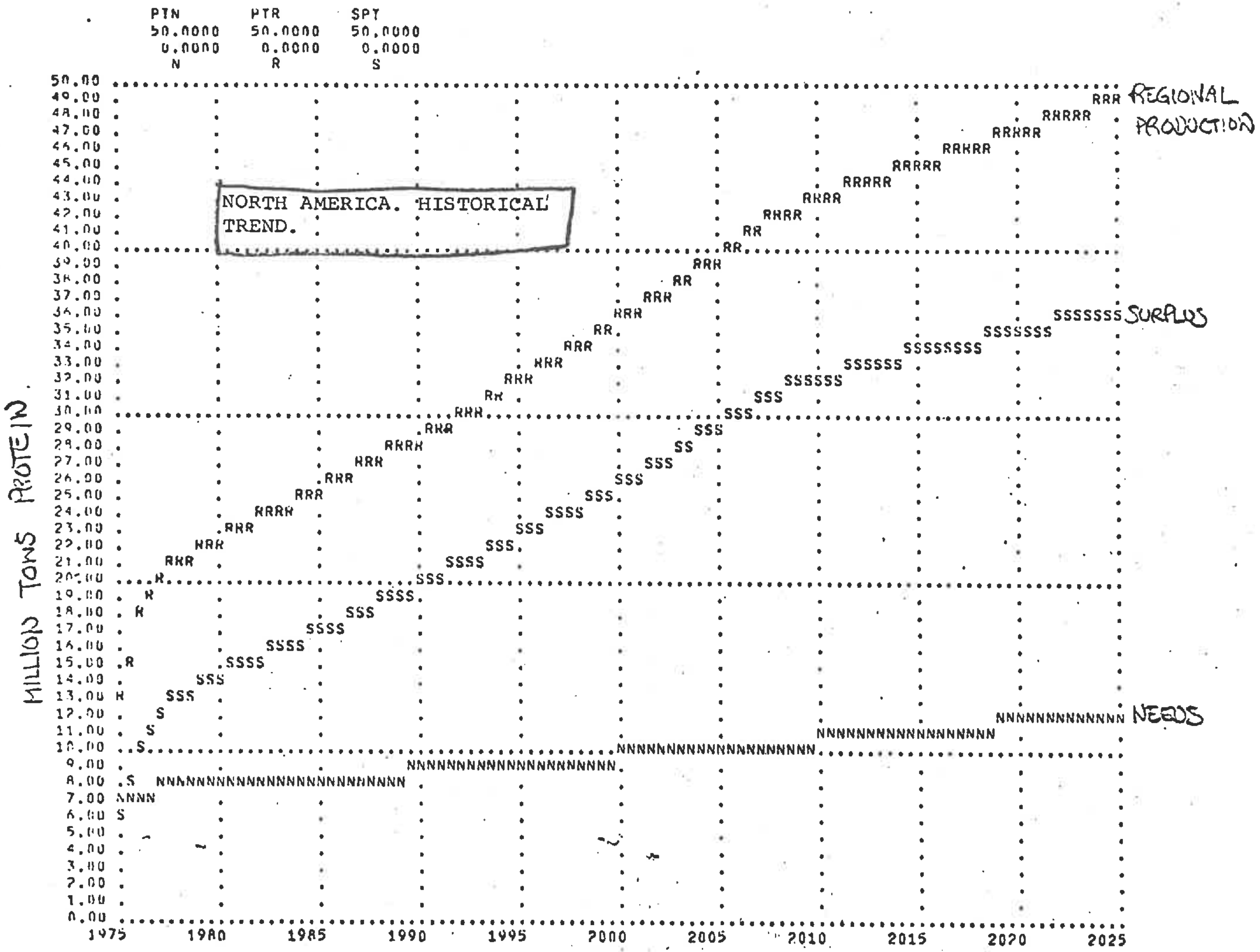
In the second scenario we have compared the food needs of South Asia, with population unrestricted, and the capabilities of North America.

By exporting all of its surplusses to South Asia, North America could meet the protein deficit until about 1997. After 2008 the entire production of North America would be needed to meet the deficit (Figure 3-13).

This analysis ignores, of course, the physical problems of shipping and distributing more than 200,000,000 tons of food per year.

PAGE 2 04/05/74 14:18 PROTEIN INDICATORS

Figure 3-12



PAGE 24 04/05/74 14:18 EFFECTS OF REGION 9 DEMANDS ON REGION 1

Figure 3-13

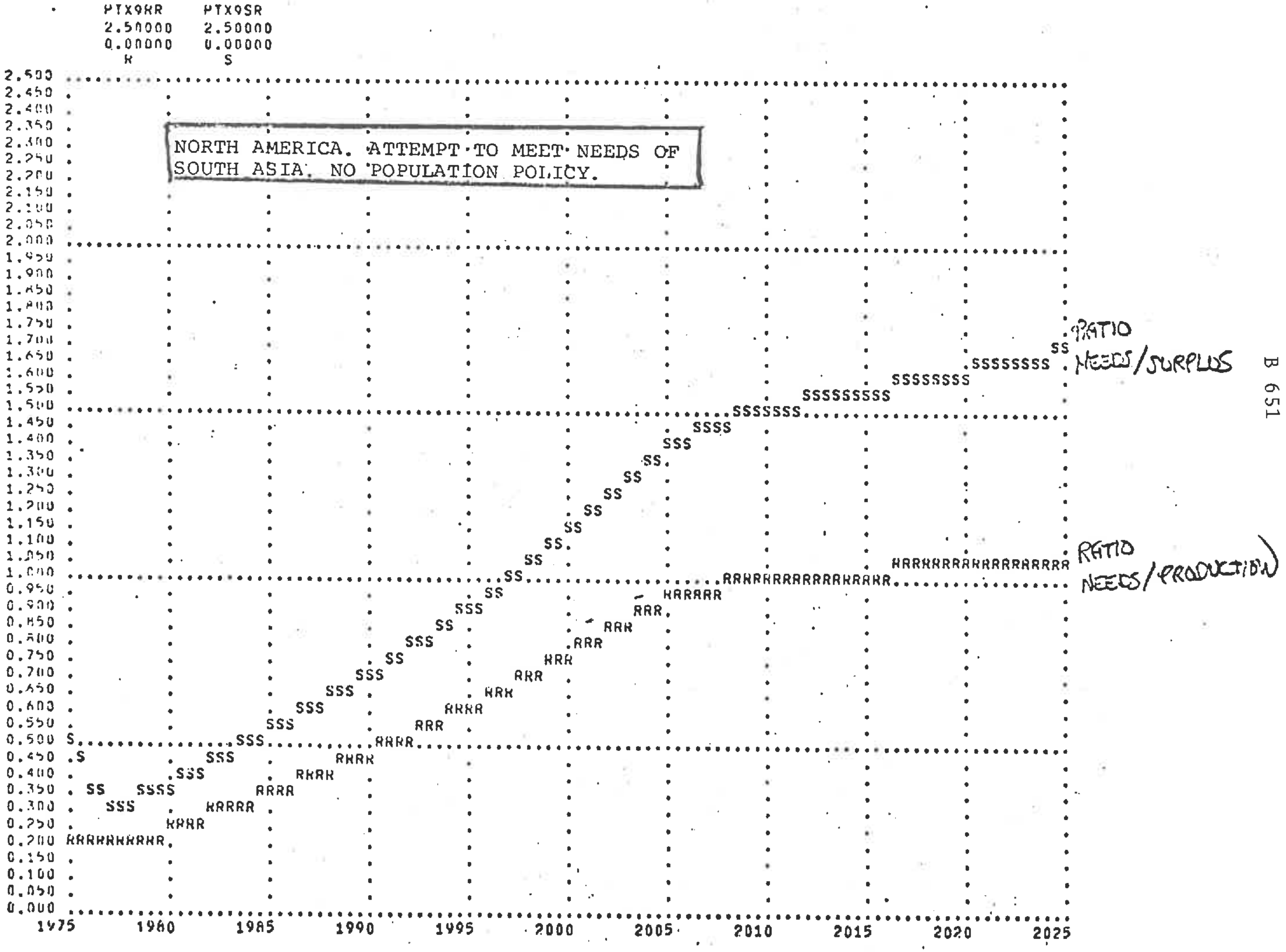


Figure 3-14 pictures one of the economic effects of this policy. Consumption would drop by 15 percent in comparison with the historical trend. Most of this would come from food. By 2025, six percent of total GRP would be in food exports.

Scenario 7. Population Control in Southeast Asia. North America Attempts to Meet Needs. Aid Affects Investment, Consumption and Government Expenditure Equally.

If the population policy in South Asia were successfully implemented, it would be possible to meet the food needs while self-sufficiency was attained.

The analysis in Figure 3-15 shows that 60 percent of the possible agricultural surplusses or 40 percent of total agricultural production would be required. Consumption would be reduced by about six percent.

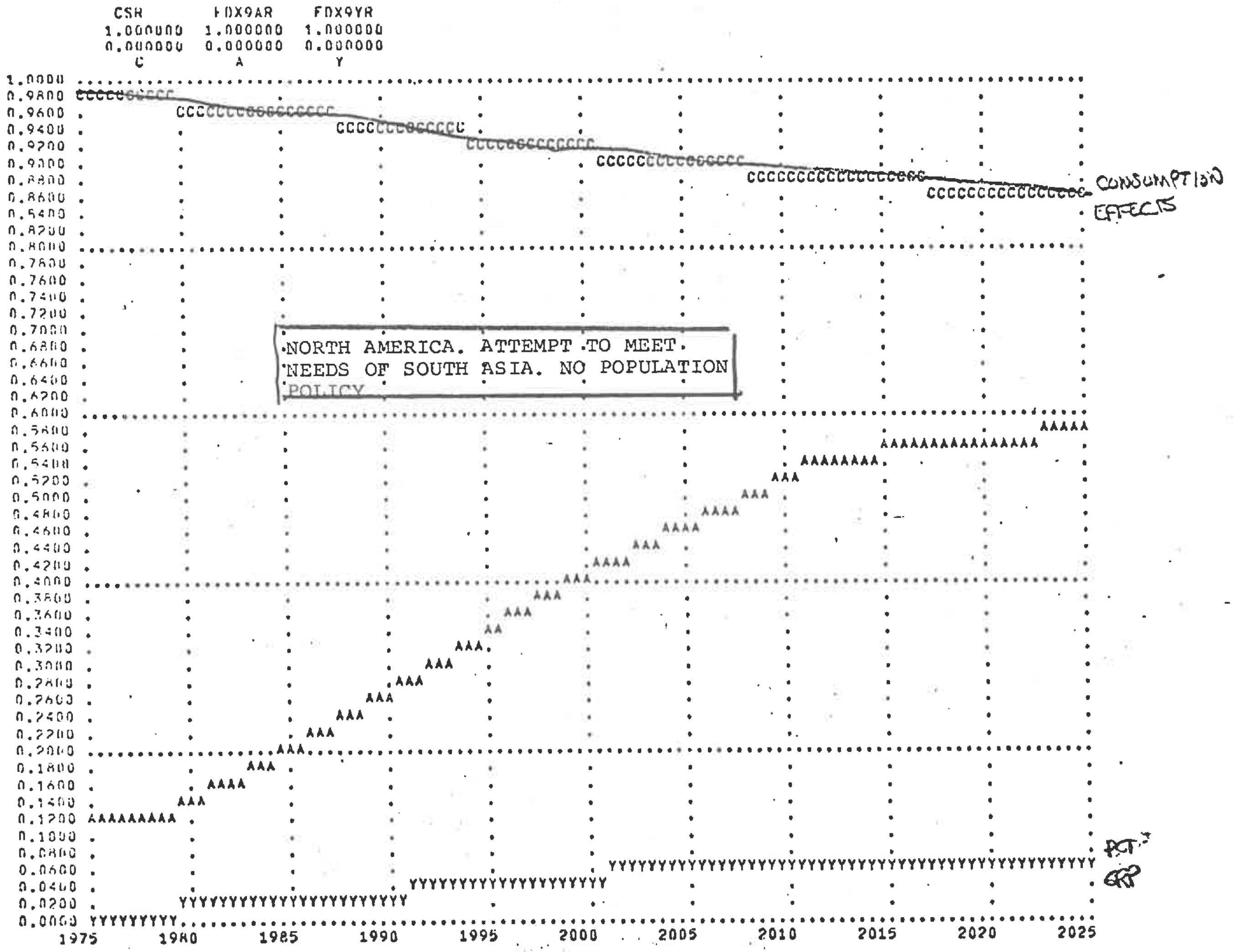
In this scenario we have divided the costs of the aid program equally between government expenditure, investment and consumption The effects are shown in Figure 3-16.

Scenario 8.

In a final scenario we have examined the possibility of meeting the agricultural investment needs of South Asia. Earlier scenarios showed that self-sufficiency could be attained, largely with self-generated investment in the industrial sector, or that, alternatively, starvation could be avoided for a period of time by shifting investment. If needed investment were supplied from outside sources for agriculture, balanced economic growth would be possible.

PAGE 17 04/05/74 14:18 EFFECTS OF REGION 9 DEMANDS ON REGION 1

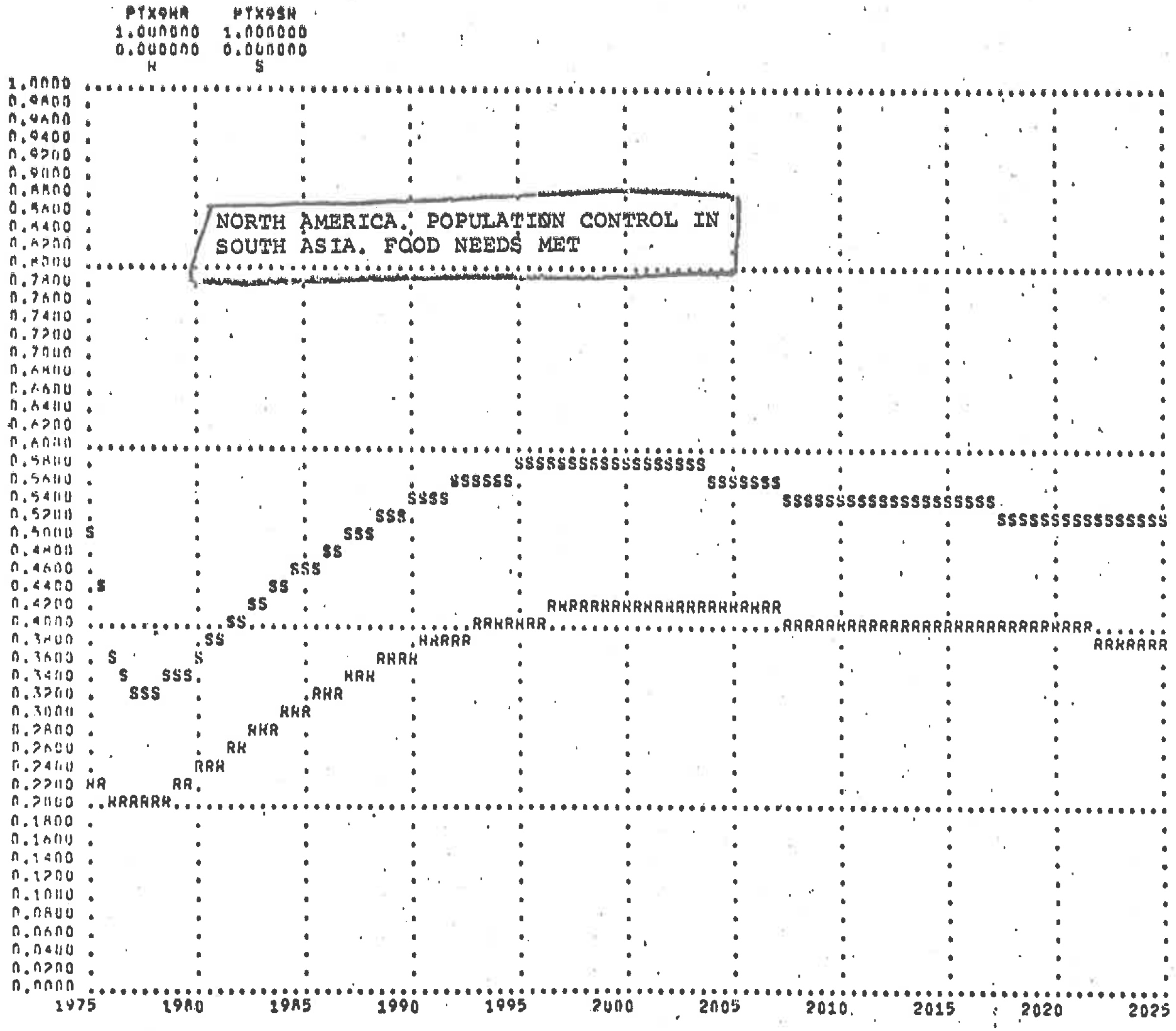
Figure 3-14



NORTH AMERICA. ATTEMPT TO MEET NEEDS OF SOUTH ASIA. NO POPULATION POLICY

PAGE 20 04/05/74 14:18 EFFECTS OF REGION 9 DEMANDS ON REGION 1

Figure 3.15



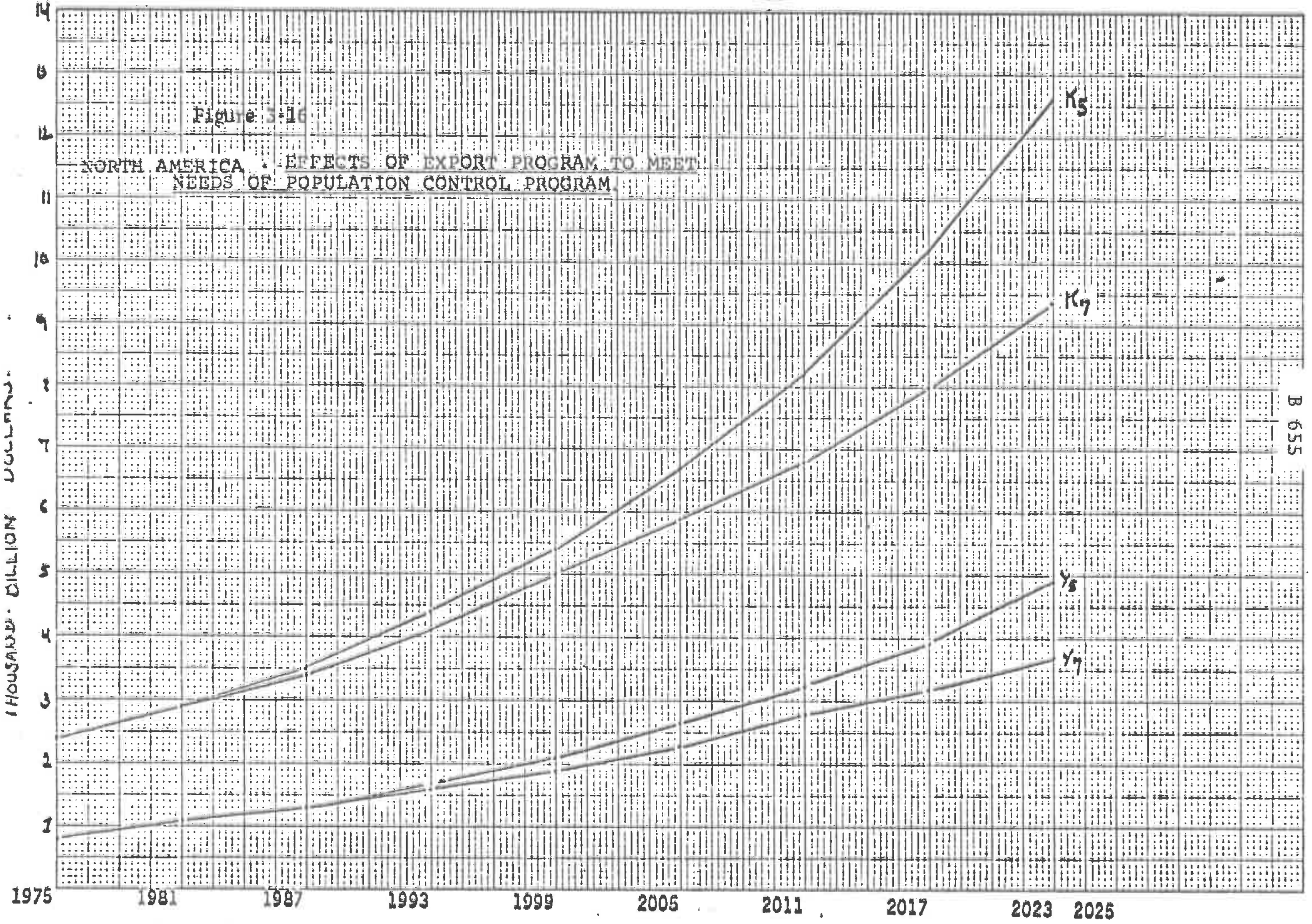


Figure 3-16

NORTH AMERICA . EFFECTS OF EXPORT PROGRAM TO MEET NEEDS OF POPULATION CONTROL PROGRAM

In Figure 3-17 we have pictured what we regard to be the minimum amount needed for this region alone. The total sum is about $350 billion at 1963 constant dollars. This amount is roughly equivalent to that which would be required for food aid. The aggregate economic effects would be similar to those which have just been examined.

In sum, to avoid starvation in South Asia, the developed world must provide in the neighborhood for 350 to 400 billion dollars (at 1963 values). In current values the amount is about 600 billion. The amount will be roughly equivalent whether food aid or investment aid is chosen; however there are strong arguments, in our judgment, favoring the latter.

A program of this magnitude is within the capabilities of the developed world, but not of a single nation.

3. Conclusions

The most significant conclusions from our analysis are the following:

1. First, the analysis confirms the existence of a severe, long term world food problem. Here we have presented data only on South Asia, but the situation in Africa is equally grave, though it involves a fewer number of people in absolute numbers.

2. Implementation of a population policy must be the top priority objective. Without it, discussions of food policy are, in the long run, meaningless.

B 657

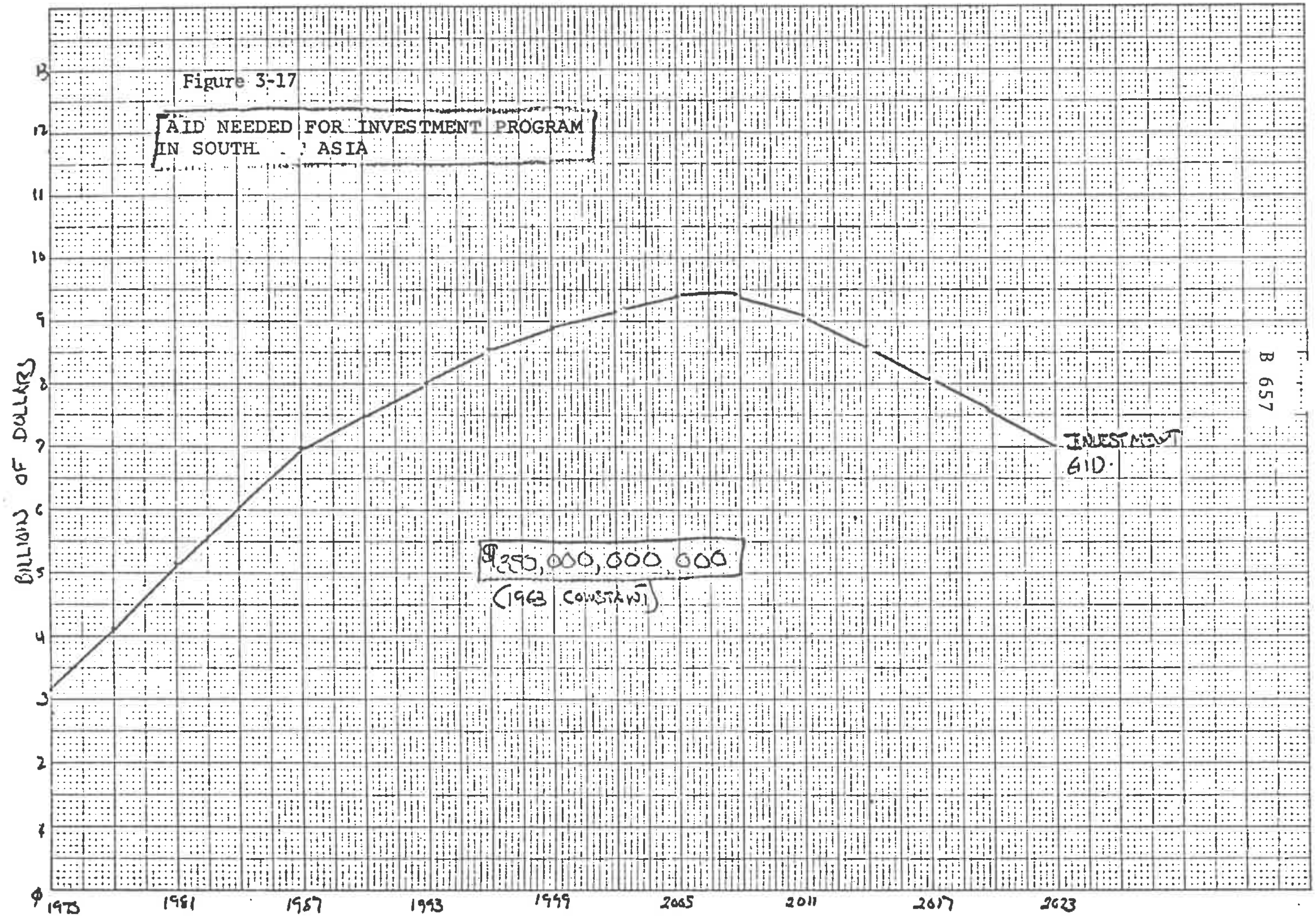


Figure 3-17

AID NEEDED FOR INVESTMENT PROGRAM IN SOUTH ASIA

3. However, in our judgment, the results of the analysis are encouraging. With a population policy which we regard as reasonable, dietary and economic self-sufficiency in South Asia are possible.

4. We conclude that the most effective way of achieving this objective is for the developed nations of the world to provide assistance in the form of investment support for the agricultural sector. While some short term commodity aid may be desirable, we do not believe this is a viable solution in the long run.

5. Balanced economic development is essential if self-sufficiency is to be achieved over the long term.

6. Finally, and most important, the program of aid which we envision must be coordinated and implemented within a global framework. The program of assistance we are proposing must be of a far greater magnitude and for a longer term than anything which has been undertaken to date. But it is technically and economically feasible. Whether it is politically feasible, whether the leaders and peoples of the developed world will support such a program, is yet to be determined.

4. Detailed Scenario Results

Results of the detailed scenario analysis are presented in the IIASA full report. In this paper the following sixteen scenarios are described:

REGION 9. SOUTH ASIA

(9-1) Historical pattern. Full reliance on outside aid. No starvation

(9-2) Shift of investment to the agricultural sector. Fertilizer subsidy program. Full reliance on outside aid. No starvation.

(9-3) Historical pattern. No outside aid. Starvation possible.

(9-4) Shift of investment to the agricultural sector. Fertilizer subsidy program. No outside aid. Starvation possible.

(9-5) Thirty-five year population control program. Historical pattern. No outside aid. Starvation possible

(9-6) Population control program. Shift of investment to the agricultural sector. Fertilizer subsidy program.

(9-7) Population control program. Historical pattern. Full reliance on outside aid. No starvation.

(9-8) Population control program. Shift of investment to the agricultural sector. Fertilizer subsidy program. Full reliance on outside aid. No starvation.

REGION 1. NORTH AMERICA

(1-B) Historical pattern. No aid program.

(1-1) Scenario (9-1) implemented. North America provides maximum assistance. Cost is borne by reducing consumption.

(1-2) Scenario (9-5) implemented. North America provides maximum assistance. Cost is borne by reducing consumption.

(1-3) Scenario (9-1) implemented. North America provides maximum assistance. Cost is borne by reducing investment.

(1-4) Scenario (9-5) implemented. North America provides maximum assistance. Cost is borne by reducing investment.

(1-5) Scenario (9-1) implemented. North America provides maximum assistance. Cost is divided equally between investment, consumption and government expenditures.

(1-6) Scenario 9-5 implemented. North America provides maximum assistance. Cost is divided between investment, consumption and government expenditures.

(1-7)North America provides investment development assistance to South Asia.

As seen on the illustrations the output from the first scenario is presented here.

Readers who are unfamiliar with the format of our model output, often have some difficulty in sorting the results of one scenario from another and making any sense out of the voluminous output provided. Accordingly, a few remarks may be helpful.

Before the data for the first run in each region is reported, there is a listing of parameters. This contains some, but not all of those used in the model. Some of the parameters which are vector inputs to the food model have been omitted, however. These are provided in the article by Clapham in this series.

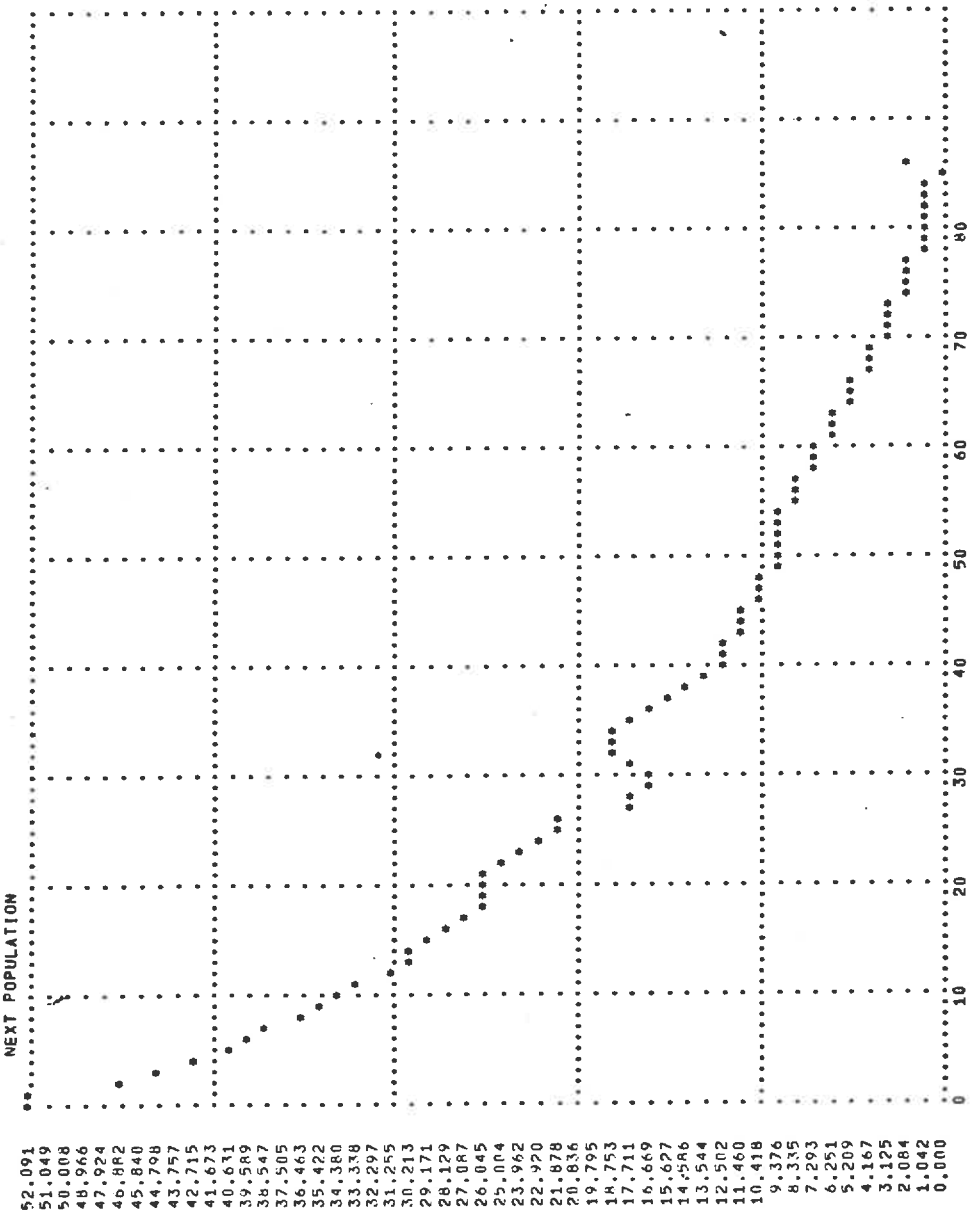
A sheet labled parameter, at the top will also begin each subsequent run. However only one or a few parameters will be reported. These are parameters whose values have been altered from the base run . [illegible] for the run in question.

The notation "time series" will also appear on some of these sheets, followed by a scenario variable name. This indicates that time series data has been read in exogenously for that variable.

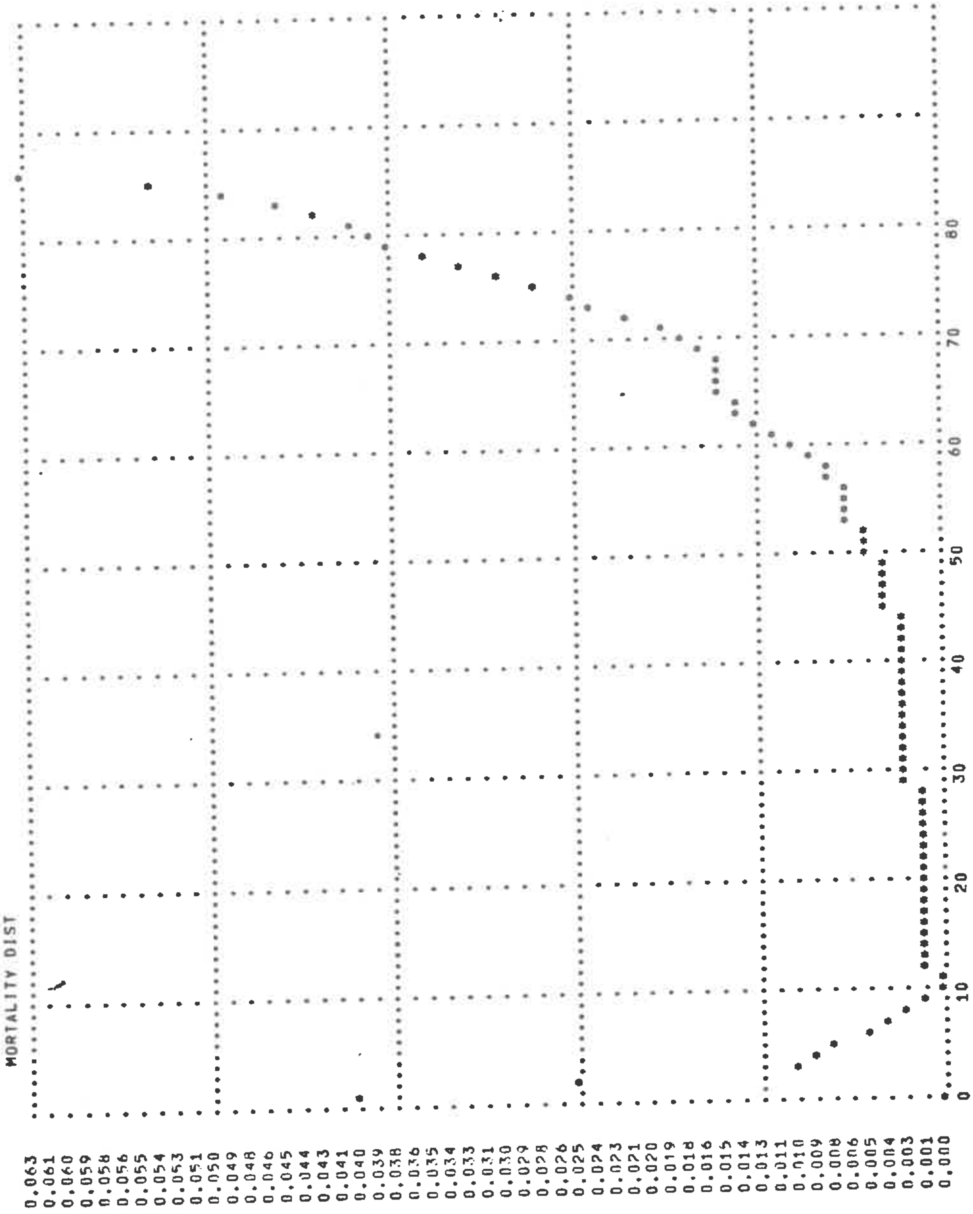
```
  PAGE    1     04/04/74     02:38

PARAMETER
          RUN
        1.000000

PARAMETER
           DA        DNA        KA         KNA        QNA        GC         GG         GI         GM         YSNA75     PTPCB
        0.0555534 0.0285702  39.4990    225.496    2.49994   0.759979 0.0999985  0.128593   0.124996   1.000000   1.000000

PARAMETER
          IAK        IRK        IAPK       IALVK      MAK        RPXPTM     PXPTM      GZPHK      TA         TB         RLLVS
        0.144997   0.299995   0.499992 0.0499992  0.173996 0.0239992   2.69995   0.666672  -48.6982   0.796951   87.7129

PARAMETER
          CLM        CLW        GL         CLGR       CLWK       GLWK       FB         FC         FD         FE         FAK
          278.000    1.19998    287.813    171.844  0.0699978 0.0699978  0.919983 0.0238991  -66.1973   1.71991    1.000000

PARAMETER
          WB         PXPF       UAFK       RPXPF      HPXK       PXK        PXLV       PXGR       PXNG       PXFS       PXLVK
        0.0099998  0.149998   0.229996 0.0199995 0.0249991  1.000000   1.49997    0.114996 0.0899982  0.899994   1.000000

PARAMETER
          EO         EU         EA         PRONOR     PROD       PRODST     FERT       MORT
        1.000000   0.249996   10.00000   44.0000    25.0000    0.699982   2.95447    2.80493

TIME SERIES
          FERT

PARAMETER
          A          A          A          A          A1I        A1I        A1I        A1I
             1          2          3          4          1          2          3          4
        0.289818 0.0554028 0.0691948  0.202423   1.41760  0.0984764  0.122993   1.26230

PARAMETER
          FWCM       UFWP       ENZPLK     FWCNTK     AFWMK      UFWPK      FWMM
          13.0901  0.0011044   12.2214   0.449966 0.0709934   2.07410    16.3008

PARAMETER
          SLV        SLV        SLV        SLV        SLV        SLV        SLV        SLV        SLV
          CATTLE     PIGS       SHPGTS     HORSES     MABC       HONEY      POULTR     MPOUL      CBSG
          266.258    33.1152    200.238    3.13495    100.654    1.49997    612.859    537.000    327.711
```

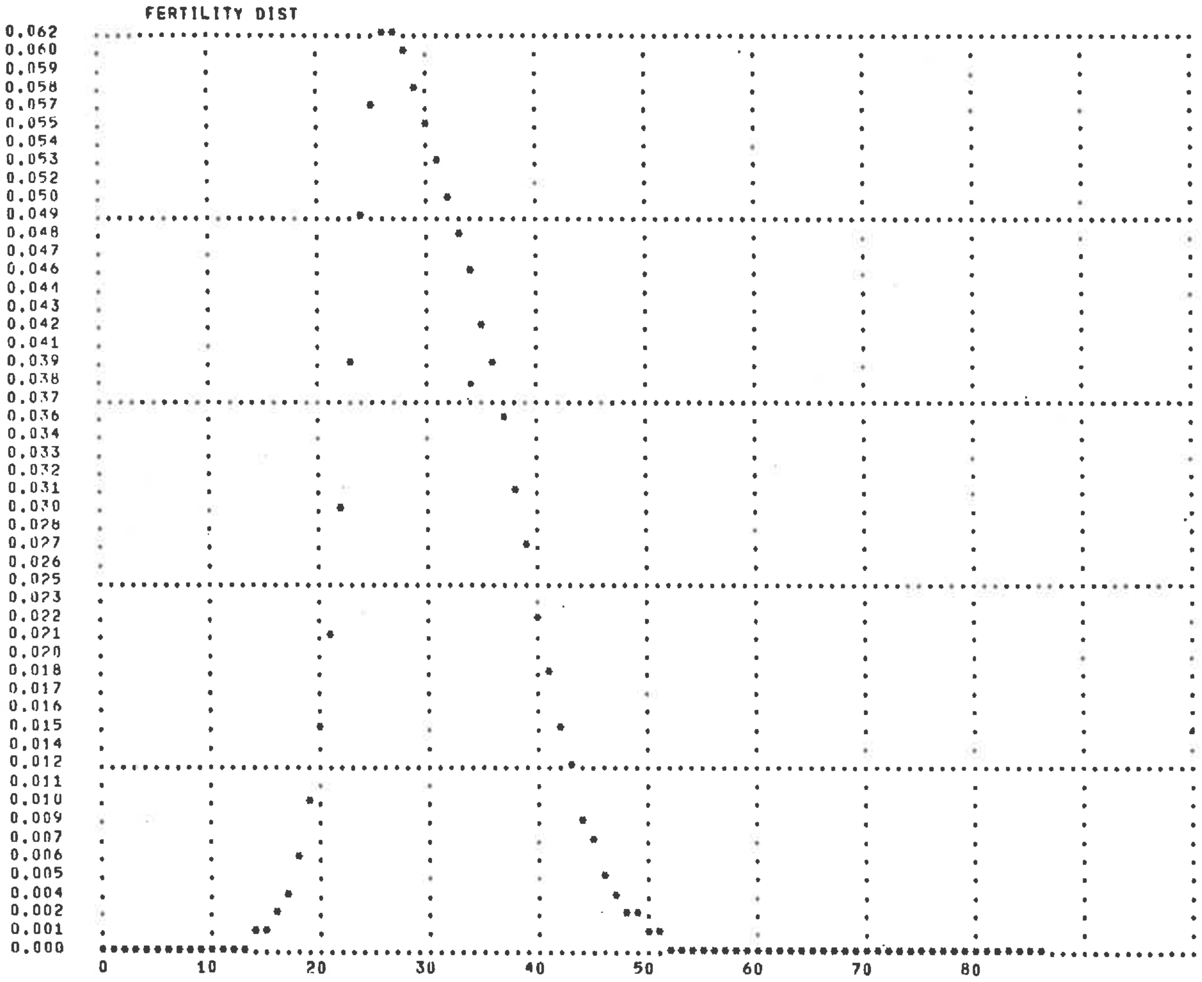
```
    PAGE    2     04/04/74     02:38



PARAMETER
            SLVK      SLVK      SLVK      SLVK      SLVK      SLVK      SLVK      SLVK      SLVK
            CATTLE    PIGS      SHPGTS    HORSES    MABC      HONEY     POULTR    MPOUL     CBSG
           0.649979  0.199997 0.0999985  1.000000  1.000000  0.00000 0.0099998 0.0099998  1.000000


PARAMETER
            PXLVB     PXLVB     PXLVB     PXLVB     PXLVB     PXLVB     PXLVB     PXLVB     PXLVB
            CATTLE    PIGS      SHPGTS    HORSES    MABC      HONEY     POULTR    MPOUL     CHSG
           0.124996 0.0429983 0.0149996 0.0999985 0.0809975 5.000E-04 5.000E-04 5.000E-04 0.0809975
        PAR (FAK,PRODST)=1.5,1 ! NOLOG RUN ENDCOM                                                3

    RUNNING PROGRAM   54     FROM    1975     TO    2025       3
```

B 663


NEXT POPULATION
52.091
51.049
50.008
48.966
47.924
46.882
45.840
44.798
43.757
42.715
41.673
40.631
39.589
38.547
37.505
36.463
35.422
34.380
33.338
32.297
31.255
30.213
29.171
28.129
27.087
26.045
25.004
23.962
22.920
21.878
20.836
19.795
18.753
17.711
16.669
15.627
14.586
13.544
12.502
11.460
10.418
9.376
8.335
7.293
6.251
5.209
4.167
3.125
2.084
1.042
0.000
0
10
20
30
40
50
60
70
80

B 664

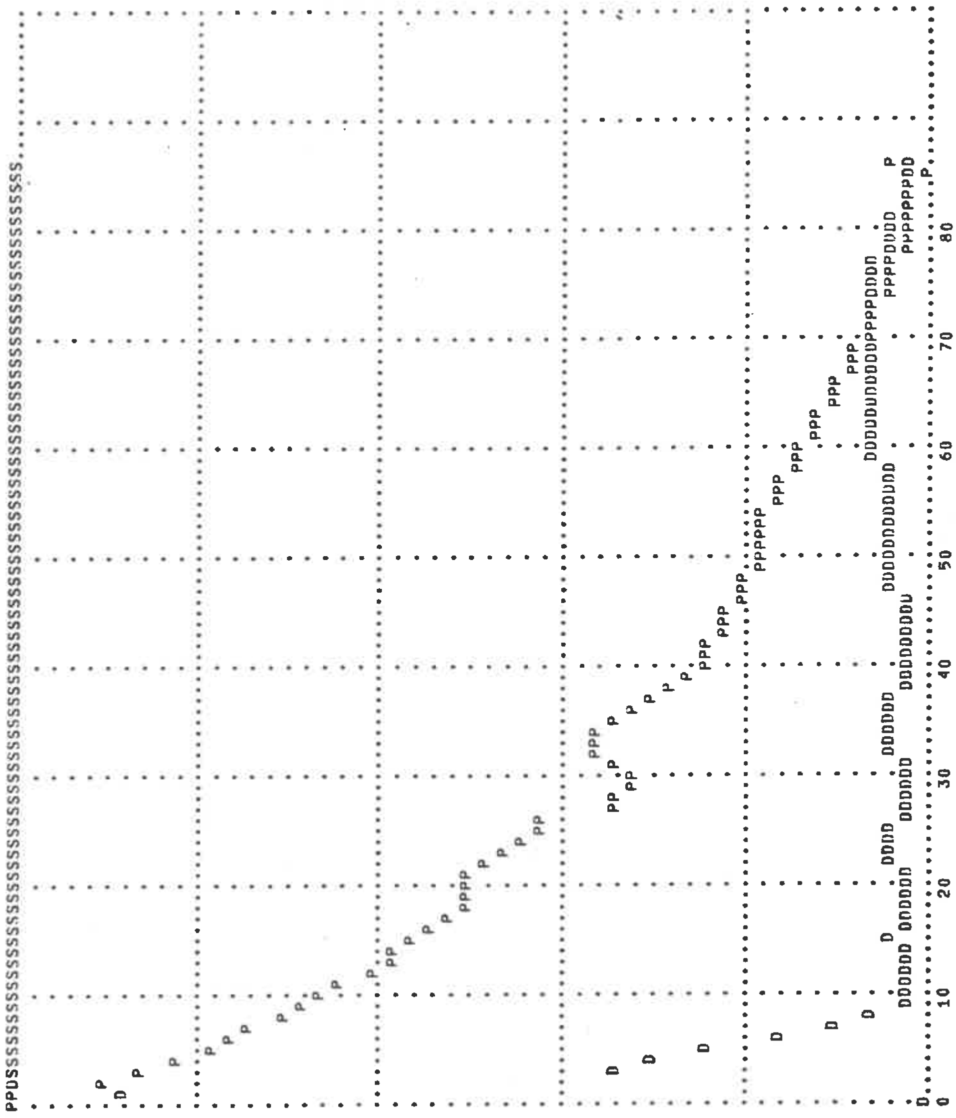

MORTALITY DIST
0.063
0.061
0.060
0.059
0.058
0.056
0.055
0.054
0.053
0.051
0.050
0.049
0.048
0.046
0.045
0.044
0.043
0.041
0.040
0.039
0.038
0.036
0.035
0.034
0.033
0.031
0.030
0.029
0.028
0.026
0.025
0.024
0.023
0.021
0.020
0.019
0.018
0.016
0.015
0.014
0.013
0.011
0.010
0.009
0.008
0.006
0.005
0.004
0.003
0.001
0.000
0
10
20
30
40
50
60
70
80



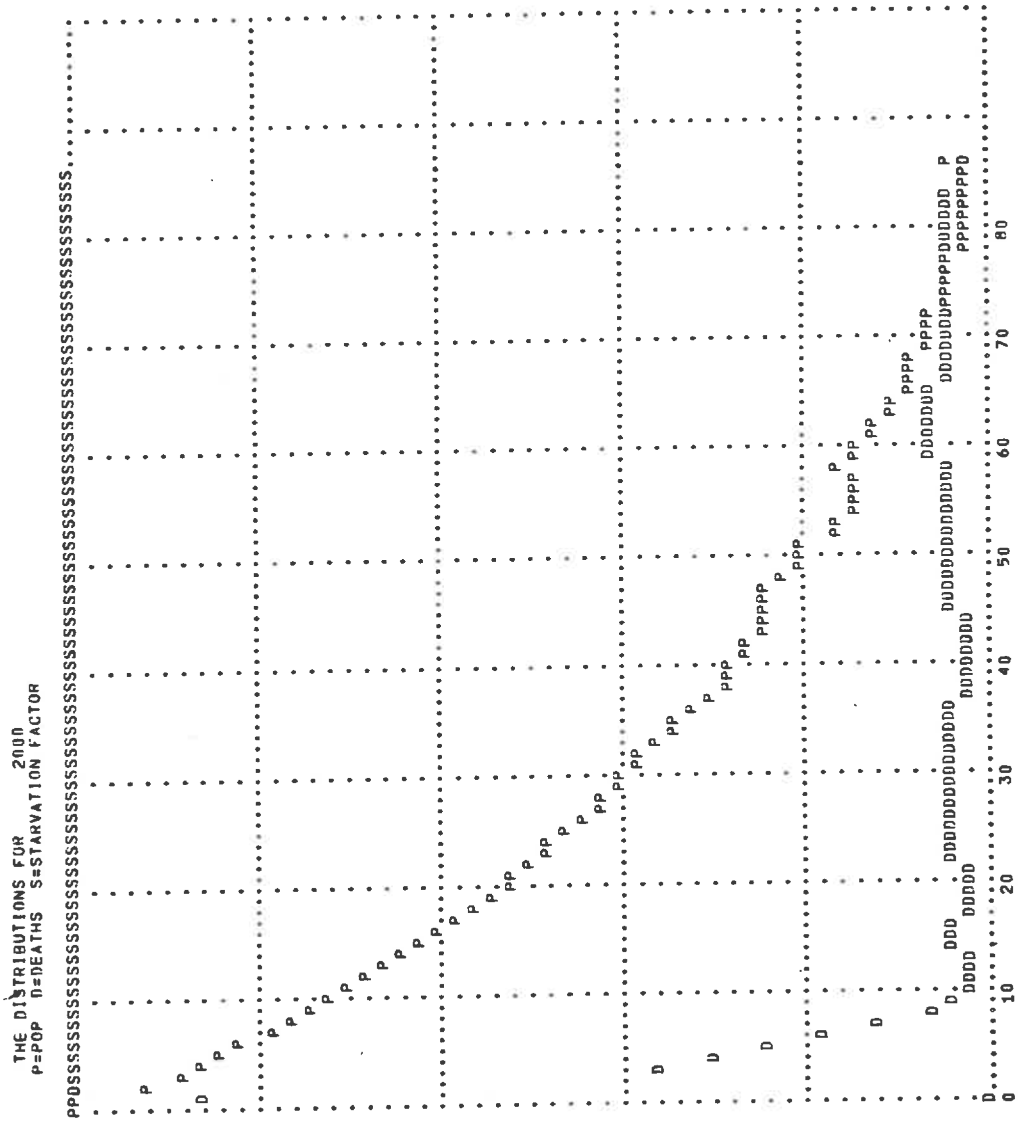
```
PARAMETER
          RUN
          2.00000
        : INVESTMENT SHIFT
       SERIES !AKS=.145,1@2005,1: ! NOLOG                                  3
                                                                           3
```

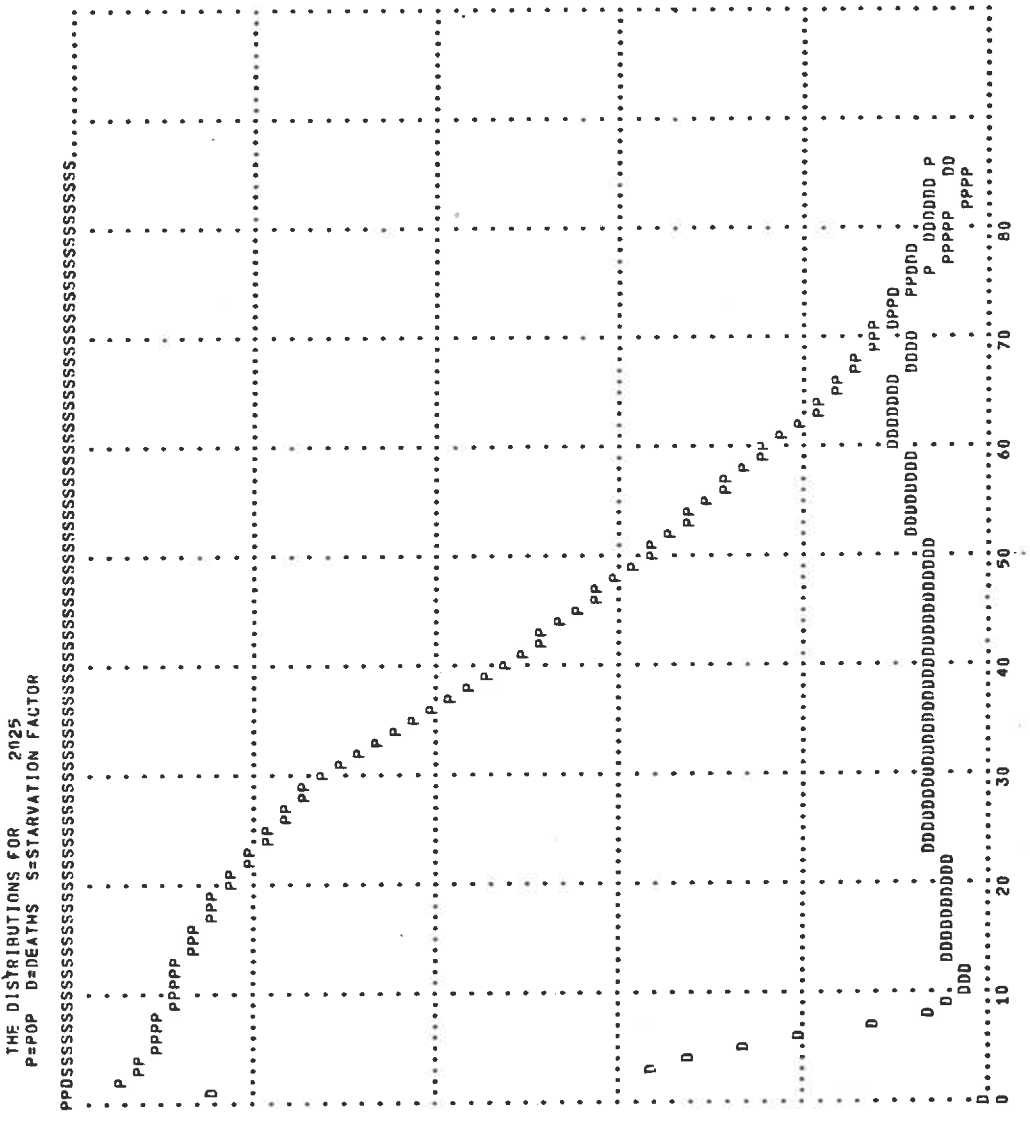
```
    PAGE    3     04/04/74     02:38     INTEGRATED FOOD ECON AND POP MODELS REGION 9


PARAMETER
            YSNA75
            1.89297

PARAMETER
            RUN
           1.000000
        NOLOG :   REMOVE INVESTMENT SHIFT                                                    3


PARAMETER
            IAKS
           0.144997

    RUNNING PROGRAM   54     FROM    1975     TO    2025      5
```

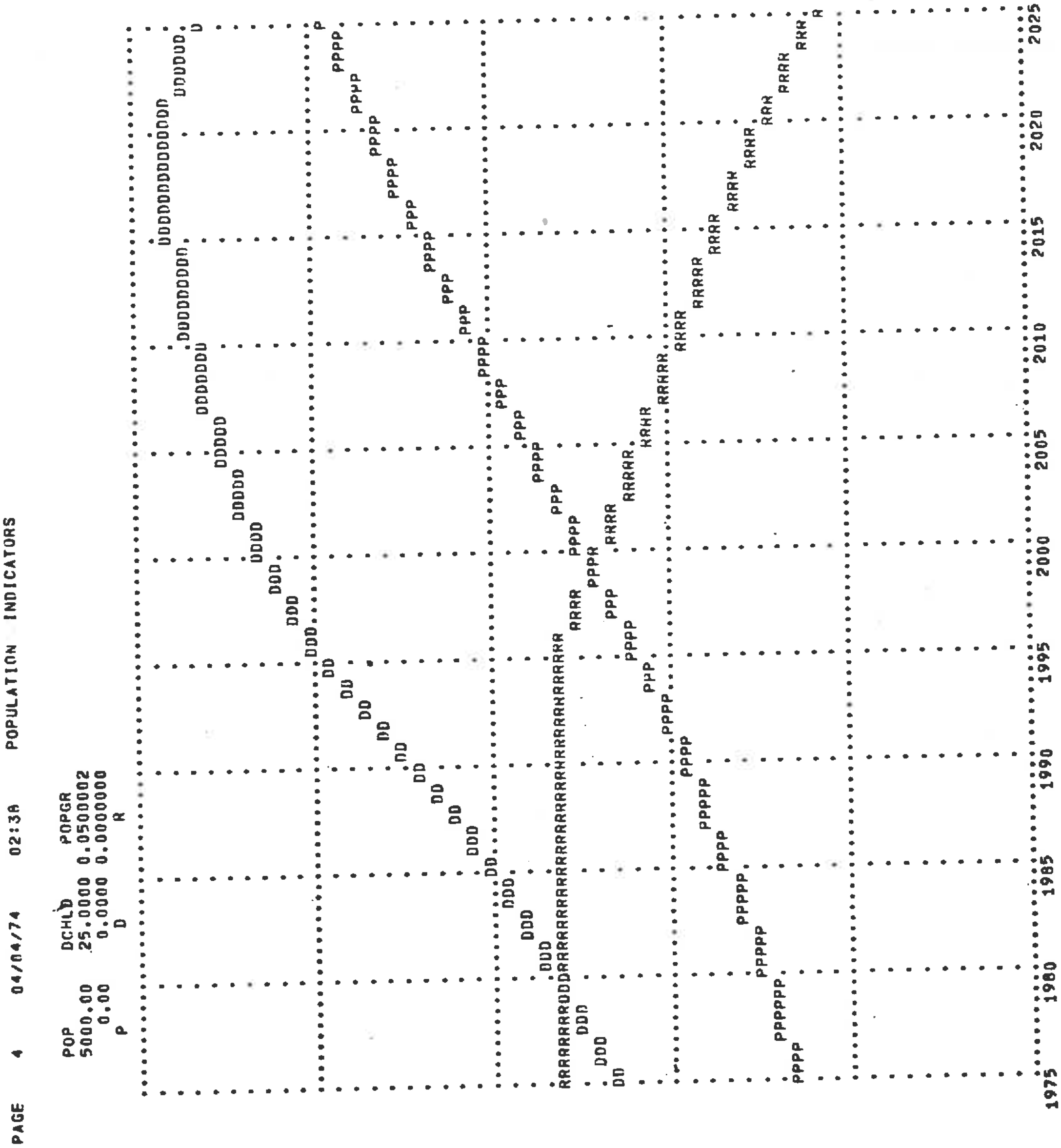
THE DISTRIBUTIONS FOR 1975
P=POP D=DEATHS S=STARVATION FACTOR



B 668


THE DISTRIBUTIONS FOR 2000
P=POP D=DEATHS S=STARVATION FACTOR
0
10
20
30
40
50
60
70
80

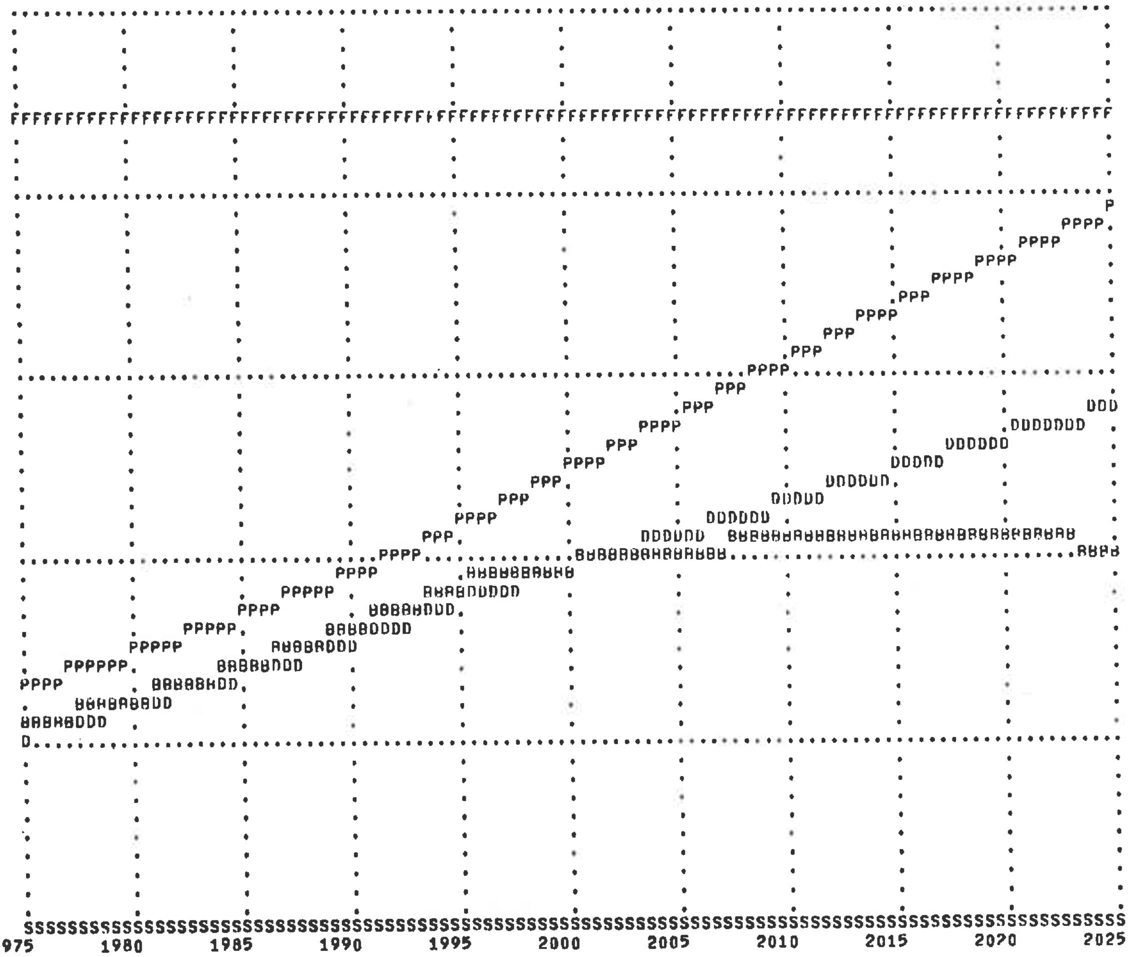

THE DISTRIBUTIONS FOR 2025
P=POP D=DEATHS S=STARVATION FACTOR
0
10
20
30
40
50
60
70
80



PAGE 4 04/04/74 02:38 POPULATION INDICATORS

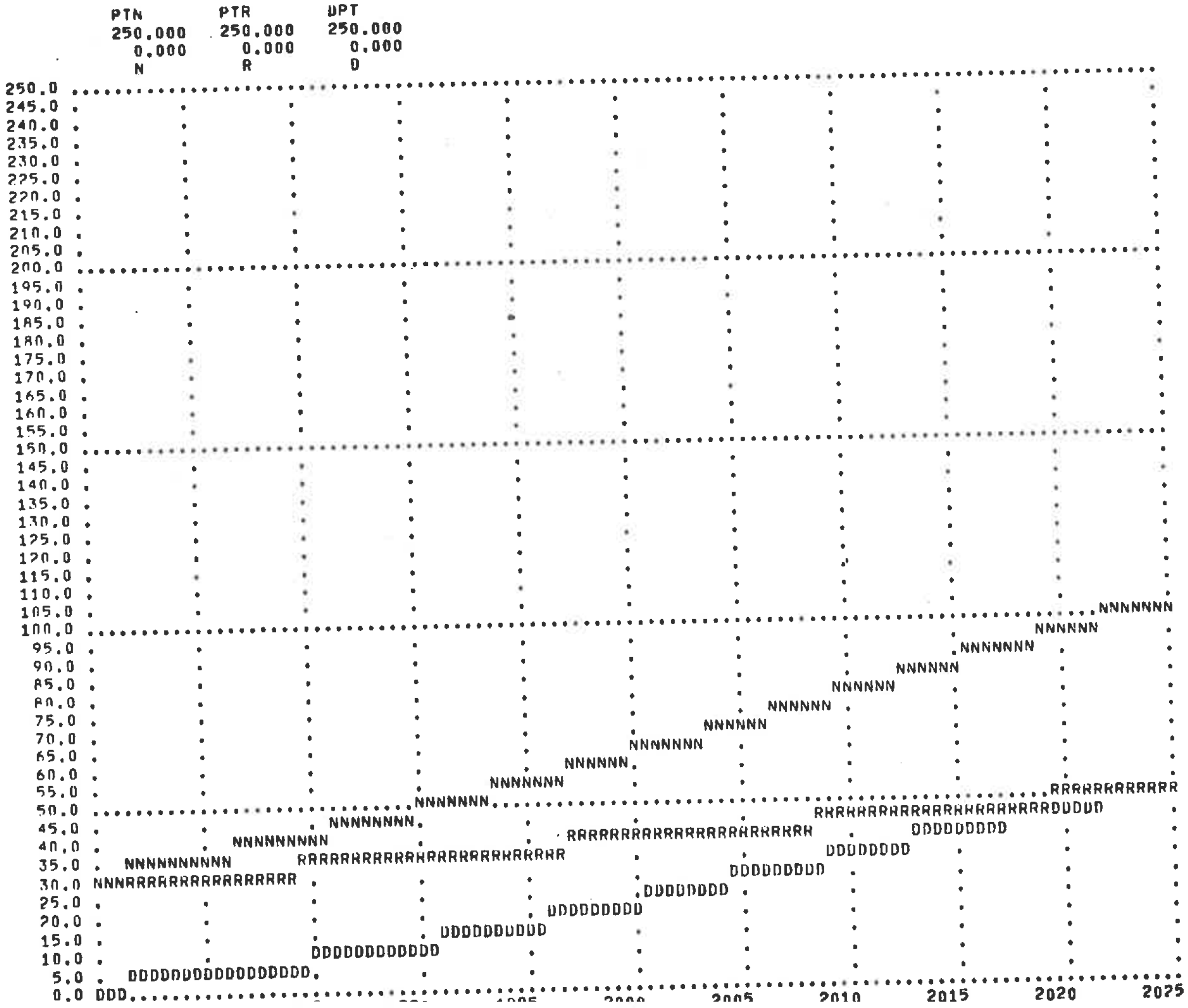
```
POP      DCHLD    POPGR
5000.00  25.0000  0.0500002
0.00     0.0000   0.0000000
P        D        R
```

```
PAGE    5     04/04/74     02:38      POPULATION  INDICATORS

        POP        BABIES    DEATHS    PROFAC     PROPCN
        5000.00    250.000   100.0000  2.500E-05  50.0000
           0.00      0.000     0.0000  0.000E 00   0.0000
          P          B          D         S          F
```

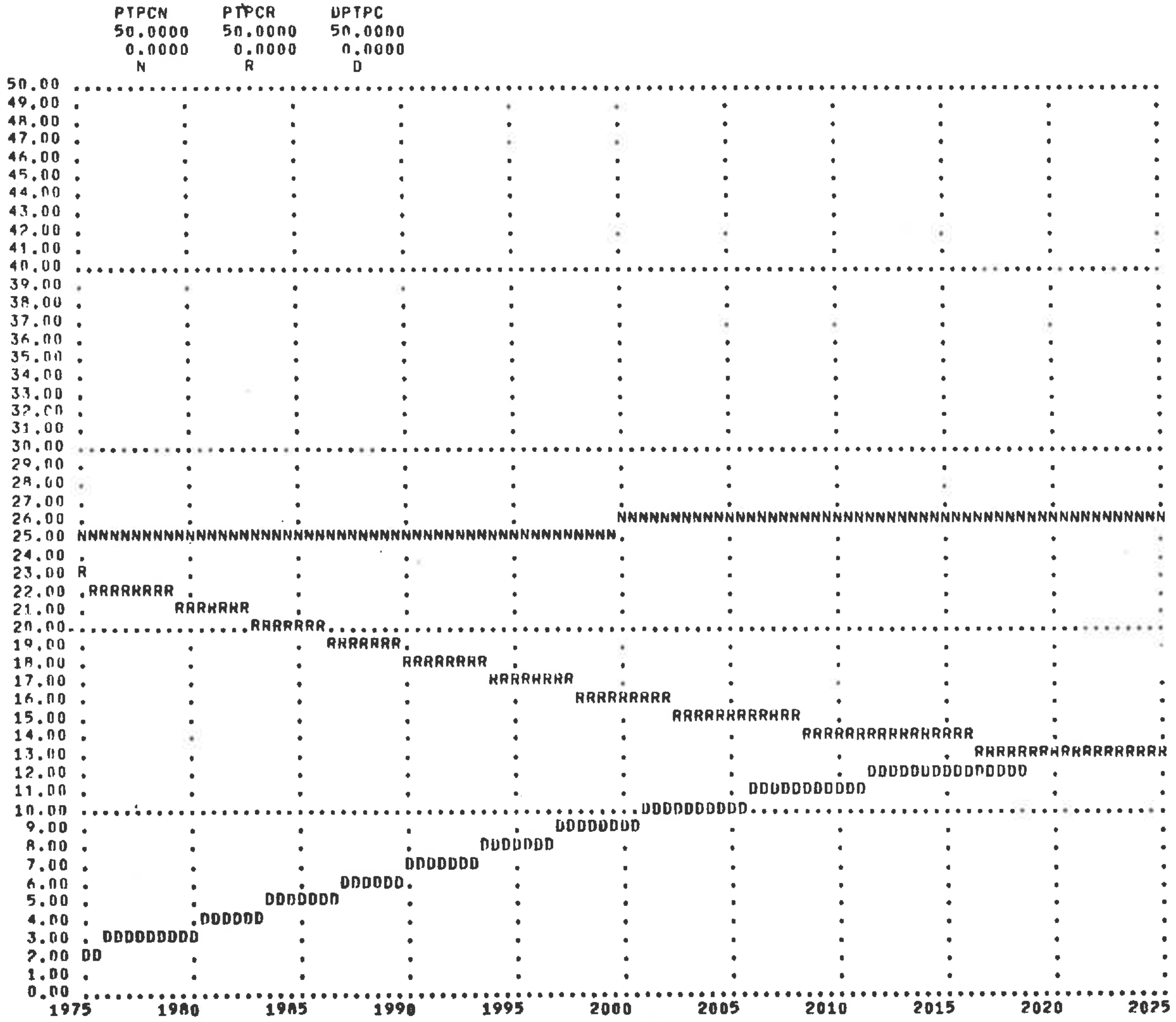


B 672

PAGE 6 04/04/74 02:38 PROTEIN INDICATORS

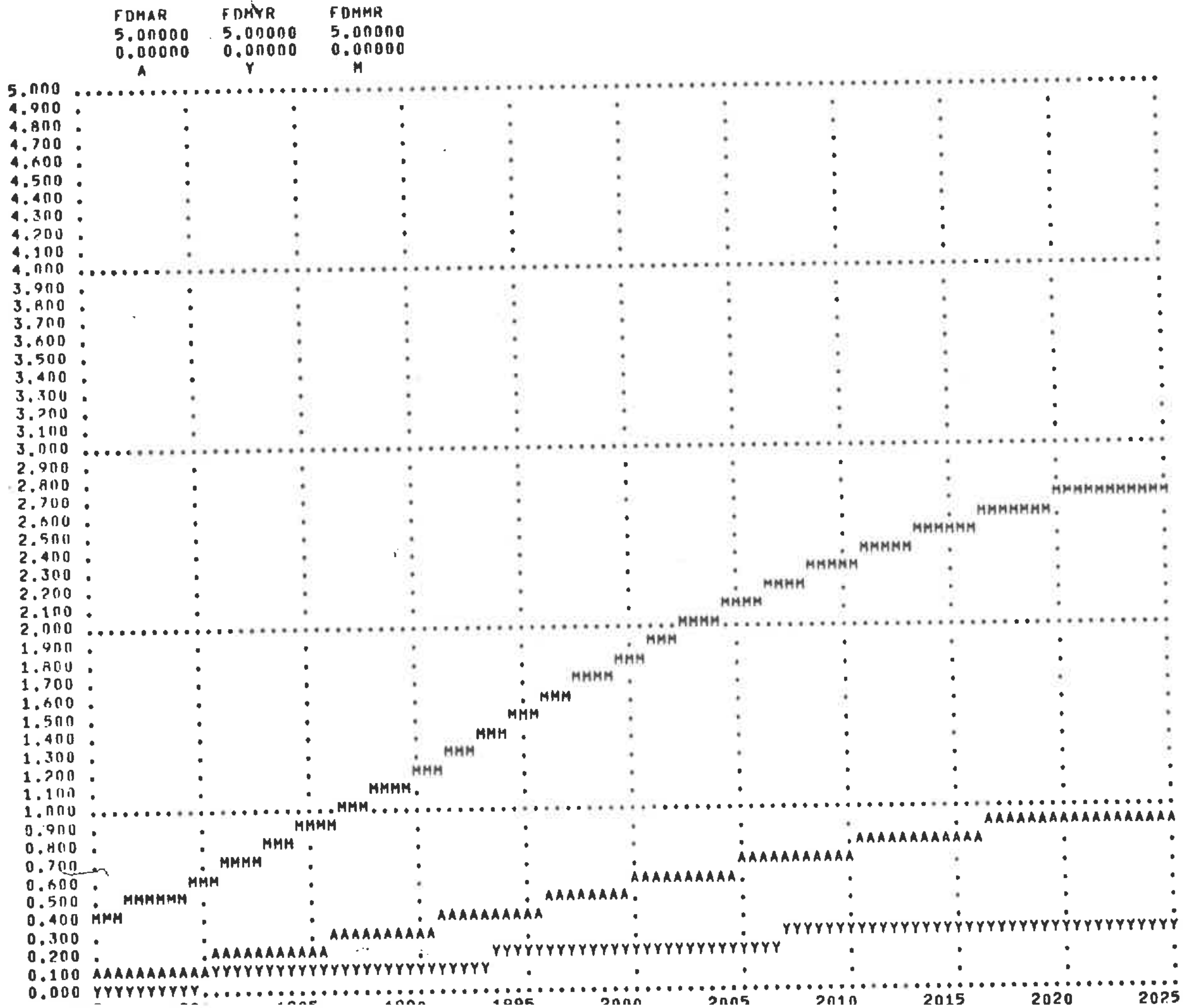


PAGE 7 04/04/74 02:38 PROTEIN INDICATORS



B 674

```
PAGE    8     04/04/74     02:38     IMPORT INDICATORS
```



B 675

```
PAGE    9     04/04/74     02:38     POPULATION. INDICATORS

          POP       BABYES    DEATHS    FERT      MORT      CBR       CDR       POPGR       DCHLD       Y         YA
1975      1307.50    55.190   21.4111   2.95447   2.80493 0.0422106 0.0163755 0.0258355   11.6345    170.76     80.559
1976      1341.16    56.742   21.9736   2.95447   2.80493 0.0423079 0.0163841 0.0259237   11.9482    178.39     83.260
1977      1375.88    58.299   22.5518   2.95447   2.80493 0.0423727 0.0163908 0.0259814   12.2725    187.58     87.246
1978      1411.66    59.846   23.1445   2.95447   2.80493 0.0423937 0.0163951 0.0259981   12.6060    197.05     91.303
1979      1448.22    61.366   23.7461   2.95447   2.80493 0.0423737 0.0163970 0.0259767   12.9465    206.46     95.041
1980      1485.78    62.879   24.3569   2.95447   2.80493 0.0423203 0.0163937 0.0259271   13.2886    215.91     98.545
1981      1524.19    64.408   24.9736   2.95447   2.80493 0.0422573 0.0163851 0.0258722   13.6284    225.75    102.180
1982      1563.53    65.982   25.6006   2.95447   2.80493 0.0422010 0.0163736 0.0258284   13.9695    235.99    105.947
1983      1603.78    67.633   26.2373   2.95447   2.80493 0.0421705 0.0163593 0.0258112   14.3176    246.61    109.838
1984      1645.06    69.361   26.8887   2.95447   2.80493 0.0421638 0.0163450 0.0258183   14.6772    257.64    113.867
1985      1687.47    71.182   27.5557   2.95447   2.80493 0.0421820 0.0163298 0.0258522   15.0496    269.10    118.033
1986      1731.00    73.088   28.2437   2.95447   2.80493 0.0422230 0.0163164 0.0259066   15.4387    281.00    122.344
1987      1775.78    75.084   28.9551   2.95447   2.80493 0.0422821 0.0163054 0.0259767   15.8459    293.35    126.801
1988      1821.81    77.168   29.6904   2.95447   2.80493 0.0423574 0.0162969 0.0260606   16.2715    306.17    131.406
1989      1869.34    79.344   30.4526   2.95447   2.80493 0.0424452 0.0162907 0.0261545   16.7153    319.48    136.168
1990      1918.03    81.592   31.2437   2.95447   2.80493 0.0425386 0.0162892 0.0262499   17.1772    333.29    141.090
1991      1968.34    83.896   32.0586   2.95447   2.80493 0.0426235 0.0162873 0.0263362   17.6558    347.63    146.195
1992      2020.03    86.246   32.8945   2.95447   2.80493 0.0426950 0.0162840 0.0264106   18.1475    362.52    151.473
1993      2073.25    88.631   33.7510   2.95447   2.80493 0.0427494 0.0162792 0.0264707   18.6523    377.95    156.926
1994      2128.06    91.063   34.6240   2.95447   2.80493 0.0427923 0.0162706 0.0265217   19.1660    393.98    162.566
1995      2184.25    93.551   35.5176   2.95447   2.80493 0.0428295 0.0162606 0.0265684   19.6934    410.59    168.391
1996      2242.19    94.553   36.3457   2.90704   2.80493 0.0421696 0.0162101 0.0259600   20.1460    427.83    174.418
1997      2300.25    95.541   37.0889   2.85956   2.80493 0.0415354 0.0161242 0.0254111   20.5059    445.71    180.652
1998      2358.69    96.512   37.8145   2.81207   2.80493 0.0409184 0.0160322 0.0248861   20.8325    464.75    187.086
1999      2417.13    97.465   38.5234   2.76459   2.80493 0.0403223 0.0159378 0.0243850   21.1299    483.48    193.742
2000      2476.00    98.391   39.2227   2.71710   2.80493 0.0397377 0.0158410 0.0238967   21.4014    503.42    200.621
2001      2535.13    99.281   39.9160   2.66962   2.80493 0.0391626 0.0157452 0.0234179   21.6519    524.09    207.723
2002      2594.38   100.133   40.6016   2.62213   2.80493 0.0385962 0.0156498 0.0229464   21.8862    545.53    215.066
2003      2653.88   100.938   41.2861   2.57465   2.80493 0.0380344 0.0155571 0.0224771   22.1074    567.77    222.656
2004      2713.44   101.695   41.9668   2.52716   2.80493 0.0374784 0.0154665 0.0220122   22.3184    590.80    230.500
2005      2773.06   102.410   42.6416   2.47968   2.80493 0.0369301 0.0153768 0.0215530   22.5190    614.67    238.598
2006      2832.63   103.082   43.3145   2.43219   2.80493 0.0363913 0.0152915 0.0211000   22.7109    639.41    246.969
2007      2892.31   103.709   43.9902   2.38470   2.80493 0.0358572 0.0152094 0.0206475   22.8896    665.05    255.609
2008      2951.88   104.307   44.6709   2.33722   2.80493 0.0353355 0.0151331 0.0202026   23.0571    691.61    264.531
2009      3011.44   104.865   45.3643   2.28973   2.80493 0.0348225 0.0150640 0.0197582   23.2148    719.16    273.766
2010      3070.94   105.391   46.0732   2.24225   2.80493 0.0343180 0.0150027 0.0193157   23.3579    747.67    283.297
2011      3130.31   105.875   46.7988   2.19476   2.80493 0.0338221 0.0149503 0.0188718   23.4893    777.22    293.141
2012      3189.31   106.318   47.5381   2.14728   2.80493 0.0333357 0.0149055 0.0184302   23.6118    807.83    303.305
2013      3248.00   106.697   48.2891   2.09979   2.80493 0.0328503 0.0148673 0.0179834   23.7251    839.53    313.805
2014      3306.25   107.018   49.0381   2.05231   2.80493 0.0323687 0.0148320 0.0175362   23.8262    872.38    324.641
2015      3364.19   107.258   49.7832   2.00482   2.80493 0.0318823 0.0147979 0.0170841   23.9150    906.38    335.820
2016      3421.63   107.393   50.5156   1.95734   2.80493 0.0313864 0.0147638 0.0166230   23.9868    941.59    347.391
2017      3478.38   107.408   51.2334   1.90985   2.80493 0.0308790 0.0147290 0.0161495   24.0396    978.08    359.320
2018      3534.50   107.279   51.9336   1.86237   2.80493 0.0303521 0.0146933 0.0156589   24.0693   1015.84    371.646
2019      3589.75   106.977   52.6123   1.81488   2.80493 0.0298009 0.0146563 0.0151443   24.0703   1054.94    384.367
2020      3644.06   106.490   53.2734   1.76740   2.80493 0.0292230 0.0146194 0.0146041   24.0410   1095.41    397.508
2021      3697.13   105.811   53.9141   1.71994   2.80493 0.0286198 0.0145826 0.0140369   23.9756   1137.31    411.063
2022      3748.94   104.934   54.5342   1.67245   2.80493 0.0279899 0.0145466 0.0134435   23.8726   1180.69    425.070
2023      3799.19   103.859   55.1377   1.62497   2.80493 0.0273371 0.0145130 0.0128243   23.7310   1225.59    439.516
2024      3847.63   102.598   55.7217   1.57748   2.80493 0.0266647 0.0144820 0.0121830   23.5479   1272.06    454.430
2025      3894.50   101.156   56.2842   1.53000   2.80493 0.0259743 0.0144522 0.0115223   23.3271   1320.19    469.836
```

```
PAGE   10      04/04/74      02:38      POPULATION INDICATORS

           E0        EA        EU         PRONUP     PROD     TIMLAG    PROFAC    PROUST     PROPCN    PROPCI    PTPCH
1975   1.000000  10.00000  0.249996    44.0000  25.0000   0.00000   0.00000  1.000000   44.0000   62.4902   22.8091
1976   1.000000  10.00000  0.249996    44.0000  25.0000   0.00000   0.00000  1.000000   44.0000   61.2676   22.3633
1977   1.000000  10.00000  0.249996    44.0000  25.0000   0.00000   0.00000  1.000000   44.0000   60.9062   22.2314
1978   1.000000  10.00000  0.249996    44.0000  25.0000   0.00000   0.00000  1.000000   44.0000   60.4531   22.0659
1979   1.000000  10.00000  0.249996    44.0000  25.0000   0.00000   0.00000  1.000000   44.0000   59.8389   21.8418
1980   1.000000  10.00000  0.249996    44.0000  25.0000   0.00000   0.00000  1.000000   44.0000   59.0264   21.5454
1981   1.000000  10.00000  0.249996    44.0000  25.0000   0.00000   0.00000  1.000000   44.0000   58.2334   21.2554
1982   1.000000  10.00000  0.249996    44.0000  25.0000   0.00000   0.00000  1.000000   44.0000   57.4512   20.9792
1983   1.000000  10.00000  0.249996    44.0000  25.0000   0.00000   0.00000  1.000000   44.0000   56.6738   20.6860
1984   1.000000  10.00000  0.249996    44.0000  25.0000   0.00000   0.00000  1.000000   44.0000   55.9072   20.4067
1985   1.000000  10.00000  0.249996    44.0000  25.0000   0.00000   0.00000  1.000000   44.0000   55.1416   20.1270
1986   1.000000  10.00000  0.249996    44.0000  25.0000   0.00000   0.00000  1.000000   44.0000   54.3818   19.8501
1987   1.000000  10.00000  0.249996    44.0000  25.0000   0.00000   0.00000  1.000000   44.0000   53.6240   19.5732
1988   1.000000  10.00000  0.249996    44.0000  25.0000   0.00000   0.00000  1.000000   44.0000   52.8691   19.2974
1989   1.000000  10.00000  0.249996    44.0000  25.0000   0.00000   0.00000  1.000000   44.0000   52.1133   19.0215
1990   1.000000  10.00000  0.249996    44.0000  25.0000   0.00000   0.00000  1.000000   44.0000   51.3643   18.7485
1991   1.000000  10.00000  0.249996    44.0000  25.0000   0.00000   0.00000  1.000000   44.0000   50.6201   18.4766
1992   1.000000  10.00000  0.249996    44.0000  25.0000   0.00000   0.00000  1.000000   44.0000   49.8809   18.2065
1993   1.000000  10.00000  0.249996    44.0000  25.0000   0.00000   0.00000  1.000000   44.0000   49.1406   17.9370
1994   1.000000  10.00000  0.249996    44.0000  25.0000   0.00000   0.00000  1.000000   44.0000   48.4092   17.6694
1995   1.000000  10.00000  0.249996    44.0000  25.0000   0.00000   0.00000  1.000000   44.0000   47.6826   17.4043
1996   1.000000  10.00000  0.249996    44.0000  25.0000   0.00000   0.00000  1.000000   44.0000   46.9590   17.1401
1997   1.000000  10.00000  0.249996    44.0000  25.0000   0.00000   0.00000  1.000000   44.0000   46.2725   16.8896
1998   1.000000  10.00000  0.249996    44.0000  25.0000   0.00000   0.00000  1.000000   44.0000   45.6113   16.6484
1999   1.000000  10.00000  0.249995    44.0000  25.0000   0.00000   0.00000  1.000000   44.0000   44.9383   16.4209
2000   1.000000  10.00000  0.249996    44.0000  25.0000   0.00000   0.00000  1.000000   44.0000   44.3877   16.2017
2001   1.000000  10.00000  0.249996    44.0000  25.0000   0.00000   0.00000  1.000000   44.0000   43.8115   15.9917
2002   1.000000  10.00000  0.249996    44.0000  25.0000   0.00000   0.00000  1.000000   44.0000   43.2637   15.7913
2003   1.000000  10.00000  0.249996    44.0000  25.0000   0.00000   0.00000  1.000000   44.0000   42.7363   15.5989
2004   1.000000  10.00000  0.249996    44.0000  25.0000   0.00000   0.00000  1.000000   44.0000   42.2344   15.4155
2005   1.000000  10.00000  0.249996    44.0000  25.0000   0.00000   0.00000  1.000000   44.0000   41.7529   15.2400
2006   1.000000  10.00000  0.249996    44.0000  25.0000   0.00000   0.00000  1.000000   44.0000   41.2959   15.0732
2007   1.000000  10.00000  0.249996    44.0000  25.0000   0.00000   0.00000  1.000000   44.0000   40.8564   14.9131
2008   1.000000  10.00000  0.249996    44.0000  25.0000   0.00000   0.00000  1.000000   44.0000   40.4395   14.7607
2009   1.000000  10.00000  0.249996    44.0000  25.0000   0.00000   0.00000  1.000000   44.0000   40.0410   14.6152
2010   1.000000  10.00000  0.249996    44.0000  25.0000   0.00000   0.00000  1.000000   44.0000   39.6592   14.4761
2011   1.000000  10.00000  0.249996    44.0000  25.0000   0.00000   0.00000  1.000000   44.0000   39.2949   14.3435
2012   1.000000  10.00000  0.249996    44.0000  25.0000   0.00000   0.00000  1.000000   44.0000   38.9531   14.2178
2013   1.000000  10.00000  0.249996    44.0000  25.0000   0.00000   0.00000  1.000000   44.0000   38.6270   14.0991
2014   1.000000  10.00000  0.249996    44.0000  25.0000   0.00000   0.00000  1.000000   44.0000   38.3184   13.9863
2015   1.000000  10.00000  0.249996    44.0000  25.0000   0.00000   0.00000  1.000000   44.0000   38.0264   13.8796
2016   1.000000  10.00000  0.249996    44.0000  25.0000   0.00000   0.00000  1.000000   44.0000   37.7520   13.7798
2017   1.000000  10.00000  0.249996    44.0000  25.0000   0.00000   0.00000  1.000000   44.0000   37.4941   13.6358
2018   1.000000  10.00000  0.249996    44.0000  25.0000   0.00000   0.00000  1.000000   44.0000   37.2539   13.5979
2019   1.000000  10.00000  0.249996    44.0000  25.0000   0.00000   0.00000  1.000000   44.0000   37.0313   13.5168
2020   1.000000  10.00000  0.249996    44.0000  25.0000   0.00000   0.00000  1.000000   44.0000   36.8281   13.4421
2021   1.000000  10.00000  0.249996    44.0000  25.0000   0.00000   0.00000  1.000000   44.0000   36.6426   13.3748
2022   1.000000  10.00000  0.249996    44.0000  25.0000   0.00000   0.00000  1.000000   44.0000   36.4766   13.3142
2023   1.000000  10.00000  0.249996    44.0000  25.0000   0.00000   0.00000  1.000000   44.0000   36.3330   13.2615
2024   1.000000  10.00000  0.249996    44.0000  25.0000   0.00000   0.00000  1.000000   44.0000   36.2100   13.2168
2025   1.000000  10.00000  0.249996    44.0000  25.0000   0.00000   0.00000  1.000000   44.0000   36.1084   13.1797
```

B 677

```
PAGE   11      04/04/74      02:38      CAPITAL

              KA        KNA        YA        YNA         Y       YPC      RYNA      RYA       RY
1975       39.499     225.50     80.559     90.201    170.76  0.130600 0.0000000 0.0000000 0.0000000
1976       40.488     237.83     83.260     95.133    178.39  0.133011 0.0546741 0.0335188 0.0446997
1977       41.597     250.83     87.246    100.336    187.58  0.136337 0.0546942 0.0478792 0.0515127
1978       42.794     264.35     91.303    105.744    197.05  0.139584 0.0539017 0.0464973 0.0504580
1979       44.103     278.53     95.041    111.416    206.46  0.142559 0.0536385 0.0409441 0.0477562
1980       45.523     293.40     98.545    117.361    215.91  0.145317 0.0533705 0.0368681 0.0457687
1981       47.050     308.93    102.180    123.574    225.75  0.148113 0.0529299 0.0368843 0.0456114
1982       48.675     325.09    105.947    130.039    235.99  0.150932 0.0523319 0.0368824 0.0453348
1983       50.400     341.92    109.838    136.770    246.61  0.153767 0.0517569 0.0367126 0.0449991
1984       52.229     359.44    113.867    143.777    257.64  0.156616 0.0512238 0.0366840 0.0447483
1985       54.161     377.66    118.033    151.070    269.10  0.159470 0.0507250 0.0365868 0.0444689
1986       56.200     396.64    122.344    158.660    281.00  0.162334 0.0502415 0.0365286 0.0442305
1987       58.348     416.38    126.801    166.555    293.35  0.165195 0.0497580 0.0364304 0.0439558
1988       60.606     436.91    131.406    174.770    306.17  0.168060 0.0493231 0.0363054 0.0437031
1989       62.979     458.27    136.168    183.313    319.48  0.170906 0.0488815 0.0362520 0.0434551
1990       65.469     480.48    141.090    192.195    333.29  0.173763 0.0484686 0.0361452 0.0432224
1991       68.078     503.59    146.195    201.438    347.63  0.176613 0.0480871 0.0361862 0.0430489
1992       70.809     527.59    151.473    211.043    362.52  0.179459 0.0476751 0.0360975 0.0428009
1993       73.666     552.56    156.926    221.027    377.95  0.182297 0.0473099 0.0360003 0.0425844
1994       76.652     578.52    162.566    231.410    393.98  0.185135 0.0469761 0.0359449 0.0423956
1995       79.771     605.48    168.391    242.195    410.59  0.187977 0.0466146 0.0358267 0.0421686
1996       83.027     633.52    174.418    253.410    427.83  0.190807 0.0462971 0.0357819 0.0419846
1997       86.426     662.64    180.652    265.063    445.71  0.193768 0.0459824 0.0357447 0.0417995
1998       89.967     692.91    187.086    277.164    464.25  0.196827 0.0456705 0.0356131 0.0415945
1999       93.660     724.34    193.742    289.742    483.48  0.200024 0.0453672 0.0355692 0.0414314
2000       97.506     757.00    200.621    302.805    503.42  0.203323 0.0450840 0.0354958 0.0412378
2001      101.510     790.92    207.723    316.375    524.09  0.206734 0.0448160 0.0353985 0.0410633
2002      105.678     826.16    215.066    330.469    545.53  0.210278 0.0445480 0.0353632 0.0409193
2003      110.014     862.73    222.656    345.102    567.77  0.213940 0.0442915 0.0352907 0.0407429
2004      114.523     900.72    230.500    360.297    590.80  0.217731 0.0440197 0.0352192 0.0405655
2005      119.215     940.16    238.598    376.070    614.67  0.221657 0.0437794 0.0351400 0.0404119
2006      124.090     981.09    246.969    392.445    639.41  0.225731 0.0435429 0.0350847 0.0402536
2007      129.156    1023.58    255.609    409.438    665.05  0.229935 0.0433093 0.0349865 0.0401011
2008      134.418    1067.69    264.531    427.078    691.61  0.234295 0.0430851 0.0349045 0.0399408
2009      139.887    1113.44    273.766    445.383    719.16  0.238804 0.0428600 0.0349093 0.0398188
2010      145.563    1160.94    283.297    464.383    747.67  0.243465 0.0426512 0.0348015 0.0396624
2011      151.457    1210.19    293.141    484.086    777.22  0.248287 0.0424376 0.0347471 0.0395184
2012      157.574    1261.31    303.305    504.531    807.83  0.253296 0.0422268 0.0346870 0.0393829
2013      163.922    1314.31    313.805    525.734    839.53  0.258476 0.0420408 0.0346060 0.0392447
2014      170.512    1369.31    324.641    547.734    872.38  0.263855 0.0418463 0.0345316 0.0391121
2015      177.348    1426.34    335.820    570.547    906.38  0.269417 0.0416489 0.0344406 0.0389748
2016      184.438    1485.50    347.391    594.219    941.59  0.275192 0.0414762 0.0344419 0.0388660
2017      191.793    1546.84    359.320    618.750    978.08  0.281189 0.0412970 0.0343523 0.0387392
2018      199.418    1610.47    371.648    644.203   1015.84  0.287407 0.0411234 0.0342989 0.0386124
2019      207.328    1676.41    384.367    670.578   1054.94  0.293877 0.0409422 0.0342226 0.0384846
2020      215.527    1744.75    397.508    697.922   1095.41  0.300606 0.0407772 0.0341683 0.0383768
2021      224.027    1815.63    411.063    726.266   1137.31  0.307617 0.0406122 0.0341091 0.0382566
2022      232.836    1889.06    425.070    755.641   1180.69  0.314941 0.0404472 0.0340672 0.0381384
2023      241.965    1965.19    439.516    786.094   1225.59  0.322594 0.0403013 0.0339832 0.0380344
2024      251.426    2044.06    454.430    817.641   1272.06  0.330612 0.0401411 0.0339472 0.0379152
2025      261.227    2125.81    469.836    850.344   1320.19  0.338989 0.0399971 0.0339022 0.0378199
```

B 678

```
PAGE   12     04/04/74     02:38     INVESTMENT

             I        IA       INA       IR       IMN      IAP      IALV      IALD     KDA     KDNA
1975      21.957   3.1837   18.773   6.5869   15.370   1.5918   0.15918   1.4327   2.1943   6.4425
1976      23.159   3.3578   19.801   6.9474   16.211   1.6789   0.16789   1.5111   2.2493   6.7947
1977      24.194   3.5081   20.686   7.2581   16.936   1.7540   0.17540   1.5787   2.3109   7.1663
1978      25.421   3.6860   21.735   7.6262   17.795   1.8430   0.18430   1.6587   2.3774   7.5525
1979      26.697   3.8710   22.827   8.0090   18.688   1.9355   0.19355   1.7420   2.4581   7.9576
1980      27.965   4.0548   23.911   8.3894   19.576   2.0273   0.20274   1.8247   2.5290   8.3823
1981      29.233   4.2386   24.995   8.7698   20.463   2.1193   0.21193   1.9075   2.6138   8.8262
1982      30.549   4.4294   26.120   9.1646   21.385   2.2147   0.22147   1.9933   2.7040   9.2878
1983      31.916   4.6277   27.289   9.5747   22.342   2.3138   0.23138   2.0826   2.7999   9.7686
1984      33.336   4.8335   28.502  10.0002   23.335   2.4167   0.24167   2.1752   2.9014  10.2690
1985      34.812   5.0474   29.764  10.4431   24.368   2.5236   0.25237   2.2714   3.0088  10.7900
1986      36.343   5.2694   31.073  10.9023   25.440   2.6346   0.26347   2.3713   3.1221  11.3320
1987      37.933   5.5000   32.433  11.3794   26.553   2.7499   0.27499   2.4751   3.2414  11.8960
1988      39.583   5.7393   33.844  11.8745   27.708   2.8696   0.28696   2.5828   3.3669  12.4827
1989      41.296   5.9877   35.309  12.3884   28.907   2.9938   0.29938   2.6945   3.4987  13.0928
1990      43.073   6.2454   36.828  12.9216   30.152   3.1226   0.31226   2.8105   3.6370  13.7273
1991      44.919   6.5129   38.406  13.4751   31.443   3.2564   0.32565   2.9309   3.7819  14.3875
1992      46.834   6.7906   40.043  14.0498   32.784   3.3953   0.33953   3.0559   3.9337  15.0732
1993      48.822   7.0790   41.743  14.6462   34.176   3.5394   0.35394   3.1856   4.0923  15.7864
1994      50.885   7.3779   43.507  15.2649   35.620   3.6889   0.36889   3.3202   4.2583  16.5278
1995      53.023   7.6881   45.336  15.9067   37.117   3.8440   0.38440   3.4597   4.4316  17.2983
1996      55.242   8.0100   47.232  16.5723   38.670   4.0049   0.40048   3.6047   4.6124  18.0996
1997      57.543   8.3435   49.200  17.2627   40.281   4.1716   0.41717   3.7548   4.8011  18.9316
1998      59.931   8.6897   51.241  17.9790   41.952   4.3447   0.43447   3.9105   4.9979  19.7964
1999      62.405   9.0486   53.357  18.7212   43.685   4.5242   0.45242   4.0720   5.2031  20.6943
2000      64.975   9.4209   55.553  19.4917   45.482   4.7103   0.47103   4.2396   5.4167  21.6274
2001      67.637   9.8069   57.829  20.2900   47.346   4.9033   0.49033   4.4133   5.6392  22.5967
2002      70.395  10.2068   60.188  21.1177   49.277   5.1033   0.51033   4.5933   5.8707  23.6030
2003      73.258  10.6218   62.636  21.9766   51.280   5.3108   0.53108   4.7800   6.1117  24.6484
2004      76.223  11.0520   65.172  22.8662   53.356   5.5259   0.55260   4.9736   6.3622  25.7339
2005      79.297  11.4976   67.799  23.7881   55.508   5.7487   0.57487   5.1741   6.6227  26.8604
2006      82.482  11.9595   70.523  24.7437   57.738   5.9796   0.59796   5.3820   6.8936  28.0208
2007      85.783  12.4382   73.346  25.7344   60.049   6.2190   0.62190   5.5974   7.1749  29.2437
2008      89.203  12.9341   76.270  26.7603   62.443   6.4669   0.64670   5.8206   7.4673  30.5034
2009      92.746  13.4478   79.299  27.8232   64.924   6.7238   0.67238   6.0516   7.7710  31.8110
2010      96.472  13.9805   82.441  28.9258   67.496   6.9901   0.69902   6.2914   8.0864  33.1680
2011     100.225  14.5322   85.693  30.0669   70.158   7.2660   0.72659   6.5397   8.4141  34.5752
2012     104.164  15.1033   89.063  31.2485   72.916   7.5515   0.75516   6.7966   8.7539  36.0352
2013     108.246  15.6953   92.551  32.4736   75.773   7.8475   0.78476   7.0631   9.1064  37.5498
2014     112.473  16.3081   96.166  33.7412   78.732   8.1538   0.81538   7.3390   9.4724  39.1211
2015     116.850  16.9429   99.908  35.0547   81.797   8.4712   0.84711   7.6246   9.8523  40.7510
2016     121.383  17.6001  103.783  36.4141   84.969   8.7998   0.87999   7.9204  10.2461  42.4414
2017     126.080  18.2813  107.801  37.8232   88.258   9.1404   0.91403   8.2271  10.6548  44.1934
2018     130.945  18.9863  111.957  39.2822   91.662   9.4929   0.94930   8.5442  11.0784  46.0107
2019     135.977  19.7158  116.262  40.7920   95.186   9.8577   0.98576   8.8726  11.5178  47.8945
2020     141.184  20.4707  120.713  42.3535   98.830  10.2351   1.02353   9.2122  11.9734  49.8477
2021     146.578  21.2529  125.326  43.9727  102.605  10.6262   1.06262   9.5642  12.4453  51.8721
2022     152.164  22.0630  130.102  45.6475  106.516  11.0313   1.10312   9.9287  12.9348  53.9707
2023     157.945  22.9009  135.043  47.3818  110.563  11.4502   1.14502  10.3057  13.4419  56.1455
2024     163.926  23.7686  140.160  49.1768  114.750  11.8840   1.18842  10.6963  13.9675  58.3994
2025     170.121  24.6665  145.453  51.0342  119.086  12.3330   1.23331  11.1003  14.5120  60.7344
```

```
PAGE   13      04/04/74      02:38      AGRICULTURAL PRODUCTION


               Z            UAF       PXPF       ZPHG       GRPH       GRGP       NGGP       CLGR
                  1
1975        123.082       1.4355   0.149998     37.127    1.64621    282.891    420.344    171.844
1976        127.396       1.4355   0.152992     35.807    1.62546    283.945    422.164    174.688
1977        133.559       1.5139   0.156048     36.682    1.63977    289.133    431.078    176.324
1978        139.840       1.5968   0.159164     37.677    1.65594    293.953    439.367    177.516
1979        145.699       1.6828   0.162346     38.735    1.67307    298.469    447.141    178.398
1980        151.254       1.7731   0.165588     40.015    1.69351    302.117    453.414    178.398
1981        157.016       1.8677   0.168896     41.324    1.71423    305.820    459.781    178.398
1982        162.996       1.9666   0.172272     42.659    1.73517    309.555    466.203    178.398
1983        169.172       2.0695   0.175713     44.011    1.75607    313.281    472.609    178.398
1984        175.574       2.1766   0.179222     45.383    1.77713    317.039    479.070    178.398
1985        182.199       2.2881   0.182804     46.773    1.79825    320.805    485.547    178.398
1986        189.059       2.4042   0.186455     48.184    1.81943    324.586    492.055    178.398
1987        196.152       2.5250   0.190182     49.613    1.84067    328.375    498.570    178.398
1988        203.488       2.6506   0.193981     51.062    1.86194    332.164    505.094    178.398
1989        211.082       2.7813   0.197857     52.530    1.88330    335.977    511.648    178.398
1990        218.934       2.9173   0.201809     54.020    1.90472    339.797    518.219    178.398
1991        227.082       3.0587   0.205841     55.527    1.92642    343.672    524.875    178.398
1992        235.508       3.2057   0.209953     57.058    1.94815    347.547    531.547    178.398
1993        244.223       3.3586   0.214149     58.607    1.96991    351.430    538.219    178.398
1994        253.242       3.5175   0.218430     60.178    1.99179    355.336    544.938    178.398
1995        262.563       3.6827   0.222794     61.771    2.01373    359.234    551.656    178.398
1996        272.203       3.8544   0.227245     63.382    2.03564    363.148    558.391    178.398
1997        282.195       4.0328   0.231785     65.020    2.05774    367.086    565.156    178.398
1998        292.500       4.2181   0.236416     66.674    2.07977    371.016    571.922    178.398
1999        303.180       4.4109   0.241138     68.355    2.10193    374.977    578.734    178.398
2000        314.211       4.6111   0.245956     70.059    2.12415    378.938    585.547    178.398
2001        325.617       4.8188   0.250870     71.781    2.14642    382.906    592.375    178.398
2002        337.422       5.0349   0.255882     73.527    2.16876    386.891    599.219    178.398
2003        349.617       5.2592   0.260994     75.299    2.19110    390.883    606.094    178.398
2004        362.234       5.4921   0.266205     77.096    2.21356    394.891    612.984    178.398
2005        375.266       5.7339   0.271523     78.914    2.23602    398.898    619.875    178.398
2006        388.750       5.9849   0.276947     80.754    2.25861    402.922    626.797    178.398
2007        402.672       6.2455   0.282478     82.621    2.28113    406.945    633.719    178.398
2008        417.055       6.5159   0.288124     84.510    2.30377    410.977    640.641    178.398
2009        431.945       6.7966   0.293877     86.426    2.32648    415.031    647.625    178.398
2010        447.320       7.0880   0.299744     88.365    2.34918    419.078    654.578    178.398
2011        463.219       7.3903   0.305733     90.330    2.37189    423.141    661.563    178.398
2012        479.648       7.7039   0.311844     92.318    2.39465    427.195    668.547    178.398
2013        496.617       8.0293   0.318077     94.332    2.41748    431.266    675.547    178.398
2014        514.141       8.3667   0.324432     96.371    2.44031    435.336    682.547    178.398
2015        532.234       8.7168   0.330917     98.434    2.46313    439.406    689.547    178.398
2016        550.969       9.0798   0.337532    100.527    2.48602    443.500    696.578    178.398
2017        570.297       9.4565   0.344276    102.645    2.50897    447.586    703.609    178.398
2018        590.281       9.8469   0.351158    104.787    2.53186    451.680    710.656    178.398
2019        610.906      10.2520   0.358177    106.959    2.55487    455.773    717.688    178.398
2020        632.234      10.6716   0.365334    109.158    2.57788    459.883    724.766    178.398
2021        654.234      11.1069   0.372635    111.385    2.60089    463.992    731.828    178.398
2022        676.984      11.5579   0.380081    113.635    2.62396    468.102    738.891    178.398
2023        700.453      12.0254   0.387672    115.916    2.64703    472.219    745.984    178.398
2024        724.719      12.5100   0.395416    118.227    2.67010    476.336    753.063    178.398
2025        749.781      13.0122   0.403313    120.564    2.69324    480.469    760.172    178.398
```

B 680

```
PAGE   14      04/04/74      02:38      YIFLD

            YNAPC       PMCY      KAPH       PTFC        FA        ZPHG      GRPH
1975      0.068987   0.96776   0.151863   0.590744   3.05847    37.127   1.64621
1976      0.070932   0.97017   0.152668   0.591688   3.06201    35.807   1.62546
1977      0.072926   0.97258   0.155125   0.595352   3.06793    36.682   1.63977
1978      0.074907   0.97491   0.158329   0.599792   3.07465    37.677   1.65594
1979      0.076933   0.97722   0.162216   0.605057   3.08228    38.735   1.67307
1980      0.078991   0.97951   0.167442   0.611954   3.09143    40.015   1.69351
1981      0.081076   0.98178   0.173054   0.619110   3.10083    41.324   1.71423
1982      0.083172   0.98399   0.179031   0.626480   3.11047    42.659   1.73517
1983      0.085279   0.98616   0.185379   0.634033   3.12018    44.011   1.75607
1984      0.087399   0.98830   0.192104   0.641769   3.13007    45.383   1.77713
1985      0.089523   0.99039   0.199211   0.649658   3.14001    46.773   1.79825
1986      0.091658   0.99243   0.206711   0.657684   3.15009    48.184   1.81943
1987      0.093792   0.99443   0.214611   0.665833   3.16022    49.613   1.84067
1988      0.095930   0.99638   0.222919   0.674088   3.17047    51.062   1.86194
1989      0.098063   0.99829   0.231647   0.682419   3.18066    52.530   1.88330
1990      0.100204   1.00034   0.240803   0.690842   3.19116    54.020   1.90472
1991      0.102339   1.00403   0.250397   0.699326   3.20331    55.527   1.92642
1992      0.104475   1.00760   0.260445   0.707870   3.21545    57.058   1.94815
1993      0.106607   1.01111   0.270950   0.716461   3.22754    58.607   1.96991
1994      0.108744   1.01456   0.281937   0.725082   3.23962    60.178   1.99179
1995      0.110882   1.01794   0.293411   0.733749   3.25165    61.771   2.01373
1996      0.113018   1.02127   0.305389   0.742432   3.26367    63.382   2.03564
1997      0.115232   1.02463   0.317886   0.751144   3.27576    65.020   2.05774
1998      0.117510   1.02802   0.330910   0.759872   3.28784    66.674   2.07977
1999      0.119869   1.03149   0.344490   0.768600   3.30005    68.355   2.10193
2000      0.122295   1.03497   0.358635   0.777344   3.31226    70.059   2.12415
2001      0.124796   1.03848   0.373367   0.786072   3.32452    71.781   2.14642
2002      0.127380   1.04205   0.388702   0.794815   3.33685    73.527   2.16876
2003      0.130039   1.04562   0.404648   0.803543   3.34912    75.299   2.19110
2004      0.132782   1.04926   0.421234   0.812271   3.36151    77.096   2.21356
2005      0.135612   1.05292   0.438484   0.820984   3.37390    78.914   2.23602
2006      0.138546   1.05664   0.456421   0.829681   3.38629    80.754   2.25861
2007      0.141560   1.06039   0.475052   0.838379   3.39874    82.621   2.28113
2008      0.144680   1.06418   0.494408   0.847046   3.41119    84.510   2.30377
2009      0.147896   1.06799   0.514511   0.855713   3.42365    86.426   2.32648
2010      0.151218   1.07184   0.535400   0.864349   3.43616    88.365   2.34918
2011      0.154644   1.07574   0.557083   0.872971   3.44867    90.330   2.37189
2012      0.158192   1.07968   0.579590   0.881561   3.46124    92.318   2.39465
2013      0.161865   1.08368   0.602936   0.890137   3.47375    94.332   2.41748
2014      0.165665   1.08771   0.627167   0.898697   3.48639    96.371   2.44031
2015      0.169594   1.09177   0.652313   0.907227   3.49896    98.434   2.46313
2016      0.173664   1.09589   0.678391   0.915756   3.51160   100.527   2.48602
2017      0.177883   1.10007   0.705444   0.924240   3.52429   102.645   2.50897
2018      0.182259   1.10428   0.733490   0.932709   3.53699   104.787   2.53186
2019      0.186802   1.10855   0.762589   0.941147   3.54968   106.959   2.55487
2020      0.191521   1.11288   0.792740   0.949570   3.56244   109.158   2.57788
2021      0.196438   1.11728   0.824005   0.957962   3.57520   111.385   2.60089
2022      0.201561   1.12177   0.856400   0.966339   3.58807   113.635   2.62396
2023      0.206909   1.12631   0.889984   0.974701   3.60101   115.916   2.64703
2024      0.212505   1.13095   0.924774   0.983032   3.61395   118.227   2.67010
2025      0.218346   1.13568   0.960831   0.991333   3.62695   120.564   2.69324
```

```
PAGE   15      04/04/74      02:38      LIVESTOCK & FISH

              FWT        SLVA`       SLVMA      SLVAR       LVPLM       IALV
1975        5.89111     438.125     26709.5 0.0164032   0.901642    0.15918
1976        6.30920     440.273     26261.0 0.0167651   0.901672    0.16789
1977        6.75708     442.547     26003.0 0.0170193   0.901703    0.17540
1978        7.23657     444.922     25815.5 0.0172343   0.901718    0.18430
1979        7.33569     447.414     25675.5 0.0174255   0.901749    0.19355
1980        7.33569     450.031     25675.5 0.0175276   0.901749    0.20274
1981        7.33569     452.781     25675.5 0.0176344   0.901764    0.21193
1982        7.33582     455.648     25675.5 0.0177464   0.901779    0.22147
1983        7.33582     458.641     25675.5 0.0178628   0.901794    0.23138
1984        7.33582     461.773     25675.0 0.0179853   0.901794    0.24167
1985        7.33582     465.039     25675.0 0.0181127   0.901810    0.25237
1986        7.33582     468.453     25674.5 0.0182457   0.901825    0.26347
1987        7.33582     472.023     25674.5 0.0183849   0.901840    0.27499
1988        7.33582     475.750     25674.5 0.0185299   0.901855    0.28696
1989        7.33582     479.633     25674.5 0.0186810   0.901871    0.29938
1990        7.33582     483.688     25674.0 0.0188394   0.901886    0.31226
1991        7.33594     487.914     25674.0 0.0190043   0.901901    0.32565
1992        7.33594     492.320     25673.5 0.0191760   0.901917    0.33953
1993        7.33594     496.922     25673.5 0.0193553   0.901932    0.35394
1994        7.33594     501.719     25673.5 0.0195422   0.901962    0.36889
1995        7.33594     506.711     25673.0 0.0197372   0.901978    0.38440
1996        7.33594     511.922     25673.0 0.0199399   0.901993    0.40048
1997        7.33594     517.344     25673.0 0.0201511   0.902023    0.41717
1998        7.33594     523.000     25673.0 0.0203714   0.902039    0.43447
1999        7.33594     526.891     25672.5 0.0206013   0.902069    0.45242
2000        7.33606     535.016     25672.5 0.0208397   0.902084    0.47103
2001        7.33606     541.391     25672.0 0.0210886   0.902115    0.49033
2002        7.33606     548.031     25672.0 0.0213475   0.902130    0.51033
2003        7.33606     554.953     25672.0 0.0216169   0.902161    0.53108
2004        7.33606     562.141     25672.0 0.0218968   0.902191    0.55260
2005        7.33606     569.641     25672.0 0.0221887   0.902222    0.57487
2006        7.33606     577.422     25671.5 0.0224929   0.902252    0.59796
2007        7.33606     585.531     25671.5 0.0228081   0.902283    0.62190
2008        7.33618     593.953     25671.5 0.0231366   0.902313    0.64670
2009        7.33618     602.719     25671.0 0.0234785   0.902344    0.67238
2010        7.33618     611.844     25671.0 0.0238338   0.902390    0.69902
2011        7.33618     621.313     25671.0 0.0242028   0.902420    0.72659
2012        7.33618     631.172     25671.0 0.0245867   0.902466    0.75516
2013        7.33618     641.406     25671.0 0.0249653   0.902496    0.78476
2014        7.33618     652.047     25670.5 0.0254002   0.902542    0.81538
2015        7.33618     663.094     25670.5 0.0258307   0.902588    0.84711
2016        7.33630     674.578     25670.5 0.0262785   0.902634    0.87999
2017        7.33630     686.516     25670.0 0.0267434   0.902679    0.91403
2018        7.33630     698.906     25670.0 0.0272264   0.902725    0.94930
2019        7.33630     711.781     25670.0 0.0277276   0.902771    0.98576
2020        7.33630     725.141     25670.0 0.0282483   0.902832    1.02353
2021        7.33630     739.016     25670.0 0.0287890   0.902878    1.06262
2022        7.33630     753.422     25670.0 0.0293503   0.902939    1.10312
2023        7.33643     768.391     25670.0 0.0299330   0.903000    1.14502
2024        7.33643     783.906     25670.0 0.0305376   0.903061    1.18842
2025        7.33643     800.031     25669.5 0.0311661   0.903122    1.23331
```

```
PAGE   16     04/04/74     02:38     PRICING

          PXLVP      GRV      NGV       SLVV       LVV      FSV       YA
1975     1.49997   32.531    37.830   3.26379    4.8955   5.3019    80.559
1976     1.53745   33.468    38.942   3.27142    5.0297   5.8201    83.260
1977     1.57584   34.931    40.759   3.27948    5.1678   6.3889    87.246
1978     1.61520   36.399    42.580   3.28784    5.3105   7.0132    91.303
1979     1.65555   37.882    44.415   3.29657    5.4576   7.2869    95.041
1980     1.69687   39.303    46.163   3.30579    5.6094   7.4688    98.545
1981     1.73926   40.777    47.980   3.31537    5.7662   7.6553   102.180
1982     1.78271   42.307    49.866   3.32538    5.9281   7.8467   105.947
1983     1.82724   43.886    51.814   3.33575    6.0952   8.0427   109.838
1984     1.87289   45.521    53.834   3.34668    6.2679   8.2437   113.867
1985     1.91968   47.213    55.925   3.35791    6.4460   8.4495   118.033
1986     1.96765   48.963    58.091   3.36975    6.6305   8.6606   122.344
1987     2.01685   50.772    60.331   3.38196    6.8207   8.8772   126.801
1988     2.06720   52.642    62.647   3.39471    7.0175   9.0989   131.406
1989     2.11884   54.576    65.047   3.40790    7.2207   9.3262   136.168
1990     2.17175   56.575    67.527   3.42163    7.4308   9.5591   141.090
1991     2.22601   58.648    70.102   3.43592    7.6484   9.7981   146.195
1992     2.28162   60.793    72.768   3.45087    7.8734  10.0430   151.473
1993     2.33862   63.007    75.521   3.46625    8.1062  10.2937   156.926
1994     2.39703   65.299    78.373   3.48224    8.3469  10.5508   162.566
1995     2.45691   67.664    81.320   3.49884    8.5962  10.8145   168.391
1996     2.51831   70.111    84.369   3.51605    8.8545  11.0845   174.418
1997     2.58124   72.643    87.527   3.53394    9.1218  11.3616   180.652
1998     2.64575   75.256    90.787   3.55243    9.3987  11.6455   187.086
1999     2.71185   77.959    94.164   3.57166    9.6855  11.9365   193.742
2000     2.77960   80.750    97.652   3.59149    9.9829  12.2349   200.621
2001     2.84900   83.635   101.260   3.61206   10.2908  12.5405   207.723
2002     2.92023   86.617   104.988   3.63342   10.6104  12.8538   215.066
2003     2.99316   89.697   108.846   3.65552   10.9414  13.1748   222.656
2004     3.06793   92.879   112.832   3.67834   11.2849  13.5039   230.500
2005     3.14453   96.166   116.951   3.70190   11.6406  13.8413   238.598
2006     3.22308   99.563   121.211   3.72626   12.0100  14.1870   246.969
2007     3.30359  103.066   125.609   3.75146   12.3933  14.5413   255.609
2008     3.38605  106.686   130.156   3.77759   12.7910  14.9045   264.531
2009     3.47064  110.432   134.859   3.80450   13.2039  15.2769   273.766
2010     3.55737  114.293   139.715   3.83234   13.6331  15.6587   283.297
2011     3.64624  118.285   144.734   3.86102   14.0781  16.0498   293.141
2012     3.73737  122.402   149.914   3.89069   14.5410  16.4512   303.305
2013     3.83075  126.656   155.270   3.92133   15.0215  16.8618   313.805
2014     3.92639  131.043   160.797   3.95282   15.5203  17.2832   324.641
2015     4.02454  135.574   166.500   3.98541   16.0391  17.7148   335.820
2016     4.12500  140.254   172.402   4.01892   16.5776  18.1577   347.391
2017     4.22815  145.082   178.496   4.05347   17.1382  18.6113   359.320
2018     4.33374  150.070   184.785   4.08923   17.7212  19.0762   371.648
2019     4.44202  155.215   191.277   4.12585   18.3267  19.5532   384.367
2020     4.55298  160.523   197.988   4.16370   18.9565  20.0415   397.508
2021     4.66675  166.004   204.910   4.20264   19.6118  20.5420   411.063
2022     4.78333  171.660   212.059   4.24268   20.2935  21.0557   425.070
2023     4.90283  177.496   219.438   4.28394   21.0029  21.5815   439.516
2024     5.02527  183.516   227.059   4.32642   21.7407  22.1211   454.430
2025     5.15088  189.734   234.926   4.37012   22.5093  22.6733   469.836
```

```
PAGE   17     04/04/74      02:38      LAND

              IALD     FCLR       KCLDH       CLD        CLDGR       CLW        CL         CLR
1975          1.4327 0.0600948 3.327E-01    4.30615    2.84503    1.19998    260.094    16.7065
1976          1.5111 0.0416956 6.076E-01    2.48688    1.63803    1.20172    265.211    11.5913
1977          1.5787 0.0311084 8.723E-01    1.80975    1.19003    1.20352    268.148     8.6482
1978          1.6587 0.0234156 1.229E 00    1.34940    0.88623    1.20532    270.289     6.5095
1979          1.7420 0.0176902 4.620E 08    0.00000    0.00000    1.20715    271.875     4.9180
1980          1.8247 0.0176835 4.633E 08    0.00000    0.00000    1.20895    271.875     4.9161
1981          1.9075 0.0176773 4.646E 08    0.00000    0.00000    1.21078    271.875     4.9143
1982          1.9933 0.0176706 4.659E 08    0.00000    0.00000    1.21259    271.875     4.9125
1983          2.0826 0.0176640 4.672E 08    0.00000    0.00000    1.21439    271.875     4.9106
1984          2.1752 0.0176578 4.685E 08    0.00000    0.00000    1.21619    271.875     4.9089
1985          2.2714 0.0176511 4.698E 08    0.00000    0.00000    1.21799    271.875     4.9071
1986          2.3713 0.0176449 4.711E 08    0.00000    0.00000    1.21979    271.875     4.9053
1987          2.4751 0.0176382 4.724E 08    0.00000    0.00000    1.22159    271.875     4.9034
1988          2.5828 0.0176320 4.736E 08    0.00000    0.00000    1.22339    271.875     4.9017
1989          2.6945 0.0176253 4.750E 08    0.00000    0.00000    1.22519    271.875     4.8999
1990          2.8105 0.0176187 4.763E 08    0.00000    0.00000    1.22702    271.875     4.8981
1991          2.9309 0.0176120 4.776E 08    0.00000    0.00000    1.22882    271.875     4.8962
1992          3.0559 0.0176058 4.789E 08    0.00000    0.00000    1.23065    271.875     4.8944
1993          3.1856 0.0175991 4.802E 08    0.00000    0.00000    1.23248    271.875     4.8926
1994          3.3202 0.0175924 4.816E 08    0.00000    0.00000    1.23434    271.875     4.8907
1995          3.4597 0.0175858 4.829E 08    0.00000    0.00000    1.23618    271.875     4.8889
1996          3.6047 0.0175791 4.842E 08    0.00000    0.00000    1.23804    271.875     4.8871
1997          3.7548 0.0175724 4.855E 08    0.00000    0.00000    1.23987    271.875     4.8851
1998          3.9105 0.0175662 4.868E 08    0.00000    0.00000    1.24170    271.875     4.8834
1999          4.0720 0.0175595 4.881E 08    0.00000    0.00000    1.24347    271.875     4.8816
2000          4.2396 0.0175533 4.894E 08    0.00000    0.00000    1.24521    271.875     4.8799
2001          4.4133 0.0175471 4.906E 08    0.00000    0.00000    1.24689    271.875     4.8782
2002          4.5933 0.0175414 4.918E 08    0.00000    0.00000    1.24857    271.875     4.8765
2003          4.7800 0.0175352 4.930E 08    0.00000    0.00000    1.25018    271.875     4.8749
2004          4.9736 0.0175295 4.941E 08    0.00000    0.00000    1.25180    271.875     4.8733
2005          5.1741 0.0175238 4.953E 08    0.00000    0.00000    1.25336    271.875     4.8717
2006          5.3820 0.0175185 4.964E 08    0.00000    0.00000    1.25488    271.875     4.8701
2007          5.5974 0.0175133 4.974E 08    0.00000    0.00000    1.25638    271.875     4.8687
2008          5.8206 0.0175080 4.985E 08    0.00000    0.00000    1.25784    271.875     4.8672
2009          6.0516 0.0175028 4.995E 08    0.00000    0.00000    1.25928    271.875     4.8657
2010          6.2914 0.0174975 5.005E 08    0.00000    0.00000    1.26068    271.875     4.8644
2011          6.5397 0.0174928 5.015E 08    0.00000    0.00000    1.26205    271.875     4.8630
2012          6.7966 0.0174880 5.024E 08    0.00000    0.00000    1.26340    271.875     4.8617
2013          7.0631 0.0174832 5.034E 08    0.00000    0.00000    1.26471    271.875     4.8604
2014          7.3390 0.0174785 5.044E 08    0.00000    0.00000    1.26599    271.875     4.8590
2015          7.6246 0.0174742 5.052E 08    0.00000    0.00000    1.26724    271.875     4.8578
2016          7.9204 0.0174699 5.061E 08    0.00000    0.00000    1.26846    271.875     4.8566
2017          8.2271 0.0174651 5.070E 08    0.00000    0.00000    1.26965    271.875     4.8553
2018          8.5442 0.0174613 5.078E 08    0.00000    0.00000    1.27081    271.875     4.8542
2019          8.8726 0.0174570 5.086E 08    0.00000    0.00000    1.27194    271.875     4.8531
2020          9.2122 0.0174532 5.094E 08    0.00000    0.00000    1.27304    271.875     4.8521
2021          9.5642 0.0174494 5.101E 08    0.00000    0.00000    1.27408    271.875     4.8510
2022          9.9287 0.0174456 5.109E 08    0.00000    0.00000    1.27509    271.875     4.8500
2023         10.3057 0.0174422 5.116E 08    0.00000    0.00000    1.27606    271.875     4.8490
2024         10.6963 0.0174389 5.122E 08    0.00000    0.00000    1.27701    271.875     4.8480
2025         11.1003 0.0174360 5.129E 08    0.00000    0.00000    1.27789    271.875     4.8472
```

```
   PAGE   18      04/04/74      02:38      PROTEIN INDICATORS

           GRGP      NGGP      PTR       PTPCH      DPT       DPTPC       PTN       PTAR       PTAPCR    PTPCSN    PTPCDR
1975     282.891   420.344   29.8223   22.8091    3.0299    2.3174    32.852    2.35492    1.80112   0.907776 0.0624905
1976     283.945   422.164   29.9922   22.3633    3.7408    2.7893    33.733    2.41681    1.80203   0.889099 0.0612698
1977     289.133   431.078   30.5869   22.2314    4.0668    2.9558    34.653    2.48291    1.80466   0.882645 0.0609074
1978     293.953   439.367   31.1489   22.0659    4.4539    3.1550    35.603    2.55365    1.80899   0.874908 0.0604544
1979     298.469   447.141   31.6309   21.8418    4.9368    3.4089    36.567    2.57471    1.77789   0.864990 0.0598402
1980     302.117   453.414   32.0107   21.5454    5.5452    3.7322    37.556    2.58313    1.73862   0.852356 0.0590277
1981     305.820   459.781   32.3965   21.2554    6.1710    4.0488    38.567    2.59198    1.70062   0.839996 0.0582342
1982     309.555   466.203   32.7861   20.9702    6.8185    4.3611    39.605    2.60120    1.66373   0.827835 0.0574522
1983     313.281   472.609   33.1758   20.6860    7.4910    4.6709    40.666    2.61096    1.62799   0.815796 0.0566740
1984     317.039   479.070   33.5693   20.4067    8.1863    4.9763    41.756    2.62097    1.59329   0.803955 0.0559092
1985     320.805   485.547   33.9639   20.1270    8.9128    5.2817    42.876    2.63159    1.55951   0.792130 0.0551474
1986     324.586   492.055   34.3594   19.8501    9.6653    5.5837    44.025    2.64258    1.52664   0.780457 0.0543833
1987     328.375   498.570   34.7568   19.5732   10.4512    5.8855    45.209    2.65411    1.49463   0.768814 0.0536251
1988     332.164   505.094   35.1563   19.2974   11.2681    6.1851    46.424    2.66614    1.46347   0.757278 0.0529698
1989     335.977   511.648   35.5566   19.0215   12.1223    6.4849    47.680    2.67865    1.43295   0.745758 0.0521135
1990     339.797   518.219   35.9600   18.7485   13.0071    6.7815    48.967    2.69171    1.40338   0.734375 0.0513649
1991     343.672   524.875   36.3672   18.4766   13.9282    7.0762    50.296    2.70538    1.37448   0.723068 0.0506210
1992     347.547   531.547   36.7773   18.2065   14.8848    7.3687    51.662    2.71967    1.34637   0.711984 0.0498810
1993     351.430   538.219   37.1865   17.9370   15.8818    7.6604    53.069    2.73450    1.31897   0.700729 0.0491419
1994     355.336   544.938   37.6006   17.6694   16.9170    7.9497    54.518    2.75000    1.29230   0.689697 0.0484095
1995     359.234   551.656   38.0146   17.4043   17.9902    8.2363    56.005    2.76611    1.26642   0.678772 0.0476828
1996     363.148   558.391   38.4297   17.1401   19.1069    8.5217    57.538    2.78296    1.24118   0.667923 0.0469589
1997     367.086   565.156   38.8486   16.8696   20.2275    8.7939    59.077    2.80048    1.21750   0.657608 0.0462732
1998     371.016   571.922   39.2666   16.6484   21.3623    9.0571    60.630    2.81879    1.19510   0.647659 0.0456123
1999     374.977   578.734   39.6914   16.4209   22.4961    9.3071    62.187    2.83783    1.17407   0.638245 0.0449586
2000     378.938   585.547   40.1143   16.2017   23.6450    9.5498    63.759    2.85760    1.15417   0.629150 0.0443678
2001     382.906   592.375   40.5400   15.9917   24.8013    9.7834    65.342    2.87830    1.13541   0.620438 0.0438128
2002     386.891   599.219   40.9678   15.7913   25.9629   10.0076    66.932    2.89984    1.11777   0.612091 0.0432634
2003     390.883   606.094   41.3965   15.5989   27.1333   10.2244    68.529    2.92218    1.10114   0.604065 0.0427370
2004     394.891   612.984   41.8281   15.4155   28.3076   10.4326    70.137    2.94562    1.08560   0.596390 0.0422344
2005     398.898   619.875   42.2607   15.2400   29.4858   10.6331    71.746    2.96979    1.07095   0.589035 0.0417538
2006     402.922   626.797   42.6963   15.0732   30.6646   10.8257    73.361    2.99506    1.05737   0.582001 0.0412970
2007     406.945   633.719   43.1328   14.9131   31.8501   11.0120    74.982    3.02142    1.04465   0.575241 0.0408573
2008     410.977   640.641   43.5713   14.7607   33.0342   11.1912    76.605    3.04877    1.03284   0.568771 0.0404396
2009     415.031   647.625   44.0127   14.6152   34.2197   11.3633    78.232    3.07727    1.02188   0.562592 0.0400419
2010     419.078   654.578   44.4541   14.4761   35.4072   11.5300    79.861    3.10681    1.01169   0.556641 0.0396605
2011     423.141   661.563   44.8994   14.3435   36.5918   11.6897    81.492    3.13763    1.00235   0.550964 0.0392971
2012     427.195   668.547   45.3447   14.2178   37.7734   11.8438    83.117    3.16974    0.99388   0.545547 0.0389528
2013     431.266   675.547   45.7939   14.0991   38.9473   11.9912    84.740    3.20306    0.98619   0.540390 0.0386276
2014     435.336   682.547   46.2422   13.9863   40.1143   12.1328    86.355    3.23773    0.97928   0.535477 0.0383186
2015     439.406   689.547   46.6934   13.8796   41.2744   12.2688    87.969    3.27380    0.97314   0.530807 0.0380268
2016     443.500   696.578   47.1484   13.7798   42.4248   12.3992    89.572    3.31128    0.96777   0.526367 0.0377522
2017     447.586   703.609   47.6035   13.6858   43.5605   12.5234    91.164    3.35022    0.96317   0.522171 0.0374947
2018     451.680   710.656   48.0605   13.5979   44.6826   12.6421    92.744    3.39091    0.95935   0.518219 0.0372543
2019     455.773   717.688   48.5215   13.5168   45.7861   12.7549    94.307    3.43286    0.95631   0.514496 0.0370321
2020     459.883   724.766   48.9834   13.4421   46.8662   12.8611    95.850    3.47668    0.95407   0.511047 0.0368280
2021     463.992   731.828   49.4473   13.3748   47.9199   12.9614    97.367    3.52216    0.95268   0.507843 0.0366430
2022     468.102   738.891   49.9131   13.3142   48.9434   13.0552    98.855    3.56946    0.95213   0.504913 0.0364771
2023     472.219   745.984   50.3818   13.2615   49.9258   13.1414   100.309    3.61871    0.95250   0.502274 0.0363331
2024     476.336   753.063   50.8525   13.2168   50.8682   13.2207   101.721    3.66968    0.95377   0.499924 0.0362101
2025     480.469   760.172   51.3271   13.1797   51.7686   13.2930   103.096    3.72278    0.95592   0.497864 0.0361090
```

```
PAGE    19      04/04/74       02:38      IMPORT INDICATORS

              FDMV     FDMAR     FDMYR     FDMMR      M        PXPTM     DPT
1975          8.181  0.101547  0.047907  0.38327   21.344   2.69995    3.0299
1976         10.342  0.124218  0.057976  0.46382   22.298   2.76471    3.7408
1977         11.513  0.131958  0.061375  0.49101   23.447   2.83099    4.0668
1978         12.911  0.141411  0.065523  0.52420   24.630   2.89886    4.4539
1979         14.654  0.154190  0.070980  0.56786   25.806   2.96838    4.9368
1980         16.854  0.171036  0.078064  0.62454   26.987   3.03955    5.5452
1981         19.207  0.187969  0.085077  0.68065   28.218   3.11243    6.1710
1982         21.731  0.205112  0.092085  0.73671   29.498   3.18707    6.8185
1983         24.447  0.222572  0.099133  0.79308   30.825   3.26349    7.4910
1984         27.356  0.240246  0.106178  0.84947   32.204   3.34174    8.1863
1985         30.498  0.258365  0.113335  0.90672   33.636   3.42188    8.9128
1986         33.866  0.276810  0.120518  0.96419   35.124   3.50391    9.6653
1987         37.498  0.295723  0.127827  1.02264   36.668   3.58795   10.4512
1988         41.398  0.315048  0.135212  1.08176   38.271   3.67401   11.2681
1989         45.604  0.334915  0.142746  1.14203   39.934   3.76208   12.1223
1990         50.106  0.355141  0.150341  1.20276   41.659   3.85229   13.0071
1991         54.941  0.375809  0.158043  1.26437   43.453   3.94464   13.9282
1992         60.123  0.396927  0.165852  1.32684   45.313   4.03931   14.8848
1993         65.689  0.418594  0.173801  1.39047   47.242   4.13611   15.8818
1994         71.646  0.440720  0.181858  1.45490   49.245   4.23523   16.9170
1995         78.018  0.463310  0.190014  1.52017   51.321   4.33679   17.9902
1996         84.850  0.486481  0.198330  1.58667   53.477   4.44080   19.1069
1997         91.977  0.509140  0.206360  1.65094   55.712   4.54724   20.2275
1998         99.467  0.531662  0.214256  1.71408   58.029   4.65625   21.3623
1999        107.256  0.553604  0.221840  1.77478   60.434   4.76782   22.4961
2000        115.436  0.575394  0.229305  1.83447   62.926   4.88208   23.6450
2001        123.984  0.596878  0.236572  1.89267   65.508   4.99915   24.8013
2002        132.906  0.617966  0.243622  1.94907   68.189   5.11902   25.9629
2003        142.223  0.638748  0.250496  2.00409   70.967   5.24170   27.1333
2004        151.934  0.659149  0.257172  2.05743   73.846   5.36731   28.3076
2005        162.055  0.679184  0.263641  2.10925   76.830   5.49597   29.4858
2006        172.570  0.698746  0.269890  2.15918   79.924   5.62769   30.6646
2007        183.539  0.718033  0.275978  2.20789   83.129   5.76257   31.8501
2008        194.926  0.736877  0.281845  2.25482   86.449   5.90076   33.0342
2009        206.758  0.755234  0.287506  2.30011   89.891   6.04224   34.2197
2010        219.066  0.773285  0.292999  2.34406   93.457   6.18713   35.4072
2011        231.824  0.790833  0.298271  2.38629   97.148   6.33545   36.5918
2012        245.043  0.807907  0.303337  2.42676  100.975   6.48730   37.7734
2013        258.719  0.824463  0.308167  2.46539  104.938   6.64282   38.9473
2014        272.859  0.840500  0.312775  2.50232  109.043   6.80212   40.1143
2015        287.484  0.856064  0.317184  2.53754  113.293   6.96521   41.2744
2016        302.578  0.871017  0.321350  2.57086  117.695   7.13220   42.4248
2017        318.133  0.885361  0.325264  2.60217  122.256   7.30322   43.5605
2018        334.156  0.899124  0.328941  2.63165  126.977   7.47839   44.6826
2019        350.617  0.912186  0.332359  2.65900  131.859   7.65771   45.7861
2020        367.492  0.924484  0.335480  2.68396  136.922   7.84131   46.8662
2021        384.758  0.936005  0.338303  2.70654  142.160   8.02930   47.9199
2022        402.391  0.946655  0.340813  2.72656  147.582   8.22168   48.9434
2023        420.305  0.956299  0.342941  2.74365  153.195   8.41870   49.9258
2024        438.508  0.964966  0.344719  2.75787  159.004   8.62061   50.8682
2025        456.961  0.972595  0.346138  2.76923  165.016   8.82715   51.7686
```