# Human Population 2018

Lecture 11
Fitting data
World 3
Mind sized modeling
Lotke-Volterra model

# Questions?

World 3

# The Real Club of Rome

These are real

http://www.clubofrome.org/

https://en.wikipedia.org/wiki/Club_of_Rome

These are junk

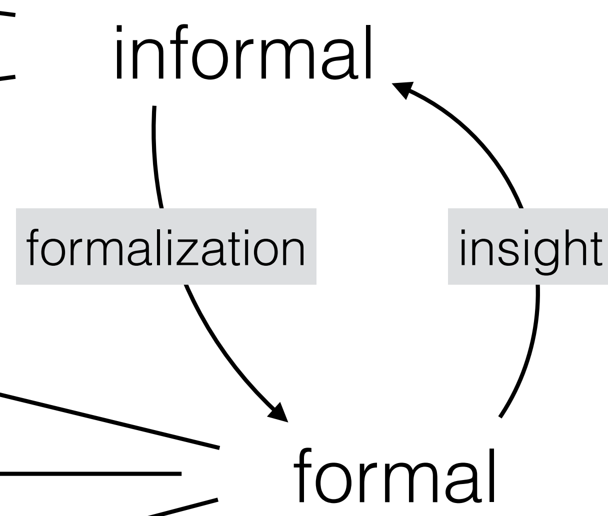
http://conspiracywiki.com/articles/new-world-order/club-of-rome/

http://www.theforbiddenknowledge.com/hardtruth/clubofrome.htm

http://green-agenda.com/globalrevolution.html

# Levels of modeling

- Mental
- Verbal
- Graphical
- Mathematical
- Physical



# Process of modeling

- data
- interpretation
  - dependencies -- What depends on what?
  - equations -- Add parameters, functional forms.
- prediction
- **fitting** -- minimize the residual between prediction and data as a function of the parameters.

# Fitting

- Manual fitting
  - explore parameter settings while observing the predictions.
  - Stop when the predictions match the data.
- Automatic
  - Calculate the "objective function", ε = mean square residual.
  - Calculate the derivative of ε with respect to the parameters.
  - Move the parameters so that ε decreases.

# In class exercise: fitting data in Excel

- Download "HP_exercise_23feb.xlsx" from the course web site.
- Open the file in Excel.

# In class exercise: fitting data in Excel

- Fill in the equation for exponential growth in row D. y = a*exp(b*x), where a and b are parameters and x is time. Use the parameters provided.
  Those not familiar with Excel:
  Type into cell D8
  =$D$1*EXP($D$2*A8)
  Select cell D8. Double-click on the drag-down box.

"$" locks row and/or column during dragging.

- In E8, type the equation for y=a*exp(b*exp(c*x))
  =$E$1*EXP($E$2*EXP($E$3*A8))
  Select E8. Double-click on drag-down box.

# In class exercise: fitting data in Excel

- Look at the graph. Does the equation (red) fit the population data (blue)?
- Look at the equation in row F. It is a linear combination of the data in row D (exponential) with row E (hyperexponential).
- Change the values in F1 and F2 to make it fit.
- Can you fit the data with zero in F2, using only F1 (exponential equation only)?
- Can you fit the data with zero in F1, using only F2 (hyperexponential only)?

# *Optional*: automated fitting using Excel's **Solver** plug-in*

- If you have the plug-in **Solver** it will be under the Data tab.

- Open **Solver**
  Minimize the value in H4 by changing F1:F2

- Did it work?
  H4 contains the "objective function", which in this case is the sum of the squared residuals.

*google: installing solver in excel

# In class exercise: fitting data in Excel

Why does human population appear to be growing hyper-exponentially?

# Purpose of the World models

- "broad sweep of the future"
- "to avoid creating an impenetrable thicket of assumptions, modelers must discipline themselves. They cannot put into the model all that they know, only what is relevant for the purposes of the model."

(LtG)

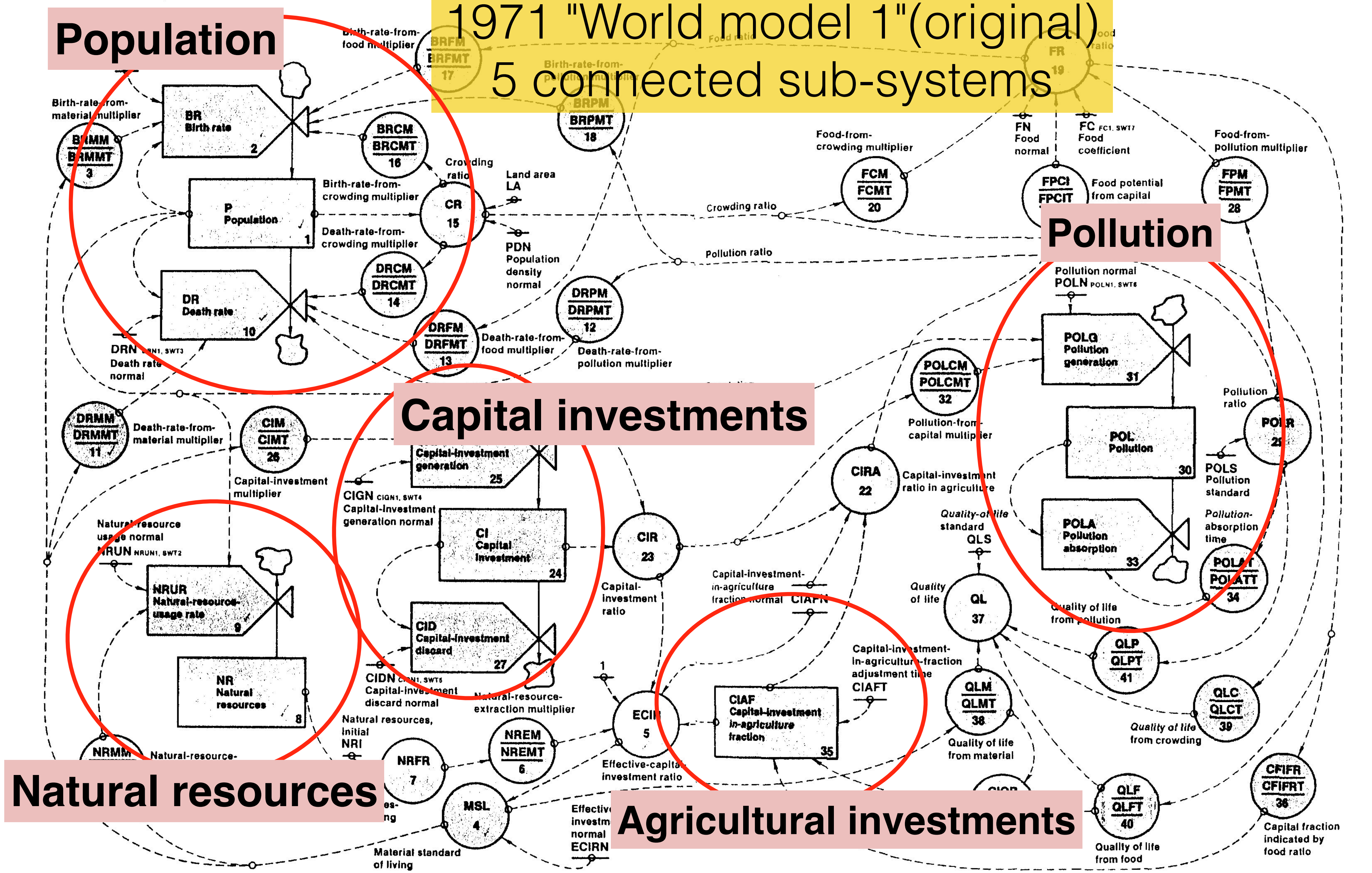
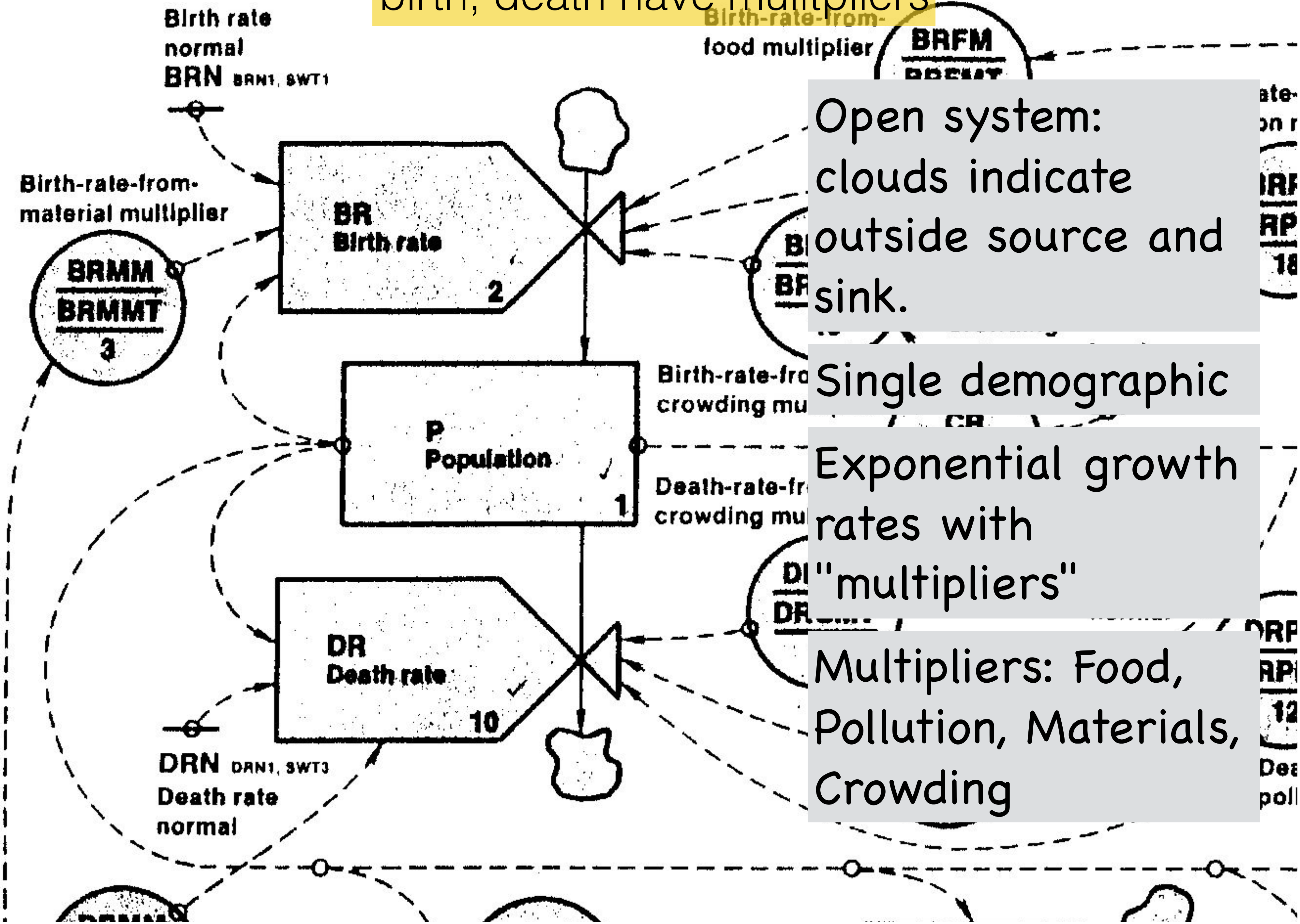



Figure 2-1 Complete diagram of the world model interrelating the five level variables — population, natural resources, capital investment, capital-investment-in-agriculture fraction, and pollution.

**population** is one stock

birth, death have mulitpliers




Open system: clouds indicate outside source and sink.

Single demographic

Exponential growth rates with "multipliers"

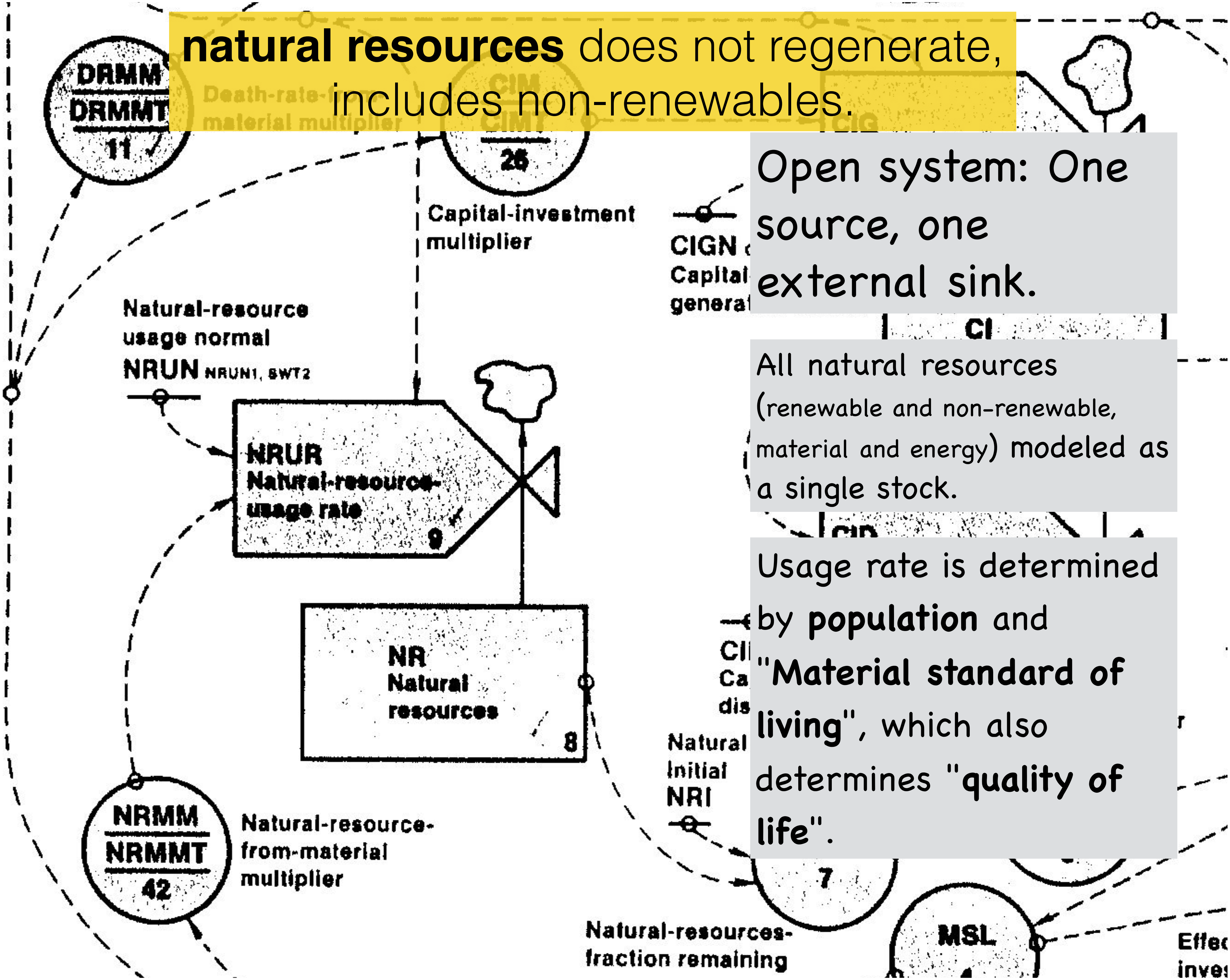
Multipliers: Food, Pollution, Materials, Crowding

**natural resources** does not regenerate, includes non-renewables.

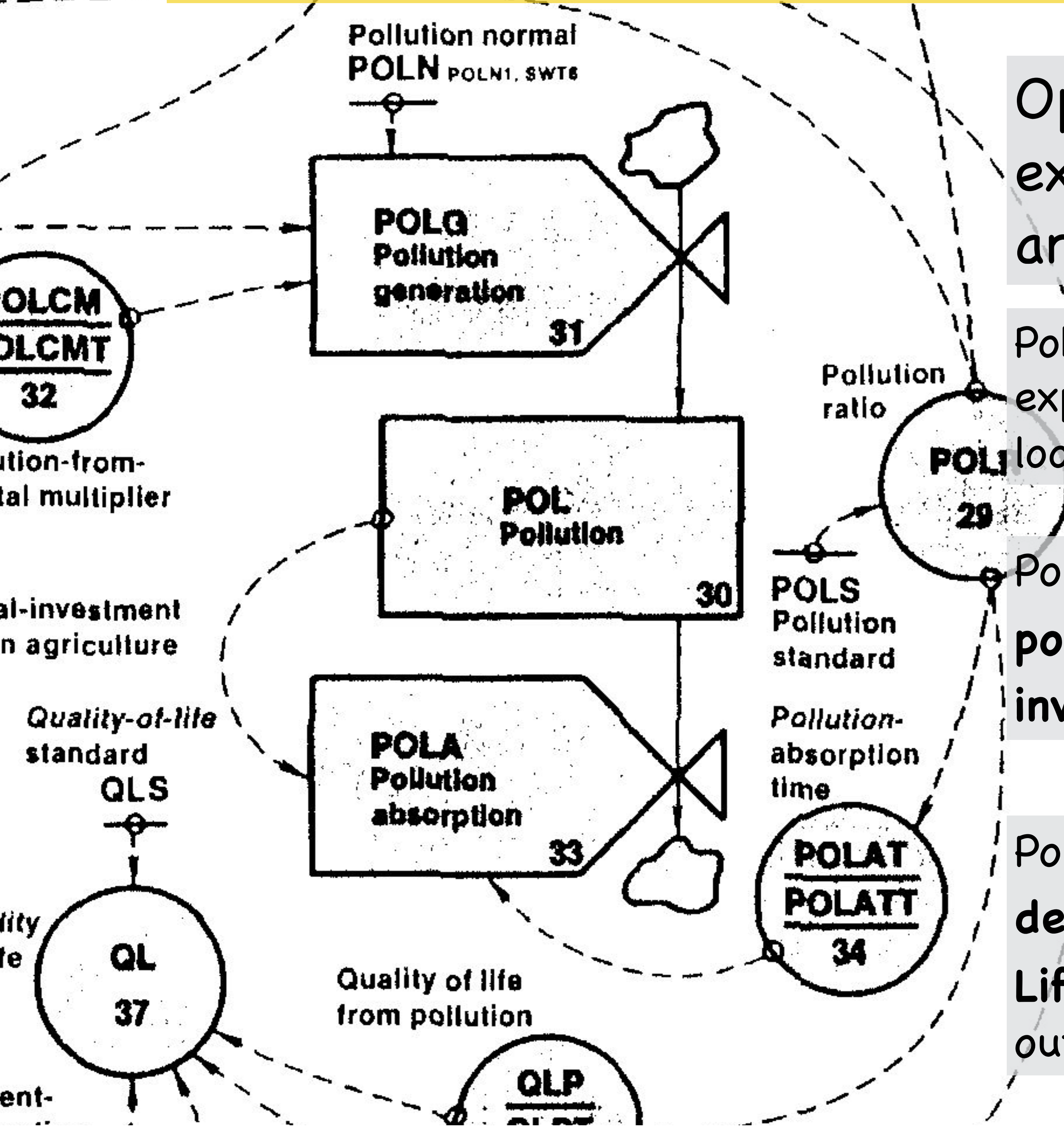
Open system: One source, one external sink.

All natural resources (renewable and non-renewable, material and energy) modeled as a single stock.

Usage rate is determined by **population** and "**Material standard of living**", which also determines "**quality of life**".



## **pollution** affects quality of life and life expectancy



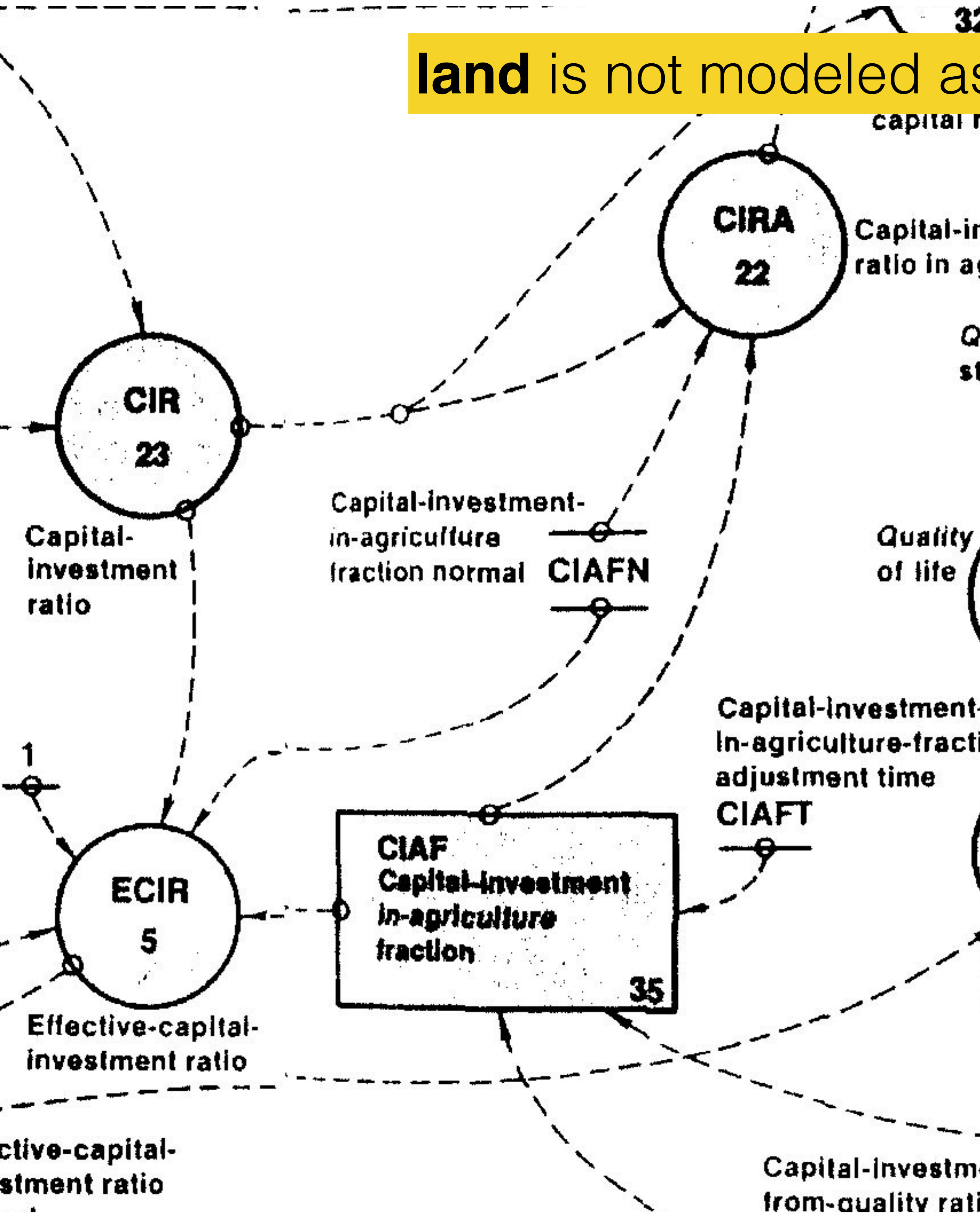

Open system: external sources and sink. No units.

Pollution absorption is exponential (see feedback loop)

Pollution has inputs from **population** and **capital investment** (affluence?)

Pollution has outputs to **death rate, Quality of Life** (QOL). QOL has no outputs. Just an index.

# **land** is not modeled as a stock

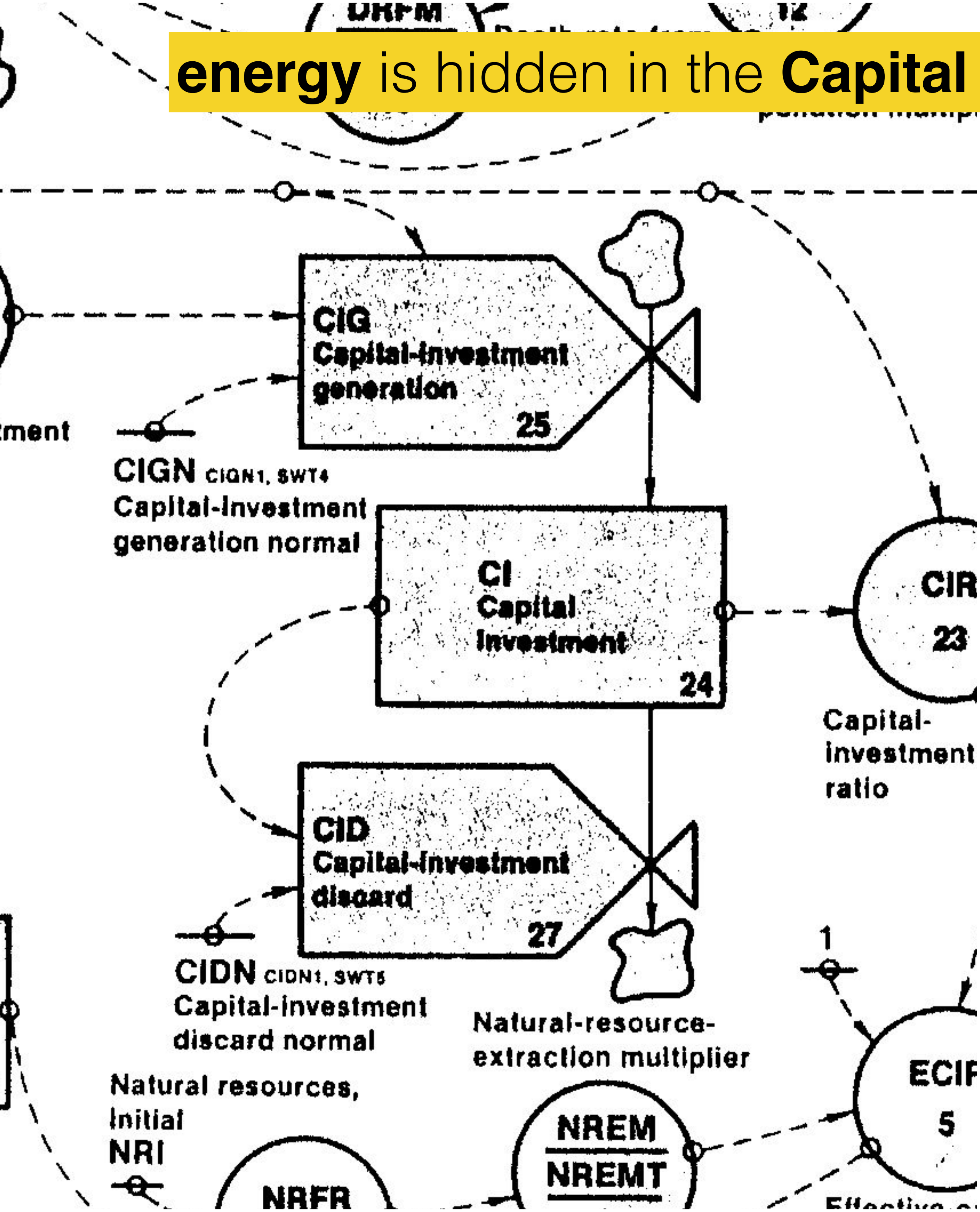



Variable, not stock: capital investment in agriculture.

Input variables are Food, Quality of life from food, quality of life from Matereials

Output to Food Potential, which becomes Food per capita, which inputs to birth and death rates

# **energy** is hidden in the **Capital Investment** stock




Capital investment (CI) stock: open system

Input to CI from **population** and **Material Standard of Living**.

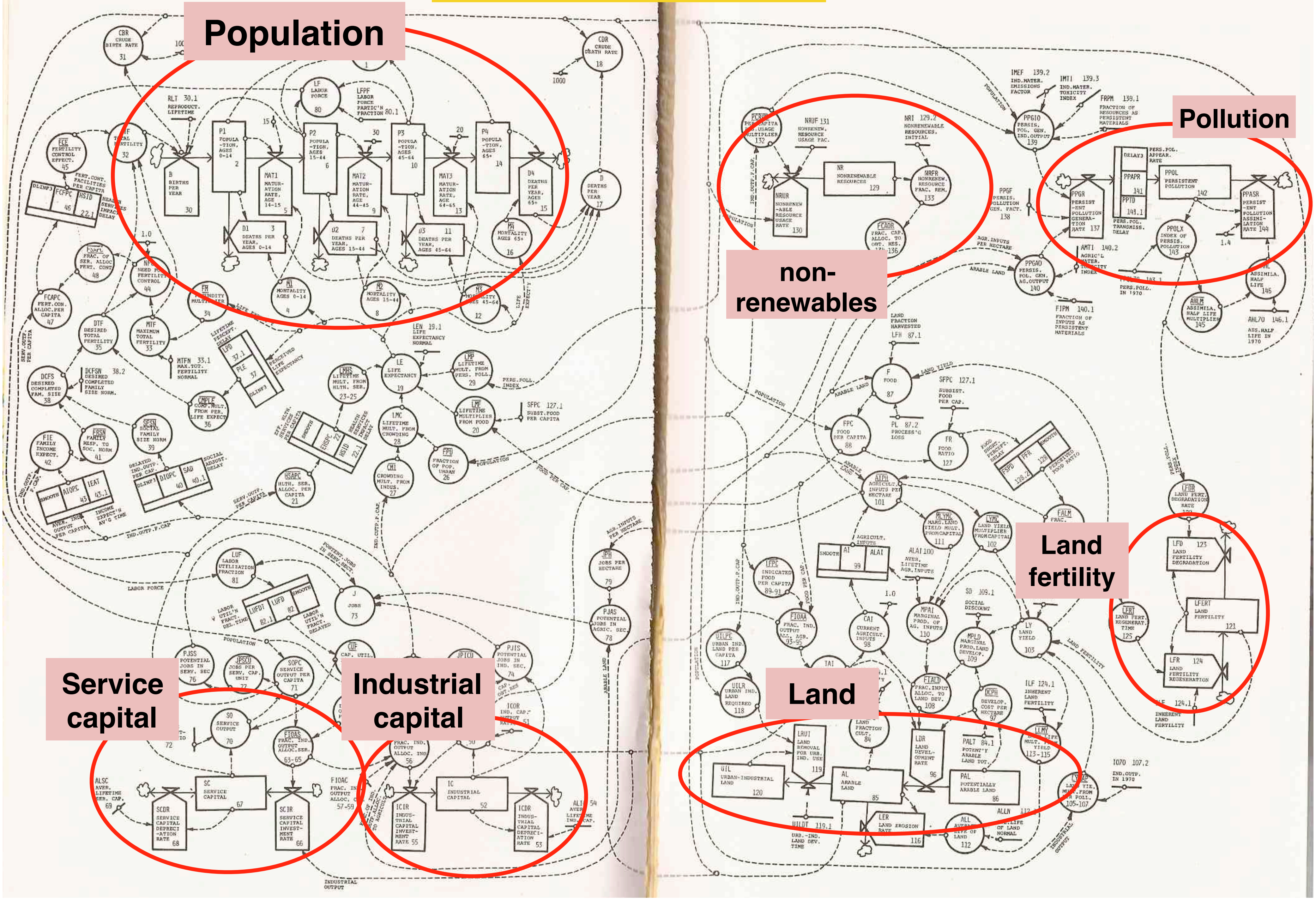
Output to **agriculture**, **material standard of living**, and **pollution.**

NOTE: I call this energy.

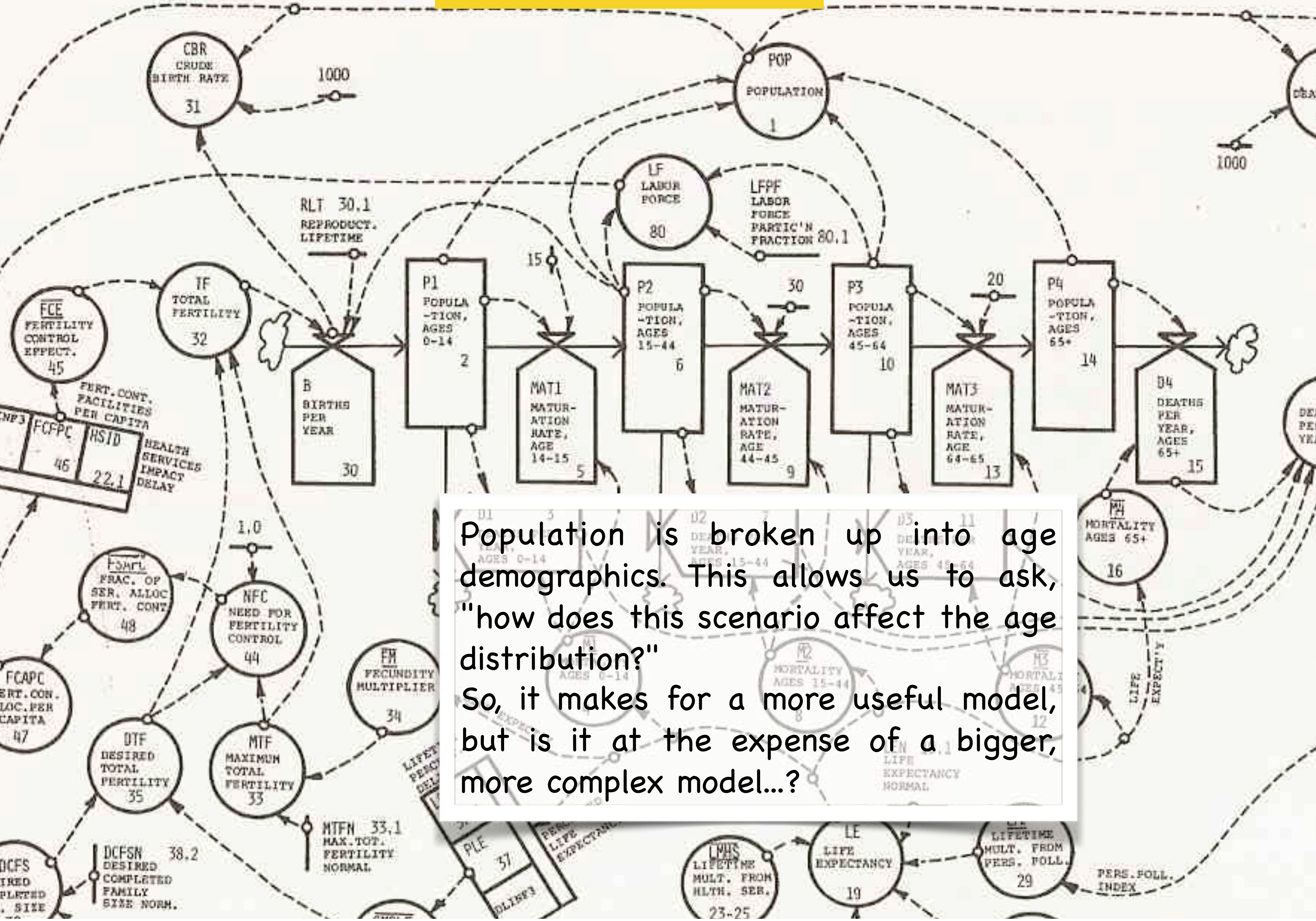
# Changes in 1972 World "1.2" model

- Non-renewables are separate from natural resources.
- Population is broken up into age demographics.
- Adds service capital, labor force.
- Land is modeled as two open systems of stocks: 1) land (potential, arable, degraded) and 2) land fertility.

# World model 1972



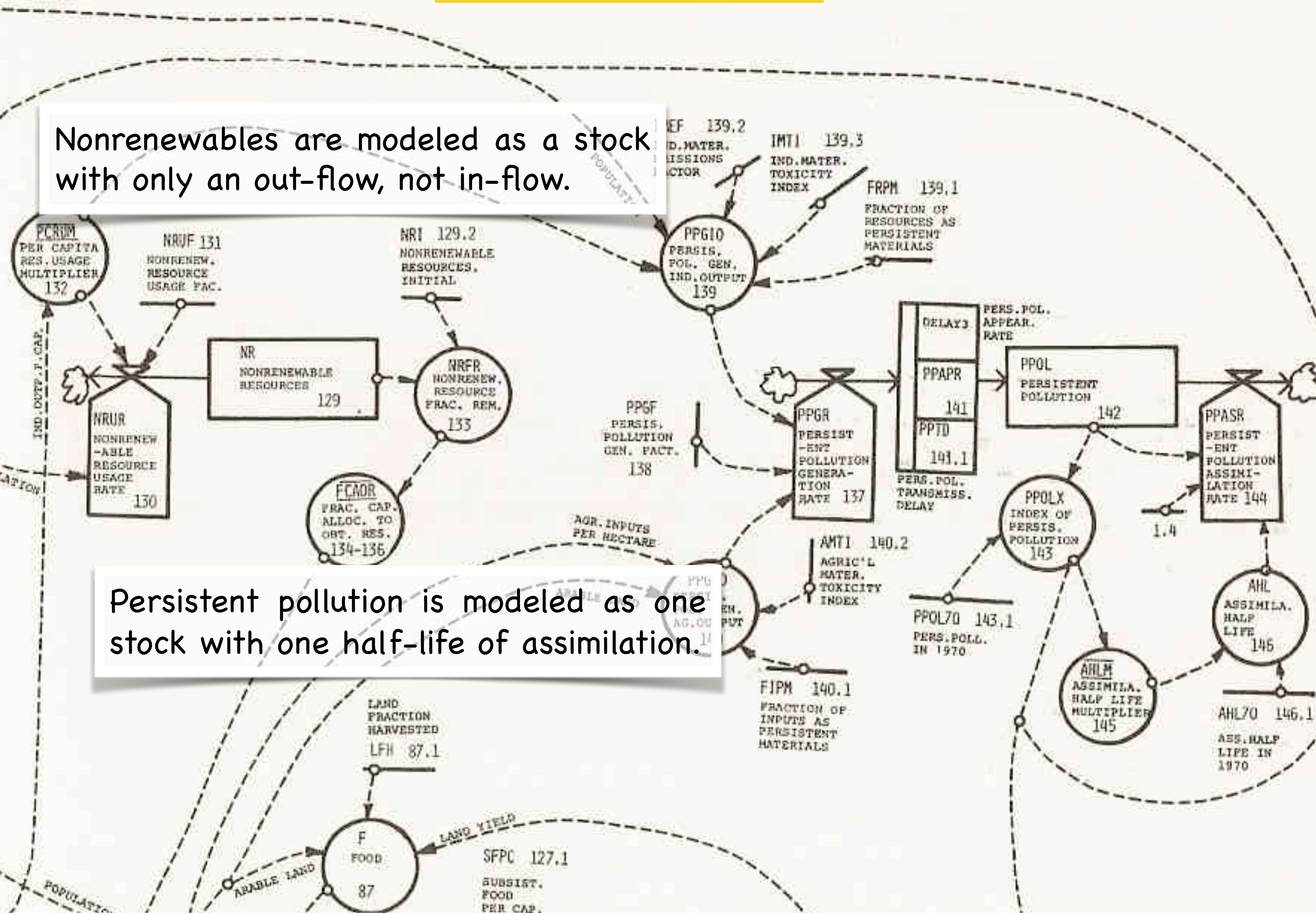
# World model 1972




Population is broken up into age demographics. This allows us to ask, "how does this scenario affect the age distribution?"

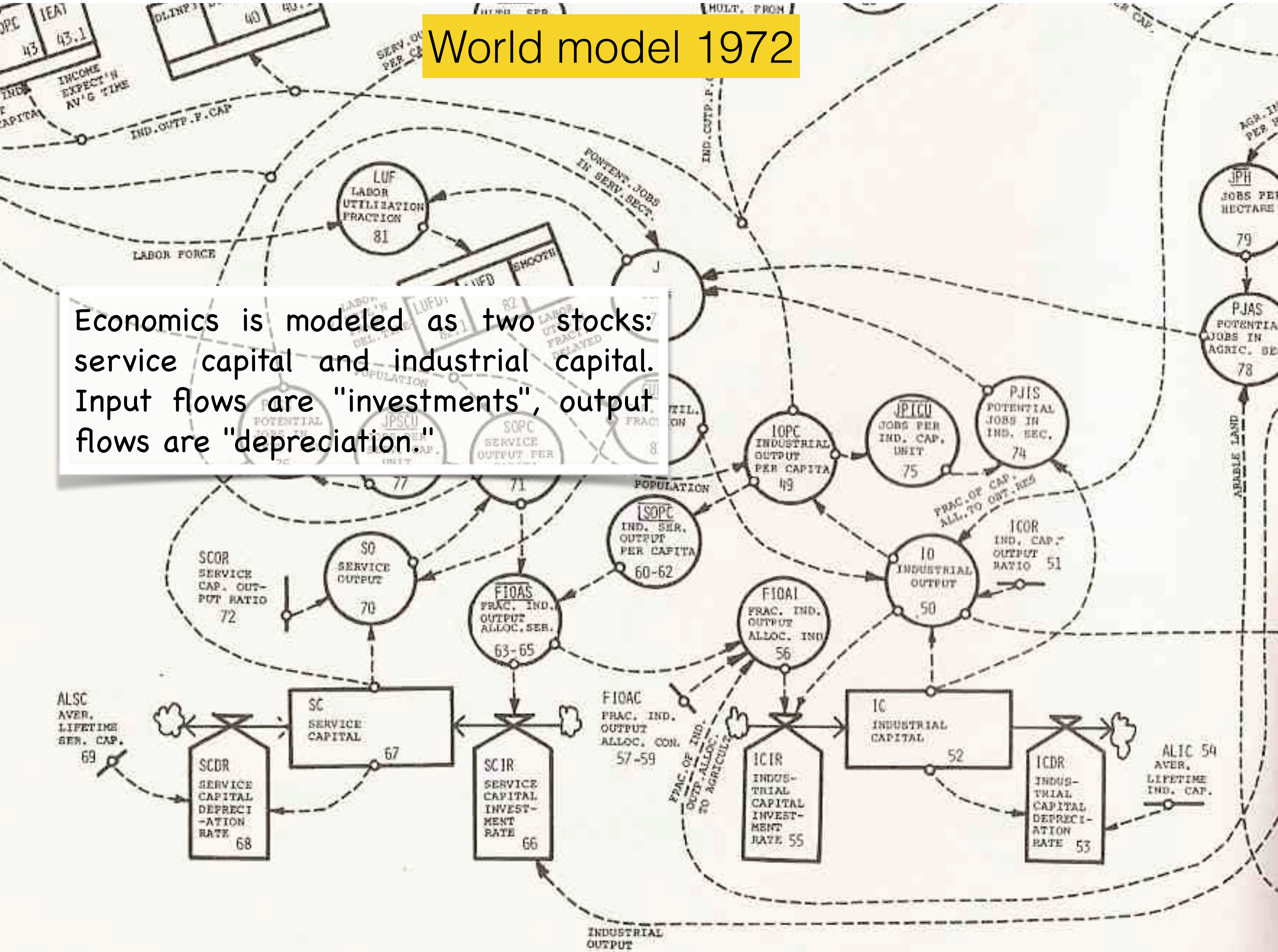
So, it makes for a more useful model, but is it at the expense of a bigger, more complex model...?

# World model 1972

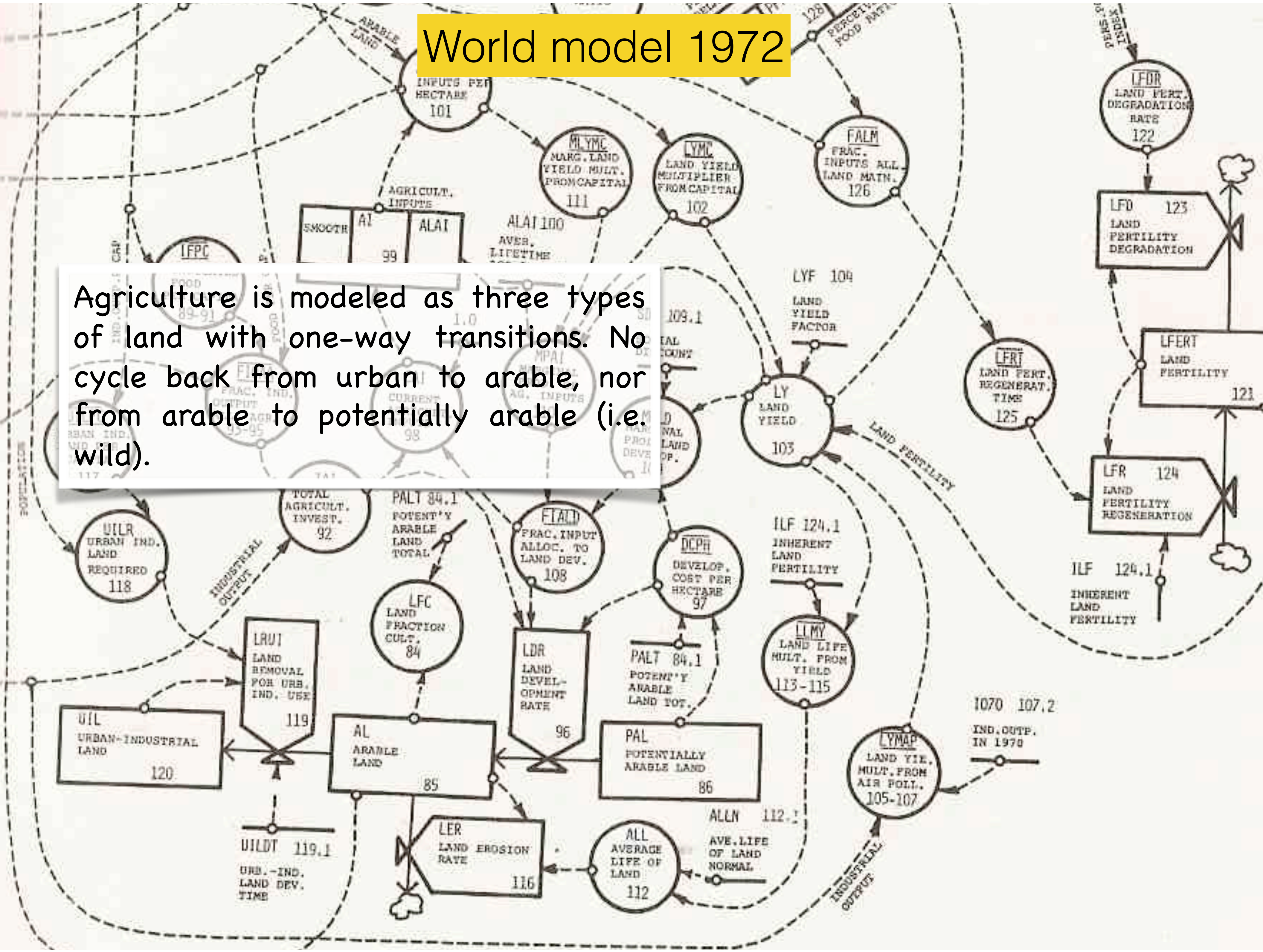


# World model 1972

Economics is modeled as two stocks: service capital and industrial capital. Input flows are "investments", output flows are "depreciation."

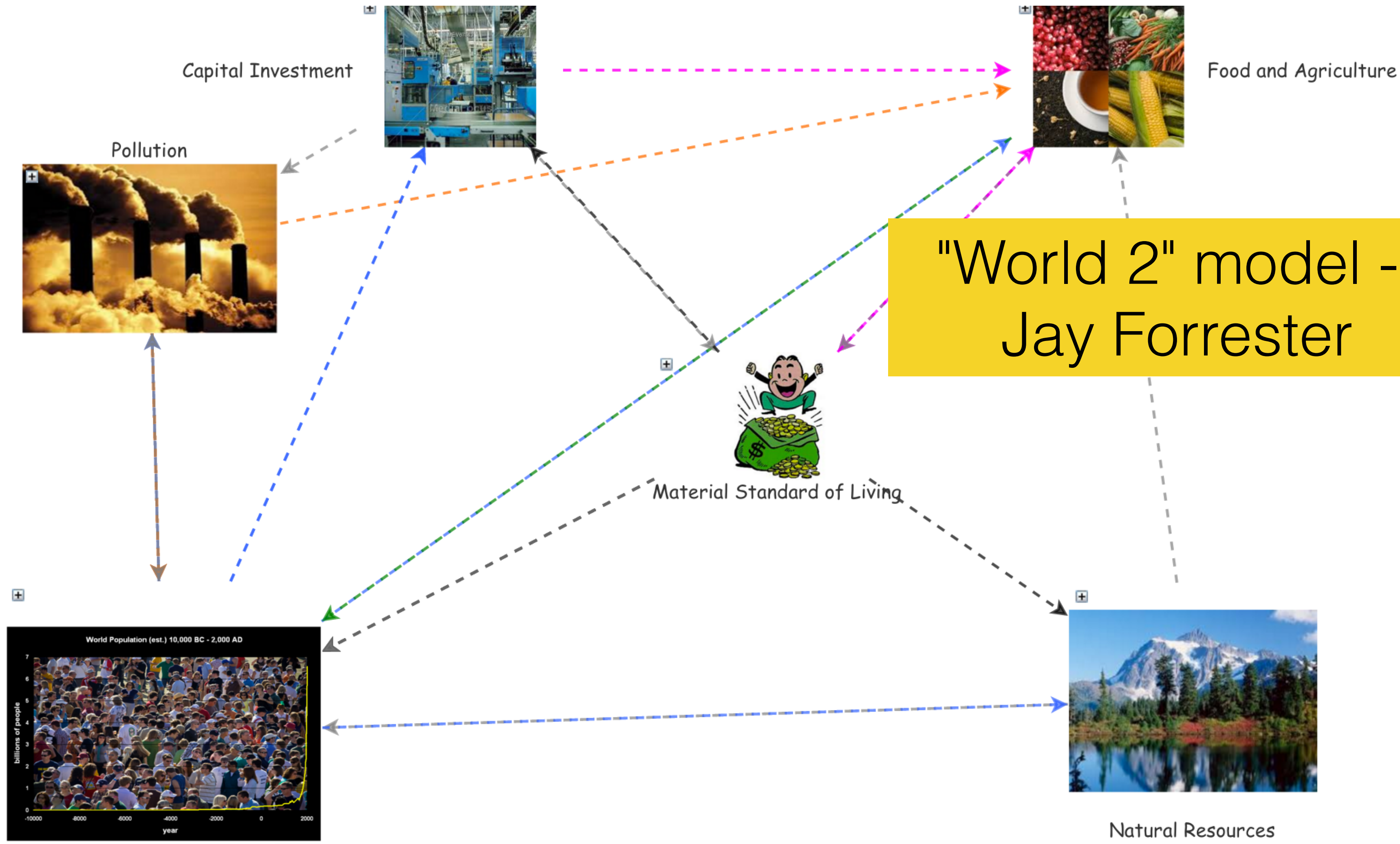


# World model 1972



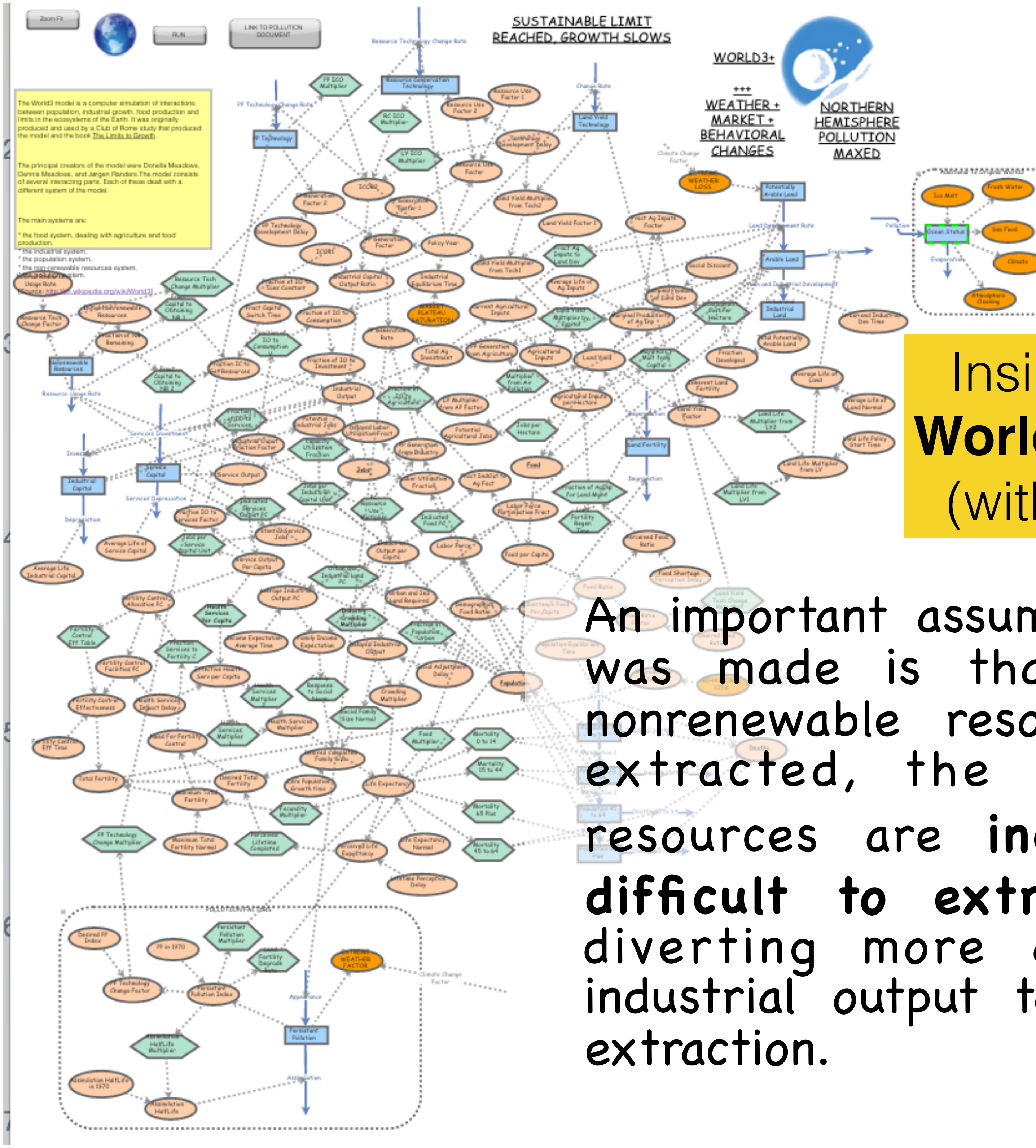

Agriculture is modeled as three types of land with one-way transitions. No cycle back from urban to arable, nor from arable to potentially arable (i.e. wild).

# "World 2" model -- Jay Forrester




- Similar to World 1 (1971 version)
  - Open systems for population, natural resources, capital investment (physical capital), capital investment in agriculture, pollution.
  - central variable in Material Standard of Living (MSL)
  - single demographic
  - non-renewable resources are not explicitly modeled


Forrester, Jay Wright, World dynamics. Vol. 59. Cambridge, MA: Wright-Allen Press, 1971.




InsightMaker
**World3+ model**
(with climate)

An important assumption that was made is that as the nonrenewable resources are extracted, the remaining resources are **increasingly difficult to extract**, thus diverting more and more industrial output to resource extraction.

# How do you assess a model?

If you agree with all of the parts of the model, then you are obligated to agree with the outcomes of the model.

# More work needs to be done on modeling

From the author of LtG

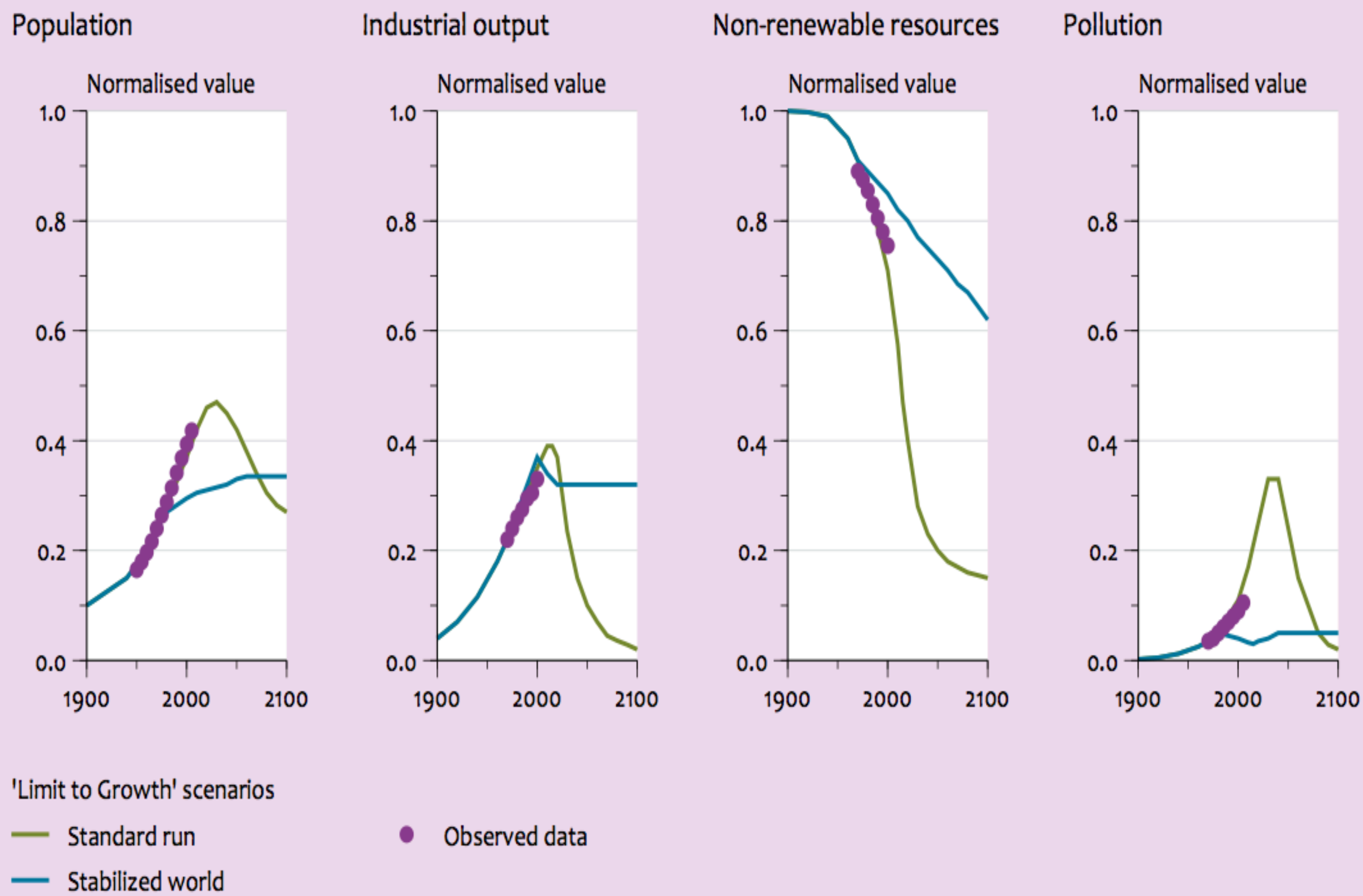
"Dana" Meadows

- Donella Meadows in "Groping in the Dark: The First Decade of Global Modelling"

"We have **great confidence in the basic qualitative assumptions** and conclusions about the instability of the current global socioeconomic system and the general kinds of changes that will and will not lead to stability. We have relatively **great confidence in the feedback-loop structure** of the model, with some exceptions which I list below. We have a **mixed degree of confidence in the numerical parameters** of the model; some are well-known physical or biological constants that are unlikely to change, some are statistically derived social indices quite likely to change, and some are pure guesses that are perhaps only of the right order of magnitude. The structural assumptions in World3 that I consider **most dubious** and also sensitive enough to be of concern are:

- the constant capital-output ratio (which assumes no diminishing returns to capital),
- the residual nature of the investment function,
- the generally ineffective labour contribution to output."

**Figure 2.2** **Comparing 'Limit to Growth' scenarios to observed global data**




*Growing Within* Limits, Netherlands Environmental Assessment Agency, Bilthoven, NL, Octobre 2009, Page 23 1

# World3 needs more feedback loops

Safa Motesharrei

## Modeling Sustainability: Population, Inequality, Consumption, and Bidirectional Coupling of the Earth and Human Systems.

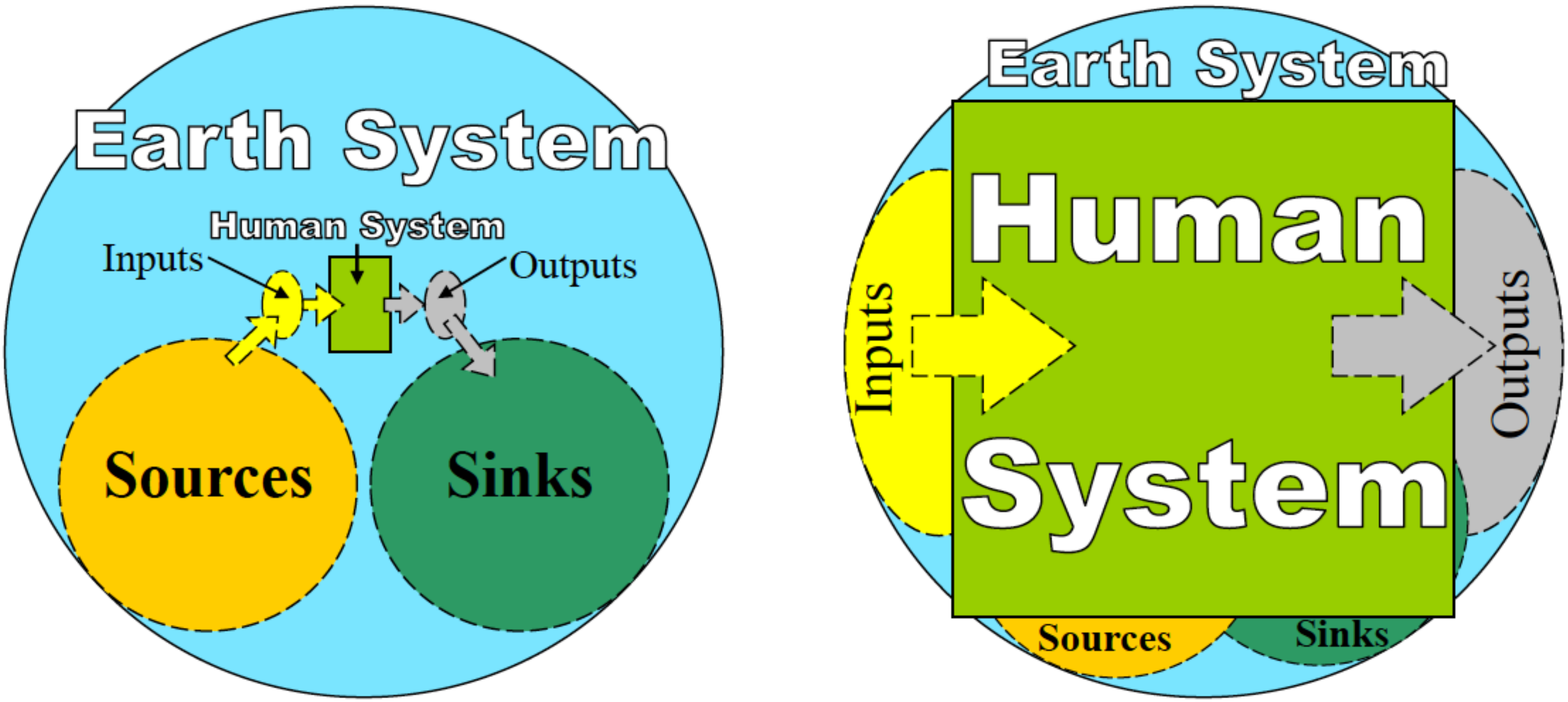
Safa Motesharrei[1,+,*], Jorge Rivas[2,+], Eugenia Kalnay[1,+], Ghassem R. Asrar[3], Antonio J. Busalacchi[4], Robert F. Cahalan[5,6], Mark A. Cane[7], Rita R. Colwell[1], Kuishuang Feng[1], Rachel

Over the last two centuries, the impact of the **Human System has grown dramatically, becoming strongly dominant within the Earth System** in many different ways. Consumption, inequality, and population have increased extremely fast, especially since about 1950, threatening to overwhelm the many critical functions and ecosystems of the Earth System. Changes in the Earth System, in turn, have important feedback effects on the Human System, with costly and potentially serious consequences. However, **current models do not incorporate these critical feedbacks**. We argue that in order to understand the dynamics of either system, **Earth System Models must be coupled with Human System Models through bidirectional couplings representing the positive, negative, and delayed feedbacks that exist in the real systems.** In particular, key Human System variables, such as demographics, inequality, economic growth, and migration, are not coupled with the Earth System but are instead driven by exogenous estimates, such as UN population projections. This makes current models likely to miss important feedbacks in the real Earth-Human system, especially those that may result in unexpected or counterintuitive outcomes, and thus requiring different policy interventions from current models. The importance and imminence of sustainability challenges, the dominant role of the Human System in the Earth System, and the essential roles the Earth System plays for the Human System, all call for collaboration of natural scientists, social scientists, and engineers in multidisciplinary research and modeling to develop coupled Earth-Human system models for devising effective science-based policies and measures to benefit current and future generations.

## The Past: "Empty World" → The Present: "Full World"

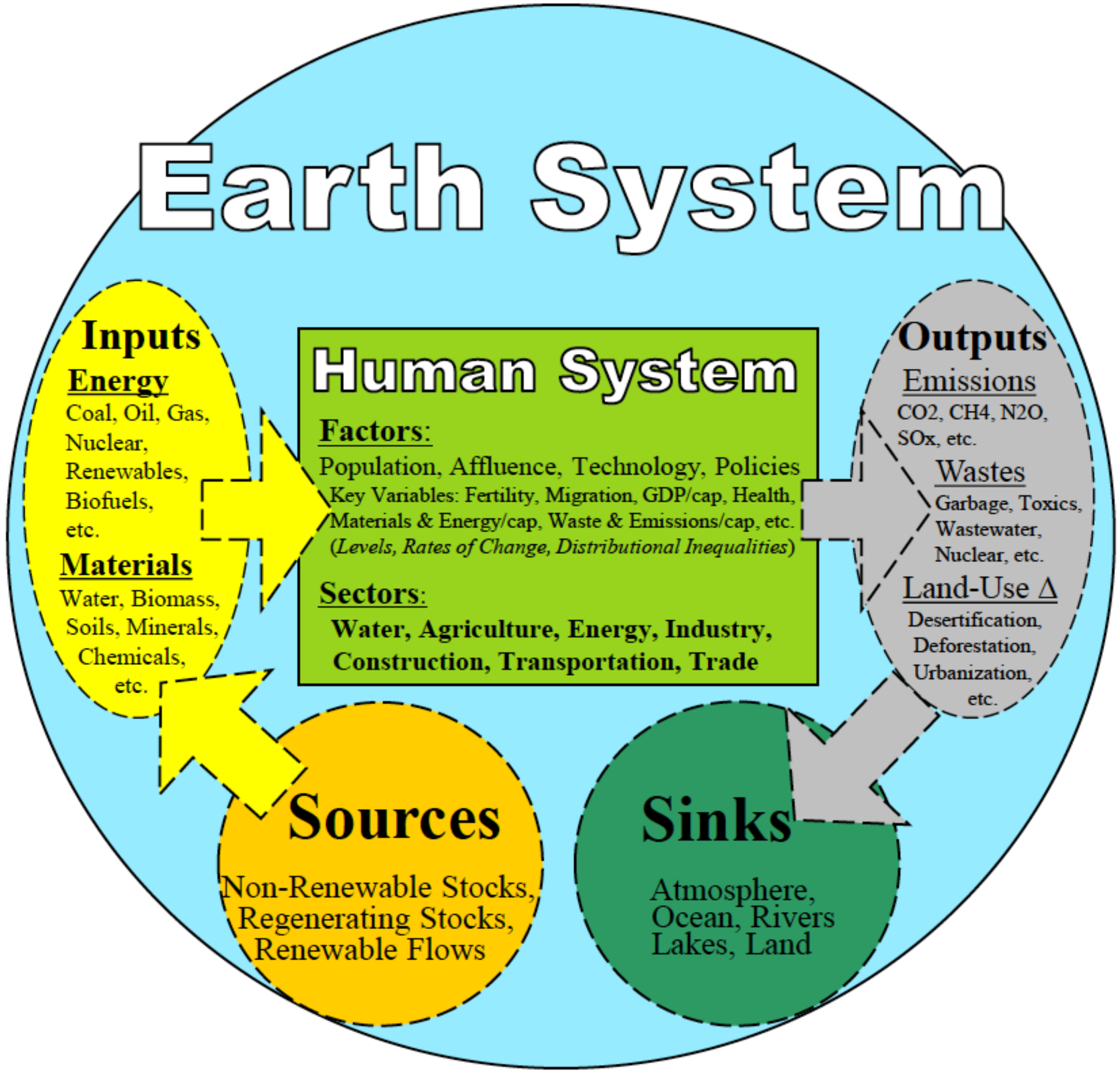
**The Past: "Empty World"**
When the Human System was small relative to the Earth System, the two could be modeled separately.

**The Present: "Full World"**
The Human System has grown so large that both must now be modeled coupled to each other.




Motesharrei, Safa, et al. "Modeling Sustainability: Population, Inequality, Consumption, and Bidirectional Coupling of the Earth and Human Systems." National Science Review (2016): nww081.

# Human System-Earth System Relationship




Motesharrei, Safa, et al. "Modeling Sustainability: Population, Inequality, Consumption, and Bidirectional Coupling of the Earth and Human Systems." National Science Review (2016): nww081.

OXFORD
UNIVERSITY PRESS

From: **Bidirectional coupling between the Earth and human systems is essential for modeling sustainability**

Natl Sci Rev. 2016;3(4):397-398. doi:10.1093/nsr/nww094

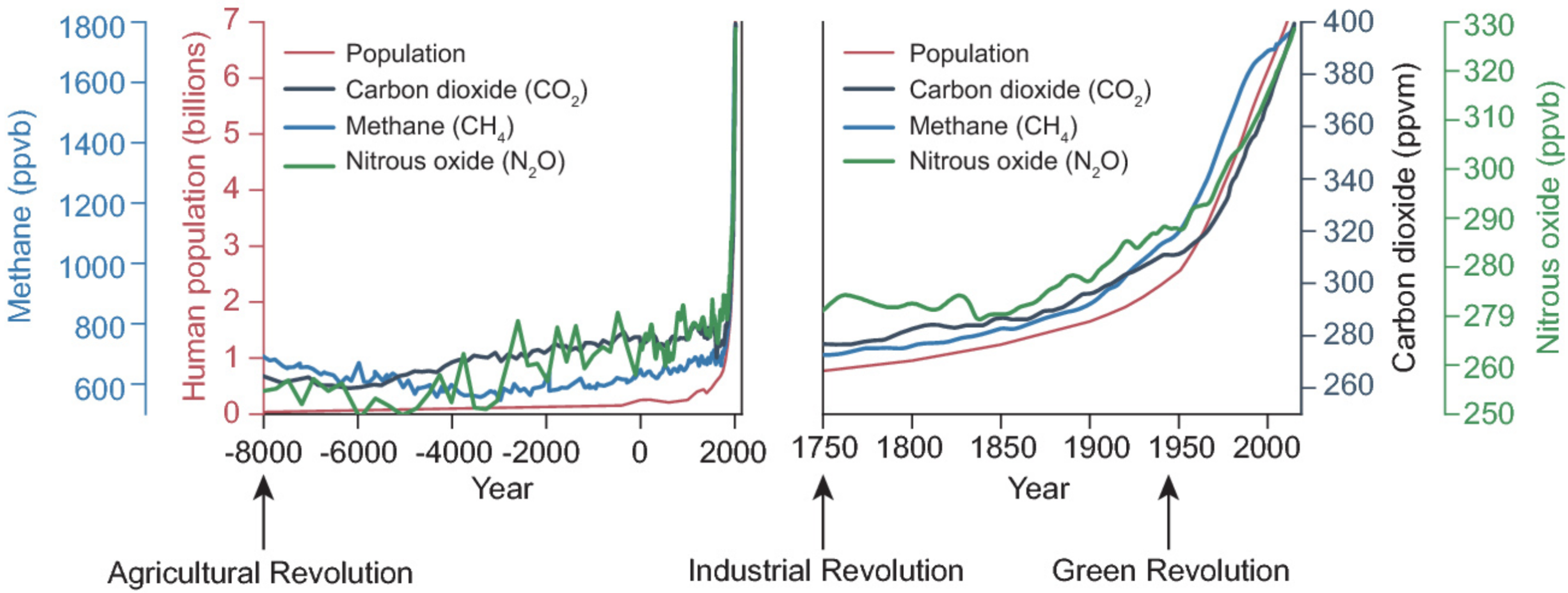



Figure Legend:

World population and atmospheric concentrations of major greenhouse gases since the beginning of the Agricultural Revolution about 10 000 years ago until the present (left), with a magnified timescale for the period after the beginning of the Industrial Revolution (right). Code, data, data sources, calculation of the rates of change and additional configurations of the figure are available at https://dx.doi.org/10.6084/m9.figshare.4029369.

# World3 was overly complex

As described in detail in —The Limits to Growth Revisited‖ [2], over the years, the debate veered more and more towards a political struggle until the study was widely rejected and forgotten in the 1990s. In general, a fundamental element of the debate was the inability of most people to understand the methods and the aims used for the LTG study.

Ugo Bardi, Florence, Italy

# Mind-sized modeling

*Sustainability* **2013**, *5*, 896-911; doi:10.3390/su5030896

OPEN ACCESS

*sustainability*

**ISSN 2071-1050**

www.mdpi.com/journal/sustainability

*Article*

## Mind Sized World Models

**Ugo Bardi**

Dipartimento di Scienze della Terra, Università di Firenze. C/o Dipartimento di Chimica, Polo Scientifico di Sesto Fiorentino, 50019, Sesto Fiorentino (Fi), Italy;
E-Mail: ugo.bardi@unifi.it; Tel.: +39-055-457-3118

*Received: 10 December 2012; in revised form: 31 January 2013 / Accepted: 8 February 2013 / Published: 4 March 2013*

---

**Abstract:** One of the factors that led to the wide rejection of the 1972 "Limits to Growth" report was the inability for most people to understand the model used in the study. In the present paper, the author builds simple "mind sized" world models designed to convey to readers the main qualitative features of world modeling. These models turn out to provide results comparable to real-world historical cases and are similar to those generated by the more complex "World3" model used for the "Limits to Growth" study.

**Keywords:** Limits to Growth; System Dynamics; world modeling

---

### 1. Introduction

When the "The Limits to Growth" (LTG) report [1] was published for the first time in 1972, it

# Components of a Mind-Sized model

(1) *Realistic*: the system should be driven by known physical laws
(2) *Simple*: it should be formed of a limited number of elements
(3) *Structured*: it should be composed of a small number of basic building blocks linked together
(4) *Testable*: the model should describe at least some historical cases.

**Figure 8.** The five-stock model, or the “Limits to Growth” model.

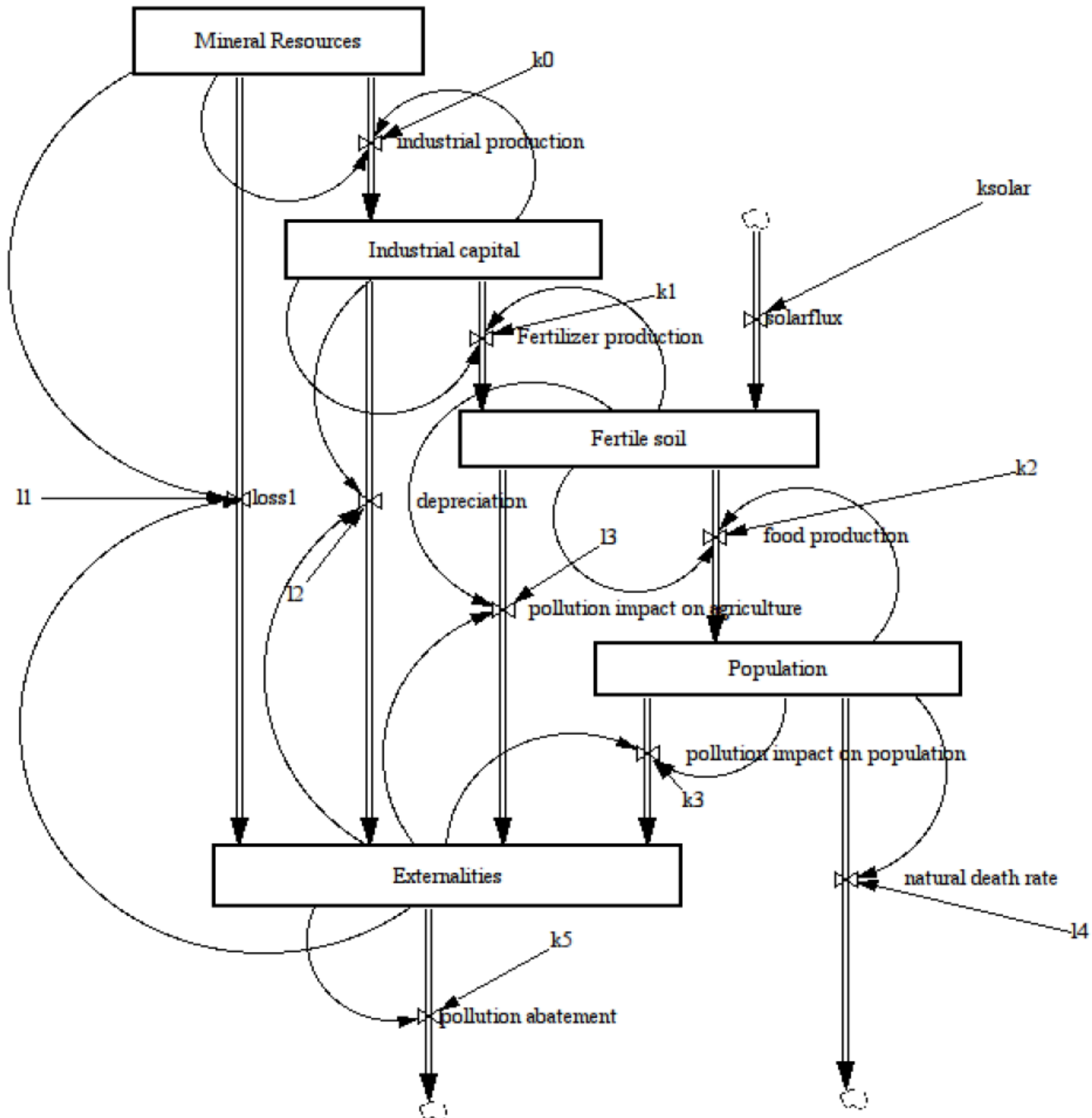
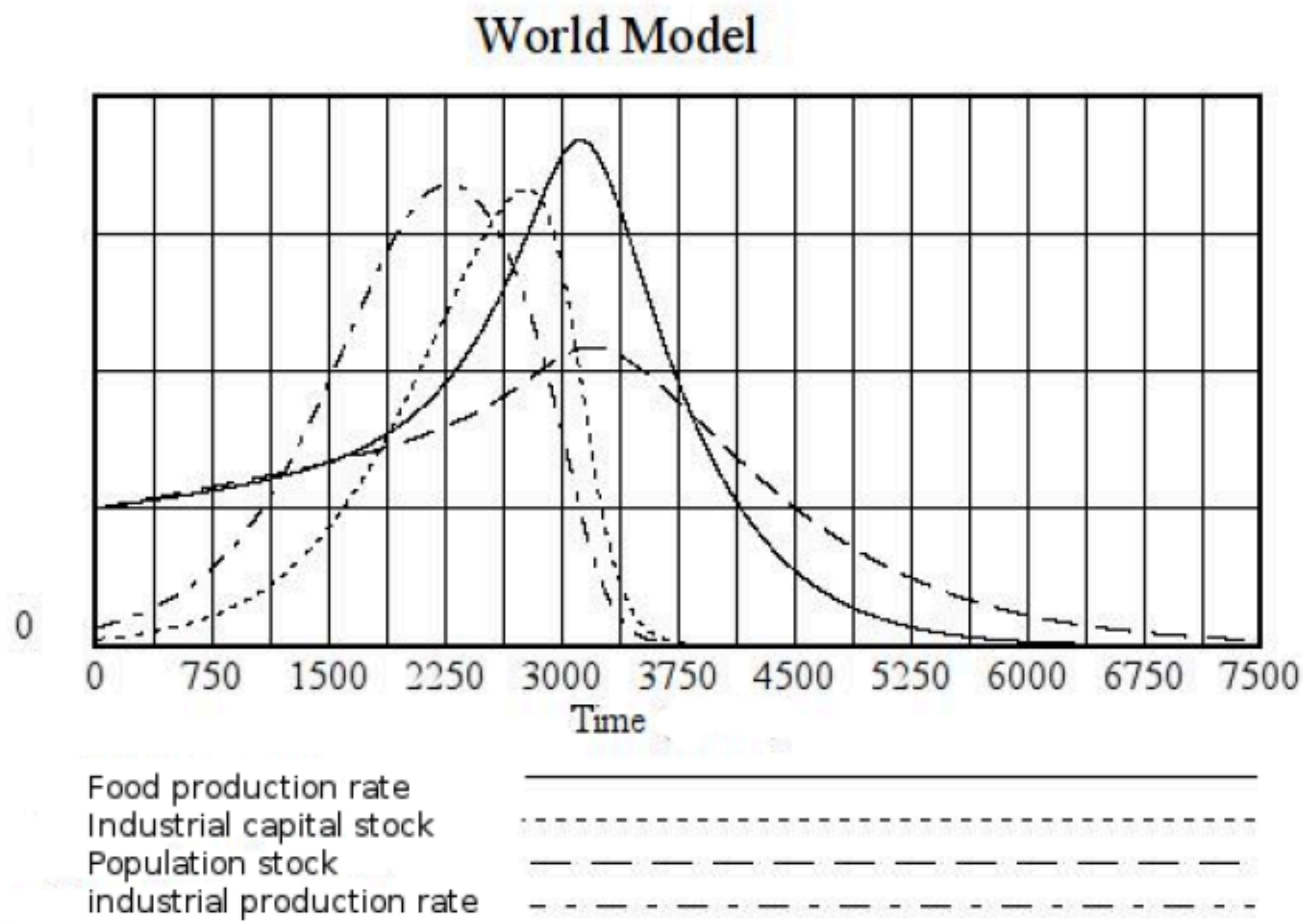


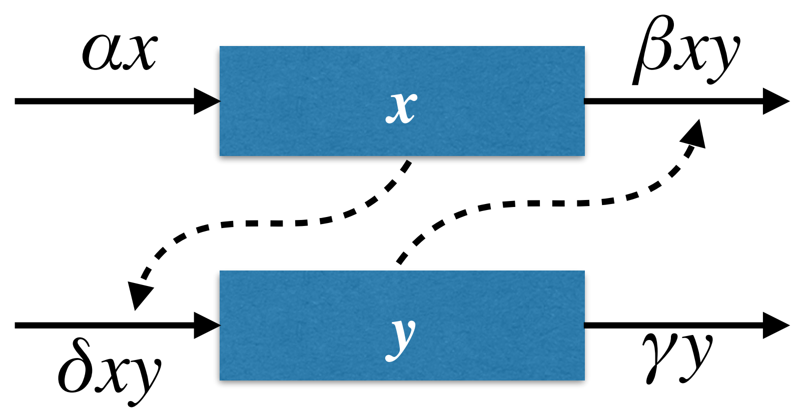
**Figure 9.** The five-stock model, typical results (this run was obtained with the following parameters: $k_0 = 2 \times 10^{-3}$, $k_1 = 1 \times 10^{-3}$, $k_2 = 5 \times 10^{-2}$, $k_3 = 1 \times 10^{-3}$, $l_4 = 3 \times 10^{-4}$. All the other constants are set to zero. Mineral resources(init) = 1, industrial capital(init) = $1 \times 10^{-2}$, fertile soil (init) = $1 \times 10^{-2}$, population (init) = $1 \times 10^{-3}$, externalities (init) = $1 \times 10^{-4}$.



# Lotka–Volterra model

$$\frac{dx}{dt} = \alpha x - \beta xy$$

$$\frac{dy}{dt} = \delta xy - \gamma y$$




insightMaker version

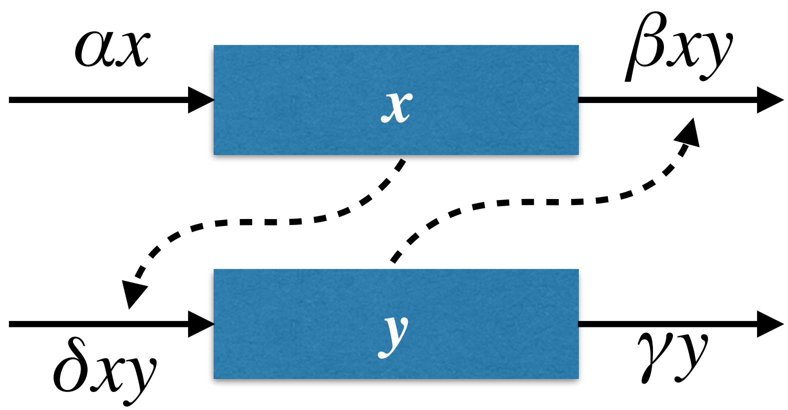
- $x$ is the number of prey (for example, rabbits);
- $y$ is the number of some predator (for example, foxes);
- and represent the instantaneous growth rates of the two populations;
- $t$ represents time; and
- $\alpha$ is the intrinsic growth rate of $x$
- $\beta$ is the predation rate of $y$ on $x$
- $\gamma$ is the intrinsic death rate of $y$
- $\delta$ is the growth rate of y due to predation of x.

# In class modeling exercise: L-V model

Make the Lotka-Voltera model in InsightMaker.
Try to find alpha, beta, delta, gamma such that x and y oscillate.

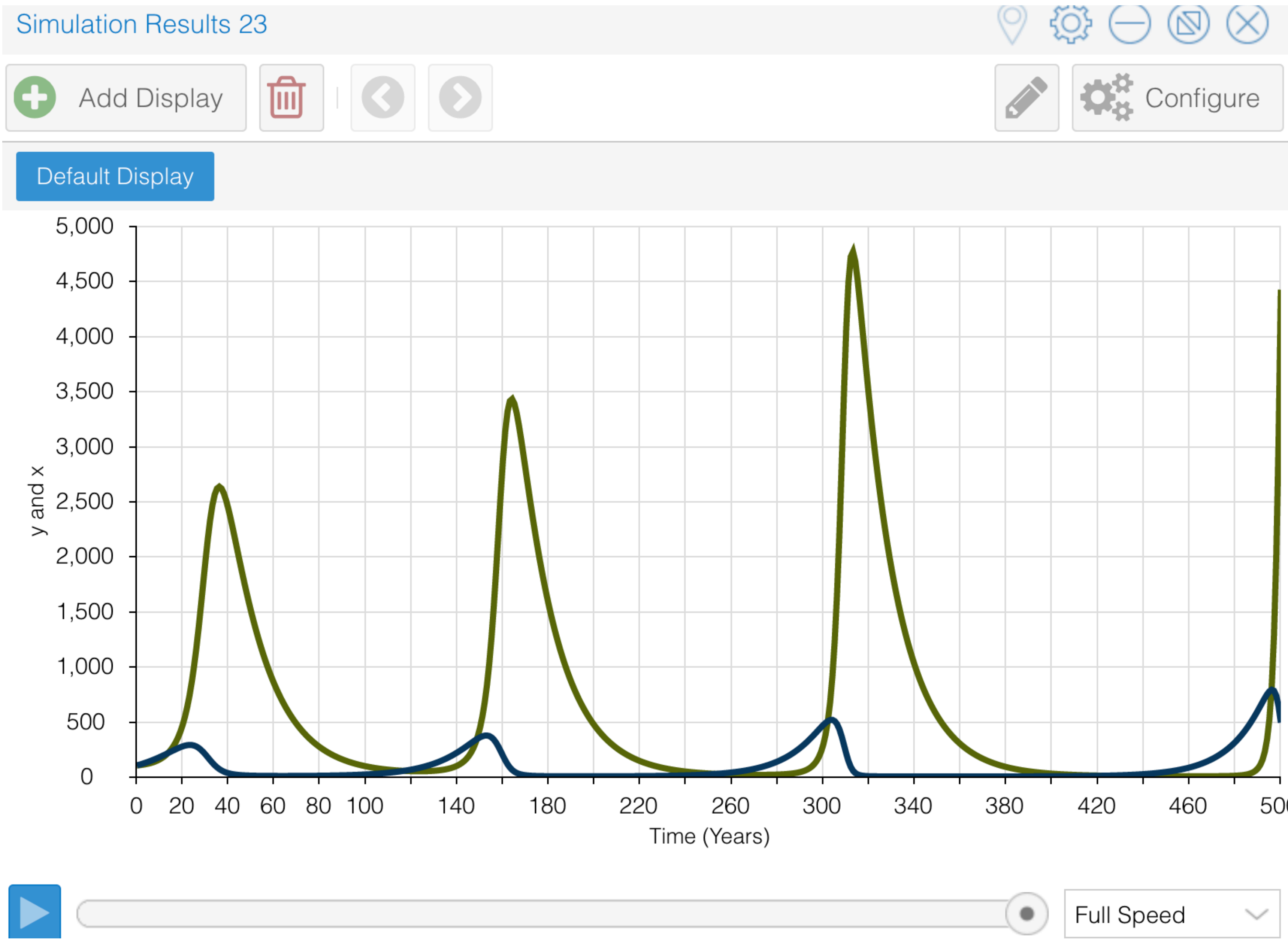
```
alpha <-
y <- alpha*[x]
return y
```

```
beta <-
y <- beta*[x]*[y]
return y
```




```
delta <-
y <- delta*[y]*[x]
return y
```

```
gamma <-
y <- gamma*[y]
return y
```




What else happens?

Everything should be as simple as possible, but no simpler. --
A. Einstein

Hey! Aren't we overmodeling human population if two simple equations reproduce 12000 years of data?

What can Lotke-Volterra tell us about our future?

# Homework 3