EARTHSYS

A Minimodel of Earth Metabolic Processe

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EXTEND is available from
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Phone: 408/365-0305
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Remarks Regarding Programs and Text

This booklet is a rewritten revision of an earlier booklet.
The calculations, calibrations, and programming of systems blocks for EXTEND have all been done over. To run these programs you need EXTEND version 3.2.1 or later and either a MacIntosh or PC computer. In addition you need the disks containing the library of object oriented programmed blocks and 4 assembled programs referred to in the booklet as follows:

For MacIntosh, the disks have:

Library of blocks for EXTEND:	File: ESlib
Screen with unconnected picture icons:	File: ESsymb
Earthsys model in picture icons :	File: EARTHSYS
Screen with unconnected general System icons:	File: ESGenS
Earthsys model in general systems symbol icons:	File: ESinGenS

For PC Windows, the disks have:

Library of blocks for EXTEND:	File: ESlib.lix
Screen with unconnected picture icons:	File: ESsymb.mox
Earthsys model in picture icons :	File: EARTHSYS.mox
Screen with unconnected general System icons:	File: ESGenS.mox
Earthsys model in general systems symbol icons:	File: ESinGenS.mox

Follow the instructions in the booklet.
To run an EXTEND model made with our preprogrammed blocks, first load Extend. Then use the library menu to load the library of blocks. Then you can display the blocks by opening the library (Library menu).
Next use the File menu to open one of the 4 programs. Or, Use the file menu to open a new model page, on which you can drag various blocks, connecting them to form a new model..

More on general systems models and simulation is found in the book:
Odum, H.T. 1994 Ecological and General Systems. Colorado Press, Niwot, Colorado, 677 pp (reprint of Systems Ecology, John Wiley, N.Y. 1983)

More on the Blocks for Extend is found in this reference:
Odum, H.T. and N. Peterson 1996 Simulation and evaluation with energy systems blocks. Ecol. Model. 93(1966):155-173.

The text and programs are commercially available as part of an educational CD for PC and MacIntosh that can be purchased from BioQUEST, 700 College St., Beloit College, Beloit, Wisconsin, 53511.

EARTHSYS Model

EARTHSYS is a minimodel of earth metabolism in the thin outer geobiosphere including photosynthetic production, input of fossil fuels, and consumption by nature and by the human urban civilization. The main processes of production and consumption are written in Figure 1.

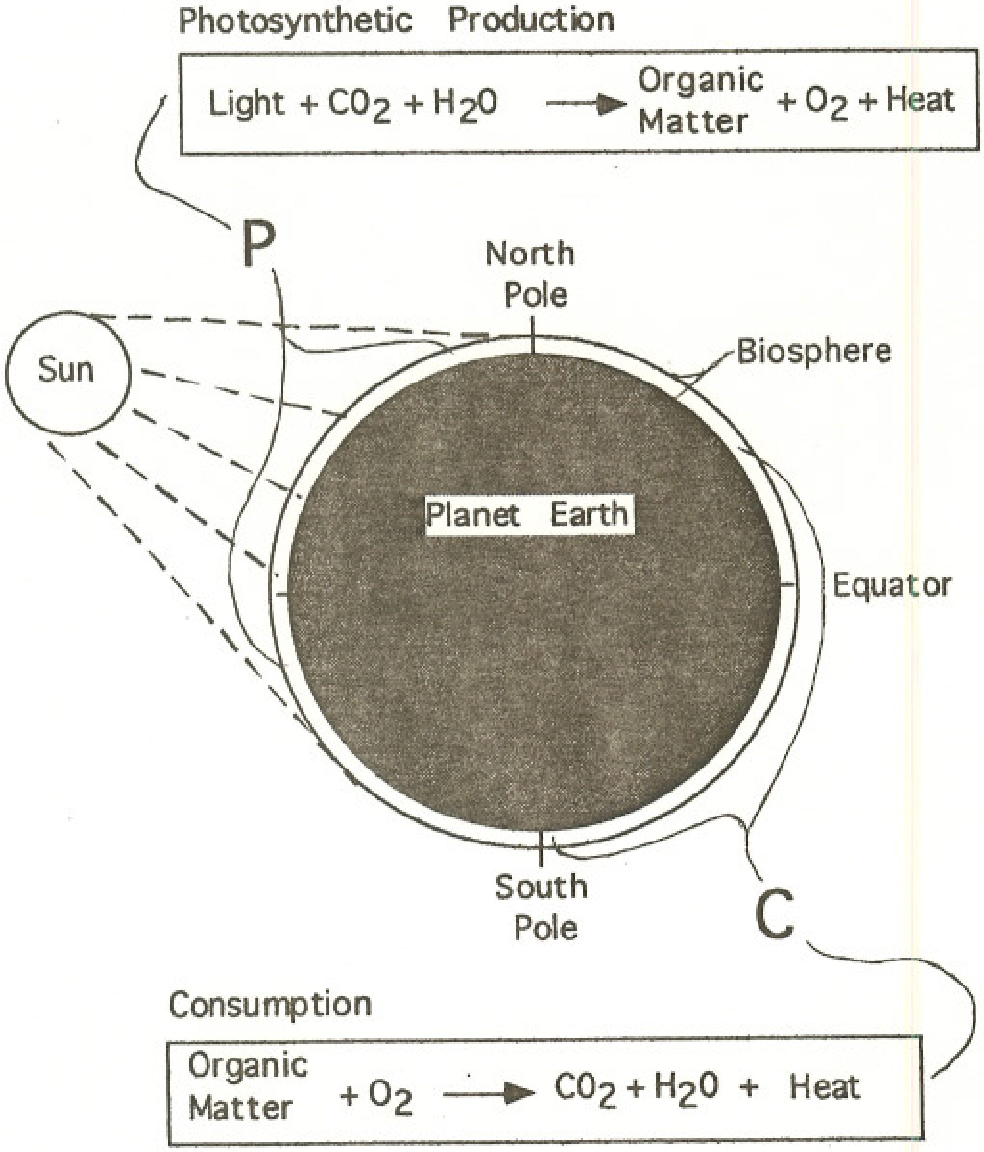


Figure 1. Production P and Consumption C on Space-ship Earth

The model is shown with an energy systems diagram in Figure 2. Plants of the earth use sunlight and carbon-dioxide to produce oxygen and plant biomass. As the plant biomass dies, it becomes dead organic matter. The consumers of the earth, including animals, microbes and cities, use the organics and oxygen to operate their growth, releasing carbon-dioxide as a by-product. Some carbon-dioxide is produced directly from plant respiration mainly at night; the two flows of carbon-dioxide from the consumers represent active and resting stages of consumption. The use of organic matter includes consumption of fossil fuels pumped from underground. Some of the carbon-dioxide is absorbed in reactions with carbonates in the ocean and alkaline soils. As the model shows there is a closed loop from production to consumption and recycle of carbon dioxide back to production.

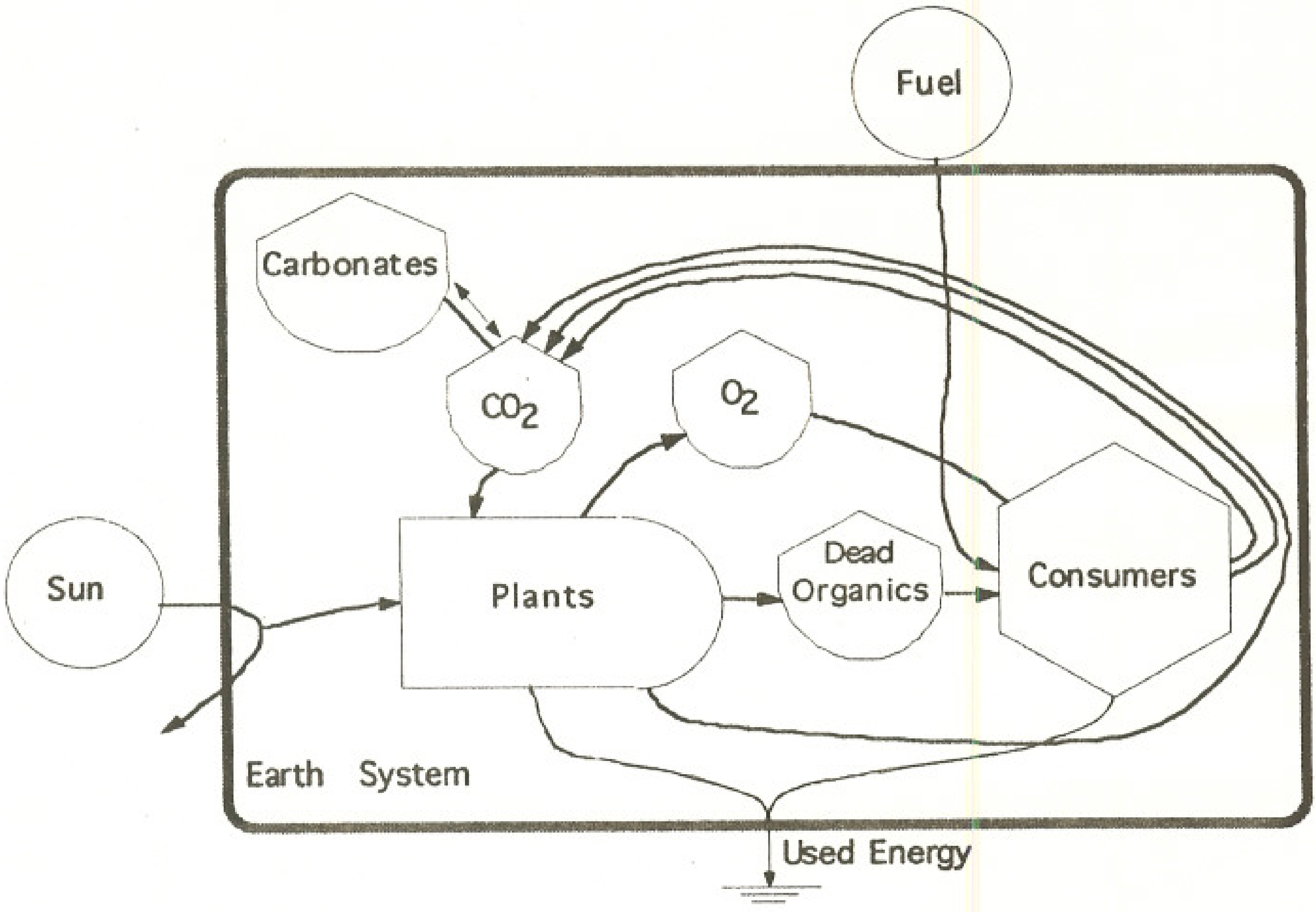


Figure 2. Systems diagram of carbon and oxygen metabolism of the biosphere using energy systems symbols.

I. System Using Picture Icons

For simulating the model with EXTEND, picture icons were developed, each programmed with its appropriate equations and calibration. These picture icons are shown in Figure 3. These blocks are stored on disk in a "library of blocks" in a named ESlib (ESlib.lix in PC).

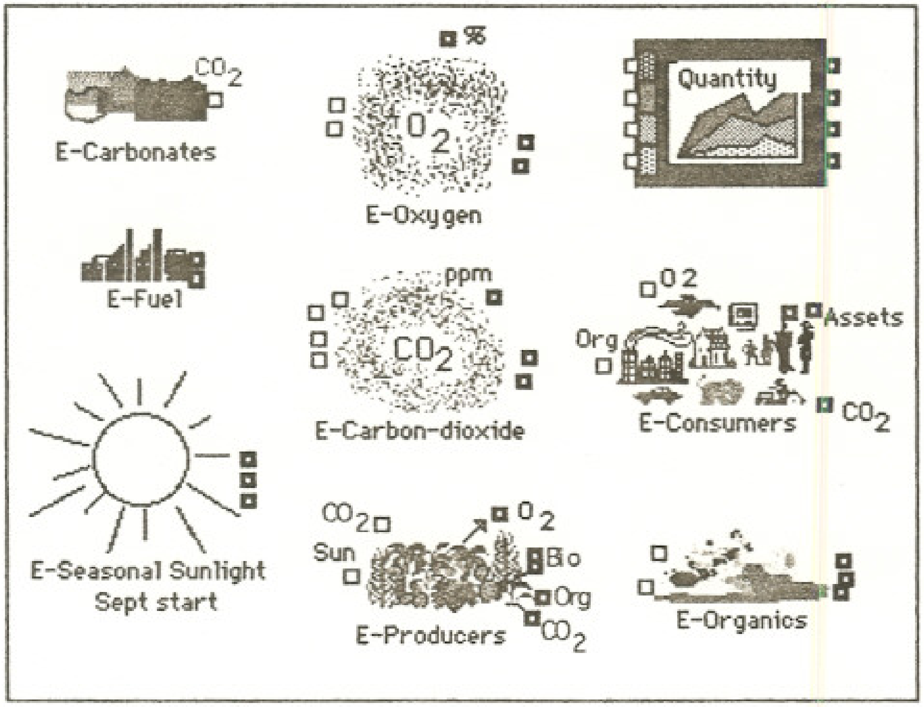


Figure 3. Blocks with pictorial icons for modeling earth system in EXTEND.

These icons were connected on the computer screen to show the system in Figure 4. The purpose of this simulation program is to understand the earth system model and experiment with it on the computer. You make simulation runs, with the software package EXTEND, using real data. Then you can try other combinations to see what might happen. You can ask real questions, like what happens to carbon-dioxide and the greenhouse effect as fuel use increases, or at the other exteme, what happens to us consumers when fuels are used up.

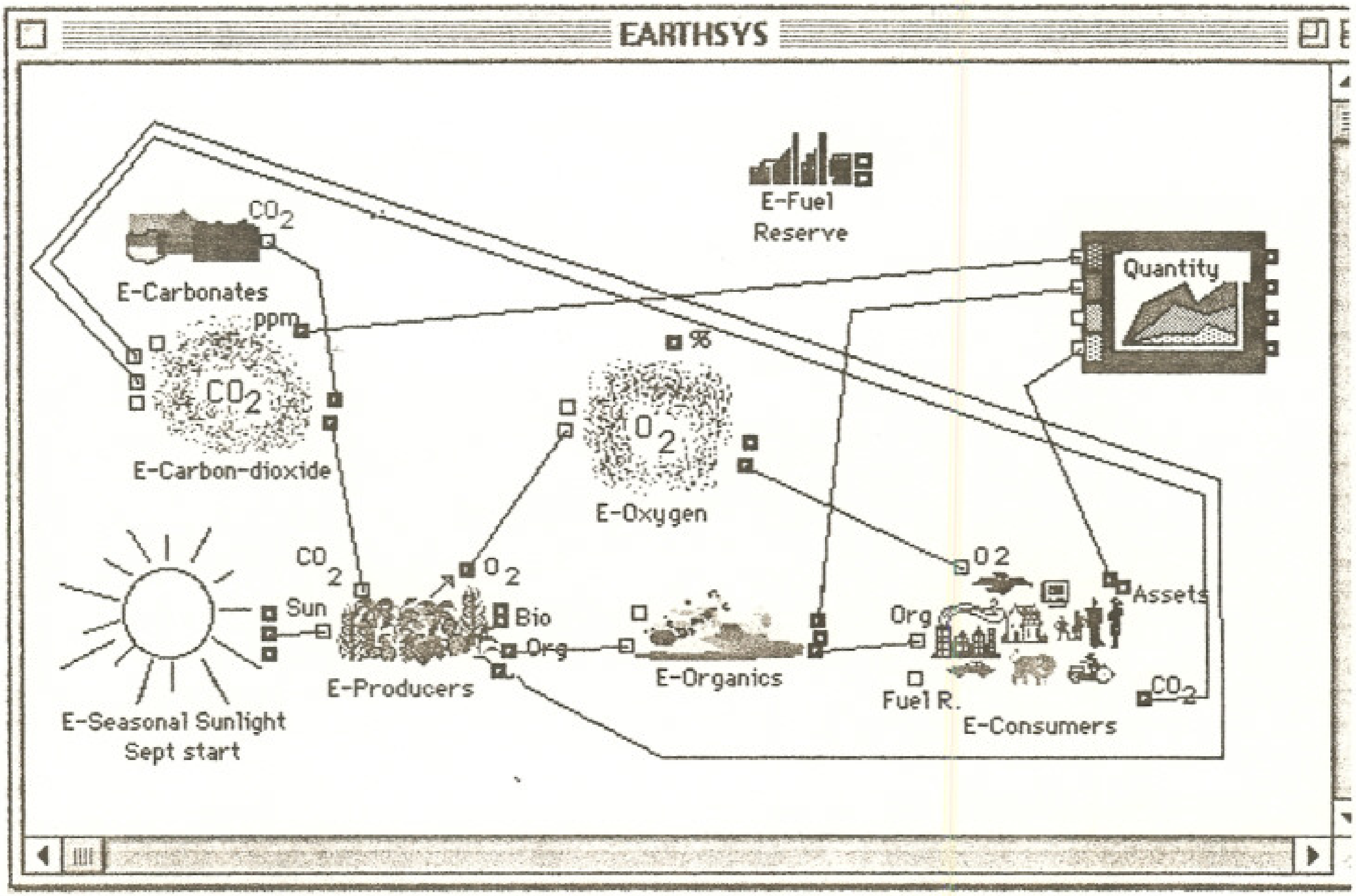


Figure 4. Computer screen with icons connected to form the EARTHSYS model (file EARTHSYS.mox on PC). Fuel Reserve is not yet connected.

System Components and Data

Each of the icon-marked blocks in the model (Figure 4) is explained next:

Sunlight
Sunlight is essential for plant production of food and oxygen. The more sunlight, the more photosynthesis. The average quantity for the earth used in the model is approximately 4000 kilocalories per m^2/day. The model starts with an average quantity for September in the northern hemisphere; this quantity is used because the greater land mass in the northern hemisphere creates an annual pulse in the total earth's production similar to that in the northern hemisphere.

Producers
The producers icon represents all the plant producers on the earth: algae, grasses, crops, shrubs, trees, and phytoplankton and plants in water. In their green cells they use sunlight and carbon-dioxide to produce oxygen and plant biomass. The inflows to the Producers icon are labeled Sun and CO_2; the quantity of plant biomass produced (to be connected to

the Plotter) is labeled Bio; and the outflows of oxygen and organic matter are labeled O_2 and Org.

Oxygen

Oxygen is about 21% of the gases in the air. The amount is so large that seasonal variations in metabolism have little effect.

Carbon-dioxide

Carbon-dioxide is about 350 ppm (parts per million) of the gases in the air. Plants use carbon-dioxide in photosynthesis to produce biomass, including food. Microbes, animals, people and industries produce carbon-dioxide from their respiration and consumption (by engines and fire).

Carbonates

Carbonates are chemical compounds found in rocks, soil and ocean water. Carbonates can absorb or release carbon-dioxide depending on its concentration. If there is an excess of carbon-dioxide in the air, carbonates will take it in; if carbon-dioxide gets low, carbonates will let it out. They act as a buffer that helps keep the carbon-dioxide at moderate levels. The rate of carbon-dioxide exchange between air and carbonates of the earth's surface is not known exactly. The carbonate icon has a dialog box in which you can change the exchange rate. Increasing the rate decreases the range of variation of carbon-dioxide in air.

Organics

Organics (dead biomass) include wood, dead leaves, twigs, roots, stumps, soil organic matter, feathers, dead animals on the ground, in the water or in the soil, ready to be decomposed and used.

Consumers

Consumers include microbes, animals, people, and industries. They use oxygen in the process of consuming dead organic matter and fuels to produce assets. Assets in the model include goods and services, processed foods, materials, buildings, infrastructure, electricity, people, education, labor and information. In the program the storage of economic assets is measured in % where 100% is the amount at present.

Fuel

Fuel includes fossil fuels: coal, oil and natural gas. Its flow is measured in kilocalories per meter squared per day (kcal/m^2/day).

Dialog Boxes

Each icon has a dialog box which appears when you double-click on the icon. Most of the dialog boxes contain the starting quantity for that component. Table 1 summarizes the starting data in the dialog boxes for the simulations in Figures 5 and 6. A more detailed diagram and calibrations are given in the Appendix.

Table 1
Starting Data in the Dialog Boxes of the Earth model

Sunlight (northern seasonal)	4000 kcal/m^2/day
Producers	800 grams/m^2
Organics	5000 g/m^2
Earth consumers (Assets)	50%
Oxygen	21%
Carbon-dioxide	300 ppm
CO_2 flow into Carbonates	0.3 g/m^2/100 ppm difference
Fuel reserve	1000 g/m^2

Simulations

Initial values were typed into dialog boxes which open when the icons are double-clicked. The first simulation run in Figure 5 is for 10 years without fossil fuel inputs. In the simulation set up in the run menu set the time per step (dt) to 1 day. The system is close to steady state, with annual oscillations of carbon-dioxide and plant organic matter due to the seasonal variation in sunlight use. Oxygen is not plotted; it was very steady at 21% by volume.

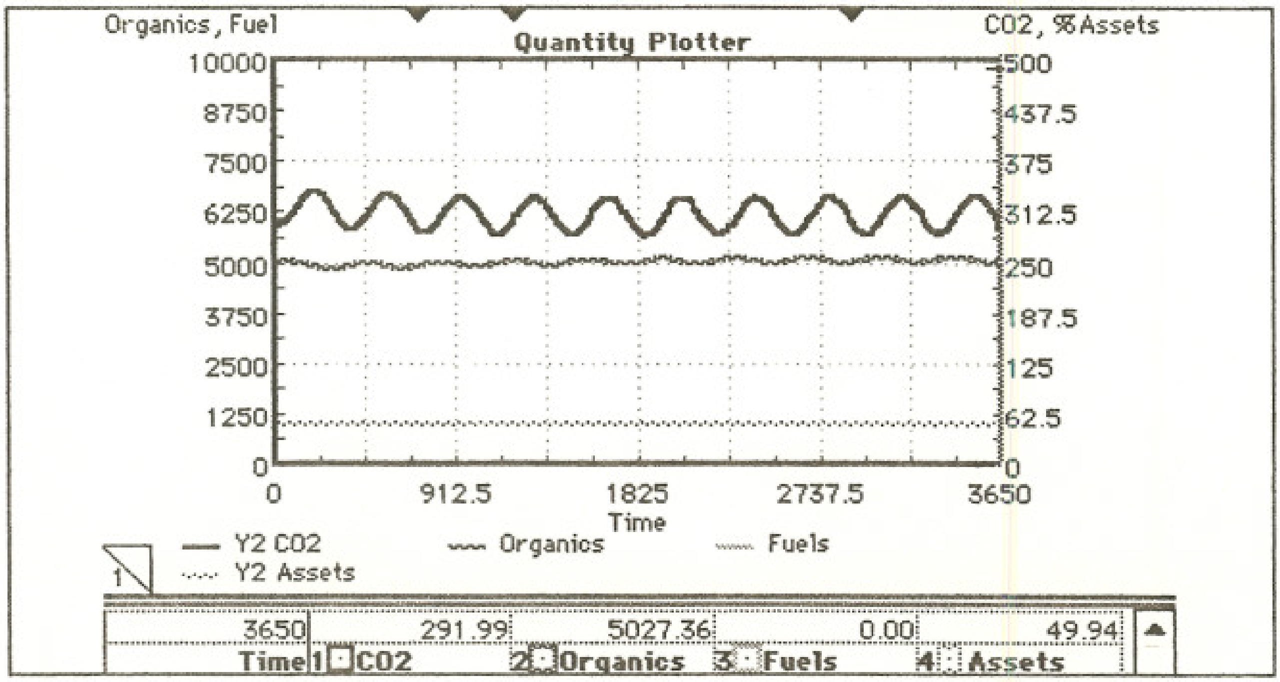


Figure 5. Simulation run of the model in Figure 4 for 10 years without fossil fuels. Organics are plotted on the left, and CO_2 and % Assets are plotted on the right.

Figure 6 shows a run with fossil fuel used by the consumers. Here the simulation set up (in the run menu) is for 36500 days (100 years) and the time step set to 5 days (dt). As fossil fuels are added, higher levels of carbon dioxide and assets result,but there are lower levels of organics (from nature). Later, as fuels are used up, carbon dioxide and assets decrease and nature starts to recover.

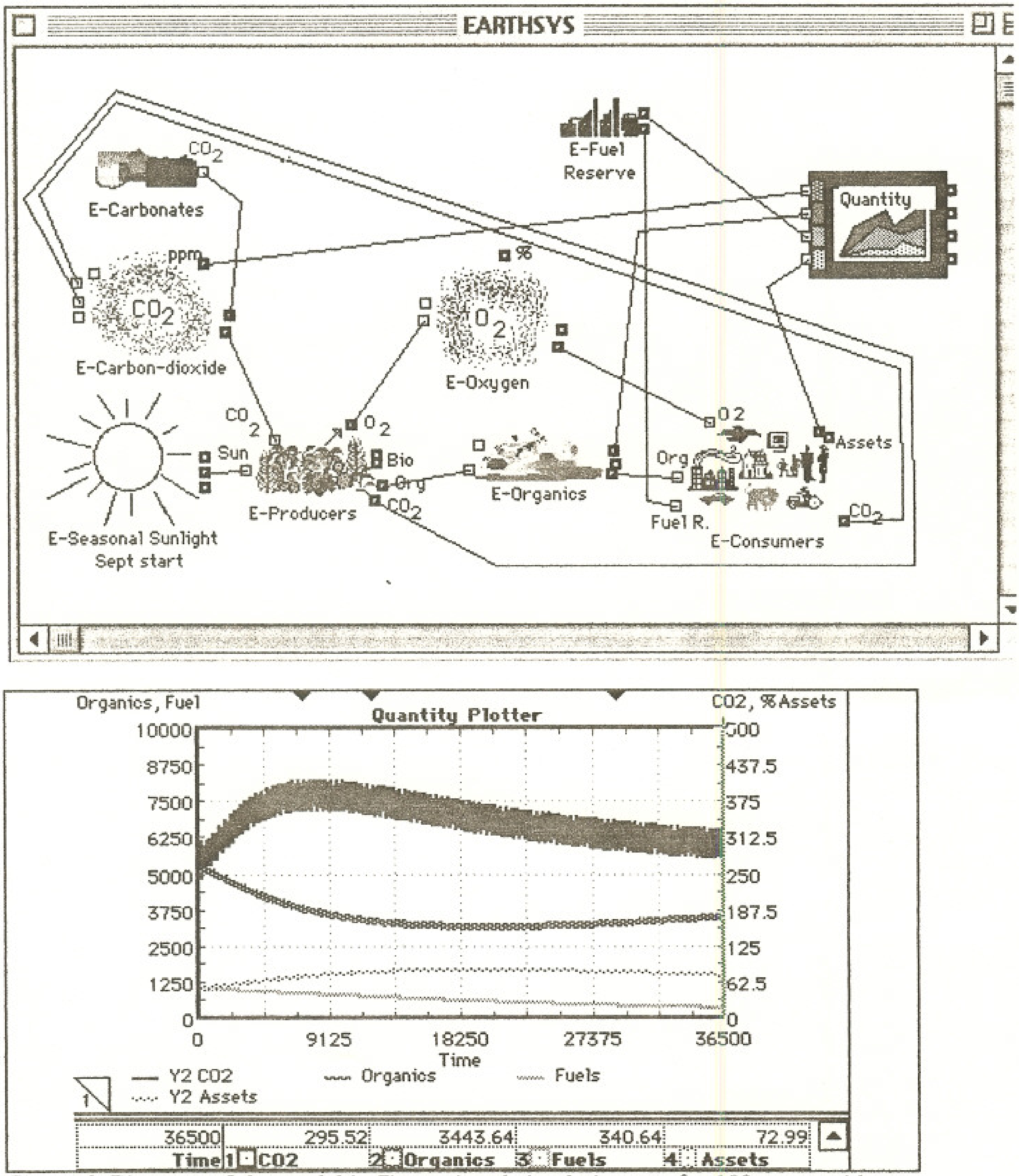


Figure 6. Diagram of the model in Figure 4 and simulation run for 100 years, with fuel reserves being used by the consumer civilization.

"What if" Questions and Simulations

It is fun to play with models as controlled experiments in which you change one factor at a time to learn the effect and sensitivity of response. You can change the starting conditions, change pathways, and add or subtract blocks.

Try these and then your own!

1. What would happen if the flow of CO_2 into the carbonates is disconnected?
2. What would happen to the CO_2 if the fossil fuel reserve is decreased? How might this change the greenhouse effect?
3. How would assets change if something reduces the sunlight availability by half (half the forests are cut and land for production is paved over)?
4. What would happen if the CO_2 exchange rate is decreased?
5. If you are using the BioQUEST programs, load SimBio2. It produces simulations of Biosphere 2, the enclosed glass earth in Arizona. Compare the graphs for Biosphere 1 (the earth) with those for Biosphere 2. The changes in CO_2 and O_2 are different. With less storage in the smaller air space, metabolism causes larger changes in oxygen and carbon-dioxide concentration.

II. General Systems Blocks

The special picture icons in Figures 3, 4 and 6 were programmed with their numbers and calibration hidden within each icon. Only the starting conditions were left to be set by the user (typing the number in the dialog box of each icon). The EARTHSYS model can also be run for EXTEND using general systems blocks. Energy systems diagrams have been widely used to represent systems. For example, see Figures 2 and 7. General symbol blocks have icons of the energy systems language (Figure 8). These blocks have the mathematical behavior of these symbols programmed inside.

The EARTHSYS model is drawn with the symbols in Figure 7. There are seven tank symbols that represent storages (stocks). On the left is the external source of sunlight with the circular source symbol. Three of the symbols are pointed blocks, interaction symbols, where inputs of different kinds combine to generate a productive output to the right. Pathways represent the flow of sunlight, materials, dead organics, oxygen (O_2), carbon-dioxide (CO_2), etc. Everything going in and out of a storage tank is of the same kind. At the bottom the thin lines converge to a heat sink symbol representing the "used energy" leaving the system, degraded in quality, unable to do further work. The language of symbols is called an energy systems language because all storages and all pathways have some energy.

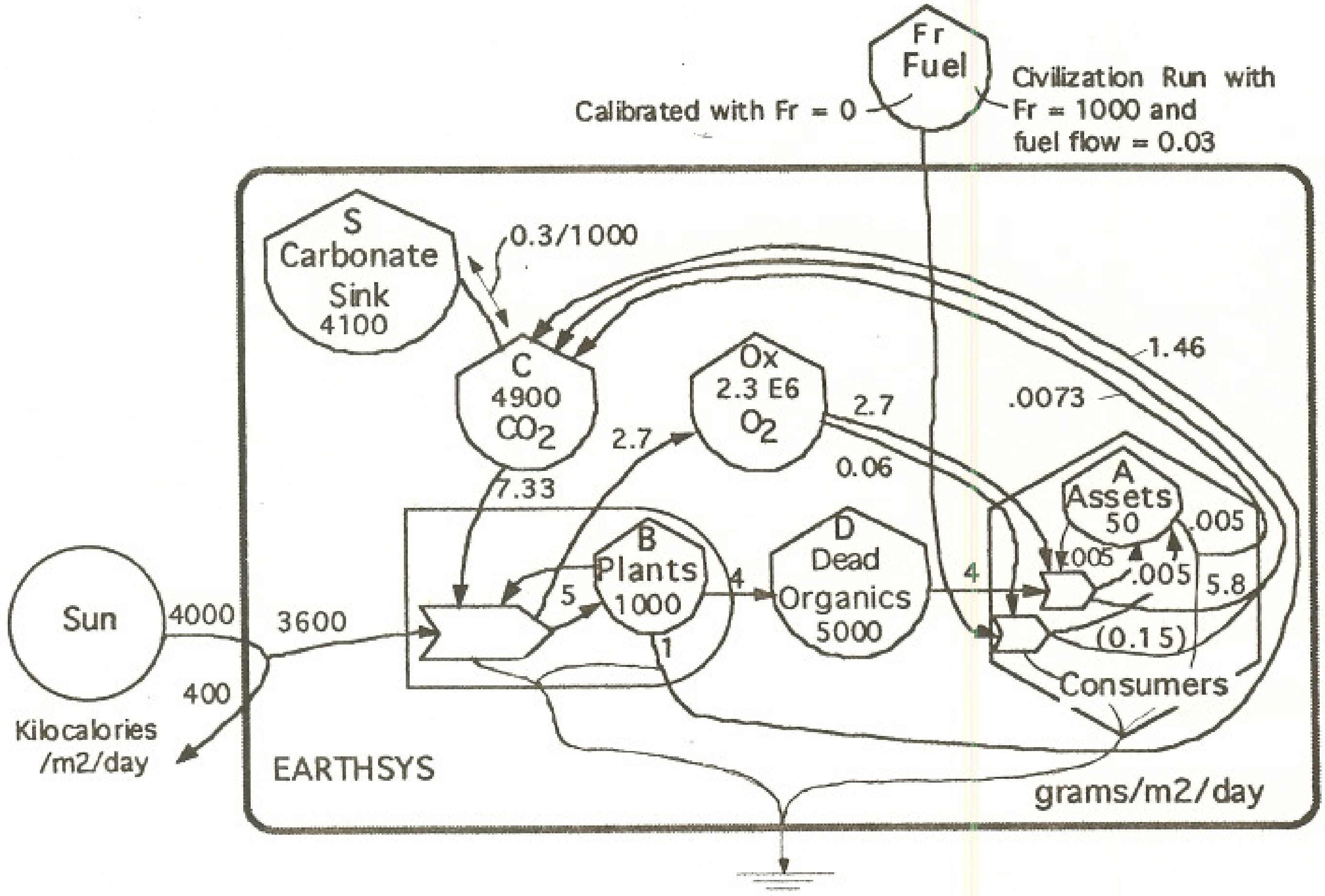


Figure 7. EARTHSYS model drawn with energy systems symbols with the numbers used to calibrate the model.

In order to make the model quantitiative, numbers are drawn on the diagram, which makes it easy to visualize flows, storages and their relationships. Numbers in the tanks are the quantities stored there in grams per square meter (g/m2). Numbers on the pathways are rates of flow in grams per square meter per day (g/m2/day), except sunlight inflows, which are in kilocalories per square meter per day. The numbers come from Table 2 in the Appendix.

The energy systems symbols were programmed for EXTEND, and those blocks needed for EARTHSYS are shown in Figure 8 from the EARTHSYS library. After loading EXTEND version 3.2, these blocks were assembled by opening (loading) the ESlib library (EARTHLIB.lix for PC). Using the library menu, these symbols were pulled down to the computer screen. In Figure 8 they are given without any connections between them. You can get this screen by running program file ESgenSym (ESgenSym.mox for PC) . Notice the clear connectors for inputs and black connectors for outputs. Connectors that require a "force" type of exchange are marked fc; those that require a "flow" of something are marked fl.

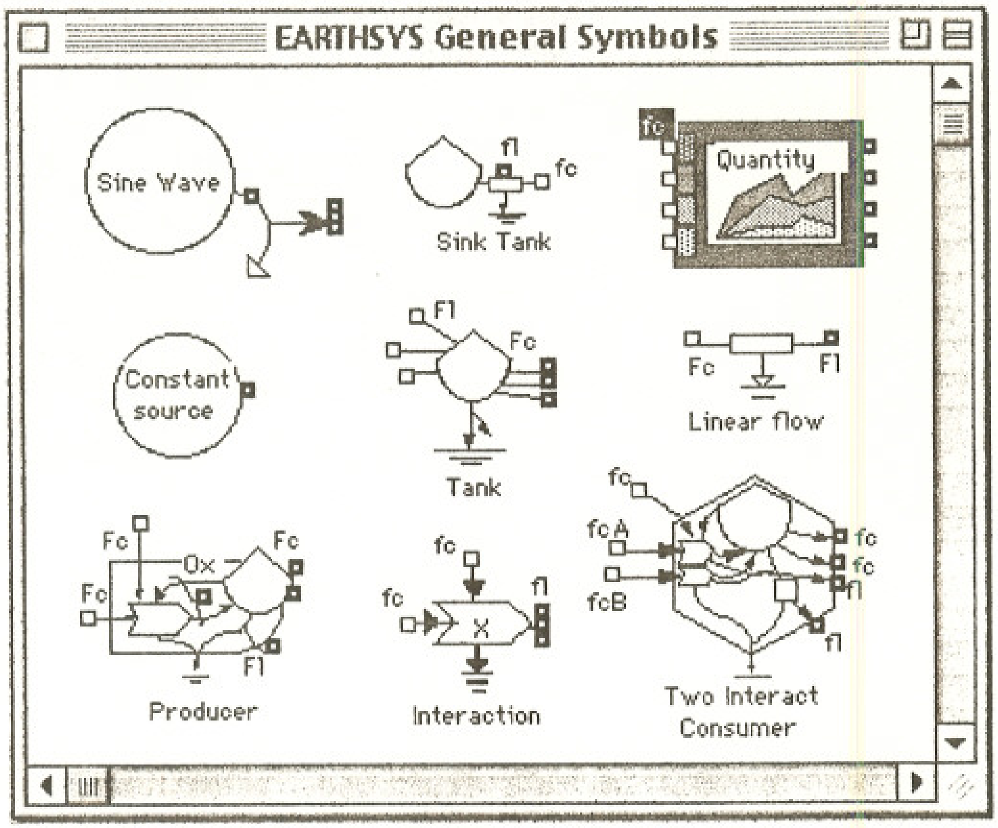


Figure 8. Icons of the general systems blocks from the EARTHSYS library programmed for EXTEND.

The general systems symbols were combined and connected in Figure 9 to form the Earthsys model in general symbols, file ESinGenS (ESinGenS.mox for PC). You can compare the symbols and pathways in Figure 9 with those illustrated in Figure 7. The quantity plotter-block has four input connectors. Whatever quantities (fc) are connected will be plotted on a graph automatically during simulation.

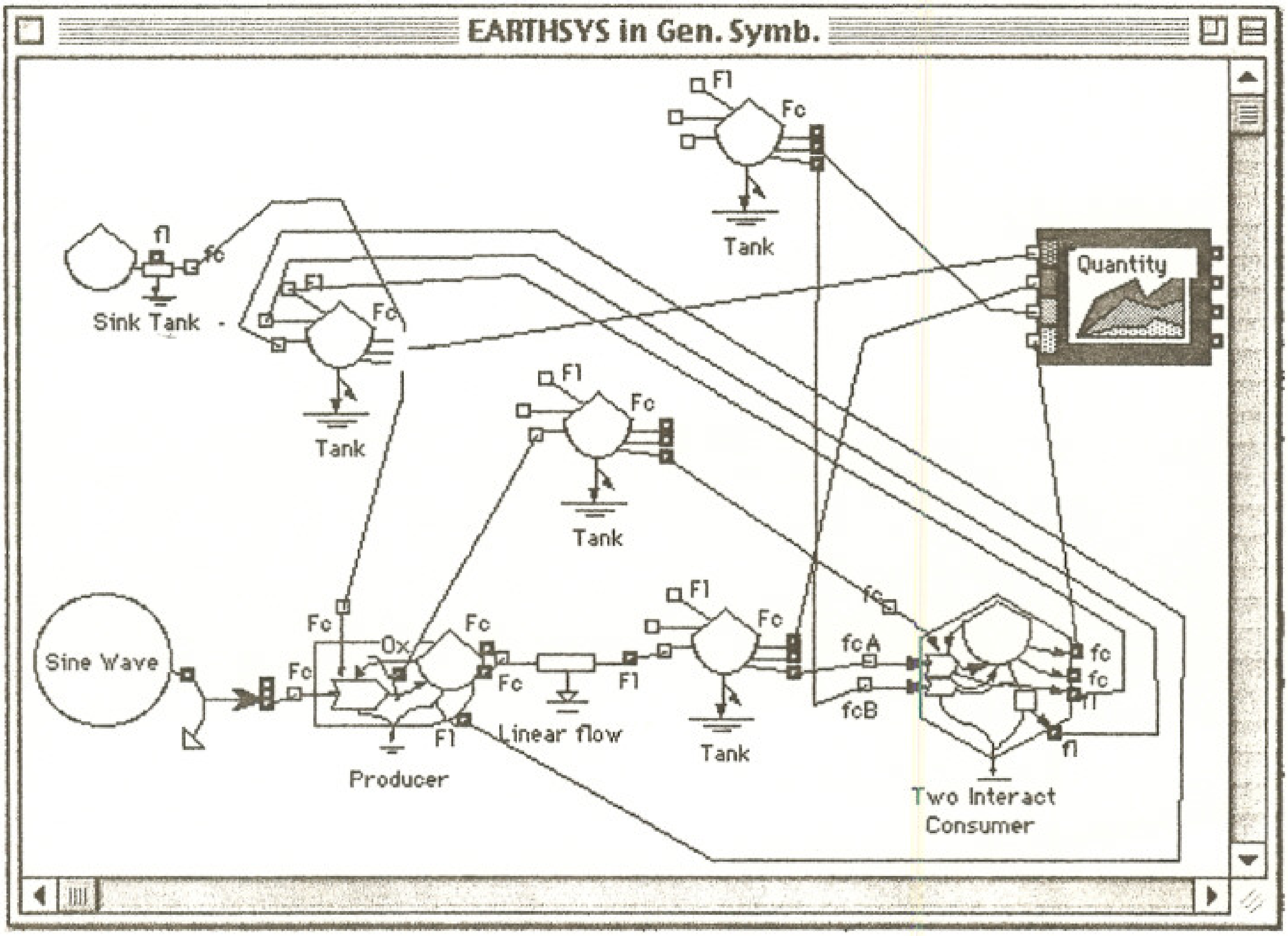
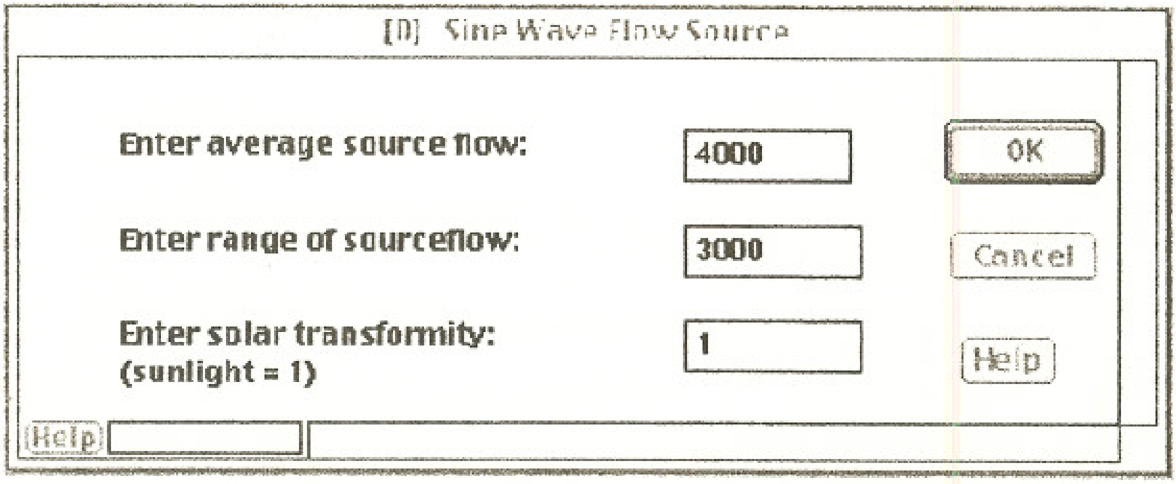


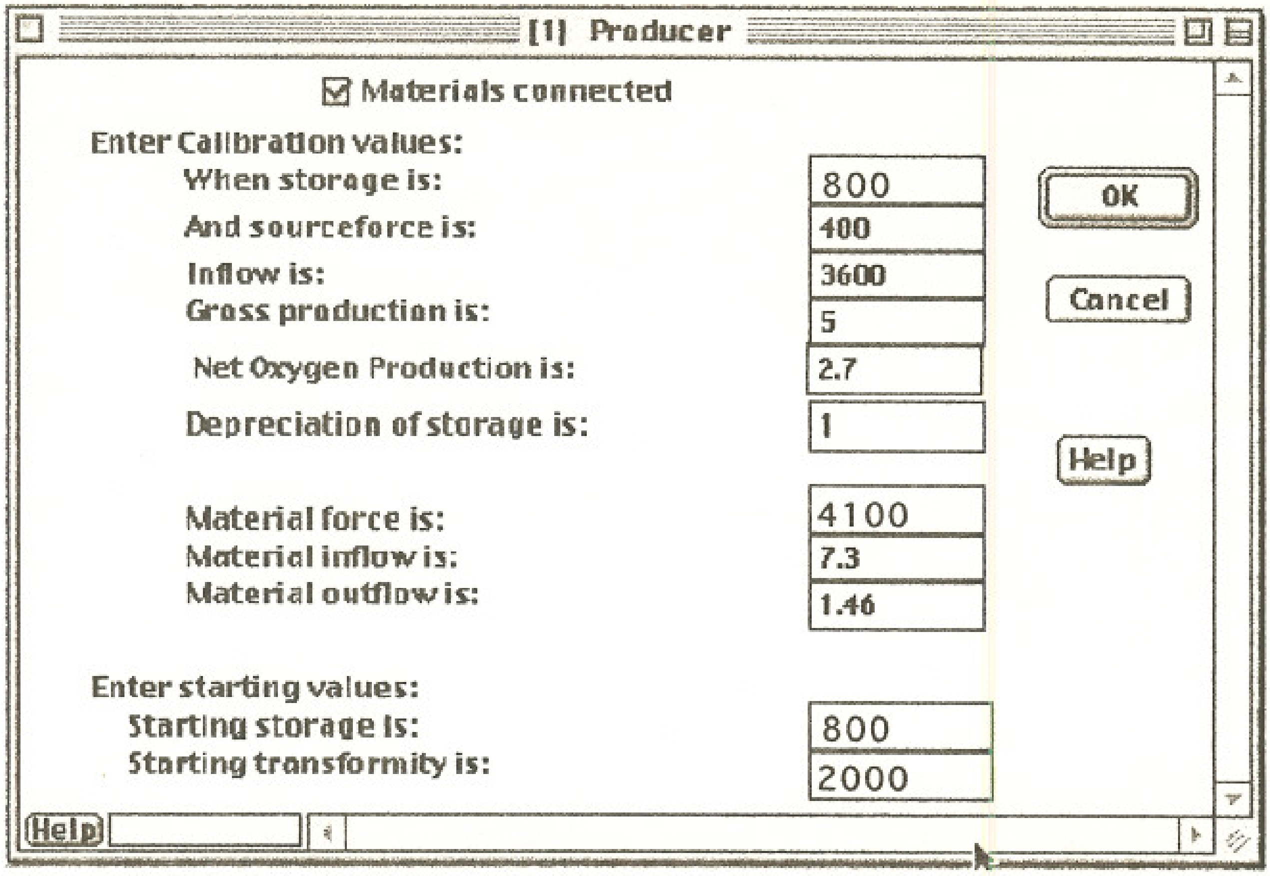
Figure 9. Computer screen of the program EXTEND with general systems blocks from the ESLIB library (ESLIB.lix in PC) arranged and connected to form the EARTHSYS model.

Calibration

With the general systems blocks, the numbers for calibration are not programmed into the block but are typed into the dialog box of each block. Double-clicking on each symbol icon will open its dialog box. With the diagram that has the calibration numbers (Figure 7) in front of you, copy these numbers for storages and flows into the dialog boxes. The block does the rest, calculating coefficients, connecting equations and simulating. Dialog boxes for the EARTHSYS model with the calibration numbers are given in Figure 10a-g so that you can check your entries.

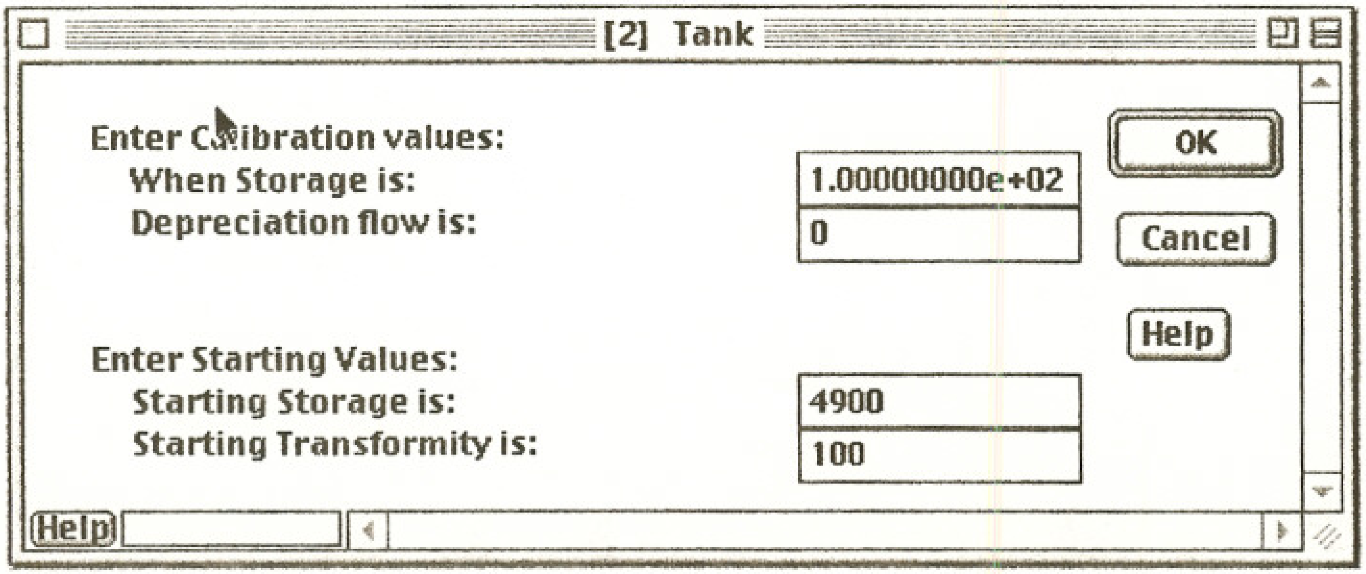


(a)

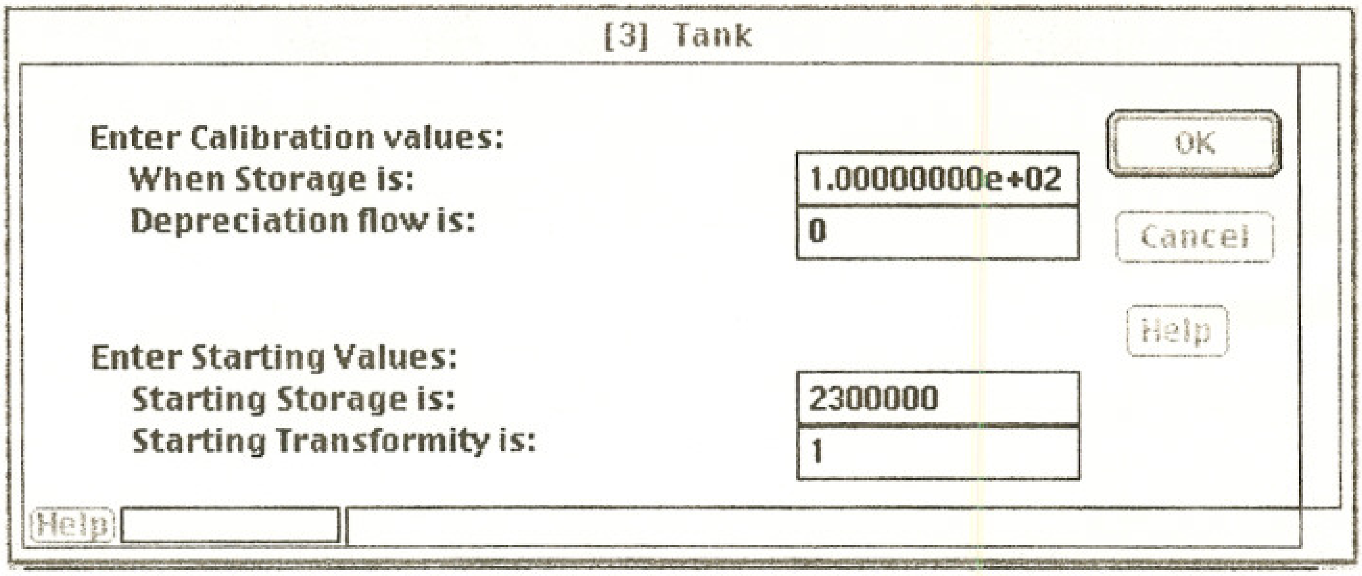


(b)

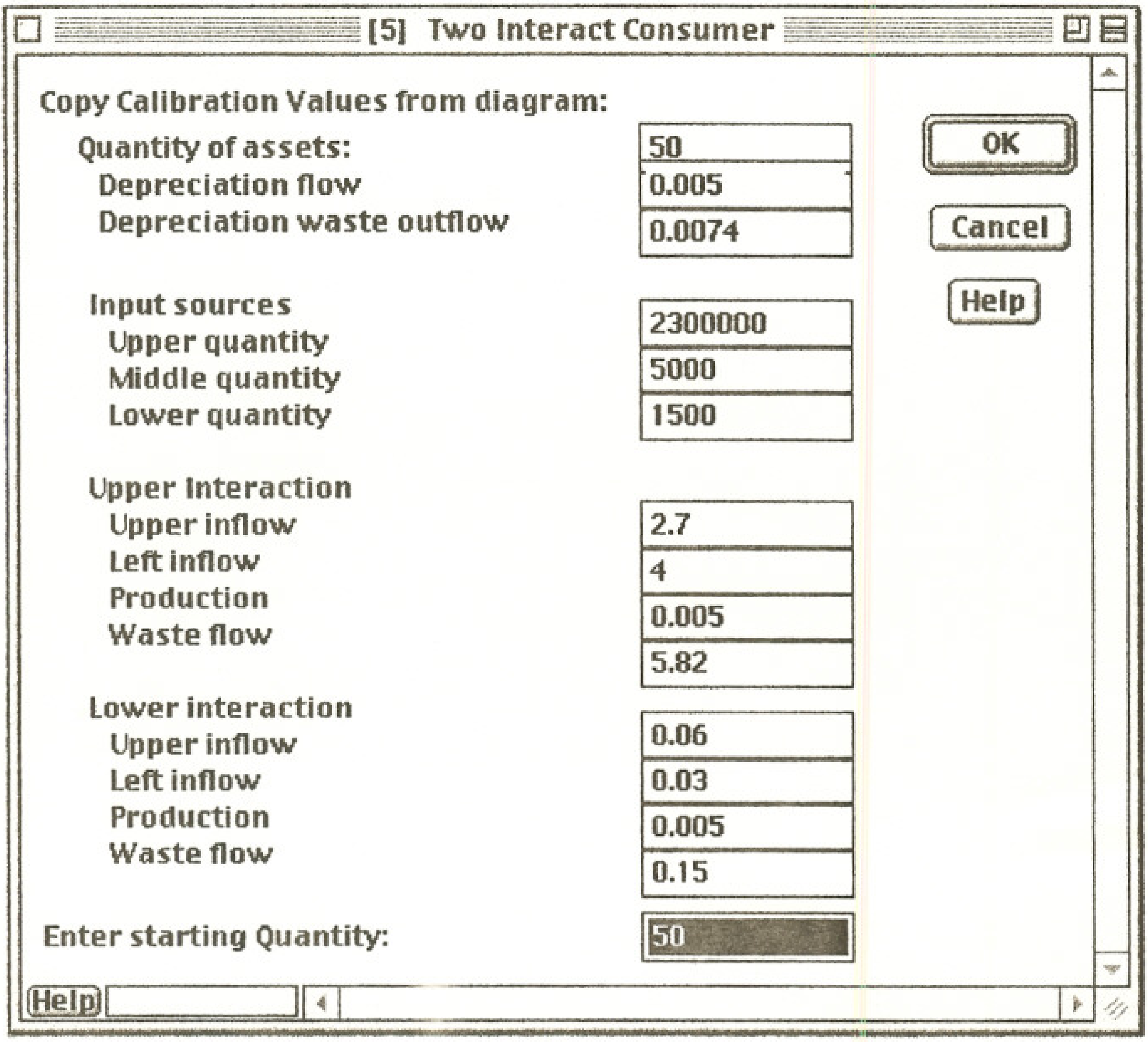
Figure 10a-g Dialog boxes for the energy systems blocks in the EARTHSYS model in Figure 9 using numbers from Table 2 (Appendix)


[2] Tank
Enter Calibration values:
When Storage is:
Depreciation flow is:
1.00000000e+02
0
OK
Cancel
Help
Enter Starting Values:
Starting Storage is:
Starting Transformity is:
4900
100
Help

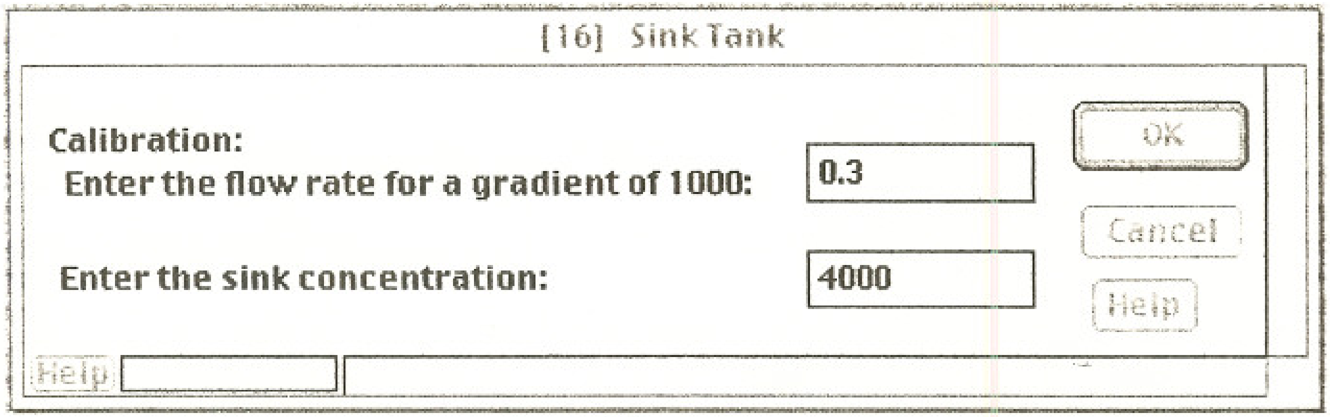
(c)


[3] Tank
Enter Calibration values:
When Storage is:
Depreciation flow is:
1.00000000e+02
0
OK
Cancel
Help
Enter Starting Values:
Starting Storage is:
Starting Transformity is:
2300000
1
Help

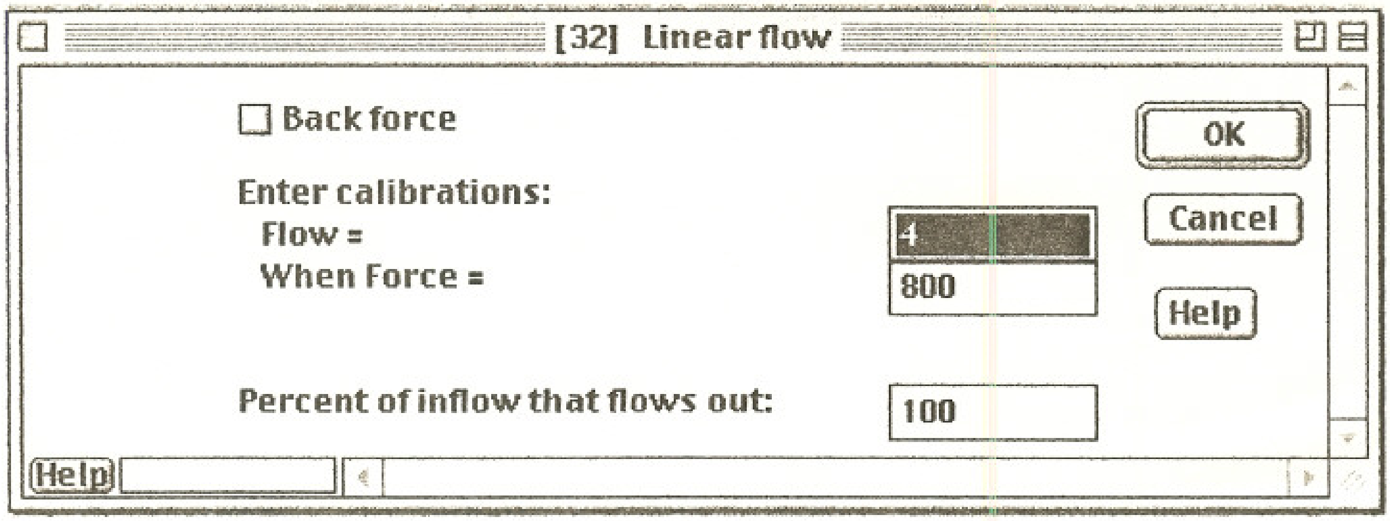
(d)


[5] Two Interact Consumer
Copy Calibration Values from diagram:
Quantity of assets:
Depreciation flow
Depreciation waste outflow
50
0.005
0.0074
OK
Cancel
Help
Input sources
Upper quantity
Middle quantity
Lower quantity
2300000
5000
1500
Upper Interaction
Upper inflow
Left inflow
Production
Waste flow
2.7
4
0.005
5.82
Lower interaction
Upper inflow
Left inflow
Production
Waste flow
0.06
0.03
0.005
0.15
Enter starting Quantity:
50
Help

(e)



(f)



(g)

Simulation

Next use the run menu to start the simulation. After numbers are in the dialog boxes, go to the Simulation Setup in the Run Menu and set the time. The time units there corresponds to the time used in the calibration, in this case days. Setting the time for 3650 days produces a graph for 10 years. You can either use the model with dialog boxes that you typed in or use the file menu to open the ready-made Earthsys model in general symbols, file ESinGenS (ESinGenS..mox in PC). Simulation generates a graph with four lines for the four quantities connected to the quantity plotter. You can print out the graph with print plotter on the print menu.

Figure 11 is a simulation run with general systems model as calibrated running on sunlight without the fuel reserve connected. Because the general symbols are plotting grams per square meter instead of parts per million, the output looks a litte different from the same run with the picture symbols in Part I Figure 5.

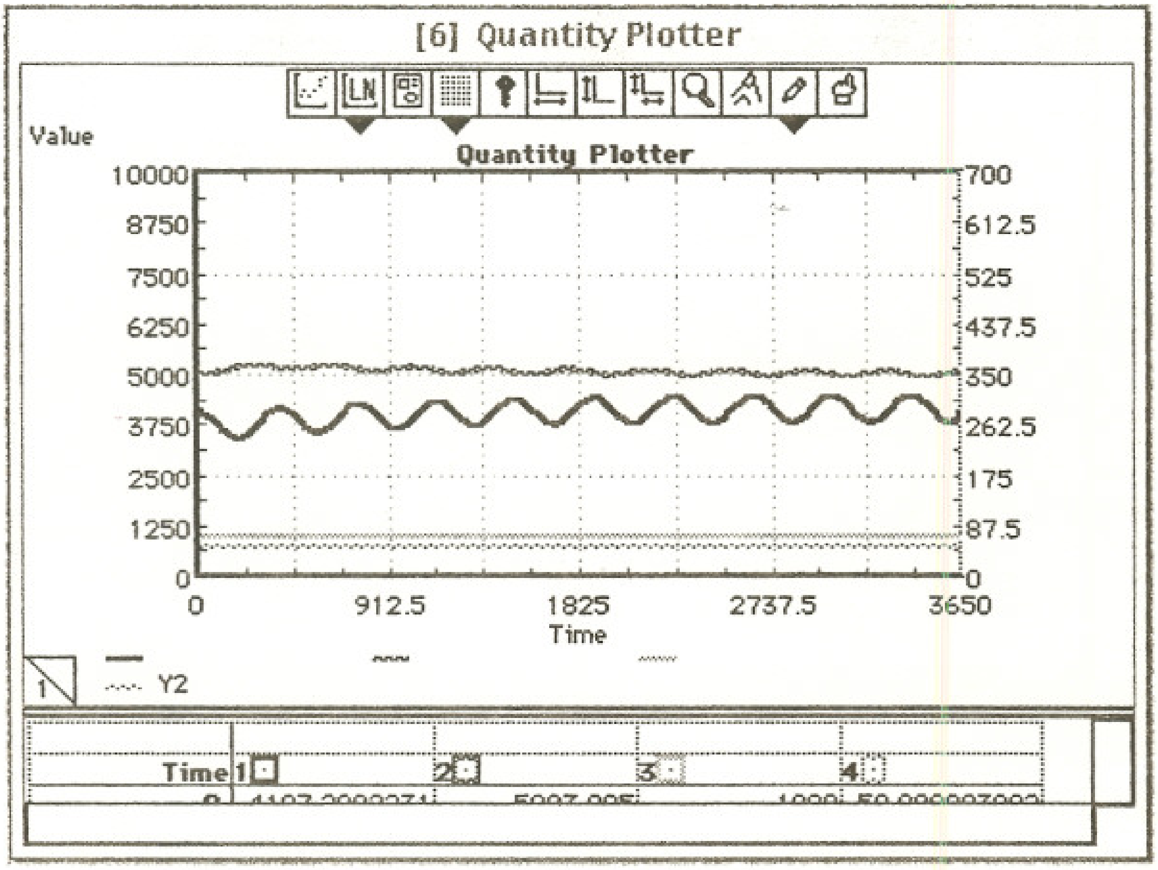


Figure 11 Graph produced by simulating the model in Figure 9 with the calibration numbers in the dialog boxes of Figure 10 but with Fuel reserve disconnected.

Next connect the fuel reserve to the lower input of the two interact consumer block and run again. Increase the simulation time and time step (dt) to run for 36500 days (100 years). Is this graph similar to the fuel-driven rise and decline of civilization assets in Part I Figure 6?

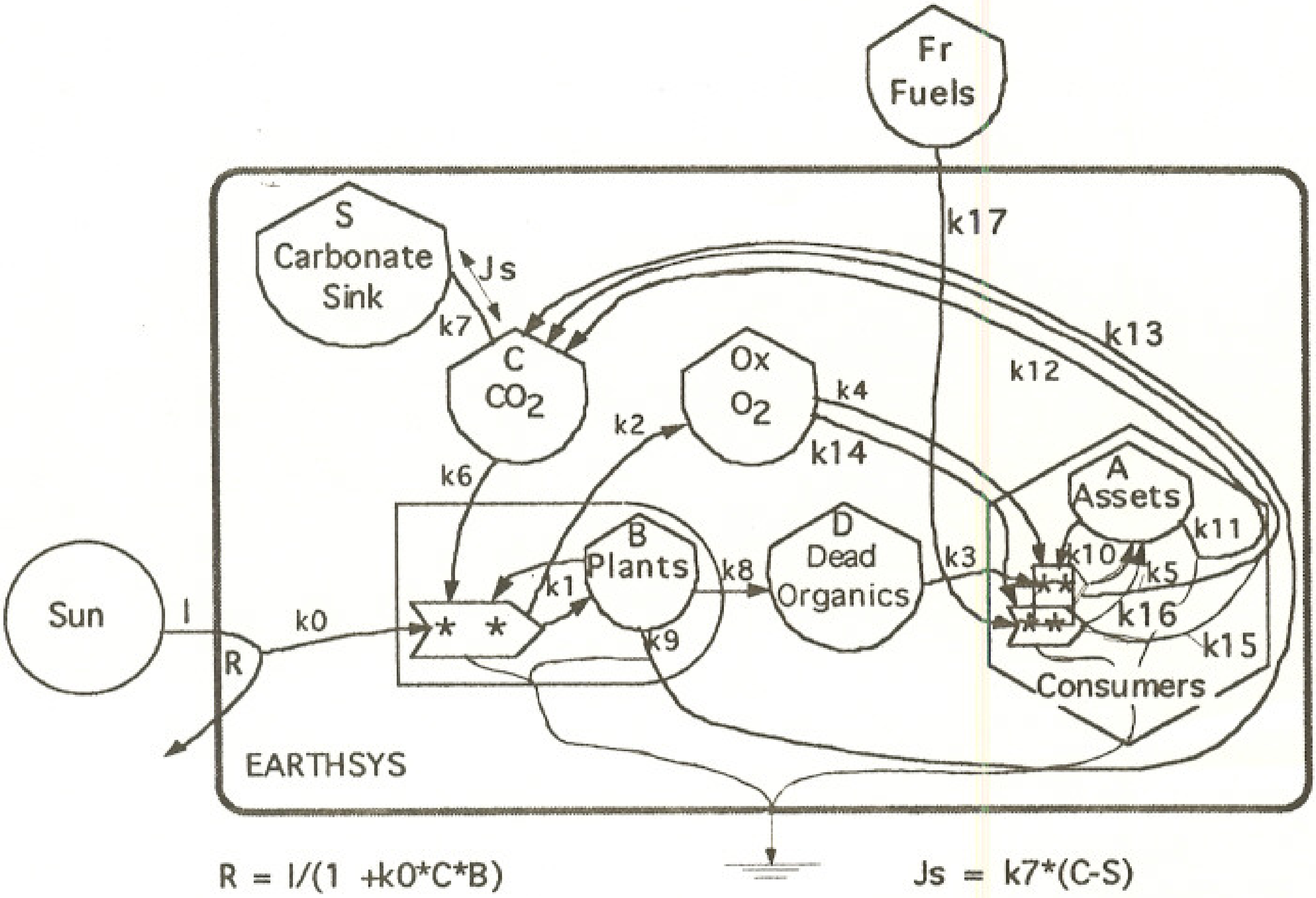
Like the pictorial simulations in Part I, simulations with general systems block do the mathematics for you. Figure 12 in the Appendix has the mathematical rate equations which were built into the blocks. The coefficients (k's) are automatically calculated from the dialog boxes by the program in each block. These k's are indicated on the pathways in Figure12 and in the calibration Table 2.

Because more of the variables show in the dialog boxes, there are many more "what if" experiments that can be run. First make numerical changes on the energy systems diagram in Figure 9. Then make the change in the appropriate dialog box. For example, what is the effect of reducing the depreciation rate of consumer assets from 0.005 to 0.002?

For more on energy systems modeling see the book: Ecological and General Systems by H. T. Odum, Colorado Press, Niwot, Colorado, 665pp.

Appendix

This Appendix contains the energy systems diagram with equations and coefficients (Figure 12) and the calibration numbers (Table 2).



$R = I/(1 + k0*C*B)$ $\qquad$ $Js = k7*(C-S)$

$dB/dt = k1*R*C*B - k8*B - k9*B$ $\qquad$ $dFr/dt = -k17*Fr*Ox*A$

$dOx/dt = k2*R*C*B - k4*D*Ox*A - k14*Fr*Ox*A$

$dD/dt = k8*B - k3*D*Ox*A$

$dA/dt = k10*D*Ox*A + k16*Fr*Ox*A - k11*A$

$dC/dt = k12*A + k5*D*Ox*A + k13*B - Js - k6*R*C*B$

Figure 12 Energy systems diagram with the rate equations (differential equations) that are implied by the conventions for the symbols. Coefficients (k's) for each mathematical term are indicated on the pathways. See Table 2.

Table 2
Calculation of Calibration Coefficients for EARTHSYS*
See numbers on Figure 7

Sources:		
Sunlight	I = 4000 kilocalories/m2/day	
Unused sunlight	R = 400 kilocalories/m2/day	
Fuel reserve	Fr = 1000 g/m2	
Calibration Storages:		
Sinktank	S = 4100 g/m2	
CO2	C = 4900 g/m2	
Oxygen	Ox = 2.3 E6 g/m2	
Dead Organics	D = 5000 g/m2	
Green biomass	B = 800 g/m2	
Assets	A = 50 %	
Calculation Products:	R*C*B = 1.31 E 9	
	D*Ox*A = 5.75 E11	
	Fr*Ox*A = 1.15 E11	
Coefficients:		
k0*R*C*B = 3600	k0 = 3600/1.31 E9 =	2.74 E-6
k1*R*C*B = 5	k1 = 5/1.31 E9 =	3.81 E-9
k2*R*C*B = 2.7	k2 = 2.7/1.31 E9 =	2.06 E-9
k3 *D*Ox*A = 4	k3 = 4/1.15 E12 =	6.96 E-12
k4*D*Ox*A = 2.7	k4 = 2.7/1.15 E12 =	4.69 E-12
k5*D*Ox*A = 5.82	k5 = 5.82/5.75 E12 =	1.01 E-11
k6 *R*C*B = 7.28	k6 = 7.28/1.31 E9 =	5.54 E-9
k7*1000 = 0.30	k7 = 0.3/1000=	0.0003
k8*B = 4	k8 = 4/800 =	0.005
k9*B = 1	k9 = 1/800 =	1.25 E-3
k10*D*Ox*A = 0.005	k10 = 0.005/5.75E11 =	8.69 E-15
k11*A = 0.005	k11 = 0.005/50 =	0.0001
k12*A = 0.0073	k12 = 0.0073/50 =	0.000146
k13*B = 1.46	k13 = 1.46/800 =	1.82 E-3
k14*Fr*Ox*A = 0.06	k14 = 1.1/1.15E11 =	5.22 E-13
k15*Fr*Ox*A= 0.15	k15 = 0.15/1.15E11 =	1.30 E-12
k16*Fr*Ox*A= 0.005	k16 = 0.005/1.15E11 =	4.35 E-14
k17*Fr*Ox*A = 0.03	k17 = 0.03/1.15E11 =	2.61 E-13

* This table was copied from a spread sheet for Excel.