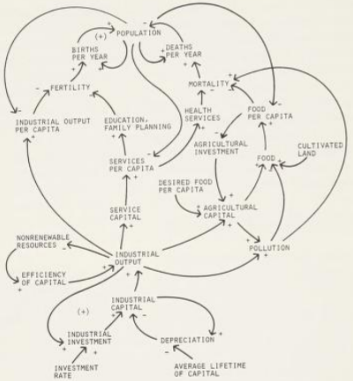

Figure 1-3 Causal-loop diagram of several important feedback loops in World3

gram, system interactions are shown by arrows leading from each element to all other variables that might be influenced by changes in that element. The polarity of each causal influence is indicated by a + or − sign near the head of the arrow. A positive polarity means that an increase in the first element will cause an increase in the second (and a decrease will cause a decrease). A negative polarity signifies that an increase in the first element will produce a decrease in the second (and a decrease will produce an increase). Causal-loop diagrams are rough sketches of the interacting feedback loops in the model. They do not contain enough information to permit a complete understanding of the possible modes of behavior or to analyze the model on the computer, but they do convey the general pattern of major system interactions.

A DYNAMO flow diagram contains considerably more information about the model structure than a causal-loop diagram. It provides information about the functional form used to represent each element in the DYNAMO equations of the model. DYNAMO, the computer language most often used to express system dynamics models, is not absolutely essential to the method—other flow diagram conventions and computer languages could be used. However, since DYNAMO was developed specifically to represent the continuous feedback interactions in system dynamics models, it was the easiest language for us to use in defining the elements of World3.

All the flow diagrams and equations in this book follow the DYNAMO format. The complete DYNAMO flow diagram for World3 is shown in Chapter 7 and is included in the pocket on the back cover of this book. The conventions used in DYNAMO flow diagrams, equations, and computer output are explained briefly in Appendixes C, D, and E.

The Structure of World3

Two important feedback loops in World3 produce the potential for exponential physical growth in the model system. The first governs human births; the second determines investment in industrial capital. In the first loop an increased number of human births increases the population, and the greater number of people then leads to still more births (after a 15–30 year delay required for newborns to mature and bear their own children). Similarly, an increased rate of capital investment adds to the stock of industrial capital, which makes possible a greater industrial output. Increased output, in turn, permits more investment, which raises the stock of capital still higher.

Growth in population and capital is exponential in form because of the nature of the processes that generate population and capital. People are needed to produce more people; machines and factories are needed to produce more machines and factories. Annual increases in population or capital thus depend in part upon the amount of population or capital already present. Whenever the rate of growth of any quantity varies directly with the amount of that quantity, a positive feedback loop is present, and growth, if it occurs at all, will be exponential.

The existence of a causal structure that provides a potential for exponential growth does not mean that the potential is always realized. In addition to the positive feedback loops that promote exponential growth, World3 contains numerous environmental, economic, and social factors that may balance or even overbalance the forces inducing growth. These factors constitute negative feedback loops within the model system. Their relative effectiveness constantly changes as growth progresses, and the resulting balance between growth forces and stabilizing forces continually shifts. In the real world, and also in World3, variations in the set of inputs from the environment can produce negative, positive, or zero rates of growth of population and capital at different times. No simple constant exponential growth rate for either population or capital was built into the world model. However, when the positive forces are dominant (when they overbalance the negative ones), the model will generate exponential growth at a rate that may vary over time.

The negative feedbacks that can balance the growth potential of population and capital are contained primarily in the agriculture, resource, and pollution sectors of the model in the form of assumptions about the physical limits of the global system. The limits are represented as dynamic, not static. They may be raised or lowered, depending on events elsewhere in the system. World3 incorporates the following assumptions about these limits:

1. The amount of potentially arable land that can be developed into actually cultivated land through the investment of capital is finite. As the stock of potentially