> The economy of nature and ecology of man are inseparable, and attempts to separate them are more than misleading, they are dangerous. Man's destiny is tied to nature's destiny and the arrogance of the engineering mind does not change this. Man may be a very peculiar animal, but he is still a part of the system of nature. [Bates 1960]

Policies derived from this model are often tempered with caution about the possibilities for human expansion and with respect for the imperfectly understood, obviously powerful forces of nature.

The technological model pictures the earth's natural systems as created expressly for the use of man, who is a creature apart, endowed with an intelligence that lifts him above the constraints of nature:

> And God blessed them and said unto them, Be fruitful and multiply, and fill the earth, and subdue it; and have dominion over the fish of the sea, and the fowl of the air, and over every thing that moveth upon the earth. [Genesis 1:28]
>
> The scientific age differs in kind, and not only in degree, from the preceding mechanical age. Not only ingenuity but, increasingly, understanding; not luck but systematic investigation, are turning the tables on nature, making her subservient to man. [Barnett and Morse 1963]
>
> There are no substantial limits in sight either in raw materials or in energy that alterations in the price structure, product substitution, anticipated gains in technology and pollution control cannot be expected to solve. [Notestein 1970]

According to the technological view, no real constraints to man's possible accomplishments exist—only a danger that his freedom to overcome natural obstacles may be curtailed by political restrictions or that his courage to innovate may fail.

Modern adherents of either theory would probably agree about one aspect of man's relation with nature—it is subject to some degree of control; there is scope for action and improvement. Although physical laws may be immutable, man's condition within the natural system is defined to a certain extent by his own decisions and actions. As his understanding of natural and social systems increases, those decisions and actions may improve the welfare of the entire human race.

Unfortunately, neither the ecological nor the technological model provides an adequate basis for increasing human understanding of the world. Both theories are based on simple mental models, intuitive generalizations from observations of real-world events. Those observations are partially correct, just as each blind man accurately described his own impression concerning part of the elephant. However, since mental models can incorporate and process only a few observations at a time, they are necessarily incomplete. The blind men could not comprehend the whole elephant, and they would have been unable, on the basis of their partial models, to control it very well.

To manage complex social systems effectively, policy makers must bring together a variety of mental models, both ecological and technological; translate them into a common language; and determine simultaneously all their important implications. That process of synthesis requires formal models, that is, models whose assumptions are stated explicitly so that they can be widely examined and discussed. Formal models can be expressed in words, pictures, or other symbols, but they are probably best stated in mathematical equations, for two reasons: mathematics is a precise and a neutral language, understood by people from many cultures and academic fields; and assumptions expressed in mathematical notation can be processed by a computer so that a great amount of information can be stored and analyzed easily.

The model presented here, called World3, is an example of a formal, mathematical model of a complex social system. It combines elements of both the ecological and the technological world views, as well as theories derived from many traditional disciplines. Like all models, it simplifies the great complexity of the total socioeconomic system (if it were not simplified, it would be as incomprehensible as the real system itself). However, it is considerably more complex than any mental model; therefore, it is a step in the direction of greater comprehensiveness.

The method we used to select, translate, and analyze the wide variety of information contained in World3 is called system dynamics. It is based on a modeling paradigm quite different from the ones most commonly used in the physical and social sciences. Since some of our readers may be unfamiliar with this technique, in this introductory chapter we describe the basic principles of the modeling procedure.*

1.2 STEPS IN THE MODELING PROCESS

Making a formal systems model is a nonlinear process that involves many experiments, regressions, and reiterations.† Nevertheless, the process must cycle through a number of logical steps in sequence; each step is dependent on the successful completion of the one before. In constructing World3 we repeated this sequence many times, with corrections and revisions in the model being made during each iteration. In this book we shall use the sequence to structure our presentation of World3. The steps in the modeling process are:

1. General verbal description of the system within which the problem is observed.
2. Precise specification of the model's purpose in terms of the dynamic system behavior to be explained.
3. Definition of the model's time horizon.
4. Identification of the major elements necessary to represent the relevant aspects of the system.
5. Postulation of the model's structure; conceptualization of causal relationships and feedback loops.
6. Estimation of the model's parameters; quantification of causal assumptions.
7. Evaluation of the model's sensitivity and utility through computer simulation.
8. Experimentation, by means of further simulation, with possible alternative policies.
9. Communication of results.

*For more complete expositions of system dynamics, see Forrester 1961, Forrester 1968, Hamilton 1970.

†For a vivid description of the typical, cyclical process of model conceptualization, see Randers 1973.