CHAPTER 3

Simulation Modelling and Systems Analysis

A simulation model is based on a mathematical representation of the dynamics of a real-life system. Some such models are analytical – in other words, once the initial conditions have been determined, the state of the system at any future point in time is given by the analytical solution of a set of differential equations. When the problem of finding an analytical solution becomes too intractable, one must turn to *simulation modelling*.

Simulation modelling uses another medium (usually mathematics, or computer programmes) to mirror the processes and interrelationships of a real-life system in a *model*. This model – this analogue – of the real world is caused to go through a series of changes controlled by its structure. The changes in the model are then said to *simulate* the changes which the real-world system, with its analogous structure and linkages, would undergo in a comparable situation. The simulation thus permits insights into the behaviour of the real-world system – insights whose reliability depends on the closeness of the analogies between the model and the real world.

Although simulation modelling may sometimes use relatively unsophisticated graphical techniques, or electrical circuitry, as an analogue of the real-life processes in the systems modelled, it usually involves the use of computers for the digital solution of large sets of differential or difference equations.

In a discrete-time simulation model (conceptually the simplest to grasp), the changes in the system during any short interval of time are expressed in terms of the state of the system at the beginning of that interval, together with any external factors known or postulated to impinge upon it during the interval. Changes during the interval are then calculated, and the new state of the system at the end of that interval and the beginning of the following one is deduced. This new state then becomes a starting point for calculation of changes during the second interval, and so forth. This discrete-time approach is often replaced by one in continuous time, where one needs to speak of rates of change rather than changes during an interval, and differential equations replace the difference equations of the discrete model.

The simulation approach gives great flexibility in expressing the dynamics of a complex system. No particular mathematical form need be assumed for the relationships existing in the system; the constraints are only those inherent in the nature of the real-life system itself, and the mathematics merely reflects the assumptions made about the physical system modelled. The individual changes may be expressed as differential equations, difference equations, look-up tables, or pre-programmed functions of time. What is important is only that all the functions should be well defined for all conditions that may exist in the system, and defined in terms of variables occurring within the system or of known or assumed inputs from the outside.

Since the operation of a deterministic model (i.e. one in which, given the current state of the system and the inputs, the future state and outputs are uniquely defined) is a straightforward process of logical deduction, it is well suited to the use of a digital computer – which is essentially a machine for performing logical processes, including the particular group of processes used in mathematics.

Of course, it may well be that the system under consideration is inherently uncertain in some way, perhaps because of random (stochastic) inputs, or because the behavioural mechanisms are defined only in a statistical sense. In this situation, the model may be designed to reflect this uncertainty either by statistical treatment or by the inclusion of explicit stochastic variables.

Simulation models to be considered in this report are mainly intended as predictive tools – that is, their prime purpose is to predict the future state of an environmental system, given its present state and a set of postulated future values for factors which may influence it. In order to represent a physical or biological process by equations, however, simplifying assumptions are generally necessary (SCOPE, 1977). Consequently, predictions provided by a simulation model are always conditional – conditional on the whole set of assumptions incorporated in the computer programme and specified in inputs being correct – and it is important that the prospective user should recognize the limitations. The built-in assumptions almost always involve a considerable degree of simplification, which may lead to neglect of elements in the system or outside it which are relevant to the results obtained. There is consequently a risk that the final results may have serious errors. The power of simulation models lies in the complexity of the systems they can examine; their weakness lies in the simplistic assumptions that may be used in some or all of the component parts.

It can, of course, be argued that there would be even *greater* risks of oversimplification if, instead of a simulation model, some simple 'mental' model were to be used (Forrester, 1971). Indeed, the great virtue of computer simulation is that it allows a much more complex set of assumptions to be made than is usually possible with either theoretical or common-sense methods. But it is important to understand that there is nothing magical about the computer, and some danger of over-simplification does remain. Moreover, the ways in which the simplification has taken place – the simplifying assumptions – are more likely to be lost to sight in a computer model than in a 'mental' model.

Within the decision process, simulation modelling is best considered as one step in systems analysis. Systems analysis may be defined (Biswas, 1975a) as an analytical study that aids a decision-maker to identify and select a preferred course of action among several feasible alternatives. It is a logical and systematic approach wherein assumptions, objectives, and criteria are clearly defined and specified. It assists the decision-maker by broadening his information base, by increasing his understanding of the linkages of the various sub-systems, by predicting the consequences of different possible courses of action or by pointing to a course of action which will best attain a prescribed result.

In this context, decisions on environmental management encompass the following steps:

1. Perception of needs;
2. problem definition;
3. problem analysis and modelling;
4. simulation to test alternative strategies;
5. evaluation of alternatives, and selection of one by decision-maker; and
6. implementation, and monitoring of operations.

Such an approach usually reveals a nest of subproblems that must be solved together. Some of them may be environmental problems that lend themselves to environmental simulation modelling, which will primarily be included in step 3, but partly 2 and 4 as well. This wider context of perception, information flow, decision processes and management, within which the modelling of environmental systems takes place, is illustrated in Figure 3.1.

An advantage of systems analysis is that its methods and techniques are available to everyone for critical analysis and examination. Thus, anyone who has the necessary expertise and experience can exactly duplicate the analysis. The models developed can be constantly modified as more data become available or our understanding of the system improves. In principle, systems analysis uses all the relevant information available, and bases its conclusions on a combination of the most suitable scientific methods from a variety of disciplines.

Systems analysis may be viewed as a problem-solving technique which attempts to build a replica of part of the real world, and to experiment with the replica in order to gain some insight into, or obtain better understanding of, the real-world problem. Simulation modelling is central to the analysis.

Over the years, some modelling efforts have had difficulties in meeting their goals and objectives – particularly where the systems-analysis approach has not been used to link modelling with the decision process. Such difficulties may be avoided if some important rules are taken into consideration. To begin with, the question should be posed whether the model is necessary and justified for

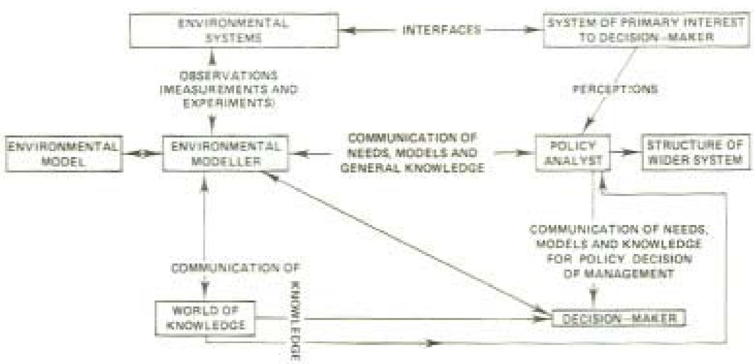

Figure 3.1 The place of environmental modelling in a broader systems context

the solution of the problem. If this question can be answered in the affirmative, the next is: For what and for whom is the model being built? Therefore, it is important that decision-makers and users become involved in model development. It may also be advisable to start with a simple model and to develop it further as more information becomes available, or as the problem demands – always on a sound conceptual framework; a small model with a few good assumptions is likely to be more useful than a large one with many flaws. Finally, it should always be kept in mind that the model is not a substitute for thought; it is mainly an *aid* to thinking, and only when used together with close acquaintance with the system being analysed will it also be a means of gaining insight to the system and a guide to decision making.