CHAPTER 1

Introduction

Before the mid-20th century, recognition of the environment as a complex of interrelated factors influencing human life was uncommon. Although individual problems – pollution, noise, and depletion of resources – were recognized, the fact that there was a general and continuing deterioration in man's surroundings as a result of his own activities was not widely realised until after the Second World War. During this period, several forces combined to make it increasingly difficult for man to ignore environmental degradation. These included the intensity of industrial impact on air, water, and land, and the consequent effects on human health and on biological resources; the marked acceleration in the use of non-renewable resources; and the failure of the rate of replacement of renewable resources to keep up with the increased demands which have resulted from exponential tendencies in population growth and growing industrialization. New environmental dangers, such as those related to the harnessing of atomic energy and the introduction of innumerable synthetic materials and chemicals, have accentuated existing environmental hazards. Rapid, enhanced, and ubiquitous communication facilities have made all these facts common knowledge. The result has been a rapidly broadened public awareness of the problems which man is already facing, and may well be facing in a far graver way in the years to come.

At the present time, the relations between man and his environment are very complex indeed, and it is becoming increasingly difficult for decision-makers concerned with environmental questions to determine appropriate strategies and to assess the likely consequences of the different courses of action they might choose. Methods are needed for integrating the information available about natural and economic systems – information which may often appear indigestible and incoherent – into a usable form, and for predicting changes due to natural and man-made perturbations. Without such predictive aids inappropriate grazing practices may result in rapid deterioration of rangeland to a condition approaching that of a desert; or a scheme for irrigation which extends cultivation to new areas may have undesirable side effects (e.g., salinization), or result in the spread of human and plant diseases.

A promising approach to the prediction of environmental change is modelling. Consciously or subconsciously, we use a mental image or a model to guide us as to the benefits and costs of specific courses of action, and we decide on a solution by comparing several possibilities (Biswas, 1974). These mental images or models are simple, but are, in principle, the same as the most complex mathematical models. The question is thus, not whether we should use models for decision-making, but what type of models they should be.

A model is a representation of some part of the real world in another medium – or occasionally in the same medium, but with differences of scale or simplification. For instance, a map is a model of terrain, while a genealogical tree is a model of relationships between individuals. Other models are physical. One may cite the use of aircraft models in wind tunnels as an example. Still other models are mathematical, and among them are the simulation models* with which this report is concerned.

A simulation model imitates (simulates) the behaviour of a complex system in some different medium – most commonly a computer – so that the behaviour of the model is *conceptually* similar to that of the real system. The behaviour of the model can be studied far more quickly, cheaply, and simply than that of the real system, and conclusions drawn from the former can be applied to the latter.

Simulation modelling of physical, biological, or socio-economic systems uses a variety of methods, from graphical mapping and empirically fitted algebraic relations to the highly sophisticated high-speed computing techniques. The main advantages of using computers for modelling are two. Firstly, a computer can store enormous amounts of data and retrieve them almost instantaneously. Secondly, computers can operate much faster than the human brain, carrying out millions of calculations per minute without making mistakes. Use of the computer thus increases our computational ability by approximately six orders of magnitude. As Biswas (1975a) remarks, 'The computer is probably the most patient and obedient servant that man has ever found to carry out instructions without asking any embarrassing questions.'; but it should be noted that the computer will obey instructions even if the instructions are nonsensical. The computer may be relied upon to perform precisely what it is programmed to do; but this may not correspond exactly with the intentions of the analysts or programmers.

Although simulation modelling existed earlier, it could not be developed to any significant extent until reasonably advanced computers were available, and these were not manufactured until the 1950's. This is not to suggest that simulation modelling cannot be performed without the use of computers; in fact, some simple models not relying on computers have had appreciable relevance in the environmental field, and will be referred to in subsequent pages. However, complex simulation models could not be developed and applied successfully – and would probably not have even been conceived – without the availability of computers.

Throughout its short history, simulation modelling has been applied to a wide variety of fields ranging beyond those of environmental science. In fact, it has been used much more extensively and effectively in some other fields than is yet the case in environmental science. For instance, prominent uses of modelling have been in the aerospace industry, in engineering, in defence, in industrial control and management, and in business. What is common to all these fields is that they are concerned with complex systems involving interactions among many components, the integrated results of which are usually not amenable to purely mental evaluation or ordinary mathematical treatment.

Within the environmental sciences, the meteorologist and water-resource planner, for instance, have made effective and consistent use of simulation modelling. This is perhaps not surprising in view of their closeness to the applied

*A number of technical words and expressions which may not be familiar to some readers are defined in the Glossary (Appendix 1).

physical sciences in which simulation modelling was first developed. More recently, however, simulation modelling has also been applied in the more complex and less easily quantified fields of ecology, soil and water pollution, population problems, and the interactions of the environment with human society. In the biological and social sciences, modelling experience remains relatively limited; this is even truer where models are to be combined from a number of different disciplines to meet a common purpose. In such broad interdisciplinary modelling, success in influencing decisions, and even in proving relevance of the models to the problems, has been particularly difficult to achieve.

Subject to these reservations, however, developed countries have acquired considerable experience in the application of simulation modelling to the solution of environmental problems. This experience can be valuable to other countries which are just beginning to apply simulation modelling in their own situations. In developing countries, environmental problems and limitations are sometimes so obvious that refined and complex techniques for their analysis may be unnecessary; in other cases, simulation methods may help. Where they are used, one may hope that hard-learned lessons in the developed countries may help their developing counterparts to avoid the difficulties that have been encountered. Possible methods of achieving this are discussed in subsequent chapters of this report.

While many areas of simulation modelling in environmental science will be covered in the following pages, emphasis will be given to those situations where models are being developed as aids for environmental management. In this context, the simulation model will be considered as a tool which the scientist offers to the decision-maker – whether an officer or group at some level of government, a private company or individual, or a whole population performing its management role in a popular vote. For all these groups, there are cases where simulation modelling has the potential to illuminate issues and help them to make decisions which will best serve the objectives they have set for themselves.

This report is intended to help all those who might seek to use simulation modelling in the analysis of environmental systems, whether they are decision-makers at various levels, systems analysts, modellers, or scientists of different disciplines contributing data to an environmental model. It should assist all these groups of varying backgrounds to cooperate in addressing their common goal of improved environmental management by use of this rather new and – to some – unfamiliar tool.