INTRODUCTION

1.1. ENVIRONMENTAL SCIENCE - AN INTERDISCIPLINARY FIELD.

The past two decades have created a new interdisciplinary field: environmental science, which is concerned with our environments and the interaction between the environment and man. Understanding environmental processes and the influence man has on these processes requires knowledge of a wide spectrum of natural sciences. Obviously biology, chemistry and physics are basic disciplines for understanding the biological/chemical/physical processes in the environment. But environmental science draws also upon geology for an understanding of soil processes and the transport of material between the hydrosphere and lithosphere, on hydrodynamics for an understanding of the transport processes in the hydrosphere, and upon meteorology for an explanation of the transport processes in the atmosphere, just to mention a few af the many disciplines applied in environmental science.

Some also believe that general political decisions are of importance in environmental management and that sociological conditions influence man's impact on the environment.

It is true that a relationship exists between all these factors and that a complete treatment of environmental problems requires the inclusion of political science and sociology in the family of environmental sciences. At present, however, it seems unrealistic to teach all these disciplines simultaneously or to presume that one person has all the background knowledge required for a complete environmental solution taking all aspects into consideration at the same time.

The right solution to environmental problems can be found only by co-operation between several scientists, and it is therefore advantageous if all the members of such a multidisciplinary team know each other's language.

Traditionally, scientists have worked to discover more and more about less and less. In environmental science, however, it is necessary to know more and more about more and more to be able to solve the problems. Environmental science has therefore caused a shift in scientific thinking, by demonstrating that although so much detailed knowledge and so many independent data have been collected, such details cannot be used by man to improve the conditions for life on this earth, unless they can all be considered together.

It is the aim of environmental science to interconnect knowledge from all sciences - knowledge that is required to solve environmental problems.

It is the scope of this book to demonstrate how our present knowledge of natural sciences can be used and interconnected to understand how man influences life on earth. The role of socioeconomic disciplines will only be mentioned briefly. The author feels that it might over-complicate the issue to include these disciplines in the present treatment of environmental science.

The past two decades have seen an unprecedented accumulation of knowledge about the environment and man's impact upon it. Unfortunately, the very mass of this information explosion has created problems for those concerned with the application of this material in research and teaching. University courses structured to meet the growing demand for multidisciplinary treatment of environmental problems became a struggle for teacher and students. The teacher, inevitably a specialist in only one of the number of disciplines, had to gather information from areas remote from his own field. Even after relevant information was obtained the rational organization of the material for meaningful presentation in an environmental course became a massive problem.

Many excellent volumes about environmental science have been published during the last decade, but although some contain a pure interdisciplinary treatment of the subject, most concentrate on one particular aspect. Of course this raises a series of questions. How could one person write on so many diverse topics and still retain a sound factual base? How could so much material be organized to maintain continuity for the reader? How could such a book avoid containing only series of independent facts and problems?, and so on.

This book attempts to solve these problems by focusing on the principles used to solve environmental problems within the framework of natural sciences. The multidisciplinary field of environmental science is growing rapidly: other sciences are bringing new knowledge into the field with an ever increasing velocity, and new problems or new connections between existing problems are continually appearing. Consequently a book dealing with facts and problems will quickly become out of date and the knowledge learned by the students useless. By focusing on the principles instead of events, these obstacles can be overcome, as the same principles are equally valid in the solution of different and new environmental problems.

The purpose of this book is to discover which methods and principles we are using when we wish to understand environmental processes and to use this knowledge to solve concrete environmental problems. Throughout the book the application of methods and principles has been illustrated by examples of real environmental problems, but to give the reader an overview of the problems of today, the last chapter of part A of the book is devoted to a general survey of environmental problems.

1.2. RELATION BETWEEN ENVIRONMENTAL SCIENCE AND TECHNOLOGY, MANAGEMENT, ECOLOGY AND MODELLING.

Concern about the environment has developed from man's ever-increasing impact on the earth. The increasing industrialization, urbanization and population, which we have faced during this century have forced us to consider whether we are changing the very conditions essential to life on the earth? Environmental science is the multidisciplinary field concerned with man's influence on environmental processes, and as such it takes human activity as well as environmental processes into consideration. This relationship is demonstrated in Fig. 1.1, where it can be seen that environmental science is concerned with the interaction between man and the environment. Man's impact on the environment is often termed pollution in its broadest sense.

Fig. 1.1 shows the relationship between environmental science and ecology. Usually ecology is defined as the study of the relationship of organisms to their environment, or the science of the interrelations between living organisms and their environment. Because ecology is concerned especially with the biology of groups of organisms and with functional processes on land, in the oceans, and in fresh water, it is more in keeping with the modern emphasis to define ecology as the study of the structure and function of nature, remembering that man is a part of nature (E.P. Odum, 1971).

One of the definitions of ecology in Webster's Dictionary seems especially appropriate for the closing decades of this century: "The totality or pattern of relations between organisms and their environments".

From these definitions of ecology it is clear that ecology is closely related to environmental science. When man intrudes on an ecosystem (e.g. a lake, a forest, a desert) - he inevitably disturbs the delicate balance of organisms and substances and their activities that have evolved in nature.

The ecosystem can adapt to man's disruptive activities, but only to a certain point. It is therefore crucial to understand the nature of ecosystems to be able to understand the consequences of man's impact on his environment. Today, everyone is acutely aware of the environmental science as indispensable tools for creating and maintaining the quality of human civilization. Consequently ecology is rapidly becoming the branch of sciences that is most relevant to environmental problems or possibly even to the everyday life of every man, woman and child (E.P. Odum, 1971).

But how can we diminish the effect of human activity on the environment? The first step is to understand the relation between the activity and the effect - by means of environmental science - and the second step is to control human impact on ecosystems - by means of environmental management.

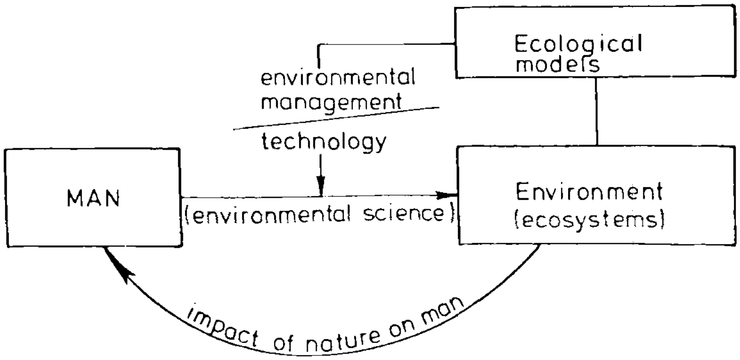

Fig. 1.1. Relations between environmental science, ecology, ecological modelling and environmental management and technology.

Technological development has increased the human impact on the ecosystem, but a new technology aimed at solving the pollution problem has been developed simultaneously. This has occured in the field of environmental technology, in which new methods of purification and recirculation of pollutants are being developed and attempts are being made to change existing technology to reduce pollution. This field must be distinguished from the classical discipline of sanitary engineering, which is limited to water treatment methods, with especial emphasis on design and planning of sewage- and water-supply systems.

Environmental management is often expensive, but many case studies have shown that it can also be economically advantageous to solve environmental problems, e.g. by the recirculation of valuable raw materials. This creates a new and equally important question of how we select the best ecological and economical method for solving a specific environmental problem. Selecting the best ecological solution is a very complex problem. Many organisms and processes interact in the ecosystem, and therefore to map the effects of human activity on ecosystems is a very complicated task.

Ecological modelling, or systems ecology, offers a unique opportunity to screen and select the best methods for pollution control, and as we can see in Fig. 1.1 the circle is closed. Ecosystems are very complex systems and it is not possible to consider all their processes in a management situation. However, for a given problem, it is possible, with a good grounding in chemistry and biology and a good knowledge of the ecosystem considered, to make a simplified model of the ecosystem and its processes, to determine and include the relevant variables and to omit processes of minor importance. Such a model will consist of a mathematical description of processes crucial to the problem, and it is then possible to use the model to simulate different management alternatives. Often the model is based on the principle of mass conservation, in which case a set of differential equations describe the rate of change in concentrations. For an introduction to the subject, see Jeffers (1978), Jørgensen (1981) and Jørgensen (1987) where several concrete examples of the application of ecological models in environmental management, are discussed.

1.3. LEVELS OF ORGANIZATION.

Ecology is considered to be a discipline or division of biology, the science of life. Biology can be divided in two distinct ways. In Fig. 1.2 the divisions form a matrix. The horizontal division is concerned with the fundamentals of biology: morphology, physiology, genetics ecology, molecular biology, evolution theory, etc., while the vertical division is a taxonomic one: bacteriology, ornithology, botany, entomology, etc.

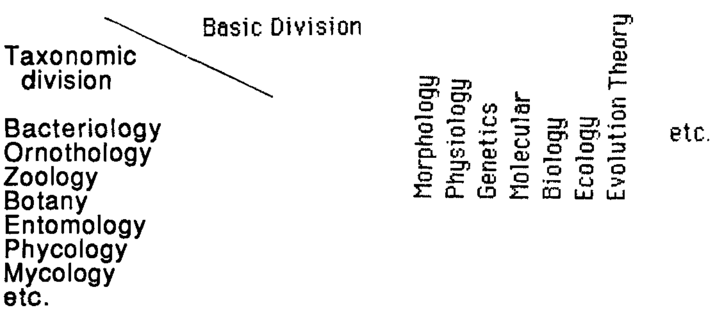

Fig. 1.2. Division of Biology.

Different levels of biological organization can also be considered to illustrate the content of modern ecology. Fig. 1.3 shows how the biosystem is formed by a combination of a biotic component and an abiotic component.

The biotic components are organized in a hierarchial arrangement from the subcellular level (genes) to communities. The biotic components interact with the physical environment - the abiotic components to form the system, which is meant the regular interaction of interdependent components to form a unified whole. Ecology is concerned with the right hand portion of the spectrum shown in Fig. 1.3. In biology the term population is used to denote groups of individuals of any kind of organism, and community in the ecological sense includes all populations occupying a given area. The community and the non-living environment together form the ecosystem.

Biotic Component	Genes	Cells	Organs	Organisms	Populations	Communities
+						
Abiotic Component			Matter and Energy			
‖						
Systems:	Genetic-	Cell-	Organ-	Organismic-	Population-	Ecosystems

Fig. 1.3. Levels of Biological Organizations.

Environmental science is concerned with the study of the environment of all life forms within the life-bearing layer of the earth. This shallow life layer can be further divided into the gaseous realm (the atmosphere), the liquid water realm (the hydrosphere), the solid realm (the lithosphere) and the living part of the earth (the biosphere). Often the term ecosphere is used to denote the biosphere plus its non-living environment; it refers to the parts of the atmosphere, hydrosphere and lithosphere that bear life.

1.4. THE ENVIRONMENTAL CRISIS.

As mentioned in this chapter three pronounced developments have caused the environmental crisis, we are now facing: the growth in population, industrialization and urbanization.

Fig. 1.4 illustrates world population growth, past and projected. From the graph it can be seen that population growth is experiencing decreasing doubling time, which implies that growth is more than exponential (exponential growth corresponds to a constant doubling time). Fig. 1.4 shows that growth from one billion to two billions took about 100 years, while the next doubling in population took only 45 years.

The net birth rate at present is about 350,000 people per day, while the death rate is 135,000 per day. The population growth is determined by the differences between the two:

population increase = birth rate - death rate.

This implies that the world's population is increasing by more than 200,000 per day, or about 1.5 million per week corresponding to 80 million per year.

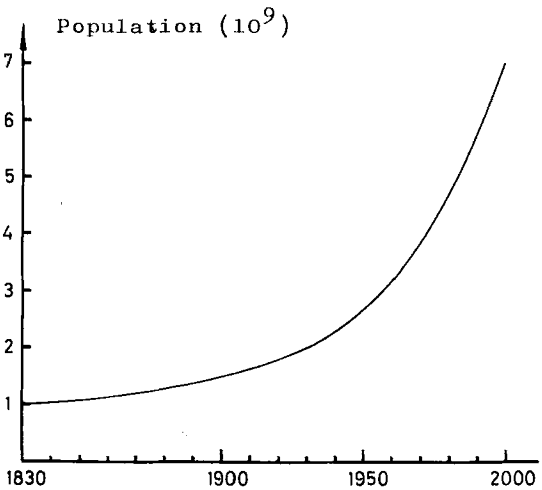

Fig. 1.4. World population growth plotted against time. Notice that the doubling time is decreasing, which implies that the growth is faster than exponential growth.

The need to limit population growth is now more clearly perceived than before. Every living organism requires energy and material resources from its environment. Resources can be classified as renewable and non-renewable (Skinner, 1969). Renewable resources are those that can maintain themselves or be continuously replenished if managed wisely. Food, crops, animals, wildlife, air, water, forest, etc., belong to this class. Land and open space can also be considered as renewable, but they shrink as the population increases. Although we cannot run out of these resources, we can use them faster than they can be regenerated or by using them unwisely affect the environment (Meadows et al., 1972)

Other resources, such as fossil fuels and minerals are non-renewable resources, whose finite supplies can be depleted. Theoretically some of these resources are renewable, but only over hundreds of millions of years, while the timescale of concern to man, is hundreds of years only.

When we talk about finite supplies of resources we should qualify this by discussing finite supplies of substances presently considered to be resources. Often our most important consideration is whether the pollution costs from extraction and use of a resource outweigh its benefit as population or per capita consumption increase.

During the last few decades we have observed a distinct increase in pollution. Many examples illustrate these observations. The concentrations of carbon dioxide, sulphur dioxide and other gaseous pollutants have increased drastically. The concentrations of many toxic substances have increased in soil and water, and the ecological balance has been changed in our ecosystems. In many major river systems oxygen depletion has been recorded, and many recreational lakes are suffering from eutrophication (high concentrations of nutrients - mainly nitrogen and phosphorus).

What has caused this sudden increase in pollution? The answer is not simple, but the growth in population is obviously one of the factors that influences our environment. Other factors include man's rate of consumption and the type and amount of waste, he produces.

Many now recognize two basic causes of the environmental crisis. The first, which occurs in the developing countries, is overpopulation relative to the food supply and the ability to purchase food even if it is available. The second occurs in the technologically advanced countries, in North America, Australia, Japan and Europe. These countries use 80-90% of the world's natural resources, although they only account for about 25% of the world's population. As a result the average consumer in these contries causes 25-50 times as great an impact on our life-supporting system as a peasant in a developing country (Davis, 1970).

The debate centers on the relation between pollution - or environmental impact - and the population, consumption and technology. We can use the crude but useful model proposed by Ehrlich and Holdren (1971). They obtain the environmental impact, I, by multiplying three factors - the number of persons, P, the units of consumptions per capita, C, and the environmental impact per unit of consumption, E,:

$$I = P \cdot C \cdot E \tag{1.1}$$

All three factors are equally important. We can illustrate the importance of all three factors by considering the development in U.S.A. between 1950 and 1970. The population increased 35% during these two decades, while the per capita consumption increased about 51%. In the same period the production of environmentally harmful material has increased by between 40 and 1900%. It is, of course, easy to get the false impression that the percent increases in production as illustrated in Table 1.1 represent percent increases in pollution, whereas in fact only a fraction of these increases actually contributes to environmental pollution.

TABLE 1.1
Changes in per capita consumption (or production) of selected items in the United States between 1950 and 1970.

Item	Percent increase
Synthetic fibers (non-cellulose)	1,890
Air freight (ton miles)	890
Plastics	556
Synthetic organic chemicals	254
All synthetic fibers	220
Total horsepower	212
Phosphates in detergents	210
Electric power	207
Aluminium	182
Natural gas	171
Synthetic rubber	165
Nitrogen fertilizers	143
Synthetic organic pesticides	115
Phosphate rock	110
Motor fuel	74
Motor vehicles registered	65
GNP (per capita 1958 constant dollars)	51
Truck freight (tons)	50
Paper	48
Energy use	46
Petroleum (production)	40
Cement (production)	30
Meat	28
Mercury	20
Protein	8
Steel (production)	1
Food energy	1
Vegetables	0
Fish	-3
Railroad freight (tons)	-4
Coal	-15
Poultry	-17
Lead	-18
Fruits	-20
Synthetic fibers (based on natural cellulose)	-23
Cropland acres	-27
Cigarettes	-28
Natural fibers (cotton, wool, silk)	-43
Natural rubber	-43
DDT	-48
Soap	-52

Indeed, during the same two decades we have learnt to diminish the discharge into the environment. However, the total environmental impact has increased considerable in U.S.A. during these two decades. The two first factors in Equation (1.1) are easy to find from the facts mentioned above, but in such a simple model the third factor will always be a subjective judgement. If we take the rapid growth in production of harmful substances (40-1900%) and also consider the measured increased concentration of such substances in major ecosystems, a reasonable value for the third factor would be around 2. It would give us the following increase in the total impact on the environment:

$$I = 1.35 \cdot 1.51 \cdot 2 = 4 \text{ times} \tag{1.2}$$

This is a very crude simplification, but the increase in environmental impact of 4 times during such a short period as 20 years must give us reason to worry about man's future on this earth, unless we can use all our efforts to manage the problem.

Two major forces can lead to apathy: naive technological optimism - the idea that some technological wonder will always save us regardless of what we do - and the gloom and doom pessimism - the idea that nothing will work and our destruction is assured. The idea behind such a book as this is, of course, that something can be done, but the problem is very complex and difficult to solve. The best starting point must be an understanding of the nature of the problems and the principles and methods that can be used to solve them. It is hoped that by working through this book the reader will be able to grasp these basic concepts.

1.5. FOCUS ON PRINCIPLES OF ENVIRONMENTAL SCIENCE.

An understanding of environmental problems requires only the application of a few principles which must be coupled with environmental data. The principles are discussed in the next three chapters, while the last in Part A, chapter 5, is devoted to a survey of the environmental problems of today.

All life on this planet is dependent on the presence of a number of elements in the right form and concentration. Other elements not used in the life-building processes should not be present in the biosphere or present only in very low concentrations.

If these conditions are not fulfilled, life is either not possible or will be damaged. It is therefore of major importance in understanding environmental deterioration to keep a record of elements and compounds to ascertain whether an abnormal concentration of one or more elements or compounds can explain the environmental problem considered. Therefore the law of mass conservation should be widely used in understanding ecological reactions to pollution. Chapter 2 is devoted to the application of mass balances in the environmental context and the translation of a mass balance results concentration - to environmental effects.

Energy is also required to maintain life. In a thermodynamic sense the earth can be considered a closed, but not isolate, system, which implies that the earth exchanges energy but not matter, with the universe. The same consideratione is somethimes also valid for ecosystems, although the characteristic pollution situation is an input of pollutants, which changes the concentrations in the ecosystem.

The earth's input and output of energy are approximately balanced. Solar radiation is the basic energy requirement for all life on earth, but after this energy has been used to maintain the biological, chemical and physical processes, it is converted to longwave radiation from the earth out to the universe. The balance between input and output assures that a constant average temperature is maintained.

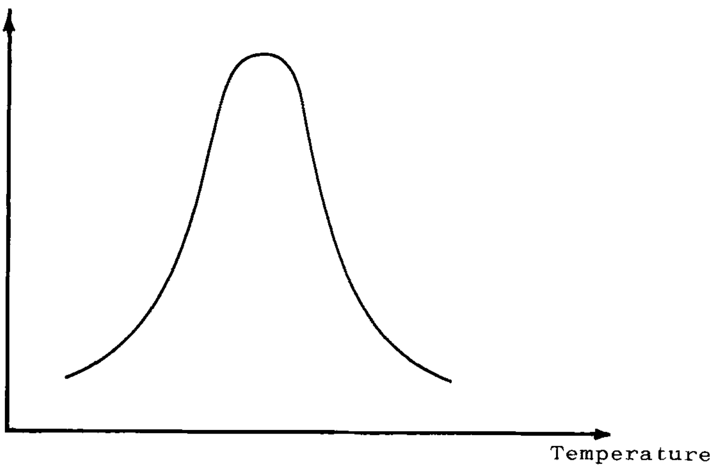

Fig. 1.5. Biological processes are strongly dependent on the temperature. A characteristic biological process rate is plotted versus the temperature.

The rate at which biological processes take place is strongly dependent on temperature. In Fig. 1.5 a characteristic response of biological rates to temperature is shown. As seen an optimum temperature exists, at which the biological rate is at its maximum. The present life on earth is dependent on a certain temperature pattern. Changes in the present temperature pattern can therefore have enormous consequences for all life on earth.

Not only is the global energy balance of importance, but also the energy balance within ecosystems can give important information about the life conditions. Chapter 3 is concerned with energy problems related to these environmental issues.

An ecosystem is a complex system that reacts to changed chemical concentrations and temperature in a very complicated way. Sometimes an ecosystem is able to diminish the effect of changed concentrations, in which case the ecosystem is said to have a buffer capacity, but in other ecosystems the effect of pollution is enhanced by "upconcentrating" a harmful component. Chapter 4 on Ecological Principles and Concepts is devoted to an understanding of such ecological reactions to change.

Emphasis will be laid on quantification of environmental problems throughout part A, because it is only through the application of environmental principles for quantification of a problem that we have the right basis for selection of a feasible solution.

A solution might be found in what is named ecological engineering, which implies that the ecosystem is assisted or modified to resist an environmental impact. Ecological engineering requires sound ecological knowledge of the ecosystem reactions. It is only through a profound knowledge of ecosystems and their reactions that good ecological engineering solutions can be found. Whenever such solutions can be used, this will be mentioned in part A, and a survey of these methods will be presented in the last section of chapter 4.

The importance of environmental principles is illustrated throughout Part A by many examples. These examples are not necessarily the most important environmental problems, but they have been selected as those which best illustrate the principles. Hopefully, the use of many examples gives the principles reality and demonstrates that the theory can be used to solve practical problems.

1.6 PRINCIPLES OF ENVIRONMENTAL TECHNOLOGY.

The selection of the rigth technology for the solution of an environmental problem requires a profound understanding of the problem itself. Therefore environmental science is an essential basic field for environmental technology.

Also Part B which deals with environmental technology, attempts to focus on the principles and their application to find technological solutions to environmental problems. Such a solution is not always readily available, but can be obtained by use of environmental legislation. For example considerable lead pollution orginated from the use of lead as an additive in gasoline, but as a result of legislation and the setting of a maximum permitted lead concentration in gasoline, such pollution has now diminished.

Each section in chapters 6-9 discusses a specific environmental problem and all unit processes that are involved in solving that problem will be mentioned. Many processes used in environmental technology are the same processes as are used in nature. References will be given to similar processes already mentioned in part A.

Part B is not written only for the engineer, but rather for all concerned with the solution of environmental problems.

Design criteria are not included, but the following properties of the technological solutions mentioned are considered:

1. Function, expected capacity and efficiency.
2. Advantages and disadvantages.
3. Relation between process variables and capacity/efficiency.
4. Process troubles and how to solve them.
5. Area of application.
6. Environmental evaluation of the method in the broadest possible environmental sense.

The reader is thus given a basic knowledge of environmental technology to enable him to select the best solutions available today and to discuss them with specialists who must design and build the project.

He should obtain a critical view of technological solutions, by considering the environments rather than the economy of prime importance, but also understand when technological solutions have clear advantages over other possibilities. In this context (see above) point 6 is of great importance, as many technological methods solve one problem only to create another. Only a clear environmental analysis of both the problems can reveal whether it is advantageous from an ecological point of view to apply a technological solution.

Environmental technology has developed very rapidly during the last two decades. Many new methods are available today, and for most environmental problems a wide spectrum of methods (processes) are applicable. As a result it is considerably more difficult today to find the very best solution, but at the same time there are better possibilities for an acceptable technological solution.

The problems have been classified in terms of: water pollution, air pollution and solid waste pollution. This is a reasonable classification of environmental technology, as the methods and processes are dependent on the state of the pollutants.

Chapter 6 is devoted to water pollution problems and to water resources, including the technology applied to production of potable and process water from surface and ground water. Chapter 7 discusses solid waste problems and Chapter 8 deals with air pollution problems. Chapter 9 deals with problems related to examination of pollution.

Each chapter is divided into sections dealing with problems, that are considered of importance today.

1.7 HOW TO SOLVE ENVIRONMENTAL PROBLEMS.

Principles and quantifications are used as keywords in our search for solutions to environmental problems.

Fig. 1.6 gives a flow chart of a procedure showing how to go from emission of mass and energy to a solution of the related environmental problems. Emission is translated into imission and concentration. The effect or impact of a concentration of a compound or energy is found by considering all the chemical, physical and biological processes that take place in the ecosystem. This evaluation leads us to an acceptable ecological (and economic) solution by use of ecological engineering or environmental technology. The former attacks the problem in the ecosystem, while the latter attempts to reduce or dilute the emission.

The procedure requires the application of principles and knowledge of environmental processes. Furthermore, the problem must be well understood and quantified so as to be able to find the right solution.

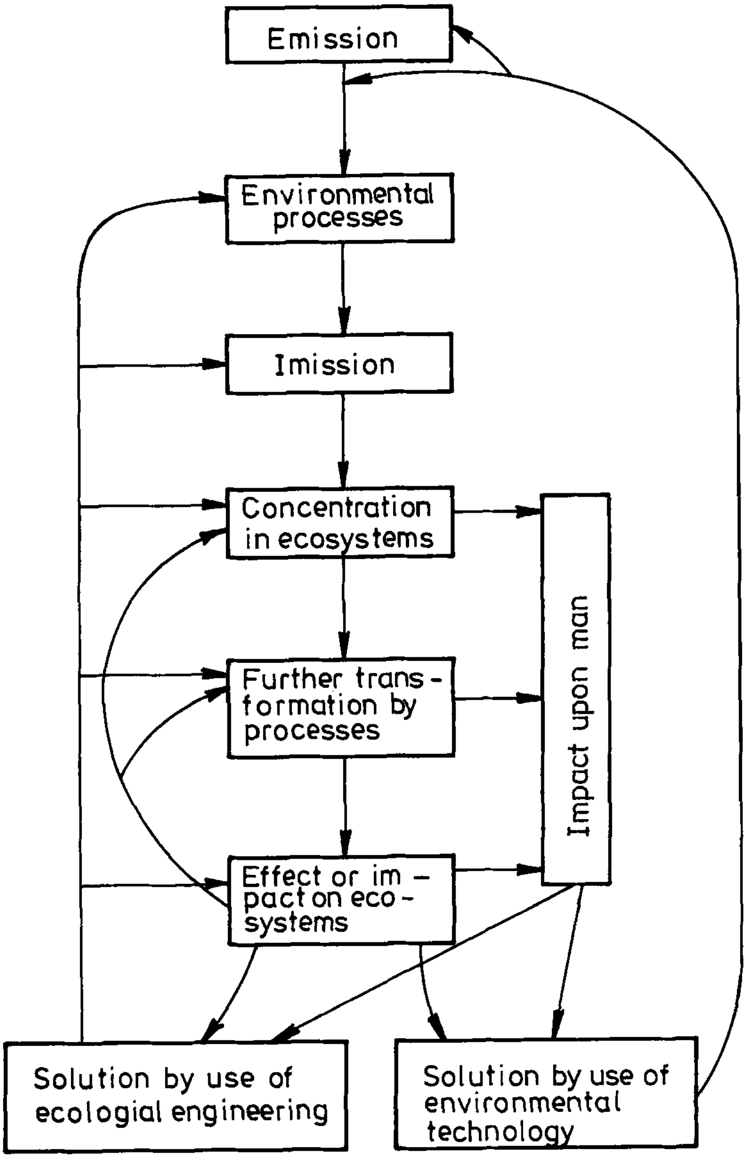

Fig. 1.6. Flowchart illustrating a procedure which can be used to go from emission to solution.
Part B of the book is devoted to how impact on ecosystems or man is translated into an environmental technology solution which attacks the problem by reduction or dilution of the emission. Part A is devoted to all other steps of the procedure.