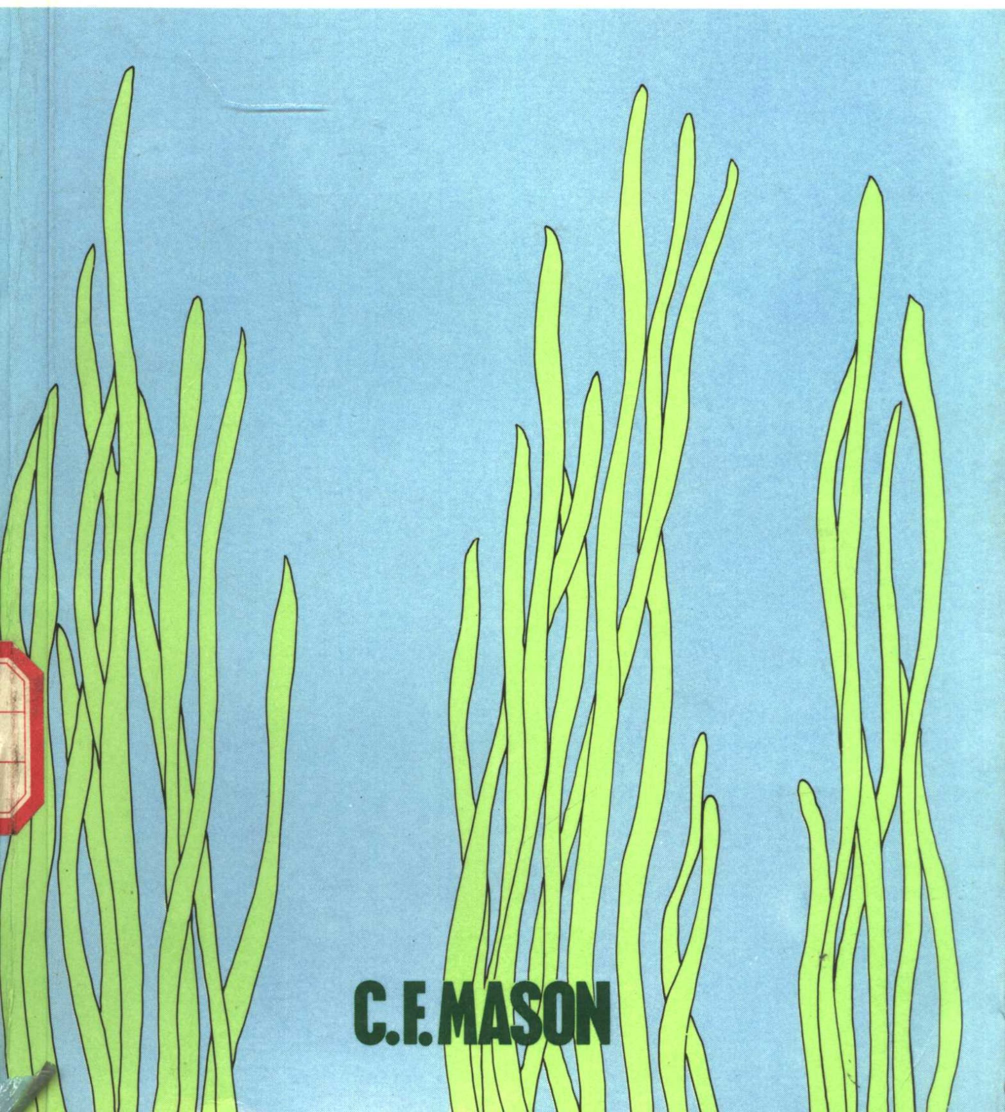
BIOLOGY OF FRESHWATER POLLUTION



C.F. MASON

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PREFACE

The control of water pollution is important not only for amenity and public health reasons but also because clean water for domestic and industrial use is in short supply even in comparatively wet countries such as the British Isles. The water shortage that developed in England and Wales during the hot, dry summer of 1976, causing severe problems to agricultural, industrial and domestic users, provided ample proof of this.

It is the biological effects of pollution, including those on man, which are of greatest importance, so it would seem natural that biologists should be involved in pollution control. Until recently, however, the management of water resources has been largely the domain of the engineer. The great increase in the number of biologists employed in the water industry over the last decade is evidence that biological expertise has much to offer in the fields of pollution detection and assessment, and in the management of the water cycle as a whole.

Since the publication of H. B. N. Hynes' classic *The biology of polluted waters* in 1960 there has been a tremendous increase in knowledge concerning pollution, particularly in the fields of eutrophication, toxic pollution and pollution assessment. The present work provides an introduction to the biological effects of water pollution and to ways of detecting, describing and quantifying these effects in the field and in the laboratory. It is intended not as a review, but an overview, which has had, of necessity, to be highly selective. At all stages, however, I have referred to modern reviews so that the reader can follow up, in depth, areas of particular interest to him. Some knowledge of the fundamentals of freshwater biology and of the factors which influence the distribution of animals and plants has been assumed. The book should enable a student to see how the academic content of much of the curriculum is used daily by biologists in an applied manner and it should provide enough practical information for interested students to carry out pollution assessments of their own.

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C. F. Mason
Wivenhoe, July 1980

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Chapter 1

INTRODUCTION

What is pollution?

There are a number of definitions of pollution in current usage. A recent dictionary of life sciences (Martin, 1976) defined pollution as 'the presence in the environment of significant amounts of unnatural substances or abnormally high concentrations of natural constituents at a level that causes undesirable effects, such as bronchial irritation, corrosion or ecological change'. Such a definition is probably too broad to be useful. Streams flowing through deciduous woodlands receive large autumnal inputs of leaves which may de-oxygenate the water and result in an impoverishment of the fauna. To the angler, wishing to catch trout, the leaves are pollutants, though the ecologist would consider de-oxygenation as a normal seasonal feature in the dynamics of such streams. The angler would be similarly distraught if he fished the headwaters of streams flowing from granite, in which the input of nutrients and energy is too low to support more than an impoverished fauna.

To avoid the consideration of naturally stressed environments, definitions of pollution are often restricted to include only the effects of substances or energy released by man himself on his resources (Edwards *et al*, 1975). The definition followed in the present book is that of Holdgate (1979):

> The introduction by man into the environment of substances or energy liable to cause hazards to human health, harm to living resources and ecological systems, damage to structure or amenity, or interference with legitimate uses of the environment.

Why need we be concerned about pollution?

From the definition above, it would seem obvious that pollution is important because man's resources are being damaged. Pollution emanates from man himself and from his activities so he should be able to control pollution. However, pollution control is extremely costly and the benefit in resource terms may be far outweighed by the cost of control. Furthermore individual (or nation) 'A' might, through pollution, be damaging the resources of individual (or nation) 'B' rather than his own and he may be unwilling to reduce his profits to benefit his neighbours. Stringently applied laws, or a high degree of altruism, are required to control pollution.

The management of water resources must be done in such a way that the water provides the capacity for sustaining life for the existing population and social activities of different scales and provides the potential for further expansion and growth, thus enabling an improvement of the social wellbeing by an upgrading of the quality of life (Lindh, 1979).

We can look at the water resources of England and Wales as a specific example of why pollution control is important. A generalized diagram of the water cycle is given in Fig. 1.1.

The population of England and Wales in 1975 was estimated at 49.2 m. people, occupying a land area of 151 139 km^2 and giving an average density of 325 people per square kilometre. The actual distribution of population of high density is shown in Fig. 1.2.

The average consumption of water in England and Wales in 1975 was equivalent to 307 litres per person per day, which amounted to 5500×10^6 m^3 per annum. The residual rainfall (Fig. 1.3) in 1975 was 360 nm, which amounted to a total of $54\,410 \times 10^6$ m^3 of water. The residual rainfall is the difference between precipitation and actual evaporation (including transpiration) and represents the total amount of water available to replenish rivers, aquifers, lakes and reservoirs; in other words it is the total quantity of water theoretically available for use. Not all of this is actually available; for instance, rain falling in coastal areas may go directly into the sea. Nevertheless, if we divide the residual rainfall by the actual consumption, the theoretical water resources in England and Wales in 1975 were some ten times more than the actual demand. If one includes direct abstractions by industry and agriculture, the total resources are some five times greater than demand. These figures do not take into account the considerable re-use of water which increases the discrepancy between resources and demand.

However, the demand for water is greatest during the summer, whilst most rain falls during the winter. Also the rainfall is not evenly distributed over England and Wales. If the distribution of residual rainfall (Fig. 1.3) is compared with the regions of high population

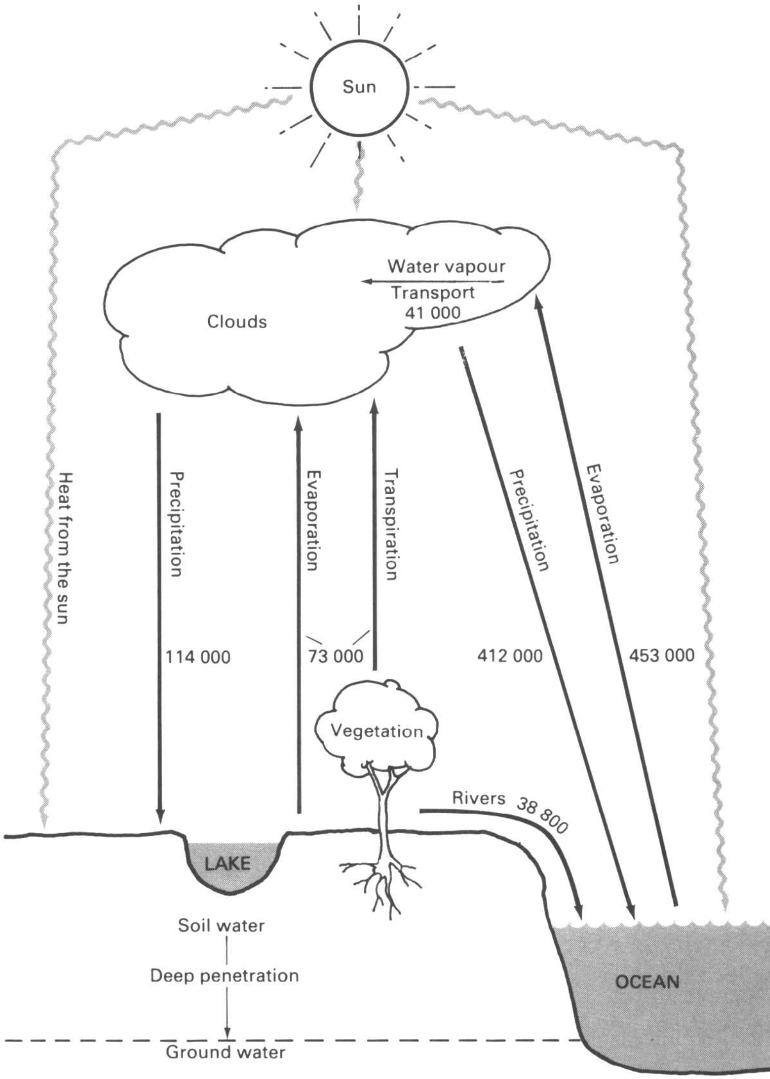

Fig. 1.1 The hydrological cycle. Global flows of water in $km^3\ y^{-1}$ (from Lvovich 1973).

(Fig. 1.2) we can see that a number of regions of high population and industry, for instance the Midlands, London and the south-east, are in areas of low rainfall. Furthermore, arable farming, with its requirements for irrigation, is also concentrated in the drier areas of the country. Annual rainfall, of course, also varies and a ten-year

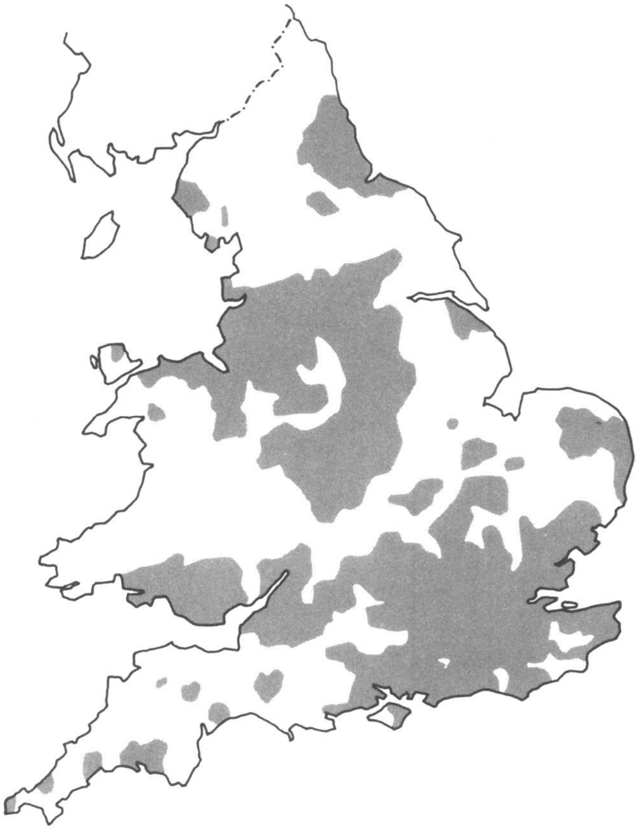

Fig. 1.2. The areas of high population density (shown black) in England and Wales.

periodicity has been demonstrated for the rainfall of England and Wales (Rodda *et al*, 1978).

This discrepancy between water availability and water use means that the actual resources may fall at times below demand, as happened in the exceptional drought year of 1976, when considerable restrictions on water use became necessary. There are similar problems of supply and demand in many other areas of the world, e.g. the Potomac River in Washington D.C. can no longer safely supply the population demands for water in dry years (Withers, 1978). Evapotranspiration exceeds precipitation in large areas of the world, including many developing countries, where rational water management is of paramount importance (Kalinin and Shiklomanov, 1974).

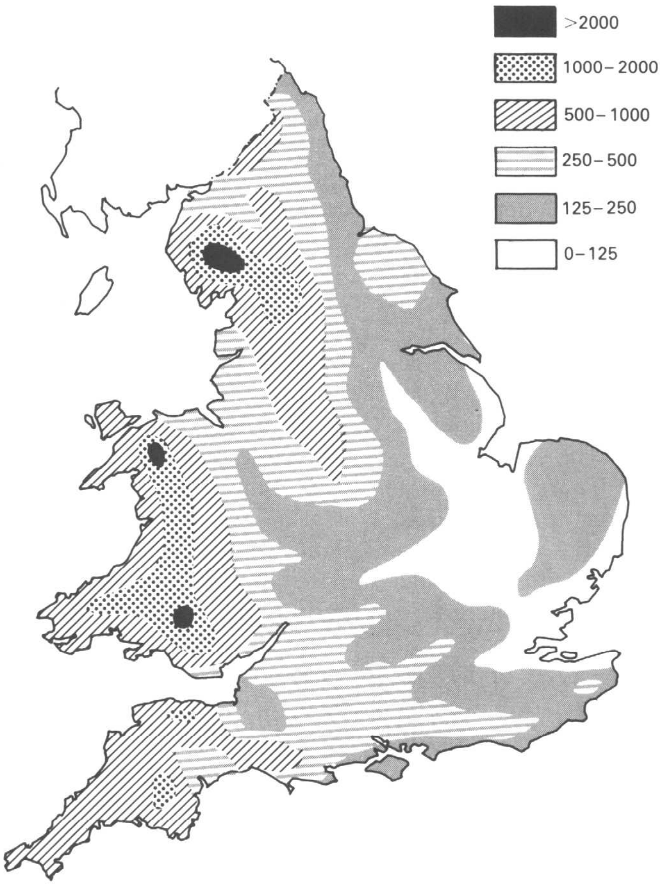

Fig. 1.3 The residual rainfall (mm) in England and Wales.

The disparity between areas of high rainfall and areas where water is needed result in large quantities of water in England and Wales being abstracted for the public water suppply from the lowland reaches of rivers and there is also considerable direct abstraction by industry and agriculture. *Such water must be of an acceptable quality*. Abstractions from the lower reaches of a river may be sustained by a controlled discharge from a reservoir usually situated in the headwaters where rainfall is heavier, this being an economical way of transporting water to where it is needed. Water may also be transferred from one catchment to another which is short of water. Many rivers are being used in this way as aqueducts.

Domestic, industrial and agricultural users produce large quantities of waste products and waterways provide a cheap and effective way of disposing of many of these. During dry weather, the flow of some rivers consists almost entirely of effluents. The effluents of some towns become the water supplies of other towns downstream. For this reason alone it is important that the effluent discharged into a watercourse is of high quality and the degree of pollution is such that the self-purifying capacity of the river (see p.34) is not overloaded.

In addition to providing a source of water and a sink for effluents, freshwaters have an important amenity role, including such activities as boating, angling and wildlife studies. Some of these pastimes require water of a very high quality. In 1970, some 2.79 m. people went fishing in England and Wales, making angling by far the largest participating sport in the country (Natural Environment Research Council, 1971). The service industries for these pastimes are locally very valuable. There are also lucrative commercial fisheries for salmon, migratory trout and eels. It is also very desirable that the natural communities of animals and plants in freshwaters be maintained and in England and Wales the Regional Water Authorities have a statutory requirement to consider the biota of freshwaters in any management scheme.

Finally, the resources of the seas are vast and most of the pollutants travelling down rivers will eventually end up in the sea. Animals such as arctic seals and antarctic penguins are already loaded with pollutants and we should not be complacent that the immense quantities of water in the oceans can absorb pollution indefinitely without effect.

There are, therefore, a number of reasons why the control of pollution is important. We do not, of course, have equal concern for all the components of our environment and this is especially so when the enormous costs of pollution abatement are taken into account. Holdgate (1979) has ranked target organs for pollutants in order of decreasing concern to man:

Man → Domestic livestock → Crops and structures → Most wildlife and amenity → Pests and disease vectors

Man's prime concern is to reduce the risk of pollution affecting his own health, whilst at the other extreme, if pollution kills organisms which are pests to man then it might be considered positively beneficial. Some groups of organisms may be of fairly low priority in terms of man's, or at least politicians', concern, but they may require water of an especially high quality. We can list a number of potential uses of water in terms of decreasing water quality requirements (Poels *et al*, 1978):

nature reserves → recreation → fisheries → water for potable supply → watering cattle → irrigation → processing water → cooling water → shipping.

Thus nature reserves may need completely unpolluted water (though this is not necessarily so, it depends rather on what is being conserved), whereas a grossly polluted water will suffice for shipping. Note that because of the efficiency of water treatment processes water for potable supply need not be of the highest quality.

It would obviously not be economically feasible to clean all waters to such an extent that they would make pristine nature reserves and economic considerations may make it unrealistic to improve the quality of some waters for recreation and fisheries. Increasingly the concept of maintaining water quality at a standard relating to the use to which that water is put is being adopted. Thus a classification system for water uses is constructed and for these uses water quality criteria are formulated (see p.192).

What are pollutants?

In terms of the definition given at the beginning of this chapter almost anything produced by man can be considered at some time to be a pollutant. Indeed, to the farmer whose land is about to be lost under a new reservoir scheme, pure water is itself a pollutant in almost every sense of the definition given. Substances which are essential to life (e.g. copper, zinc) can be highly toxic when present in large amounts.

Some 1500 substances have been listed as pollutants in freshwater ecosystems and a generalized list is given in Table 1.1. Some of the categories are not necessarily mutually exclusive, e.g. domestic sewage may contain, in addition to oxidizable material, detergents, nutrients, metals, pathogens and a variety of other compounds.

Whether or not a compound will exert an effect on an organism or a community will depend on the concentration of that compound and the time of exposure to the compound (i.e. the dose). The effect of a pollutant on a target organism may be either acute or chronic (Saunders, 1976). Acute effects occur rapidly, are clearly defined, often fatal and rarely reversible. Chronic effects develop after long exposure to low doses or long after exposure and may ultimately

Table 1.1. Categories of pollutants found in freshwater.

Acids and alkalis.
Anions (e.g. sulphide, sulphite, cyanide).
Detergents.
Domestic sewage and farm manures.
Food processing wastes (including processes taking place on the farm).
Gases (e.g. chlorine, ammonia).
Heat.
Metals (e.g. cadmium, zinc, lead).
Nutrients (especially phosphates and nitrates).
Oil and oil dispersants.
Organic toxic wastes (e.g. formaldehydes, phenols).
Pathogens.
Pesticides.
Polychlorinated biphenyls.
Radionuclides.

cause death. Sub-lethal doses result in the impairment of the physiological or behavioural processes of the organism (e.g. it may grow poorly, or fail to reproduce). Its overall fitness is reduced.

At the community or ecosystem level it is unlikely that pollution will cause irreversible effects, except possibly in the case of radioactive pollution. The effects of pollution are recorded in the loss of some species, with possibly a gain in others, generally a reduction in diversity, but not necessarily numbers of individual species, and a change in the balance of such processes as predation, competition and materials cycling.

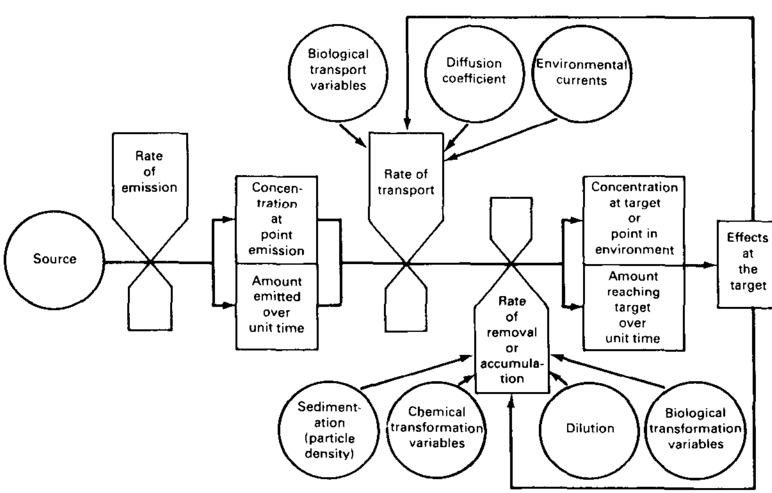

Fig. 1.4. A generalized pollutant pathway (from Holdgate 1979).

The generalized pathway of a pollutant from source to target is shown in Fig. 1.4. There are three important rate processes in the pathway: the rate of emission from the source of pollution; the rate of transport through the ecological system; and the rate of removal or accumulation of the pollutant in the pathway. The rate of transport will depend on the diffusion rate of the pollutant and on a variety of environmental factors as well as properties of transport within organisms in the pathway. The rate of removal or accumulation will depend on rates of dilution or sedimentation and on chemical and biological transformations. These determine the dose reaching the target organisms. Processes within the target will either transport the pollutant to where it exerts an effect or will excrete the pollutant. We can see how this basic pathway can be repeated along a food chain. Also, with slight terminological changes, Fig. 1.4. can illustrate the basic pathway from entry point to site of action within a target organism.

Monitoring pollution

Holdgate (1979) has pointed out that to effectively manage an environment receiving polluting substances we need information concerning:

1. The substances entering the environment and their quantities, sources and distribution.
2. The effects of these substances within the environment.
3. Trends in concentration and effect, and the causes of these changes.
4. How far these inputs, concentrations, effects and trends can be modified and by what means at what cost.

The first stage in this management is to carry out a *survey*, which is a programme of measurements that defines a pattern of variation of a parameter in space. As an example, we may be concerned about the output of zinc into a river in an effluent from a rubber-processing factory. Our initial survey may involve measuring the levels of zinc in the river sediment at a number of stations downstream from the factory, together with sampling the fauna and flora at these stations. The survey will only inform us of the situation at one point in time.

The next stage will be *surveillance* and *research*, which will enable us to learn more about a problem before any policy decisions are made. Surveillance is defined as the repeated measurement of a variable in order that a trend may be detected. In our example we may measure the level of zinc in the sediments at three-monthly intervals