Chapter 1

# Introduction

**Learning Objectives**

- To explain what is meant by the term ‘environment’.
- To identify reasons for concern over the current and future quality of the environment.
- To appreciate the diversity of pollution.
- To evaluate the role of chemical analysis in dealing with these problems.

## 1.1 The Environment

We live in a world where the environment is of major concern. In our newspapers we read of governments attempting to find agreement over global environmental problems. We can use ‘green’ fuel in our transport, shop for ‘environmentally friendly’ products and recycle much of our waste. However, what do we mean by our **environment**? Are we referring here to:

The place where we live or work?
The atmosphere which we breathe and the water which we drink?
Unspoilt areas of the world which could soon be ruined?
Parts of the atmosphere which shield us from harmful radiation?

The environment must include all of these areas and anywhere else which could affect the well-being of living organisms. Concern must extend over any process which would affect this well-being, whether it is physical (e.g. global warming and climate change), chemical (e.g. ozone layer depletion) or biological (e.g. destruction of rain forests).

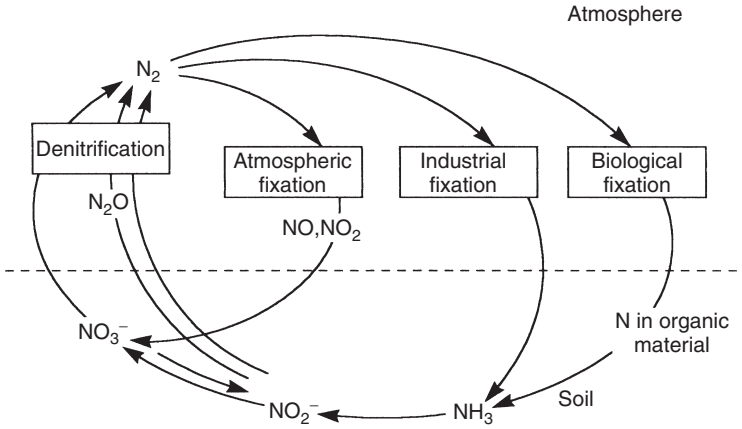


**Figure 1.1** Illustration of a simplified nitrogen cycle.

Anyone who has more than a passing interest in the environment has to learn and understand a very broad range of subjects. The purpose of this introduction is first of all to show how analytical chemistry fits into this broad spectrum, and later to demonstrate how it is an essential part of any scientific study of the environment and its problems. The book then goes on to discuss how analytical chemistry is applied to the three spheres of the environment, namely water, land and atmosphere.

In order to understand the environment, we must first realize that it is never static. Physical forces continuously change the surface of the earth through weather, the action of waves and natural phenomena, such as volcanoes. At the same time, they release gases, vapour and dust into the atmosphere. These can return to the land or sea a great distance away from their sources. Chemical reactions high up in the atmosphere continuously produce ozone which protects us from harmful ultraviolet radiation from the sun. Living organisms also play a dynamic role through respiration, excretion, and ultimately, death and decay, thus recycling their constituent elements through the environment. This is illustrated by the well-known nitrogen cycle (Figure 1.1). There are similar cycles for all elements which are used by living organisms.

## 1.2 Reasons for Concern

The current interest in the environment stems from the concern that the natural processes are being disrupted by people to such an extent that the quality of life, or even life itself, is being threatened.

Many indicators would suggest that the world is at a crisis point; for instance, the rapid population growth of the world, as shown in Figure 1.2, and the

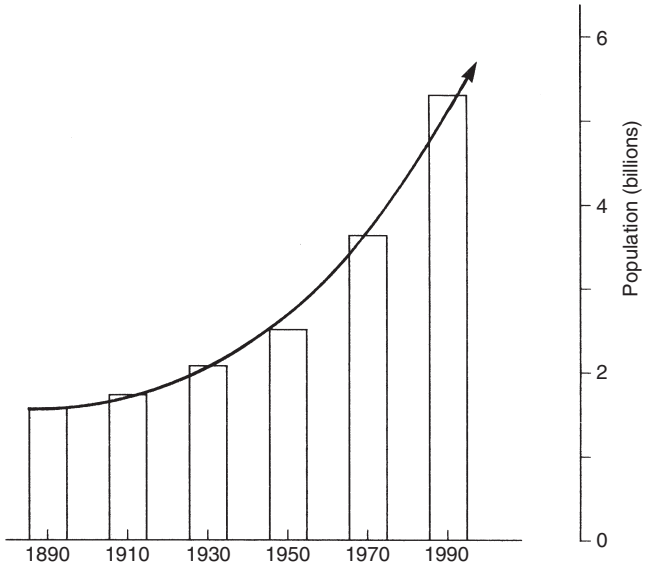


**Figure 1.2** The growth of world population.

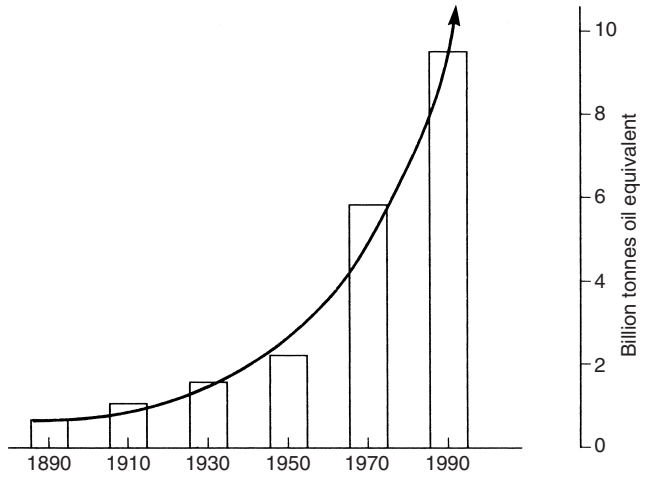


**Figure 1.3** The growth of energy consumption.

consequential growth in energy consumption shown in Figure 1.3. Not only will the earth be depleted of its resources, with the inevitable environmental damage that will result, but there will almost certainly be a parallel increase in waste produced and in pollution of the earth. The increase in production of carbon dioxide follows an almost identical curve to the energy consumption increase.

This concern has become heightened by a greater awareness of problems than in previous ages, due to greater ease of communication, which bring news from distant parts of the world. It seems ironic that the greater prosperity of the developed world, giving sufficient leisure time for concern over global problems, but also giving increased resource consumption, is currently a large contributing factor to the problems themselves.

### *1.2.1 Today's World*

The type of discussion above can lead to a pessimistic view of the future. However, there has been much national and international legislation leading to the control of pollution, and the ordinary person in the street can immediately see the benefits of taking a greater concern for the environment. The choking sulfurous fog which used to engulf London on winter days is now only found in history books. The lower reaches of the River Thames were once dead but now it is one of the cleanest in Europe, with at least 115 different species of fish. Care of the environment is on everyone's lips and in their lifestyle. There are few people who will never have heard of the potential problems of increased greenhouse gas emissions. Legislation is continuously being introduced to improve our environment. In many countries, we have moved to the stage where concern for the environment is an integral part of everyday life.

### *1.2.2 Past and Current Crimes*

Some of the concern today is centred on problems inherited from less enlightened ages which will be with us for many years to come. Examples include spoil heaps from mining operations, contaminated land from previous industrial sites, and pesticides which are now banned but have such a long lifetime in the environment that they will continue to pollute for many decades. Current concerns include emissions from our automobiles, waste production, production of toxic particulate matter from combustion and incineration processes, use of pesticides which build up in the food chain and the use of inorganic fertilizers in agriculture. Although more environmentally friendly methods for power production are being introduced, there is still a large-scale reliance on fossil fuel for energy production with its inevitable production of carbon dioxide.

## 1.3 Pollution

All of us have concepts of what pollution is but have you considered how it may be defined?

**DQ 1.1**

What you would consider to be a definition of pollution?

*Answer*

*The following definition is from the Organization of Economic Co-operation and Development:*
*'Pollution means the introduction by man, directly or indirectly, of substances or energy into the environment resulting in deleterious effects of such a nature as to endanger human health, harm living resources or interfere with amenities or other legitimate use of the environment.'*

Before we concentrate on the chemical aspects of pollution, it is worth remembering that this is not the only form of pollution. Noise is an example of physical pollution. Simply adding water to a river at a different temperature to the ambient can effect life in the river. This is a form of thermal pollution. Pollution is, however, often associated with the introduction of chemical compounds into the environment. Popular opinion usually sees these as unnatural (and therefore harmful) substances. Perhaps one of the best known recent examples was the concern over the emission of chlorofluorocarbons (CFCs). These have been used in aerosol sprays and other applications. They are linked with the depletion of ozone in the stratosphere, which could lead to an increase in the intensity of harmful ultraviolet radiation from the sun reaching the earth's surface and increasing the incidence of skin cancer. Although the production of CFCs themselves is now banned in developed countries, the existing CFCs will take many years to be removed from the atmosphere and related ozone-depleting compounds (e.g. hydrochlorofluorocarbons, (HCFCs)) are still being manufactured. The effects on the ozone layer will therefore remain for many decades.

More frequently, problems occur by the release of substances into the environment which are naturally present, with the problem arising simply from an increase in concentration above the 'natural' levels. Carbon dioxide is a natural component of the atmosphere produced by the respiration of living organisms. The potential problem of global warming is primarily associated with an increase in its concentration in the atmosphere as a result of fuel combustion, together with a decrease in the world's forests which recycle the carbon. Increasing concentrations of a number of other naturally occurring gases, such as methane and nitrous oxide, add to the problem. Nitrates occur naturally as part of the constant cycling of nitrogen in the environment (see Figure 1.1). The over-use of fertilizers can, however, produce a build-up of nitrate in water courses which leads, first of all, to excessive plant growth, but ultimately to the death of all living species in the water. The process is known as *eutrophication*. Apart from nitrogen itself, all of these species in the nitrogen cycle have been shown to exhibit environmental problems if their concentration increases greatly above the 'natural' level in water or in the atmosphere. This is summarized in Table 1.1

You should be able to think of many pollution examples of your own. Try grouping the problems into different categories, for instance, whether the pollution is a global problem (e.g. ozone-depletion) or a more local issue (e.g. waste dumping). When you read the next chapter, which deals with the transport of

**Table 1.1** Examples of problems caused by excessive concentrations of nitrogen species

| Species | Problem |
|---|---|
| $N_2O$ | Contributes to the greenhouse effect and is a potential ozone-depleter |
| $NH_3$ | Highly poisonous to fish, particularly in its non-protonated form |
| $NO_2^-$ | Highly poisonous in water to animals |
| $NO_3^-$ | Contributes to eutrophication (excessive plant growth) in watercourses; associated with 'blue-baby syndrome' which can cause fatalities in infants |

pollutants, you may find that you change your mind about some of the problems. Lead pollution, which has been associated with the retardation of intellectual development in children, is normally thought to be a highly localized problem. Increased lead concentrations in the environment, largely from the use of leaded petrol in cars, can be detected hundreds of kilometres from likely sources.

**DQ 1.2**

If a pollutant is discharged into the environment, what causes the effect on individual living organisms:

- the total amount discharged;
- its concentration in the environment?

*Answer*

*It is the* ***concentration*** *which is of concern with respect to individual living organisms.*

This statement may seem surprising but consider the following facts. All compounds are toxic at high enough concentrations. Even something apparently as innocuous as sodium chloride has adverse effects when present in high concentration. For example, you cannot drink more than a small quantity of sea water without being made ill. Some metals, which are necessary for plant growth when found in small concentrations in the soil, would kill the plant life when found in larger concentrations on, let us say, a waste dump. These include elements such as chromium, cobalt and manganese, and are often known as 'essential' elements.

Of course, if we are considering the effect of a particular pollutant on the global environment, we would have to consider the total quantity emitted. Excessive amounts would ultimately increase the background concentration, as is the case with carbon dioxide emissions.

It would then appear, that in order to limit the adverse effect of a particular ion or compound, it is necessary to ensure that the concentration in water or in the atmosphere is maintained below a pre-determined 'safe' level. As will be shown in the next section, the establishment of such levels is fraught with difficulty. Nonetheless, much of the world's environmental legislation is drafted in terms of specifying maximum concentration of ions and compounds (Table 1.2).

**Table 1.2** Extract from European Community Directive 80/778/EEC relating to the quality of water intended for human consumption – parameters concerning substances undesirable in excessive amounts[a]. Reproduced by permission of the Official Journal of the European Communities

| Parameter | Expression of the results[a] | Guide level (GL) | Maximum admissible concentration (MAC) | Comments |
|---|---|---|---|---|
| 20 Nitrates | $NO_3$ (mg $l^{-1}$) | 25 | 50 | — |
| 21 Nitrites | $NO_2$ (mg $l^{-1}$) | — | 0.1 | — |
| 22 Ammonium | $NH_4$ (mg $l^{-1}$) | 0.05 | 0.5 | — |
| 23 Kjeldahl nitrogen (excluding N in $NO_2$ and $NO_3$) | N (mg $l^{-1}$) | — | 1 | — |
| 24 ($KMnO_4$) oxidizability | $O_2$ (mg $l^{-1}$) | 2 | 5 | Measured when heated in acid medium |
| 25 Total organic carbon (TOC) | C (mg $l^{-1}$) | | | The reason for any increase in the usual concentration must be investigated |
| 26 Hydrogen sulfide | S ($\mu$g $l^{-1}$) | — | Undetectable organoleptically | — |
| 27 Substances extractable in chloroform | Dry residue (mg $l^{-1}$) | 0.1 | — | — |
| 28 Dissolved or emulsified hydrocarbons (after extraction by petroleum ether); mineral oils | $\mu$g $l^{-1}$ | — | 10 | — |
| 29 Phenols (phenol index) | $C_6H_5OH$ ($\mu$g $l^{-1}$) | — | 0.5 | Excluding natural phenols which do not react with chlorine |
| 30 Boron | B ($\mu$g $l^{-1}$) | 1000 | — | — |
| 31 Surfactants (reacting with methylene blue) | Lauryl sulfate ($\mu$g $l^{-1}$) | — | 200 | — |

[a]Certain of these substances may even be toxic when present in very substantial quantities.

**DQ 1.3**

What are the maximum concentrations that the substances listed in Table 1.2 can be considered to be acceptable in drinking water?

*Answer*

*These, of course, vary from substance to substance, but you should have noted that most of the maximum admissible concentrations are expressed in units of mg* $l^{-1}$ *(sometimes called parts per million (ppm)), whereas others are expressed as* $\mu g\ l^{-1}$ *(or parts per billion (ppb)).*

**SAQ 1.1**

How would you see the following situations as contributing to pollution problems?

1. An increase in the developed world's population.
2. Volcanic emissions.
3. Production of methane by cows, as part of their natural digestion.
4. Excessive quantities of nitrate fertilizers used in farming.

## 1.4 The Necessity of Chemical Analysis

If you were performing a simple pollution monitoring exercise, it is evident that a detailed analysis of pollution levels would be an essential part. Let us now consider a complete control programme and look in detail at what stages chemical analysis would be necessary.

**DQ 1.4**

List what steps you think would be necessary for a national government or international agency to control a potential pollution problem, starting from the initial recognition. At what stages would chemical analysis be involved?

*Answer*

*1. Recognition of the Problem*

This would appear to be an obvious statement until you consider how recently many pollution problems have become recognized. The term 'acid rain' originally referred to localized effects of sulfur oxides ($SO_2$ and $SO_3$) produced from coal combustion and was introduced in the 19th century. Trans-national problems, such as may arise from the transport of the gases from the power stations in the north of England to Scandinavia, have only been recognized in the last three decades. The

contribution of other chemical compounds, such as nitrogen oxides (NO and $NO_2$), to acid rain was only acknowledged several years later. Alternatives to the ozone-depleting CFCs were introduced in the late 1980s and early 1990s. These included hydrofluorocarbons (HFCs) which have no ozone-depleting potential. There was little regard originally taken of their large greenhouse-warming effect. Currently, there is much concern over endocrine disruptors, known in the popular press by terms such as 'gender benders' or 'sex-change chemicals', which have recently been shown to effect the early stages of foetal development in some species. This leads to mixed sexual characteristics, usually seen as the feminization of males. Such compounds are widespread in the environment. Some have long been known to have environmental effects (e.g. polychlorinated biphenyls and the pesticide DDT), while others had been previously considered completely benign (e.g. phthalate esters which are used as plasticizers in PVC materials).

*2. Monitoring to Determine the Extent of the Problem*
As we have already seen, this may either involve analysis of a compound not naturally found in the environment, or determination of the increase in concentration of a compound above the 'natural' level. The determination of 'natural' levels could itself involve a substantial monitoring exercise since these levels may vary greatly with location and season. Large quantities of waste materials have been produced for many centuries, and it may even be a difficult task to assess what an unpolluted environment is. For example, it has been discovered that the highly toxic and potentially carcinogenic compounds commonly referred to as 'dioxins', which were originally assumed to be completely anthropogenic (man-made), occur naturally at trace levels.

*3. Determination of Control Procedures*
Determination of the most appropriate method should involve testing the options with suitable analytical monitoring. Possibilities include technological methods, such as the use of flue gas desulfurization processes to lower sulfur oxide emissions from coal-fired power stations, and socially orientated methods, such as the promotion of the use of public rather than private transport to reduce vehicle emissions.

*4. Legislation to Ensure the Control Procedures are Implemented*
Few pollution control methods are taken up without the backing of national or international legislation. As shown in Table 1.2, this legislation is very often drafted in terms of analytical concentrations.

*5. Monitoring to Ensure the Problem has been Controlled*
A large proportion of current monitoring is to ensure compliance with legislation. This may range from national programmes to confirm air and

water quality to local monitoring of discharges from industries and to the yearly checking of emissions from individual automobiles. Monitoring also provides scientific evidence for possible further developments in legislation.

Have you noticed the cyclical nature of the process which includes monitoring to show that a problem exists, reduction of the problem by control procedures, and monitoring to confirm that the problem has been reduced, with the final stage leading back to the start for improvement in the control procedures?

You should also have noticed that chemical analysis is a necessary component of *almost all* of the stages!

**SAQ 1.2**

Consider a factory producing a liquid discharge, consisting partly of side products of the process and partly of contaminants present in the starting materials. What analytical monitoring programme would be useful to assess and control the effluent?

## Summary

This introduction answers the question of what is meant by the terms 'environment' and 'pollution'. Pollutants are often materials which are naturally present in the environment, with their adverse effects being caused by concentrations higher than those which would be expected from natural causes. A study of pollution would then involve a large amount of quantitative chemical analysis. Analytical chemistry is also involved in devising pollution control procedures, in drafting legislation and in monitoring the effect of any control procedure. In fact, analytical chemistry is a necessary component in almost all aspects of scientific investigations of the environment, the problems caused by mankind and their possible solution.