POLLUTION IN CUMBRIA

INSTITUTE of TERRESTRIAL ECOLOGY

NATURAL ENVIRONMENT RESEARCH COUNCIL

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INSTITUTE OF TERRESTRIAL ECOLOGY

Pollution in Cumbria

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Edited by
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Roosecote Sands, Barrow-in-Furness
(Photograph P Ineson)

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This volume appears in the year when Mr S E Allen, current Head of Merlewood Research Station, retires. As this work is a product of his encouragement and support, I dedicate this volume to him.

The *Institute of Terrestrial Ecology (ITE)* was established in 1973, from the former Nature Conservancy's research stations and staff, joined later by the Institute of Tree Biology and the Culture Centre of Algae and Protozoa. ITE contributes to, and draws upon, the collective knowledge of the 14 sister institutes which make up the *Natural Environment Research Council*, spanning all the environmental sciences.

The Institute studies the factors determining the structure, composition and processes of land and freshwater systems, and of individual plant and animal species. It is developing a sounder scientific basis for predicting and modelling environmental trends arising from natural or man-made change. The results of this research are available to those reponsible for the protection, management and wise use of our natural resources.

One quarter of ITE's work is research commissioned by customers, such as the Department of Environment, the Commission of the European Communities, the Nature Conservancy Council and the Overseas Development Administration. The remainder is fundamental research supported by NERC.

ITE's expertise is widely used by international organizations in overseas projects and programmes of research.

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INDUSTRIAL POLLUTION

Preface

There has been much recent concern about the effects of pollution on the environment and inhabitants of Cumbria: the Lake District has been identified as an area at risk from 'acid rain'; the west coast of Cumbria is nationally known for elevated levels of radioactive wastes; tourists are damaging the fabric of the remote areas they come to enjoy; some of the lakes receive large loads of effluents; the list is a large and growing one.

In 1985, the Merlewood Research Station of the Institute of Terrestrial Ecology hosted a meeting at Grange-over-Sands, and invited specialist speakers to address a general audience on aspects of pollution problems facing Cumbria. The speakers were chosen to provide views of pollution in Cumbria from several viewpoints, with the expectation that much of the available evidence and data would be presented. The audience contained local people, councillors, industrialists and environmentalists, and anyone with an interest in the environment in Cumbria was welcomed.

The evidence presented at that meeting is published here, and we are grateful to the authors for their contributions. However, the Natural Environment Research Council, of which ITE is a component institute, cannot accept responsibility for the views expressed in this volume; they are solely those of the authors, and in publishing them ITE is simply providing a forum for those views to be expressed. An assessment of the extent of the problems is left to the reader, and I hope that this volume will prove to be informative and, above all, thought-provoking.

'Don't you know it seems to go,
But you don't know what you've got 'til
it's gone,
They paved paradise,
Put up a parking-lot.'
Joni Mitchell

Philip Ineson

ACID RAIN

Acid deposition in Cumbria

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Summary
Cumbria is a region receiving amounts of wet deposited acidity from the atmosphere as large as any other area of Britain, Scandinavia or Europe. This large deposit of acidity is a consequence of a combination of the very large annual precipitation and its weighted acidity, typically pH 4.4 in Cumbria.

Dry deposition also contributes substantial quantities of sulphur, nitrogen and acidity, accounting for up to half of the total annual deposition of acidity from the atmosphere.

The large chemical inputs, interesting mechanisms of deposition and unusual topography are drawing a growing number of scientists to Cumbria to help unravel the complexities of the chemical and physical aspects of acid deposition. It is probable, therefore, that Cumbria will play an important part in the next few years of acid rain research in the UK.

1 Introduction
The meaning of 'acid rain', which is a term now more familiar to the UK public than it was a decade ago, has been stretched to cover all facets of acidic air pollution. In the process, however, its meaning has become vague. To consider the components of 'acid deposition', one must separate the processes of wet deposition (acid rain in the strict sense) and dry deposition of acidic gases and particles. Precipitation (rain, snow and hail) is generally regarded as acidic if it is more acid than pH 5.6 (equivalent to 2.5 $\mu M\ H^+$), the acidity of pure water in equilibrium with atmospheric concentrations of CO_2. This reference point is entirely arbitrary and does not form an exact basis for gauging the influence of man on the acidity of precipitation, as there are natural processes which may be involved. Gaseous sulphur compounds (eg dimethyl sulphide, carbonyl sulphide and hydrogen sulphide) are released by natural processes (on land and at sea), and these gases are oxidized through a variety of mechanisms to sulphur dioxide, and ultimately to sulphuric acid or sulphate salts. These sulphates are eventually incorporated into cloud water and lead to acidification of precipitation. Nitric oxide may also be released from natural processes (eg denitrification) and is oxidized in the atmosphere to nitrogen dioxide and nitric acid, which may be incorporated into precipitation. The natural mechanisms by which precipitation is acidified create a range of expected acidities in rain events from about pH 4.8 to pH 6.0, with median values of about pH 5.0 (10 $\mu M\ H^+$) (Charlson & Rodhe 1982). Such values of rainfall acidity are observed on remote islands in the Indian Ocean (Galloway & Gaudry 1984) and are quite close to the average values observed in the north of Norway (European Monitoring Evaluation Programme 1984) and Hebridean Islands (Cape *et al.* 1984).

Natural emissions of sulphur- and nitrogen-containing gases are augmented by industrial emissions, largely as a consequence of fossil fuel combustion and smelting processes. The sulphur dioxide and oxides of nitrogen released are oxidized in the atmosphere to their respective acids and returned to the surface in precipitation, which is acidified as a consequence. In the main industrial regions of Europe and eastern North America, the acidity of precipitation events is generally in the range pH 3.0–6.0, with annual mean values between pH 4.0 and pH 4.2 (100 to 60 $\mu M\ H^+$), about an order of magnitude more acidic than levels of acidity resulting from natural processes.

The other major deposition pathway for atmospheric acidity is dry deposition, in which the pollutants as gases or particles are 'captured' by the surface directly. The gases SO_2 and NO_2 may be deposited on external surfaces of vegetation or absorbed within the leaves following diffusion through the stomata. The gases are then oxidized to sulphate and nitrate respectively, generating acidity on or inside leaves.

A third mechanism by which pollutants are transferred from the atmosphere to the ground is termed 'occult deposition'. In this process, the pollutants are first incorporated into cloud droplets, as in wet deposition, but are subsequently deposited when cloud droplets are intercepted by vegetation. The mechanism is of importance to sites which are enveloped in cloud for a significant proportion of time.

The particles generated from oxidation of SO_2 and NO_2 are found in the size range 0.1–1.0 μm (diameter), and, unlike the gases, are not efficiently absorbed at the ground by dry deposition. The particles are too small to have significant rates of sedimentation under the action of gravity, and are transported through the free atmosphere by turbulent diffusion. However, close to surfaces where turbulence is suppressed, gases diffuse to the surface by molecular diffusion, whereas the particles are too large to 'diffuse' at significant rates. The major removal pathway for these particulate pollutants is by wet deposition. Sulphate- and nitrate-containing aerosols form suitable cloud condensation nuclei for the production of cloud droplets, and are efficiently scavenged from the air by precipitation.

These characteristics of the chemical conversion of pollutants and wet and dry deposition pathways lead to a systematic change from inputs dominated by dry deposition of gases close to source areas, where gas concentrations are largest, to inputs dominated by wet deposition in regions remote from sources.

In the industrial regions of central England, for example, gas concentrations of SO_2 and NO_2 considerably exceed those of particulate sulphate and nitrate, and dry deposition is the dominant removal mechanism. In contrast, the west coast of Scandinavia experiences only small concentrations of SO_2 and NO_2 similar to the concentrations of sulphate and nitrate particles, and in these areas wet deposition contributes the majority of deposited sulphate and nitrate.

2 Cumbria

Cumbria is located only 100–200 km from major sources of SO_2 and NO_x ($NO+NO_2$) in the UK, so that in appropriate meteorological conditions significant concentrations of these pollutant gases are advected over Cumbria by wind. Inputs by dry deposition are, therefore, important to the annual 'budget'.

The very high rainfall in Cumbria also makes wet deposition inputs important. In general, the concentrations of major ions (sulphate, nitrate, ammonium and hydrogen) are smaller than at east coast sites (Figure 1), but the lower concentrations are more than compensated for by larger rainfall (up to 3000 mm), so that wet deposition in Cumbria exceeds that at east coast sites by a factor of at least 2.

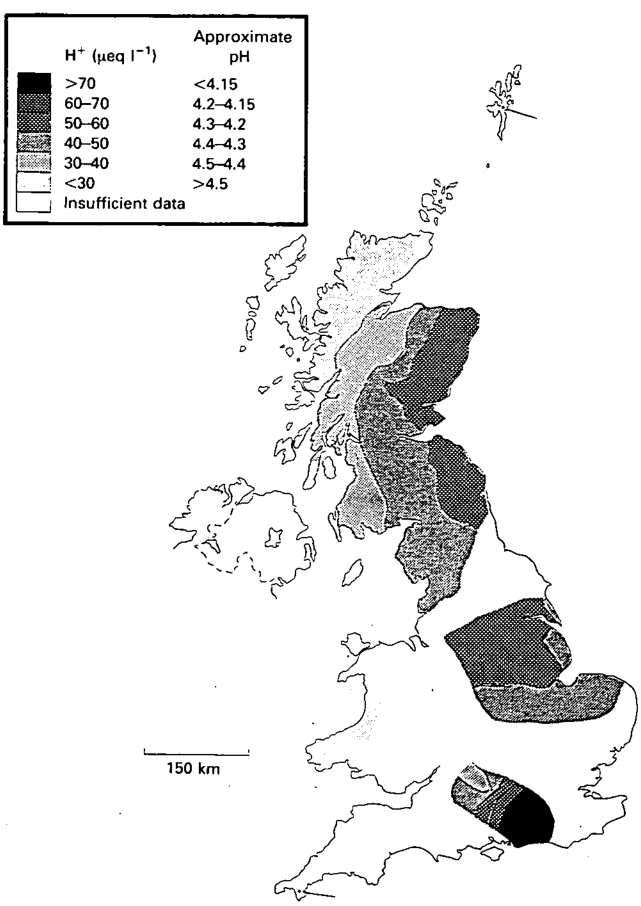

Figure 1. Rainfall weighted annual average hydrogen ion concentrations (source: Barrett et al. *1983)*

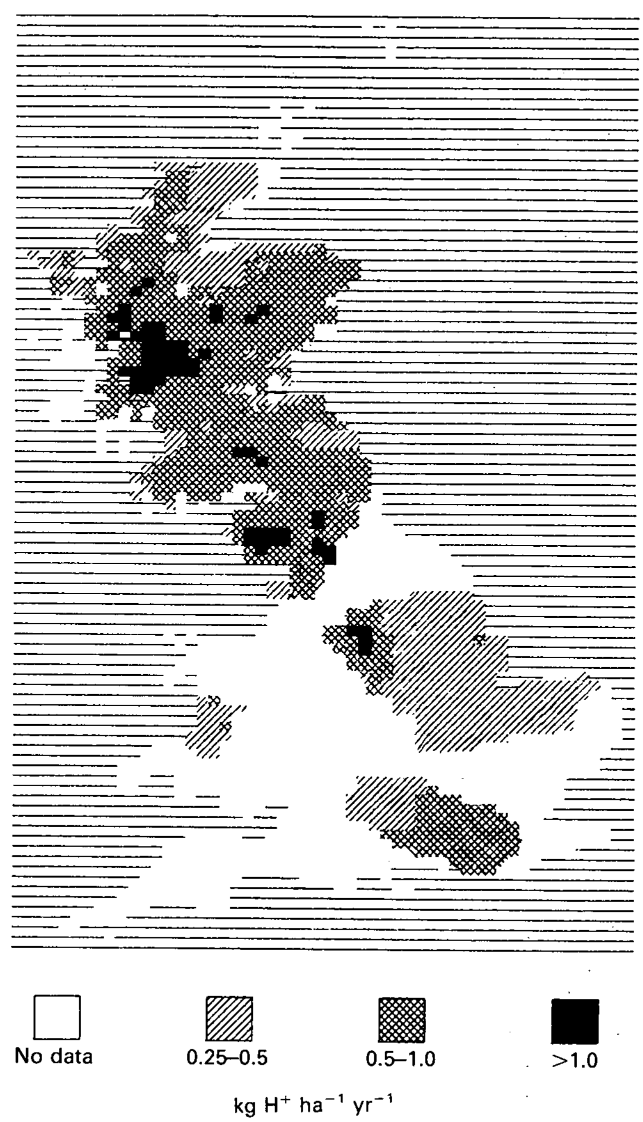

Figure 2. Wet deposited acidity in the UK

The average wet deposited acidity in Cumbria, shown in Figure 2, is as large as any other region in the UK, and is similar to the west central highlands of Scotland and the high rainfall areas of south-west Norway. The topography of Cumbria also generates considerable local variability in the distribution of wet deposition, the hills receiving the largest amounts. The proximity to source areas of pollutants (relative to Scandinavia and western Scotland) makes the dry deposition inputs larger, so that total inputs of acidity (and related ions) are larger in Cumbria than in other parts of the UK.

The geographical position of Cumbria places major source areas of air pollutants to the east and south, and clean maritime air to the west. This situation creates rainfall episodes in Cumbria with a large range of chemical composition. The acidity, for example, typically covers the range pH 4.0–7.0, or 3 orders of magnitude in hydrogen ion concentrations. Rain associated with maritime air from the North Atlantic generally has acidities of about pH 5.0, whereas rain associated with air that has passed over major source areas of air pollutants in the UK or continental Europe is typically at the pH 4.0 end of the distribution. This variability creates an episodicity of major 'acidic rain' events such that 30% of the wet deposition occurs on just 4 or 5 out of the 250 rain days each year. The chemical variability of different rain events is similar elsewhere in Britain, but few regions experience such large variability across short distances. The coastal areas receive the lowest wet deposition, which for acidity is about 0.5 kg H^+ ha^{-1} annually, while at the hill tops 10–20 km inland wet deposition may exceed 1.5 kg H^+ ha^{-1} annually. The range of annual wet deposition of acidity within Cumbria is as great as the range throughout Britain.

3 Topographic effects

The large increase in rainfall with distance from the west coast is a consequence of the orographic enhancement of rainfall as air is lifted over the Cumbrian mountains. The larger amounts of rain may also deposit more sulphate, nitrate, acidity and other ions to the hill tops than at low altitudes, and recent studies by ITE in collaboration with the University of Manchester Institute of Science and Technology (UMIST), and with the Atomic Energy Research Establishment (Harwell), have begun investigating the chemical properties of rain- and cloud-water on Cumbrian hills. These investigations are necessary to extend our understanding of rainfall chemistry in Britain, from measurements at low altitudes, avoiding the practical problems of hill top measurements, to the processes occurring at high altitudes. In general, the concentrations of the major ionic components of rainwater (sulphate, nitrate, chloride, ammonium, sodium, magnesium and hydrogen) are much larger in cloud-water than in rain. These differences are of considerable interest as cloud occurs frequently on Cumbrian hills, and direct deposition of cloud droplets by impaction on vegetation provides a mechanism which further increases the inputs of pollutants at high altitudes.

While this research is still at an early stage, the recent measurements have generated much interest in the 'pollution climate' of hill tops, which is not readily predicted from measurements made on low ground. The ways in which an improved understanding of deposition mechanisms on hills will modify earlier 'speculative' maps of wet deposition cannot yet be quantified. However, the direction of the change is quite clear for many west coast hills, which are frequently in cloud: the wet deposition estimates (already the largest in the UK) will need to be revised upwards! The information in Figure 2 should therefore be taken as a guide to the wet deposition patterns, which in practice will be more complex and, in particular, should show the higher land in the west receiving larger amounts of wet deposition.

Estimates of dry deposition are made using different methods, as it is not easy to measure dry deposition of the gases SO_2 and NO_2. All measurements to date have been obtained in research programmes, and there are no networks of dry deposition monitoring. However, the studies to date have enabled us to gain a good understanding of the deposition mechanisms, which, in turn, has enabled estimates to be made of rates of deposition from a knowledge of the vegetation present, some of the aerodynamic properties of the vegetation, and from air concentrations of the gases.

For Cumbria, the dry deposition estimates rely on our knowledge of dry deposition rates to forests and grassland. This knowledge is based on rather few measurements, and many of the plant species present in Cumbria are 'unknown' in the dry deposition literature. So here, as with wet deposition, we have estimates, but there are important weaknesses. To improve estimates of dry deposition, measurements of the mechanism under a wider range of conditions are required, and for application to Cumbria more measurements are needed of the air concentrations of SO_2 and NO_2. The lack of such measurements has necessitated the use of numerical models (B E A Fisher, pers. comm.) to calculate gas concentrations in order that estimates of dry deposition may be obtained (Figure 3).

Figure 3. Dry deposited acidity in the UK

4 Changes with time

Data on rainfall chemistry in Cumbria include a set of observations in the 1950s (Gorham 1958) and separate measurements during the late 1970s (Fowler *et al.* 1982), but no consistent long-term detailed measurements are available for the study of trends. The growing interest in rainfall chemistry has produced a number of recent data sets for sites in or close to Cumbria. One of these sites, at Eskdalemuir in Scotland, shows a decrease in acidity during the period 1980–84 (Irwin 1986), a period during which UK SO_2 emissions also decreased. This trend has been observed at other UK and Scandinavian sites (Fowler *et al.* 1985), but it has not so far been possible to separate the relative importance of meteorological and emission factors as contributors to the trend. The year-to-year variability in meteorology makes detailed analysis of such short runs of data difficult. Climatological average rainfall amounts, for example, are generally quoted as mean annual values over a 30-year period. The considerable scientific (and political) interest in links between emissions and deposition will, however, continue to stimulate the search for the nature of such links, and in time the relative importance of changes in meteorological and emission factors on changes in deposition patterns may be quantified.

5 Conclusions

Cumbria is a region receiving amounts of wet deposited acidity from the atmosphere as large as any other area of Britain, Scandinavia or Europe. This large deposit of acidity is a consequence of a combination of the very large annual precipitation and its weighted acidity, typically pH 4.4 in Cumbria. The region shows large variations in annual inputs of wet deposited acidity, from relatively small values close to the coast (0.5 kg H^+ ha^{-1}) to very large values on the hills (1.5 kg H^+ ha^{-1}).

Dry deposition also contributes substantial quantities of sulphur, nitrogen and acidity, accounting for up to half of the total annual deposition of acidity from the atmosphere. The cloud which frequently envelops Cumbrian mountains often contains large concentrations of the major ions found in rain, and this cloud may be 'captured' by hillside vegetation, providing an additional deposition mechanism and helping to generate a unique 'pollution climate' on the tops of these hills.

6 Acknowledgements

The authors acknowledge the financial support of the Department of the Environment.

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Acid rain: a CEGB view

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Summary
In common with many others, the Central Electricity Generating Board (CEGB) shares the concern and aim of environmentalists to protect and conserve our natural environment, but we do believe that policies and actions must be based on knowledge, not speculation, and that an understanding of the consequences of emissions is a necessary prerequisite for effective control.

It is uncertain from current evidence whether any significant environmental damage in the UK is attributable to present CEGB emissions. A comprehensive programme of research is in progress, with the overall objective of identifying the cause of any damage, and understanding pollutant pathways, behaviour, and effects, so that an appropriate control strategy can be developed.

In western areas of Britain, such as Cumbria, CEGB sulphur emissions are calculated to contribute about 30% or less to total deposition, and ambient air concentrations are <15 μg SO_2 m^{-3} (ie ~5.5 ppb). In cities, CEGB emissions contribute typically only 20% or less to the SO_2 in urban air. The substantial recent reduction (40%) in national SO_2 emissions has not apparently improved S deposition, so that direct benefits of further reductions are uncertain.

1 Introduction
The CEGB has responsibility in the UK for supplying electricity efficiently and economically, while safeguarding the environment. This latter responsibility has been taken very seriously for the past 30 years, and the Board has an excellent record of striking a sensible balance between economy, efficiency and environmental care. Much of the effort provided to monitor environmental conditions in the vicinity of plant, to study and anticipate far-reaching consequences, and to develop and install appropriate emission/discharge control systems derives from the Board's acknowledgement of this statutory responsibility. Our judgements have not been taken in isolation, neither is the Board the sole judge of whether the best balance has been achieved. These responsibilities extend through the planning, design, construction and operation of generating plant throughout its lifetime.

Environmental sensitivities have heightened over the past decade (during which period no planning permission for new fossil-fuelled plant has been sought), and are changing the perception of the level of control deemed necessary. There are some who maintain that *any* detectable discharge or emission is unacceptable. This arbitrary 'zero' level is unrelated to effects, and so may have no identified environmental benefits; further, it has no economic or operational limits and is open to technological challenge. The Board takes the view that rational and effective pollution control must be based on identified environmental quality criteria, in turn supported by diagnosis of cause, understanding of pathways and effects, and then development of the appropriate control strategy. A large and comprehensive environmental programme over the past 15 years (probably greater than that of any other European utility) has still left us uncertain as to whether any significant environmental damage is attributable to current CEGB emissions, and so as to the benefits that might result from costly control measures.

2 Emissions in the UK
Burning of fossil fuels inevitably leads to the formation of SO_2 and NO_x, both gases which can be further oxidized in the atmosphere to form acid radicals. Changing patterns of fuel use, industry and employment in the UK have led to a substantial decline in national SO_2 emissions, from a peak of approximately 6.10^6 tonnes in 1965 to less than 4.10^6 t today (Barrett *et al.* 1983). Nitrogen oxides emissions increased to a peak of nearly 2.10^6 t in 1980. However, the CEGB contribution to SO_2 emissions (currently approximately 65%) has been maintained by the transfer of energy production from many small sources to a centralized agency. Sources of NO_x emissions are more widely distributed, with the CEGB contributing about 40% today. The resulting ambient SO_2 concentrations at ground level in Britain have been monitored over several decades – present rural levels are typically <12 ppb (annual mean) and in cities <35 ppb. Nitrogen oxide levels are less well documented, but rural levels seem to be 5–10 ppb and urban levels 40–50 ppb ($NO+NO_2$) (Roberts *et al.* 1983). These low levels have been achieved by the efficient operation of modern power stations with emission dispersion by tall stacks. This design has benefited urban atmospheres to a very great extent – even now, CEGB emissions contribute typically only 20% or less to SO_2 levels in cities. Use of tall stacks has contributed marginally greater long-range transport of S – the Organisation for Economic Co-operation and Development (OECD) study (1979) estimated an increase of 15%. It has also resulted in substantial improvement to urban health and reduced damage to the built environment.

In north-west Britain, upwind of the major industrial

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source regions, ambient concentrations are rather low – in the late 1970s, SO_2 concentrations were then estimated to be <5.6 ppb in Cumbria, and <3.7 ppb in Galloway (Martin 1980). The CEGB contributions to these ambient concentrations were estimated to have been about 44% and 30% respectively (Fisher 1985, pers. comm.).

3 Rain in the UK: wet and dry deposition

Rain quality, and wet and dry deposition of acidic materials have been reviewed recently (Barrett *et al.* 1983). The average concentrations of acidity, 20–40 $\mu eq\ l^{-1}$ (pH 4.7–4.4) in western regions and 50–75 $\mu eq\ l^{-1}$ (pH 4.3–4.1) in eastern regions, reflect geographic gradients in climate, and emission source location. These concentrations should be compared with those of 'pristine', or remote, areas which typically have rain of pH 5 (Galloway *et al.* 1982). The arbitrary use of pH 5.6 (equilibrium of CO_2 with distilled water) as a baseline ignores the contribution of natural S and N cycles which are thought to result in pH 4.5 to 5.6. Thus, rain in the east can be considered perhaps up to 10 times more acid than background, and in the west perhaps twice or 3 times background levels.

Deposition in rainfall is the product of concentration and rainfall volume, so that western areas which have much, albeit not very acid, rain have a larger wet acid deposition than eastern areas. Parts of Cumbria, the west central highlands and the southern uplands of Scotland are estimated to have the largest depositions, about 1 kg H^+ ha^{-1} yr^{-1}, similar to that of southern Scandinavia. Similar estimates have been made for deposition of non-marine sulphate and nitrate – about 25 kg S ha^{-1} yr^{-1} and 5 kg N ha^{-1} yr^{-1} (Buckley-Golder 1984). The CEGB contribution to this wet deposition of S is estimated at about 18% in Cumbria and 16% in Galloway. For total deposition, the CEGB contributions are 32% and 25% respectively (Fisher 1985) (Figure 1). Trajectory analysis of deposition at Eskdalemuir in south-west Scotland shows that 70–80% of acidity and sulphur deposited in rain comes from the west and south-western sectors, consistent with calculated contributions from European and UK sources (Figure 2).

4 Trends in rain quality, the linearity issue

There is rather little evidence to support the commonly held view that rain has become much more acid over the past few decades. Although, globally, we might reasonably expect deposition to match emissions over sufficient time, this is evidently not so for regions, even as large as western Europe, or for more limited time periods. At a time when European emissions of S increased by about 35% (between 1963 and 1975), wet deposition actually decreased at many of the European (EACN) monitoring sites, and Swedish monitoring has shown that by 1977 wet deposition of sulphate over Europe has remained constant, or has decreased over the previous decade (Rodhe & Granat 1984). Similarly, recent observations (Fowler *et al.* 1985) of a decline in rain acidity at some Scottish (but not English) sites is not matched by a decline in sulphate concentrations (B E A Fisher, pers. comm.) (Figure 3).

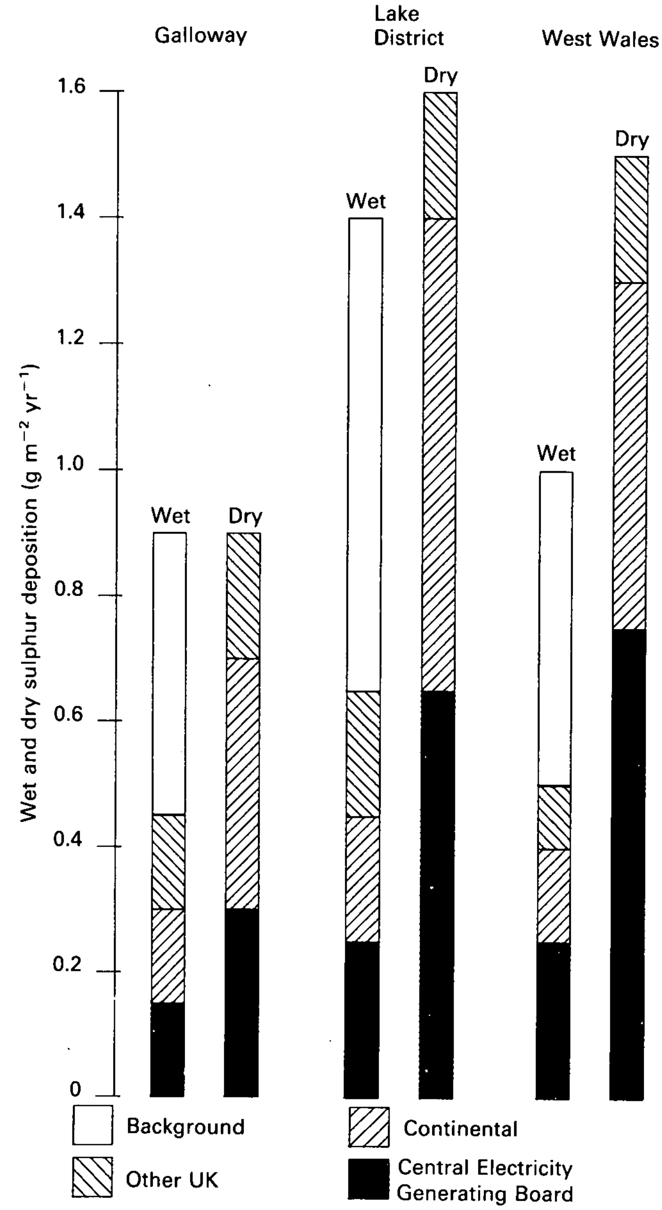

Figure 1. The estimated component contributions to wet and dry deposition in south-west Scotland, Cumbria and west Wales (source: B E A Fisher, pers. comm.)

These, perhaps surprising, observations are thought to reflect the complexity of atmospheric processes. The conversion of SO_2 to acidic $SO_4^{=}$ requires that sufficient oxidation occurs before deposition. Thus, the acidity of rain is critically dependent on the supply of oxidant (and on competing reactions) in the atmosphere, and sulphate production and deposition are not directly proportional to SO_2 emission. Similar oxidative reactions are necessary for the formation of nitrate, responsible for about a third of rain acidity. It is now known that ozone and hydrocarbons are crucial in these atmospheric processes, but it is not yet clear

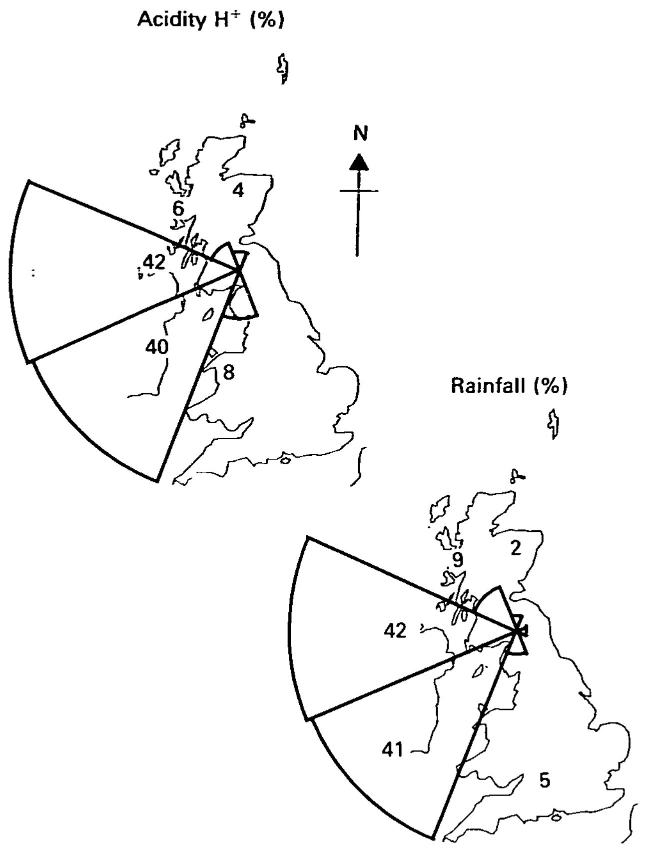

Figure 2. Sector analysis of wet deposition at Eskdalemuir EMEP station

how acid deposition or ozone at ground level would be affected by limiting S or N emissions alone.

5 Effects on crops in the UK

It has proved difficult to detect any significant effect at current levels of ambient ground level SO_2 and NO_x on crops and trees in the UK. Experimental exposure of sensitive crops to realistic concentrations of SO_2 and NO_x (combined) has, in fact, indicated only trivial reduction at 'urban' concentrations, and even some positive effects on growth and yield at typical rural concentrations. If crop yields are reduced at all in UK conditions, this reduction seems more likely to be attributable to ambient ozone for which there is some evidence of damaging concentrations in rural areas in summer (Roberts 1984).

6 Effects on forests

It is estimated that half of the total forest area in Germany is damaged. This new and serious forest decline in Germany has often been attributed to 'acid rain' (House of Commons 1984) directly, or indirectly via effects on soil (Ulrich *et al.* 1980). Current consensus amongst scientists, however, is that ozone, alone or in combination with other agents, is the principal cause (Blank 1985). Acidity of rain in south Germany has not increased over the past decade, neither are SO_2 or NO_2 concentrations high enough to cause direct damage to the trees. The initial hypothesis of damage via soil acidification is inconsistent with observations of damage on a range of soils, including those of calcareous origin. There is evidence, however, that potentially damaging ozone concentrations (*c*100 µg m^{-3}) have been reached at damaged sites in recent hot dry summers, and that levels have doubled over the past 25 years (Blank 1985). It is, indeed, possible that acid mist is a contributory factor, but experiments to test this hypothesis have only just begun. Preliminary experiments (eg Skeffington & Roberts 1985) suggest that both acid mist and ozone can contribute to needle damage in Norway spruce (*Picea abies*).

This new forest decline is now reported for Switzerland and France, and possibly to a more limited degree in Sweden. In the UK, however, a recent nation-wide survey of sites with a range of natural and polluted conditions (Forestry Commission 1985) has revealed no signs of the damage seen in Germany, and no unexpected abnormalities. S deposition in rainfall was not associated with any damaging effects. Indeed, long-term observations of 20 experimental plantings in the southern Pennines show a great improvement in growth since the 1960s, concurrent with lower ambient SO_2 concentrations (Lines 1984).

7 Effects on surface waters

The composition of surface waters derives initially from the quality and quantity of deposition, but it is profoundly influenced by transfer through vegetative canopies and soils. The degree to which deposited acidity is neutralized depends on the pathways and rates of flow to drainage waters, as well as on the contribution of ground water. The latter has been in contact with mineral soils and bedrock for sufficient time to pick up neutralizing base materials. It follows that in areas where rainfall is heavy, and soils and bedrock poor in base materials, neutralization of deposited acidity is least.

These conditions are characteristic of western, upland Britain, and so it is not surprising that some acid streams and lakes are to be found there, as they are in southern Norway. These same areas are also those often used for forestry as the climatic and soil conditions favour trees rather than agricultural crops. The growth of forests is known to create acid soil conditions, by transfer of base minerals to aboveground vegetation, and by production of inorganic and organic acids within the organic soils. A further acidifying influence is contributed by the development of *Sphagnum* bogs.

It is evident that much of the sulphate in surface waters must come from combustion sources – along with that derived from marine salt input, geological sources, and recycled biological sulphur. Fisheries problems, however, are not evidently related to the levels of sulphate, and in south Norway the lakes with least sulphate are those without fish, or with poor fisheries. It has become clear from field surveys, and

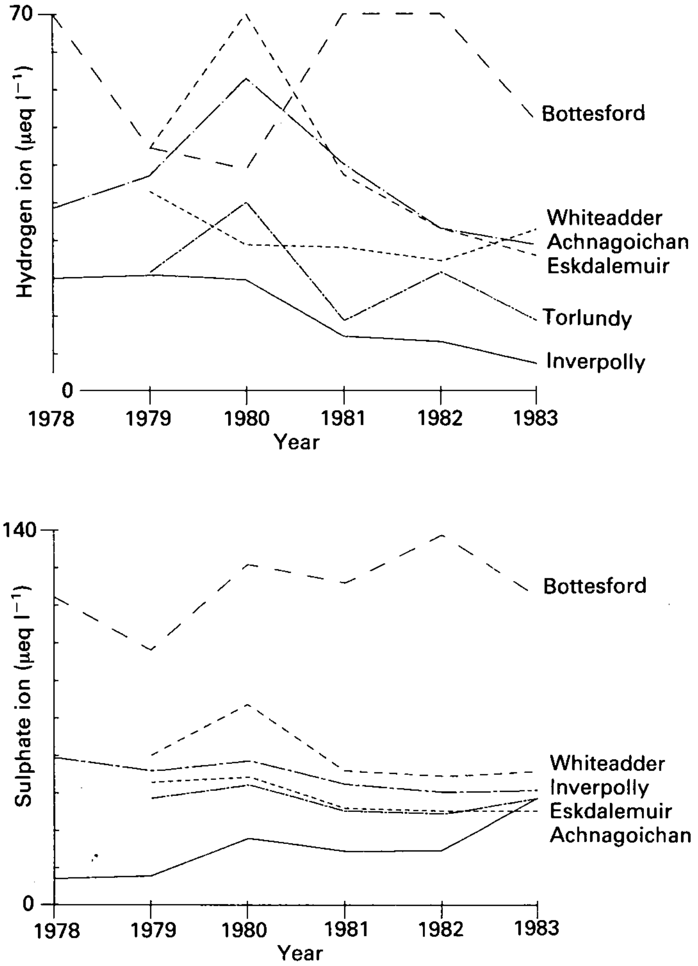

Figure 3. Trends in (i) acidity and (ii) non-marine sulphate concentration in rain at UK sites, 1978–83

from experimental studies, that the amount of calcium in water is crucial for fish well-being (Howells 1984). Many of the fishless lakes in south Norway simply have insufficient calcium for fish survival (<1 ppm Ca) (Figure 4). The main sources of calcium are, of course, the soils and underlying bedrock of the catchment, and this 'reserve' has been continually depleted by leaching and weathering processes for thousands of years. Regions of hard, unreactive, bedrock, with thin, poor soils left after glaciation, are naturally those least able to resist this natural and progressive base depletion. This process of acidification will be enhanced by increased deposition and by land use.

The upland catchments of the Lake District show such a progressive change, and lake sediments there indicate acidification dating back 5000 years (Pennington 1984); this acidification is attributed to the removal of basic ions from soils by rainfall, with effects intensified by vegetation changes, by decomposition of heather (*Calluna*) and other plants which replaced deciduous forest, and by the activity of *Sphagnum* species which colonized poorly drained habitats. In Galloway, south-west Scotland, diatoms in the sediments of 4 upland lakes indicate a much more recent acidification over the past 150 years, independent of land use or vegetation changes, including widespread afforestation (Battarbee 1984). This change in acidity has been as much as 10-fold (from pH 5.6 to pH 4.4) (Loch Grannoch). The extent of such acidification may be strictly limited as adjacent Loch Skerrow which drains forested granitic and metamorphic catchments appears to be unchanged (Battarbee & Flower 1985) (Figure 5).

8 Acidity mitigation

While control of S and N emissions might seem to be the rational step with the fallback that 'it can do no harm', this strategy could be not only ineffective, but might even have unwelcome effects. For example, the control of NO_x alone in California led to *increases* in O_3 levels. Taking surface water acidification as the most pressing problem, it is clear that a reduction of either acid or S and N deposition would not increase the calcium of fishless lakes to the level needed. Indeed, it could possibly reduce the yield of bases from a sensitive catchment. This realization has led us, like the Swedish government, to consider other mitigative actions such as land/lake manipulations designed to decrease acidity, raising calcium levels (and, *inter alia*, reducing aluminium which is known to be toxic in certain conditions). The advantages of selective action of this kind are that:

- it selects those locations that would benefit;
- it can improve water quality over a short timescale;
- it is demonstrated to be feasible, practical and successful; and
- it costs a fraction of emission control measures.

Further, it gives more time to get the diagnosis right so that longer term actions are assured of success.

To explore the potential of a range of manipulative treatments, their feasibility and costs, the Board has embarked on a collaborative project with the Scottish Boards, and the National Coal Board (NCB). A site in Galloway, Loch Fleet and its catchment, has been chosen as the site for investigation. Because UK waters have a rapid turnover, and because salmonid species, breeding in upland tributary streams, are of most interest, emphasis will be given to land treatments, so that the quality of water draining to streams will be altered.

Another project (SWAP) has been initiated by the Royal Society, financed by the CEGB and NCB together, to encourage Scandinavian and UK scientists to take a fresh look at lake acidification, its extent and progress, and to develop the ability to predict what reduction in acid deposition will benefit the fishery status of affected lakes.

9 Conclusions

Overall, CEGB-sponsored research on environmental aspects of air pollution and acid rain totals more than £2 million yr^{-1}. In addition, the Board is exploring a range of technologies for the economic control of SO_2 and NO_x emissions, including the scope for fuel

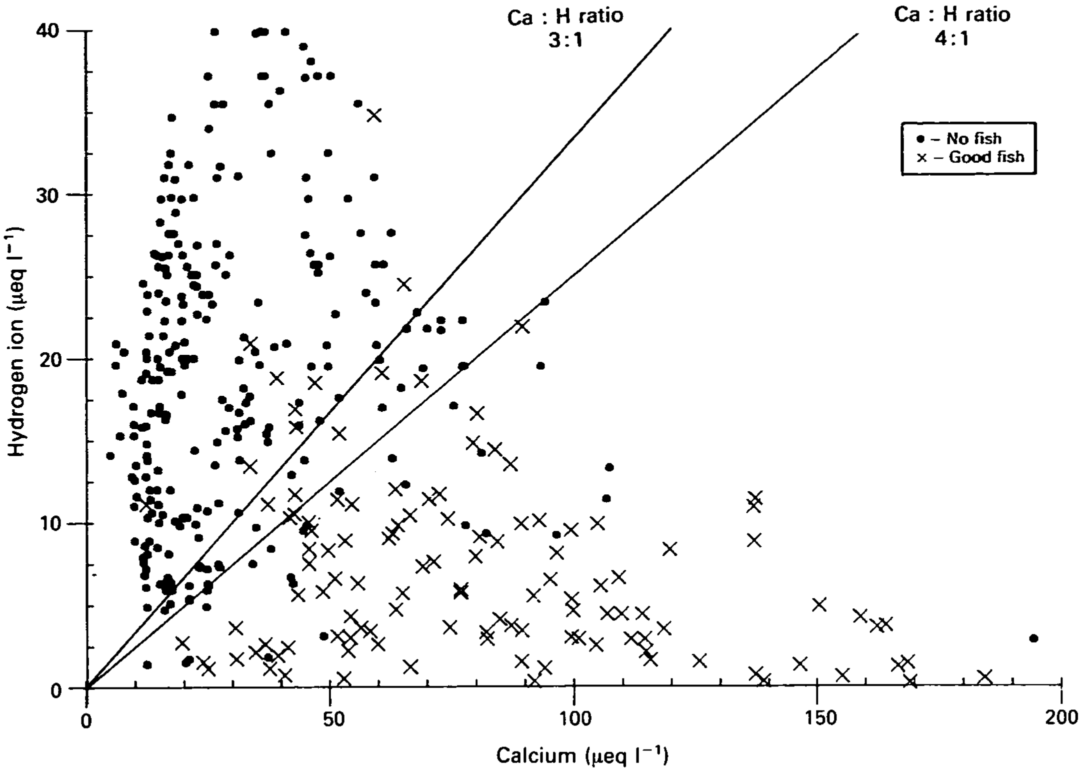

Figure 4. Acidity and calcium concentration in lakes in southern Norway. The lakes are classified according to the fish status

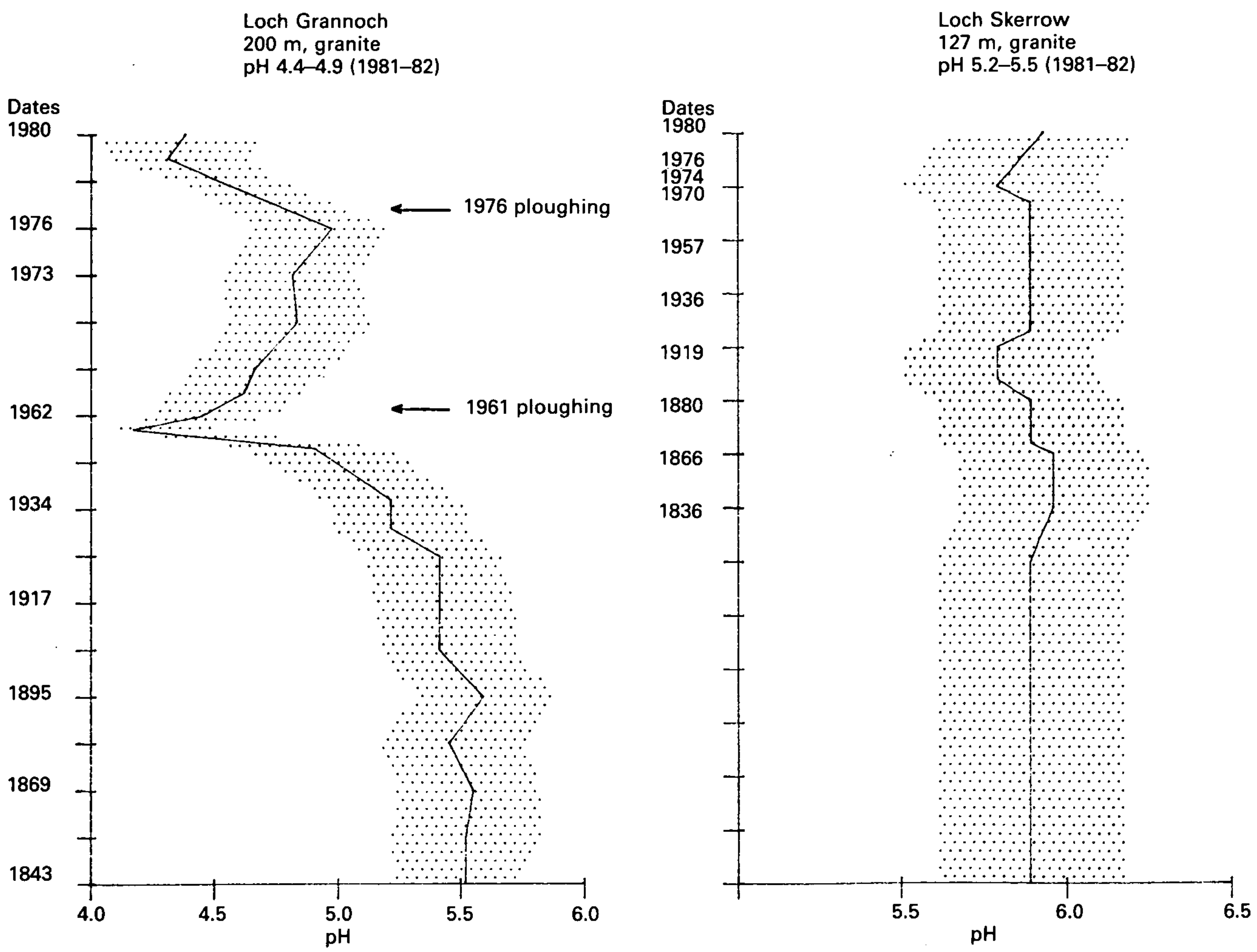

Figure 5. Inferred historic trends in pH in Galloway lakes, derived from sediment cores, 1981–82

pretreatment, the potential for coal–water substitutes for high S oil, flue gas desulphurization methods with acceptable end wastes, and low NO_x-emitting boiler designs. In the longer term, the potential for pressurized fluidized bed combustion is being tested, with the NCB, on the Grimethorpe facility, as well as the potential of gasification/combined cycle plant in the even longer term. This programme is expensive – about £30 million over the next 2 or 3 years.

We believe that we are tackling the acid rain issue rationally, and that we are responsive to changing perceptions and the public demand for cleaner technologies. We share the aim of environmentalists to protect and conserve the environment, but we do believe that environmental policies and actions must be based on knowledge, not speculation, and that an understanding of the consequences of emissions (and their control) is a prerequisite for effective action. We believe that current work on alternative control technologies, and knowledge of how effects can be mitigated, will allow us to make the right choice when new plant is required. The 'case against acid rain' has been premature and the predicted doom is not yet upon us – so there *is* time, in spite of calls for urgency, to diagnose the problems correctly, and to develop the right solution.

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Effects of acid rain on waterbodies in Cumbria

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Summary
About 30 tarns are permanently acid (alkalinity absent, pH below 5.5), have fewer species of plants, few or no molluscs, and a generally sparse fauna. Tarns and lakes containing very soft water are more numerous; the biota of some is richer in species but generally sparse in numbers (unproductive) relative to harder, productive waterbodies. Acid streams occur in headwaters of most western and central valleys; they have a markedly impoverished invertebrate fauna compared with neighbouring soft water streams. These basic faunal and floral differences have occurred in the Lake District for at least most of this century and perhaps much longer.

There has not been a progressive increase in acidity of soft water lakes and tarns in the past 35–56 years. Acidification to current levels probably occurred at least 100 years ago.

An increase in the incidence and severity of acid episodes is postulated, coupled with drier summers since 1968. These episodes can be harmful to the biota, especially in streams. Recent declines in local salmonid fisheries may also be due to cumulative effects of other factors – lack of water during droughts, high summer temperatures, and poor food supply in nursery streams.

1 Introduction

This paper briefly describes the acidity/alkalinity status of lakes and tarns, and changes (or lack of change) that have occurred over the past 3–5 decades. Occurrence of acid episodes in lakes is documented, and effects of acid water on the aquatic biota of streams and lakes are noted in relation to a general paucity of plants and animals in very soft waters.

Lake District waterbodies exhibit a wide range of productivity, partly related to concentrations of dissolved substances in the water (Pearsall 1930; Mackereth *et al.* 1957). Soft waters are unproductive; their fauna and flora are frequently sparse in numbers and species. Productive harder waters have a more diverse range of plants and animals, and have a large total biomass (Macan & Worthington 1951; Macan 1973). Examples are listed in Table 1.

Alkalinity has a direct influence on pH (Figure 1) and bicarbonate is the most important component in terms of the water's capacity to neutralize hydrogen ions, present in strong mineral acids. Bicarbonate occurs in high concentrations in hard waters but is completely absent from waters with pH values below 5.5, termed 'acid' here to distinguish them from very soft and soft waters containing small amounts of bicarbonate alkalinity (Table 1).

2 Acidity/alkalinity of lakes and tarns in summer 1983

Acid and very soft waters occur mainly on bedrocks of the Borrowdale Volcanic Series, forming the central high fells of Lakeland, and on Skiddaw Slates in northern Lakeland. Most soft and harder waters occur on Silurian Slates in southern Lakeland. Very hard waters occur on the Carboniferous Limestone Series and associated rocks on the region's outskirts (Sutcliffe & Carrick 1985).

Soft waters contain enough alkalinity to neutralize acids deposited in rain or manufactured on the catchment; pH is normally close to 7.0 (Figure 1). In very soft waters, the pH falls towards 6.0 as alkalinity is reduced, and when it disappears there is a sharp fall from pH 5.7–6.0 to pH 5.0–5.3 (approximately). This fall in pH and loss of alkalinity are critical for many aquatic organisms, which disappear when the pH is persistently below about 5.7 and alkalinity is absent.

3 Acidity/alkalinity in winter and the occurrence of acid episodes

Between June 1983 and June 1984, 43 upland tarns were sampled; 20 were permanently acid. For 23 very soft tarns, 15 lost all traces of alkalinity and became acid during the winter of 1984 (Figure 2) after heavy snowfall in January. These 'acid episodes' lasted for periods ranging from 1–2 weeks up to 2–3 months; alkalinity concentrations and pH had risen to normal summer levels by May–June 1984. Figure 3 shows 2 examples, contrasting with Red Tarn which did not lose alkalinity, although it is at 718 m altitude on Helvellyn. Another acid episode, shorter in duration, occurred in Blea Tarn (Eskdale) in November 1984 (Figure 3). Devoke Water had 3 brief acid episodes in the winters of 1984 and 1985 (Figure 4).

Larger very soft lakes (Buttermere, Crummock, Ennerdale, Wastwater) showed little change in alkalinity during the winter of 1983–84, but rather more in 1984–85. During brief periods of relatively low alkalinity (Figure 4), the pH fell to 6.1 or 6.0 (Buttermere) and

Table 1. Five types of water composition in the Lake District, based on arbitrary ranges of alkalinity*

Water type	1. Permanently acid	Unproductive 2. Very soft	3. Soft	Productive 4. Medium hard	5. Very hard
Range of alkalinity	0	1–100	101–200	201–2000	2001–5000
Range of measured pH†	4.2–5.3	5.5–7.0	6.0–7.4	6.0–10.0	7.1–10.0
Lakes and large tarns	Chapel Hill Leverswater Parkgate Red Tarn (Langdale) Seathwaite	Blea Tarn Burnmoor Buttermere Crummock Derwentwater Devoke Ennerdale Red Tarn (Helvellyn) Thirlmere Wastwater	Brotherswater Coniston Grasmere Haweswater Kentmere Loweswater Rydal Wet Sleddale	Bassenthwaite Blelham Hayeswater Overwater Ullswater Windermere	Sunbiggin

*Alkalinity determined by Gran titration (Mackereth *et al.* 1978) and expressed as micro-equivalents per litre ($\mu eq\ l^{-1} = \mu mol\ dm^{-3}$)
†Values obtained in 1983–84

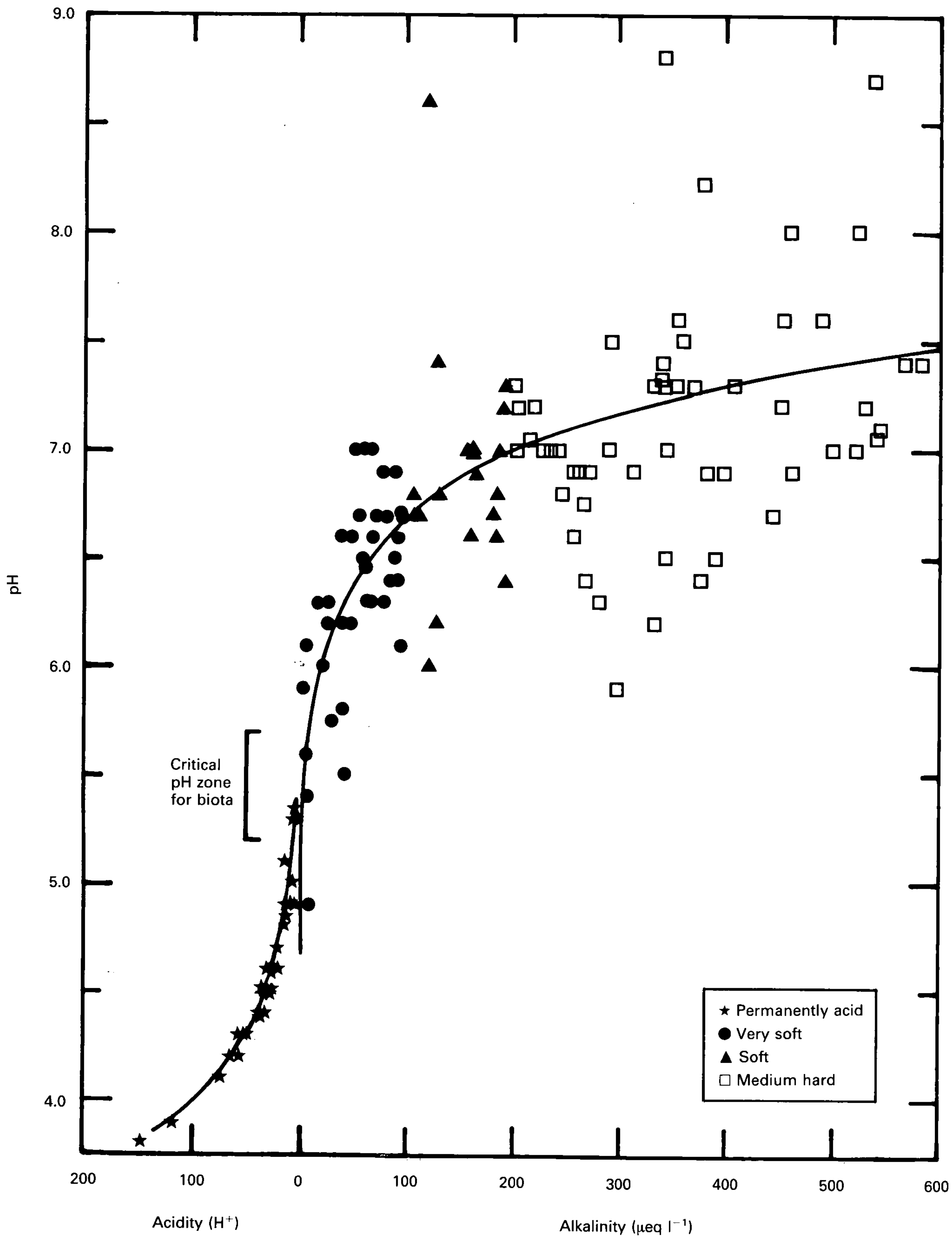

Figure 1. pH plotted against acidity/alkalinity of upland tarns in June–September 1983. Symbols denote water types (Table 1)

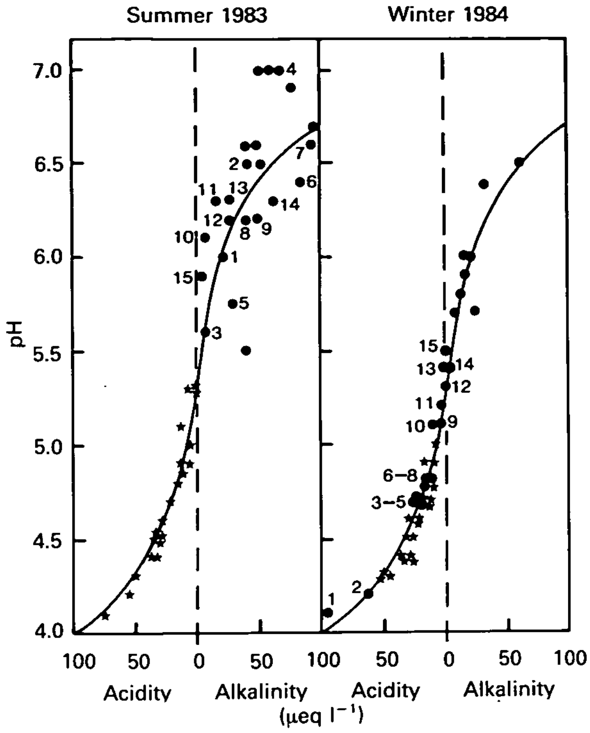

Figure 2. pH and acidity/alkalinity (mean concentrations) in 20 acid (★) and 23 very soft (●) upland tarns in June–September 1983 and January–March 1984. Numbers identify very soft tarns that temporarily became acid in winter

6.2 (Ennerdale). Similar episodes were recorded during winters 1974–75 and 1975–76 (Figure 4), when pH fell below 6.0 in Buttermere (Carrick & Sutcliffe 1983). Episodes of about one week's duration, when the pH fell from 4.7–4.8 to 4.5–4.6, occurred in Leverswater during 1984–85 (Figure 4). Acid episodes in streams occurred during snowmelt in the early 1970s (Sutcliffe and Carrick 1973a,b,c; Carrick & Sutcliffe 1983).

4 Acidity/alkalinity of lakes and tarns over the past 35–56 years

Measurements of pH and alkalinity made between 1928 and 1978 (lakes) and 1949 to 1978 (tarns) are summarized and discussed by Sutcliffe *et al.* (1982) and Sutcliffe (1983). Conclusions from recent measurements (1982–84) are briefly summarized by Sutcliffe and Carrick (1985). For most waterbodies, there has not been a systematic, progressive change in levels of pH or alkalinity since measurements began. Tarns that are permanently acid now were also acid 35 years ago. Tarns and lakes now containing very soft water had the same status 35–56 years ago, including some (eg Easedale Tarn, Figure 3) that are close to becoming permanently acid. Examples of alkalinity are shown in Figure 5. There was no significant change in the mean pH of very soft lakes between 1974–76 and 1982–84 and present-day values are similar to earlier pH measurements.

5 Effect of pH and alkalinity on the biota of streams

Streamwater pH has a very marked effect on many common invertebrate animals (Sutcliffe & Carrick 1973a,b,c). Most species of mayflies, some stoneflies and caseless caddisflies, freshwater shrimps (*Gammarus*), limpets and beetle larvae are absent from acid streams where pH is consistently below 5.7–5.4 during autumn and winter, producing a characteristic impoverished fauna that is generally sparse in numbers, poor in species and dominated by certain small stoneflies. Acid streams of this kind occur in the upper catchment of the River Duddon. No major chemical or faunal changes have occurred in the Duddon since 1968–74 (Prigg 1983).

An impoverished fauna also occurs in acid streams (pH below 5.5, alkalinity absent) in the upper catchments of Wastwater, Ennerdale, Buttermere, Derwentwater, Thirlmere, Easedale Tarn and on Blencathra. Here, as in the Duddon (Sutcliffe 1983) and Esk (Prigg 1983), acid streams frequently occur next to soft water streams which have the species-rich fauna characteristic of small hill streams in pristine condition. Some acid streams run through coniferous forests but others are on open upland fells. The acidity/alkalinity status of each stream primarily depends on the neutralizing capacity of soil and bedrock in the sub-catchment. Coniferous forests tend to acidify the underlying soil and watercourses (Harriman & Morrison 1981, 1982; Nilsson *et al.* 1982), but not all streams in local forest areas are acid. Some at Grizedale, Ennerdale, Thirlmere, Dodd Wood and Whinlatter Pass are very soft or soft, and most of these have a normal diverse invertebrate fauna (Thackeray 1984).

6 Effect of pH and alkalinity on the biota of tarns and lakes

Stokoe (1983) lists aquatic plants (macrophytes) found in 1975–80. The numbers of species in each waterbody are related to water type, and to altitude which has a dominating influence (Figure 6, Table 2). Acid tarns generally contain fewer species; the mean number of species per tarn at altitudes above 320 m is 5 for acid tarns, but twice that number in tarns containing alkalinity. Below 320 m, acid tarns have an average of 12 species, whereas non-acid tarns contain 19–25 species (Table 2). Large waterbodies, including some very soft lakes, have the largest numbers of species (Figure 6), indicating that other factors are equally important in determining suitability for aquatic macrophytes (Spence 1982; Charter 1984; Fry & Cooke 1984). The effects of declining water hardness and increasing acidity on diatom algae in lakes are well known (Knudson 1954; Altshuller & Linthurst 1984; Battarbee 1984).

Smyly (1958) examined the distribution of water-fleas (Cladocera and Copepoda) in the early 1950s. These micro-crustaceans are an important source of food for some larger invertebrates and fish. Altitude appears to have less influence on the number of species of water-fleas than it has on plants. Acidity/alkalinity status of the water also seems to have little direct effect (Table 3). Of 26 common species, only 3 were

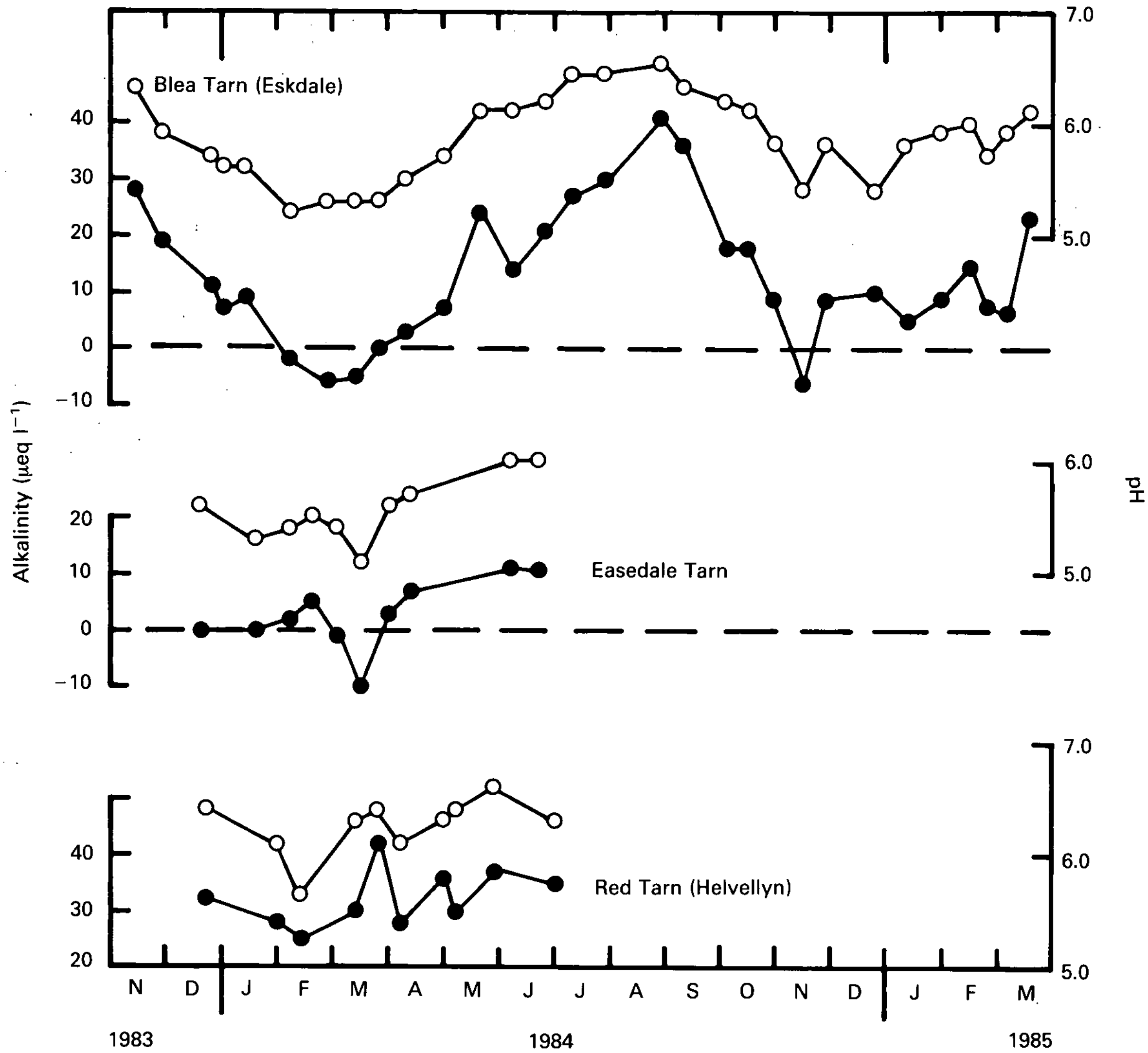

Figure 3. Alkalinity concentrations (●) and pH (○) of 3 upland tarns

completely absent from acid tarns. Some others were scarce, but Parkgate Tarn had 21 species of water-fleas; this is a shallow 'weedy' lake where pH is normally 4.2–4.5, one of the most acid tarns in the Lake District. In contrast, only 5 species occurred in Leverswater (a relatively barren, rocky lake) at pH 4.7–4.8. For water-fleas, the presence of aquatic plants and depth and area of the tarn are generally more important than pH or hardness of the water (Smyly 1958).

Leverswater was relatively barren in the autumn of 1922 (Gurney 1923), so the paucity of animals (and plants) in this acid tarn is not a very recent phenomenon.

Relative abundance and numbers of gastropod snail species are related to calcium and alkalinity content of tarns and lakes (Macan 1950; Macan & Maudsley 1969). The wandering snail (*Limnaea pereger*) is the only species in Ennerdale; this and the bladder snail (*Physa fontinalis*) occur in Crummock. In more than 1000 lakes in Norway, mean numbers of gastropod species (per lake) decline markedly with decreasing water hardness and pH; none occur at pH 5.1 or below (Økland 1983). Small freshwater mussels (*Pisidium* and *Sphaerium*) are similarly affected, although 8 species tolerate very low calcium concentrations and 4 occur at pH 4.7–5.1 (Økland & Kuiper 1982). These effects on snails are equally evident in Lake District waterbodies.

7 Discussion

Acidification (Breemen *et al.* 1984) is a slow (thousands of years), complex process of weathering of rocks and soils. The products (bases, salts and acids) leach into streams and lakes, finally entering the sea. The rate of acidification on each catchment is partly dependent on amounts and intensity of rainfall (leaching factor) and the capacity of rocks and soils to neutralize acids deposited on and manufactured in the catchment. As the latter gradually acidifies, waterbodies on it become softer and eventually may even turn acid, ie alkalinity disappears from the water and

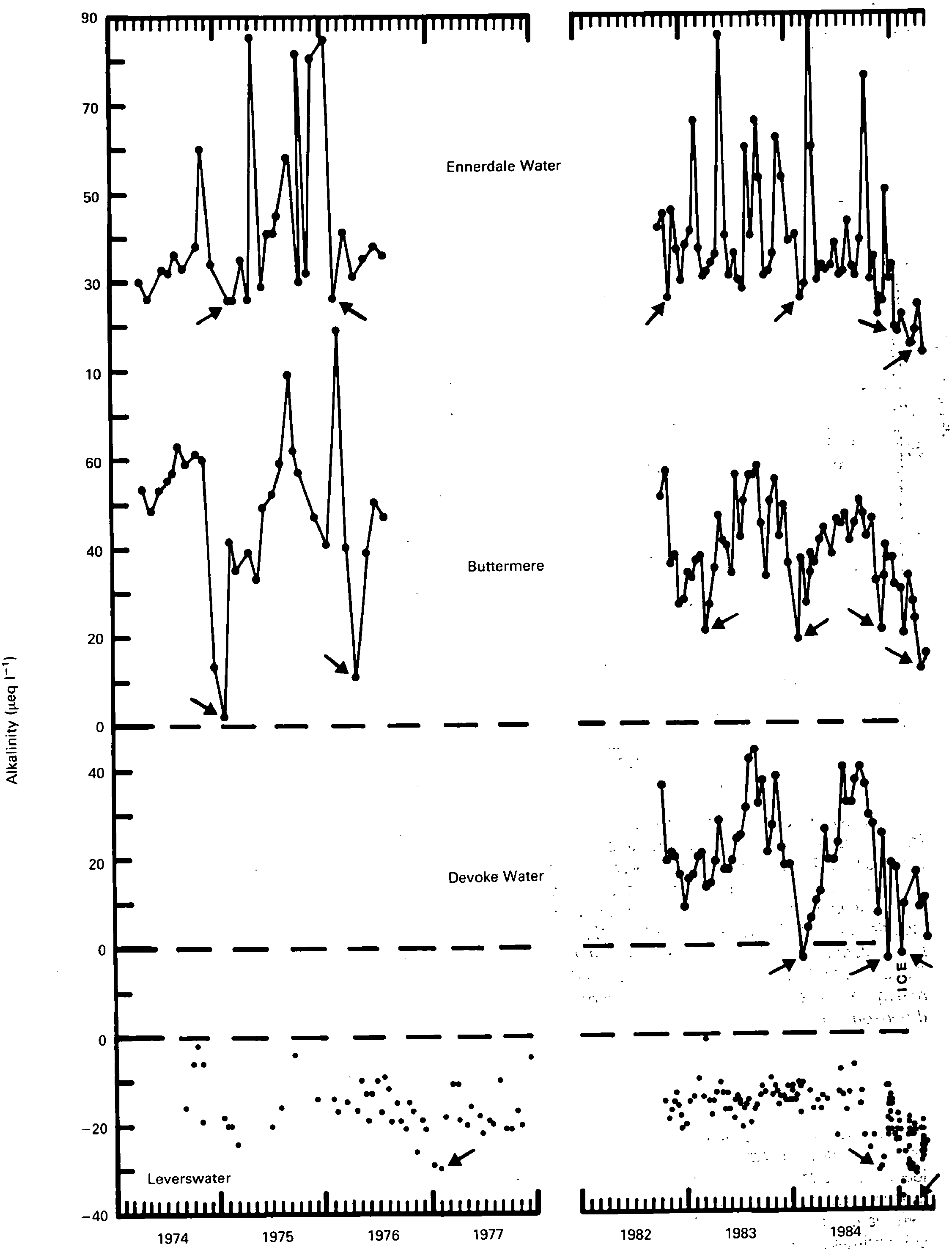

Figure 4. Alkalinity concentrations in 3 very soft lakes and one permanently acid lake during 1974–77 and 1982–85. Low alkalinities and acid episodes are indicated by arrows. Values for Leverswater are based on daily samples after mid-November 1984

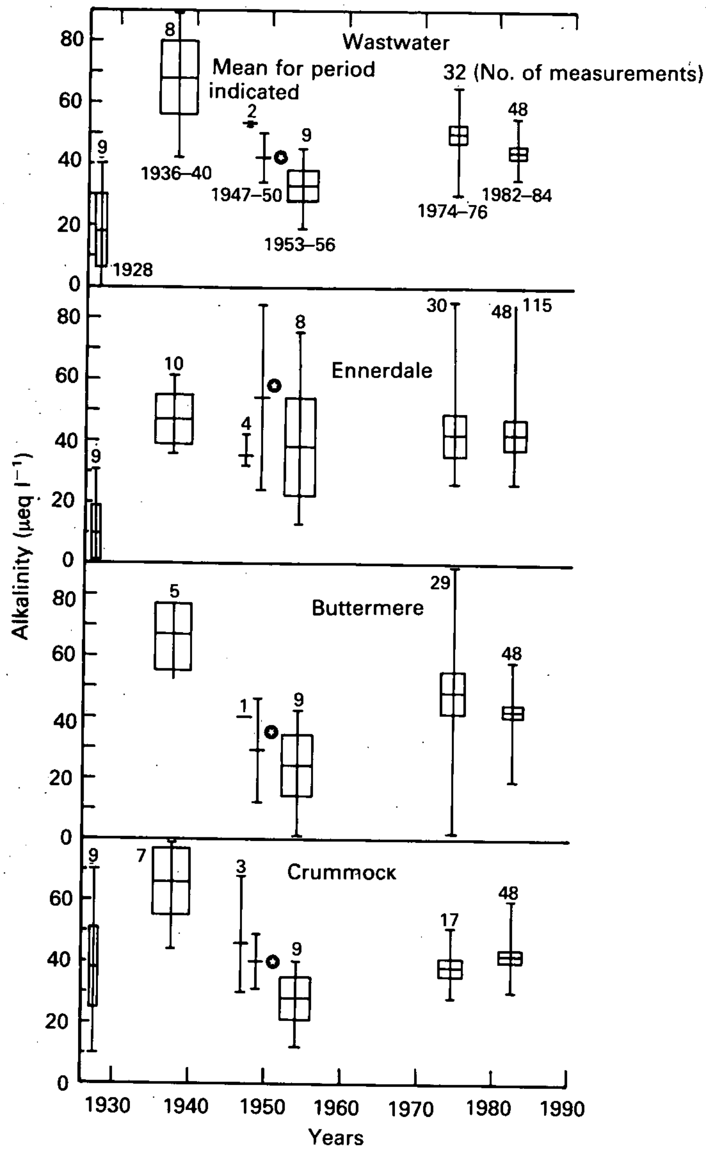

Figure 5. Alkalinity concentrations in 4 very soft lakes, from 1928 to 1984. Means are shown as boxes embracing 95% confidence limits. Vertical bars show the range of concentrations in each period of years when measurements were made. Values for 1936–40 include new data found in notebooks of C H Mortimer, not included in statistics given by Sutcliffe et al. *(1982, Table 19).* ✪ *Mean based on maximum and minimum values from a series of measurements (Knudson 1954)*

pH falls below 5.5 (Figure 1). At the same time, many aquatic organisms become scarce or absent. For at least 30 years, the freshwater shrimp *Gammarus pulex* has been scarce or absent from many of the very soft waters in western Lakeland where conditions are sub-optimal for it.

In most lakes, pH and alkalinity have remained relatively constant, at various levels in different waterbodies, for the past 35–56 years. Despite a large input of acids in high annual rainfall (Sutcliffe 1983), acidification rates of Cumbrian lakes and tarns are currently very slow; bedrocks, including igneous rocks, still have a relatively high capacity for producing bicarbonate which neutralizes acids. Any rapid, measurable increase in acidity of the lakes, resulting from industrial emissions of acids, must have taken place at the time of the industrial revolution and the biota of the lakes would respond to increased acidity at that time, like the diatoms in Galloway lochs (Battarbee 1984).

Watson (1899) briefly describes the fauna of the River Duddon. He gives a remarkably accurate summary of present-day conditions in the river, which leaves no doubt that acid tributaries of the upper Duddon were not high in alkalinity in the mid-late 19th century, and did not have a species-rich fauna that has been lost in recent years.

We conclude that major effects of industrial emissions on acidity/alkalinity status of Cumbrian waterbodies must have generally occurred more than 100 years ago. Some streams and upland tarns may have been acid (alkalinity absent) for many centuries, as the process of catchment acidification began to have noticeable effects on terrestrial vegetation 5000 years ago (Pennington 1984).

In certain circumstances, a mass of very acid water may suddenly flush out of soils, where it has accumulated, into the nearest watercourse. The highly acidic water may travel downstream in such large quantities or so rapidly that acids are not neutralized by (bi-) carbonates in the normal way. These 'acid episodes' are of varying severity. They usually last for 1–3 days, although much longer episodes occurred during the winter of 1984, particularly in some small upland tarns. During an acid episode, the pH of water may fall by 2 or 3 units, from pH 7 or 6 down to pH 4 (occasionally lower). Streamwater may then be more acid than the rainfall.

Acid episodes occur during snowmelt after heavy snowfall, when they may be particularly severe, and when it rains heavily after droughts. The rapid change in chemical composition of the water can be lethal or harmful (causing osmotic stress) to a wide range of aquatic organisms. Reasons for the accumulation and release of acids during episodes are still not fully understood. After each episode, alkalinity concentrations rise back to their normal (previous) levels.

When Lake District soils are opened to the atmosphere, acidic substances are oxidized and strong mineral acids are produced (Pearsall 1938). Presumably this process has occurred more frequently during the drier summers of the past 15 years, when soils on the fells have repeatedly dried out. It will also occur when land is drained for agricultural purposes, and growing trees, especially conifers, withdraw water

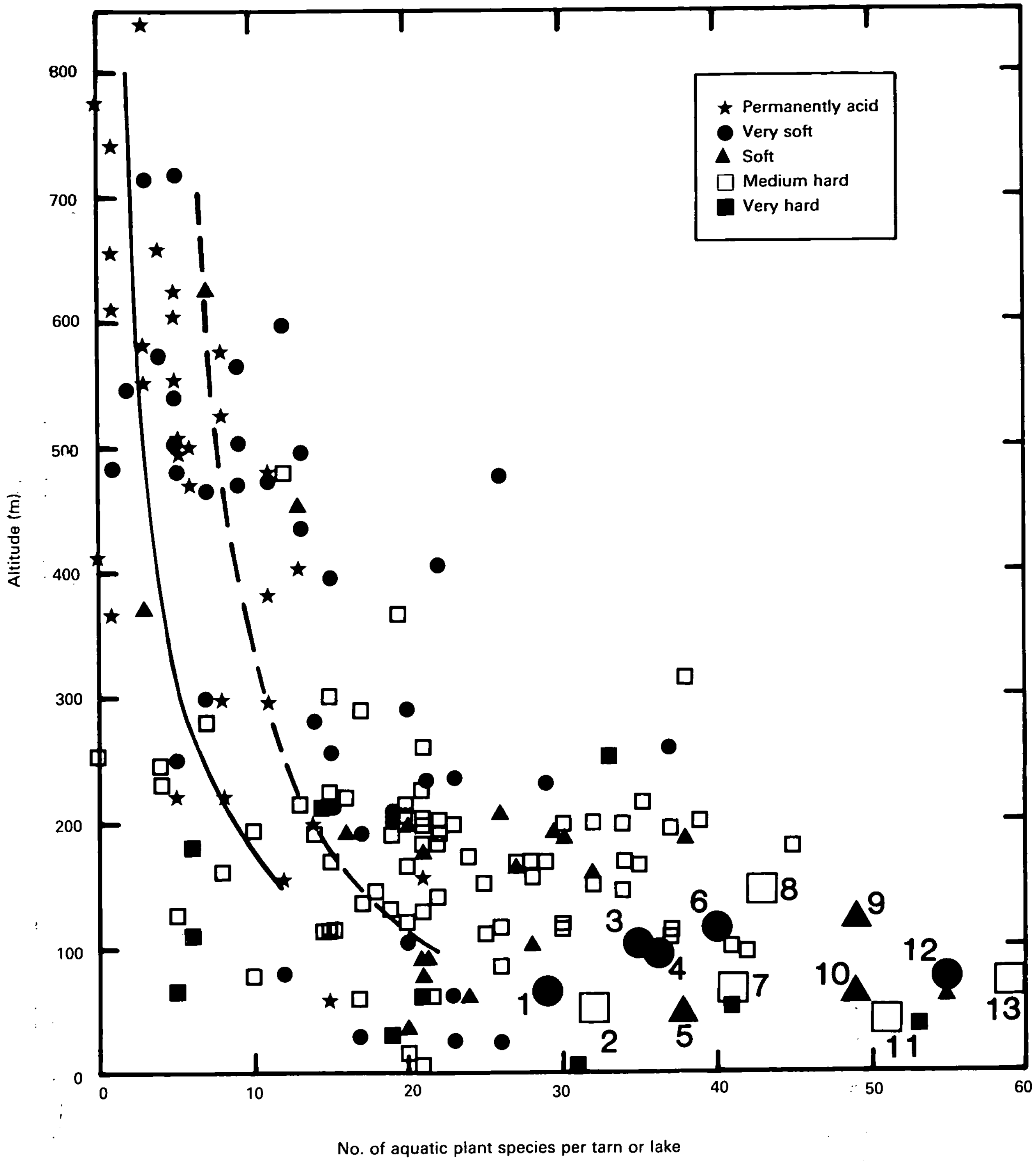

Figure 6. Number of species of aquatic plants (Stokoe 1983) in each tarn or lake, plotted against altitude and showing the water type (Table 1). Curves are drawn from mean regressions of ln number of species versus ln altitude for 30 acid tarns (——) and 36 very soft tarns (– – –). Lakes are numbered: 1, Wastwater; 2, Blelham; 3, Buttermere; 4, Crummock; 5, Coniston; 6, Ennerdale; 7, Esthwaite; 8, Ullswater; 9, Loweswater; 10, Grasmere; 11, Windermere; 12, Derwentwater; 13, Bassenthwaite

from the soil. The occurrence of severe acid episodes may be a very recent phenomenon linked to changes in weather patterns and dry deposition of acidic substances that are subsequently converted to acids. These substances would be flushed out of the soil when it rains heavily, producing an acid episode.

A change in the pattern of weather occurred during the 1970s and 1980s. Summers were dry and sometimes hot in the Lake District. Consequently the frequency, intensity (lower pH) and duration of acid episodes may have increased, compared with previous decades when summers were cool and relatively wet. Declines

Table 2. Mean numbers (± 95% confidence limits) of aquatic plants (macrophytes: Stokoe 1983) in Cumbrian tarns*, related to altitude and water type (Table 1)

Water type	Permanently acid	Very soft	Soft	Medium and very hard
Altitude > 320 m	5 ± 2	9 ± 3	8 ± 13	17†
Altitude < 320 m	12 ± 4	19 ± 4	25 ± 3	22 ± 2

*Lakes (Figure 6) are excluded
†Mean for only 4 tarns

in the numbers of salmonid fish caught in some rivers during the 1970s and 1980s might be linked to detrimental effects of severe acid episodes. Acid water from the Duddon reduced survival of salmonid eggs, although some tolerated exposure to pH 4.0 (Carrick 1979). Nevertheless, other environmental factors are also involved, not least being the frequent lack of water and high temperatures in rivers and streams used for spawning and as nurseries for salmon and sea trout. The period 1909–16 is the only other time in this century when rainfall during the 6 months April–September was consistently as low as it has been in the past 15 years (Sutcliffe *et al.* 1982).

Table 3. Mean numbers (± 95% confidence limits) of water-fleas (copepods and cladocerans: Smyly 1958) in Cumbrian tarns*, related to altitude and water type (Table 1)

Water type	Permanently acid	Very soft	Soft	Medium and very hard
Altitude > 320 m	9 ± 2	11 ± 2	11 ± 7	16†
Altitude < 320 m	13 ± 4	15 ± 4	12 ± 3	13 ± 1

*Lakes (Figure 6) are excluded
†Mean for only 2 tarns

The suggestion that acid episodes may be a very recent phenomenon, at least with regard to their frequency and severity, is conjecture, but it does help to explain some puzzling aspects of recent fish kills in the Rivers Duddon and Esk where deaths were not reported formerly. Acid waters undoubtedly occurred in the catchments of these rivers for a number of decades when salmonid populations were apparently larger than they are now. The acidity/alkalinity levels in the lakes and tarns in the 1950s and 1960s were similar to those found in the 1970s and 1980s. Therefore, some peculiarity of these acid waters (such as frequency and severity of episodes) must be present now, unless greater public and scientific awareness is responsible for an increased reportage of fish kills which previously occurred unremarked! The effects that acidic substances in the atmosphere have on terrestrial plants in the Lake District and neighbouring Pennines (Ferguson & Lee 1983; Fry & Cooke 1984) might also be exacerbated by a change in amounts or patterns of deposition during relatively dry periods. A better understanding of the causes of acid episodes is urgently needed. The continuous monitoring of episodes by the North West Water Authority (Crawshaw 1986) is an important step in that direction.

8 Acknowledgements

We thank landowners, public bodies and individuals too numerous to mention by name for their generous help in sampling the lakes and tarns, especially in 1983–84, but special thanks are due to Mrs S Johnson for regularly sampling Blea Tarn in Eskdale.

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The effects of acidic runoff on streams in Cumbria

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Summary
Mortalities of fish, principally fresh-run salmon and sea trout, have occurred and been documented in the lower reaches of the Rivers Esk and Duddon since 1980, where a general decline in migratory fish stocks has been observed in recent years. Continuous monitoring of water quality at selected sites has demonstrated consistent relationships between pH and other chemical parameters, and river flow.

A number of stream sites have been found to be fishless in electro-fishing surveys. Some of these sites supported reasonable populations of takeable fish 10–15 years ago. Good correlation is found between present river pH and both fish density and invertebrate distribution, although attention is drawn to the role of calcium and aluminium concentrations.

1 Introduction

There has been concern over declining fish runs in the River Esk in south-west Cumbria and in the neighbouring River Duddon since the mid-1970s. In June 1980, a serious fish mortality extending over several days took place during high river flows, following a long dry period. This event was associated with depression of river water pH to around 5 (possibly lower at the highest flows). Over 100 adult fish were affected, mainly fresh-run sea trout, some salmon and a much larger number of juvenile salmonids.

A considerable amount of survey work has been carried out since then, both biological and chemical. The biological work involved invertebrate and electro-fishing surveys at 75 sites (50 in the Esk and Duddon, and 25 other sites thought likely to be sensitive to acidification because of their geology). The results of the surveys have been reported by Prigg (1983).

Chemical quality has been assessed by quarterly sampling at 100 potentially sensitive sites in the Lake District area, including the 75 biological sites. A few 'non-sensitive' sampling points were also deliberately included.

The quarterly sampling programme gives a reasonable picture of the overall background concentrations of aluminium, calcium, etc, but it is apparent from laboratory studies (eg Brown 1982, 1983) that short-term variations in chemical quality can have a marked impact on the biota, at different stages in their life cycles. The finding of missing year classes in juvenile salmonid populations from the Cumbria biological field studies (Prigg 1983) is strong circumstantial evidence that an episodic event can eliminate a complete year class by producing such unfavourable water quality conditions that fish are unable to survive.

In order to investigate the nature of these 'episodes' more fully, continuous pH monitors were set up at downstream points on the Rivers Esk and Duddon, where suitable buildings and flow measurements were also available. The work has subsequently been extended to include automatic sampling at both sites during periods of high flow. The Duddon site includes information on fish movement and a fish counting weir is currently being constructed on the River Esk also, partly funded by the Department of Environment and the Commission of European Communities.

2 Biological findings

A detailed assessment of the biological status of the Esk and Duddon has been made by Prigg (1983). Some of the major findings have been included below.

A number of sites in the upper Duddon and upper Esk catchments and in some nearby catchments were unexpectedly fishless, or had exceptionally low salmonid densities and/or odd population structure. The geometric mean pH of such sites, based on limited sampling, was 5.6 or less. The sites were grouped in the upper parts of the drainage systems associated with the western mountain mass of the Lake District, in areas where the underlying rock is of the Borrowdale Volcanic Series and associated igneous intrusives and rainfall is high (mostly well in excess of 2200 mm yr^{-1}).

The relationship between juvenile salmonid stock density and pH was of particular interest and showed a good correlation (Fig. 1).

Distribution of freshwater shrimps (*Gammarus* spp.) and mayflies (*Baetis* spp.) showed clear evidence of low pH restriction, shrimps not being recorded at sites where geometric mean pH was less than 5.9 and mayflies being found only sporadically at the most acid

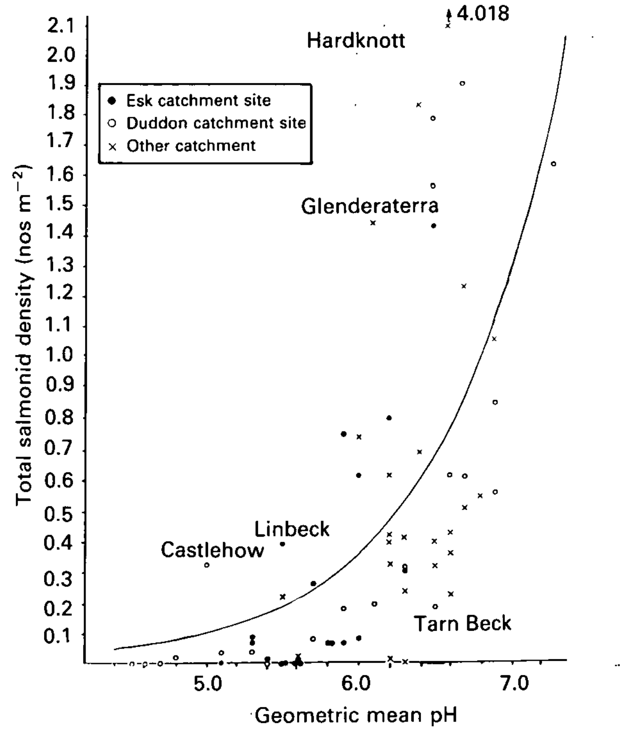

Figure 1. The relationship between total salmonid density and pH in Lake District catchments. The curve is the best fit semi-logarithmic relationship for Esk + Duddon (− Hardknott) data; density = $0.0021271e^{1.241599\ pH}$ (source: Prigg 1983)

sites, with a geometric mean pH of 5.5 or less.

The absence of mayflies would seem to be a good practical indicator of likely low-density, or non-existent, trout stocks (at these sites at least).

Robinson (1984) carried out a survey which included gathering information, from anglers' diaries and personal accounts, of the historical fish stocks of the Esk and Duddon and their tributaries. When this historic information is compared with the more recent electrofishing data, we find a number of surface waters from which fish appear to have vanished within the last 10–15 years. These waters have been summarized in Table 1, while others are suspect and still under investigation.

The findings, whilst not quantitative, do demonstrate that the concern that has been expressed over falling fish stocks is by no means without foundation.

3 Chemical sampling programme

The programme comprised, in the main, quarterly sampling at 100 sites in the Lake District, 50 of which were in the Esk and Duddon catchments. Analysis of water samples included pH, alkalinity, calcium, magnesium, aluminium (total and monomeric), nitrogen forms, conductivity, chloride and humic substances.

Table 1. The changes in fish status of several Lake District streams

Stream	Historic status	Current status
River Esk at Great Moss	Fish caught by angler up to 1965	No fish found in 1981–82 electro-fishing surveys No fish caught by angler 1970
Lincove Beck	Fish caught by angler in 1970	No fish found in 1984 electro-fishing survey
Spothow Gill	Fish caught by angler in 1970	No trout found in 1981–82 and 1984 electro-fishing surveys Caged trout succumb in spate conditions
Leverswater	Fish caught on screens *c*1975	No fish caught on screens. No fish taken in 1984 gill netting No fish found in feeder streams in 1984 electro-fishing

The detailed findings are reported elsewhere (Crawshaw 1984), but a brief summary of the most relevant findings is given below.

In general, good correlations were found between pH and other ions such as calcium and aluminium (inverse correlation) (Figures 2 & 3). Thus, the most acid sites were also generally those where the highest concentrations of aluminium and the lowest concentrations of calcium were found. However, this was not always the case. For example, Grainsgill Beck and the River Caldew immediately downstream, which drain off Gabbro intrusions into the Skiddaw Slates, had very low calcium concentrations, although they were not particularly acidic.

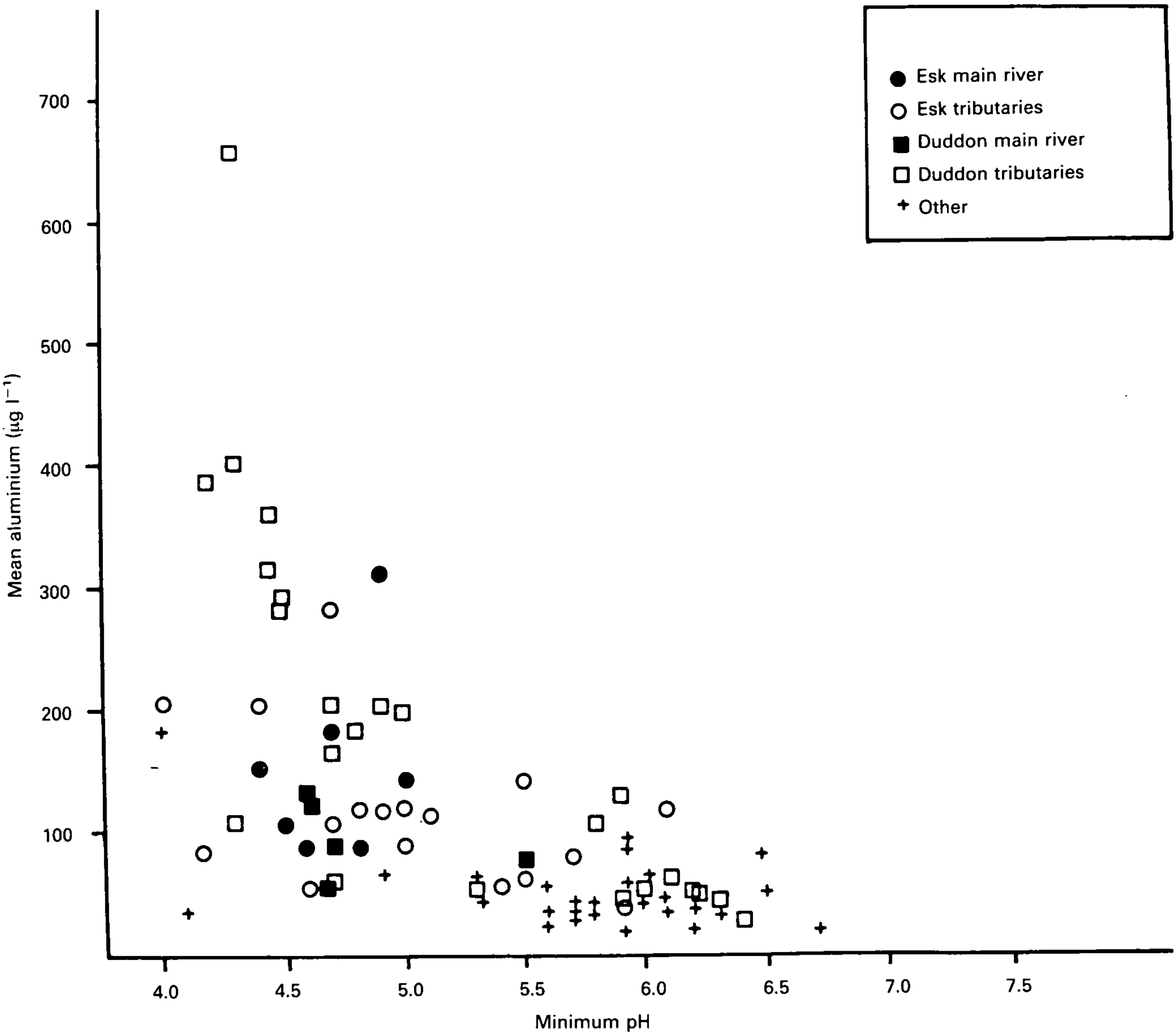

Figure 2. The relationship between mean aluminium concentration and minimum pH for the Esk and Duddon

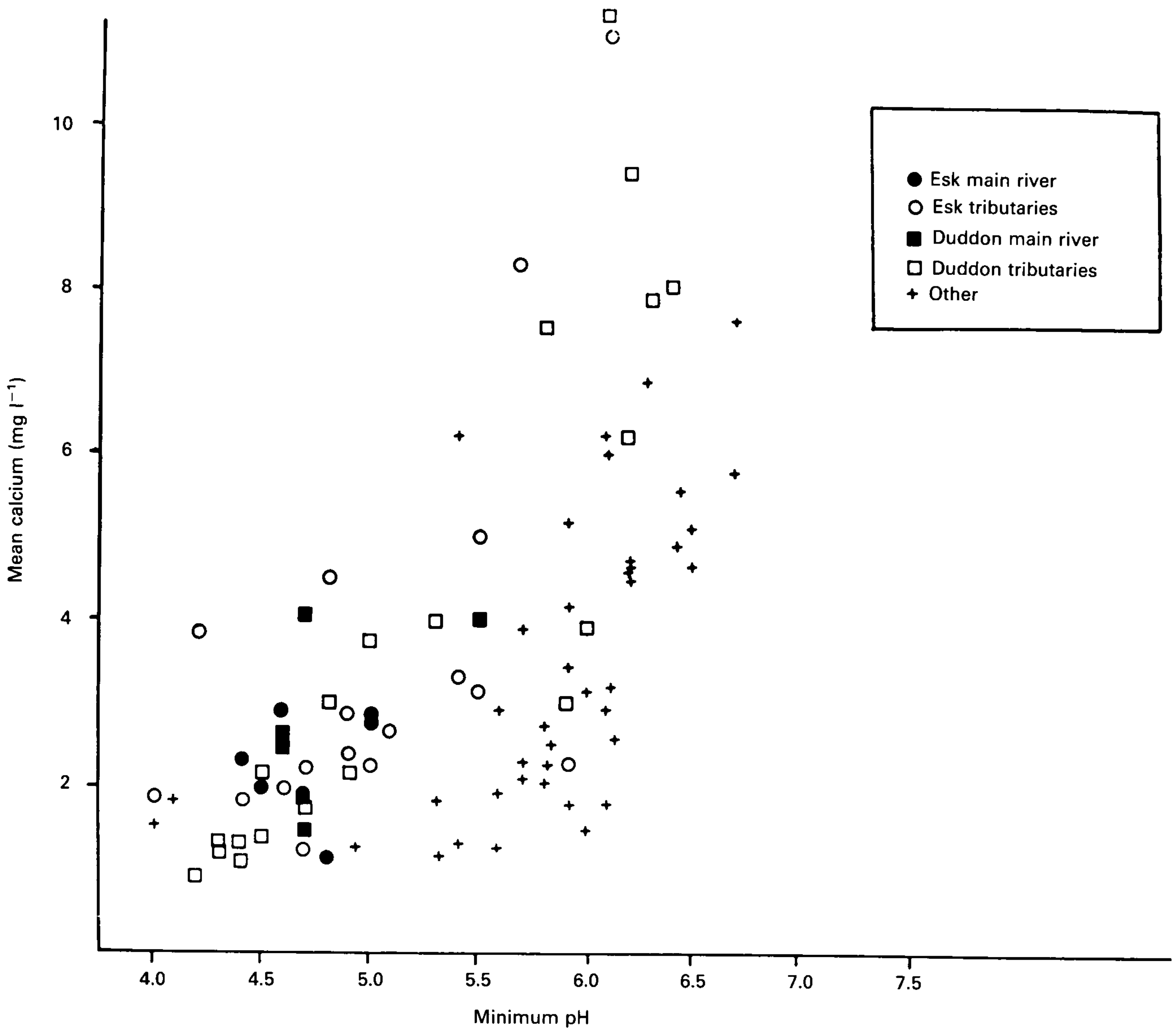

Figure 3. Graph showing the relationship between the mean calcium concentration and minimum pH for the Esk and Duddon

The amount of 'peatiness' in the streams was measured by a determination of humic substances. In general, the levels were low and showed a positive correlation with pH (Figure 4), ie the most peaty streams were also the least acid. It seems unlikely, therefore, that organic acids derived from peat are making a significant contribution to the acidity in these streams.

In both the Esk and Duddon catchments, the worst affected streams (ie low pH, low calcium and high aluminium levels) are found in the upper part of the catchment, and a gradual improvement is found as one moves downstream. In the Duddon, the improvement downstream of Tarn Beck is more rapid than in the Esk, so that by the time the monitoring station at Duddon Hall is reached the pH is about one unit higher, and the calcium concentrations are approximately double that in the Esk at Cropple How.

When the fish density data from tributary streams are examined alongside the chemical data, it is possible to discern effects of low calcium or elevated aluminium levels quite independent of the adverse effects of low pH.

In other areas, where levels of humic substances are much higher, fish can survive in pH less than 5, but, under these circumstances, the aluminium present will be organically complexed, rendering it much less toxic (Driscoll *et al.* 1980). In the Esk and Duddon, with low humic levels, the aluminium is present as soluble inorganic aluminium (monomeric aluminium) and this is much more toxic to fish, especially at low calcium concentrations.

4 Results from continuous pH monitors

The monitors have operated more or less continuously from May 1983, and have produced some very

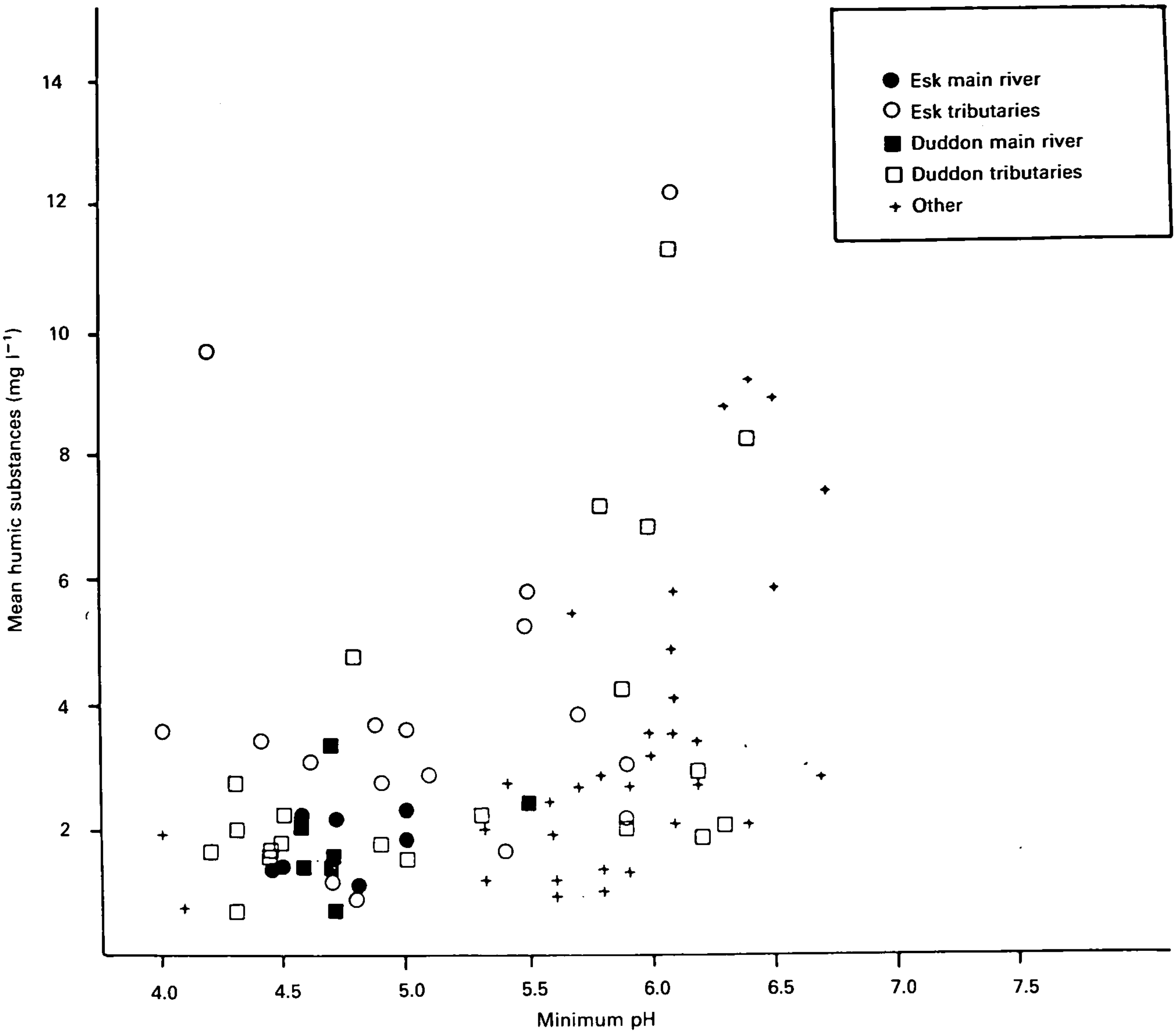

Figure 4. The relationship between mean humic substances concentration and minimum pH for the Esk and Duddon

interesting data. One major finding is that virtually every substantial rise in river flow is accompanied by a fall in pH. This characteristic is true for both stations, except that the Duddon at Duddon Hall tends to be about one pH unit more alkaline than the Esk at Cropple How throughout the record. Figures 5 and 6 demonstrate the strong correlation between pH and river flow. This relationship seems to hold good regardless of the pH of the rainfall, which is measured daily at a nearby site. There is a considerable variation in rainfall pH, and at times of high river flow it is not uncommon for the river water to be more acid than the rainfall. More usually, however, the river pH is less acid than that of the rainfall. The controlling factor is most probably the time that water spends in contact with soils in the catchment, and will be determined largely by the intensity of the rainfall.

Figures 7 and 8 show the pH records for the September 1983 fish mortality. Rainfall samples taken at this time were found to have pH in the range 5.2–6.4, which was considerably above that of the river water. The pH in the River Esk, having fallen below 4.5, lay for several days between 5.0 and 5.5, which is the range when maximum toxicity due to aluminium may be expected. Brown (1983) found that one-year-old trout survived for only a few hours in water of a very similar chemical composition.

In field studies with caged fish, Gee and Stoner (1984) found that in one Welsh stream, where calcium and aluminium levels were similar to those in the Esk, caged salmon were killed fairly rapidly and only 30% of caged trout were still alive after 7 days.

This combination of laboratory and field studies, in very comparable conditions, provides strong supportive

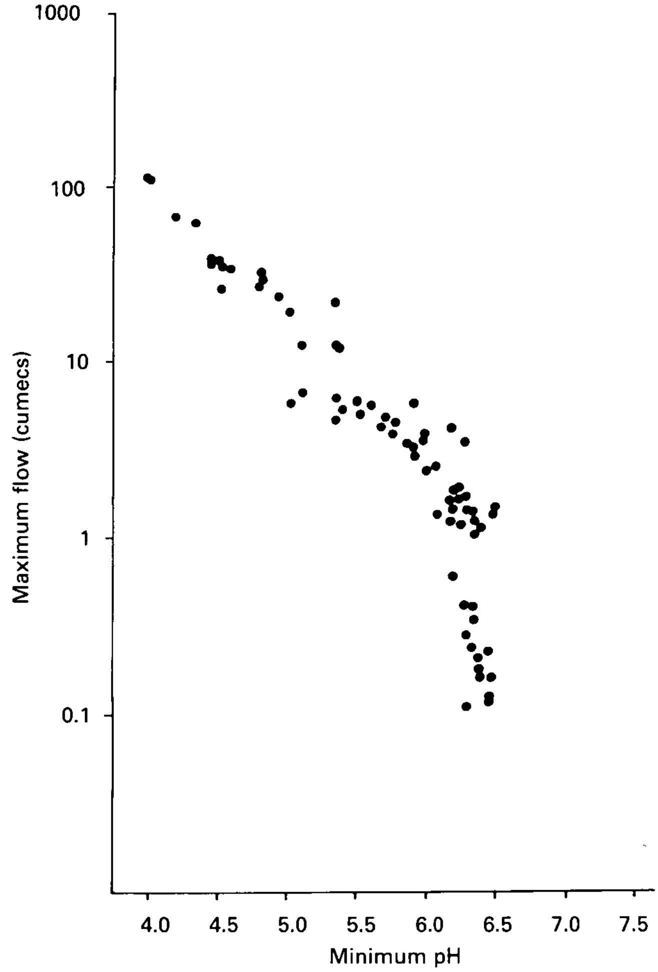

Figure 5. Maximum flow plotted against minimum pH for the River Esk at Cropple How, August 1983–February 1984

evidence that the Esk mortality was caused by increased concentrations of aluminium, almost certainly accompanied by a reduction in calcium concentrations, which would also increase the toxicity of aluminium to fish.

5 Catchment liming

Robinson (1984) showed that since 1976 the amount of lime applied to the Esk catchment had reduced by a factor of about 7. Indeed, there are a number of fields in the catchment that have had no application of lime since the liming subsidy was removed. Table 2 shows approximate figures (expressed as calcium) for lime applied to land and that lost to the river system.

The conclusion from these figures is that a return to 1976 levels of agricultural liming would be likely to have quite a significant impact on calcium levels in the River Esk. Raising the calcium levels would have the effect of raising the pH and reducing the overall toxicity of aluminium in spate conditions. It is possible that the actual concentrations of soluble aluminium would also be reduced.

Table 2. Approximate figures (expressed as calcium) for lime applied to the land and lost to the river system in the Esk catchment

	Lime ($t\ yr^{-1}$)
Pre–1976 lime applied	2000
Present-day (1983) levels of lime applied	280
Estimated contribution from natural sources	100–200
Present-day (1983) calcium flux at Cropple How	300
Likely contribution to the river system from current liming	100–200
Possible pre–1976 contribution to river system	700–1400

Regrettably, catchment liming would be unlikely to affect most of the spawning tributaries, as these are mainly in areas where liming would be difficult.

It is clear that the water quality of the Esk is, at best, only just capable of supporting viable fish populations. Any disturbance of this relatively fine balance (such as a reduction in calcium concentrations) would have

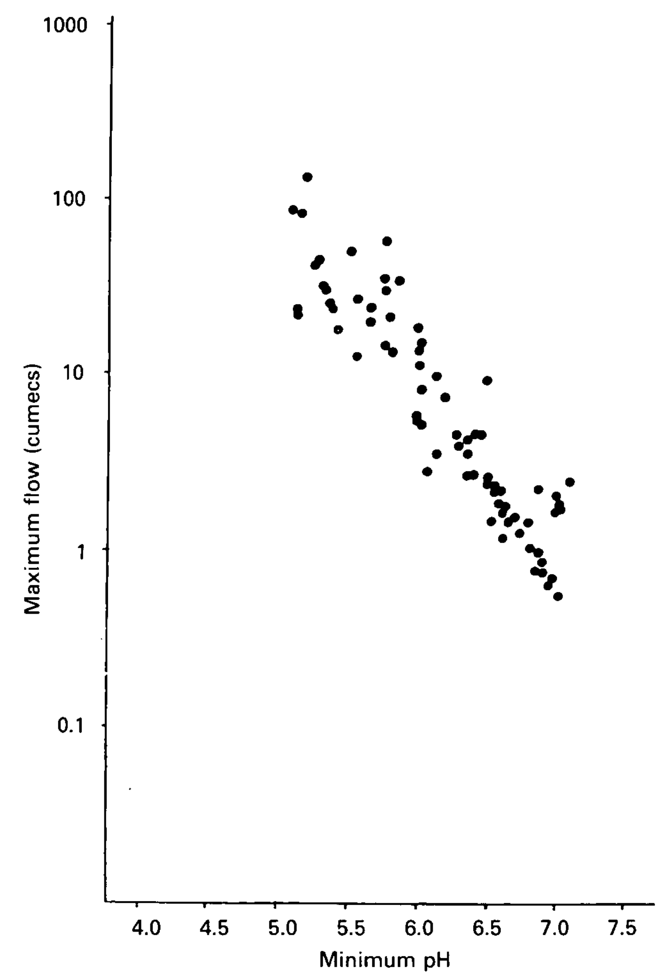

Figure 6. Maximum flow plotted against minimum pH for the River Duddon at Duddon Hall, August 1983–February 1984

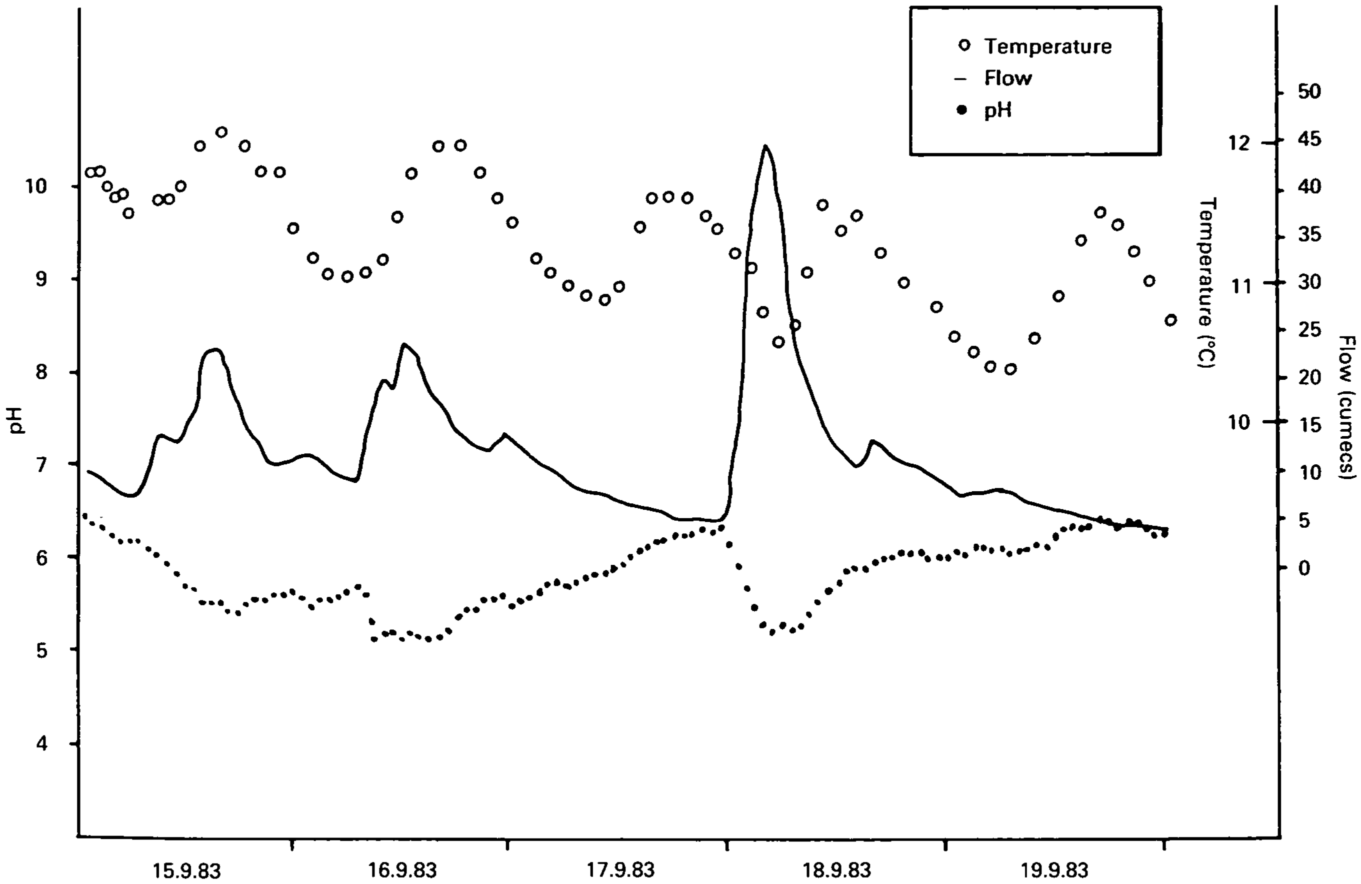

Figure 7. The pH and flow rates of the River Duddon at Duddon Hall during the September 1983 fish mortalities

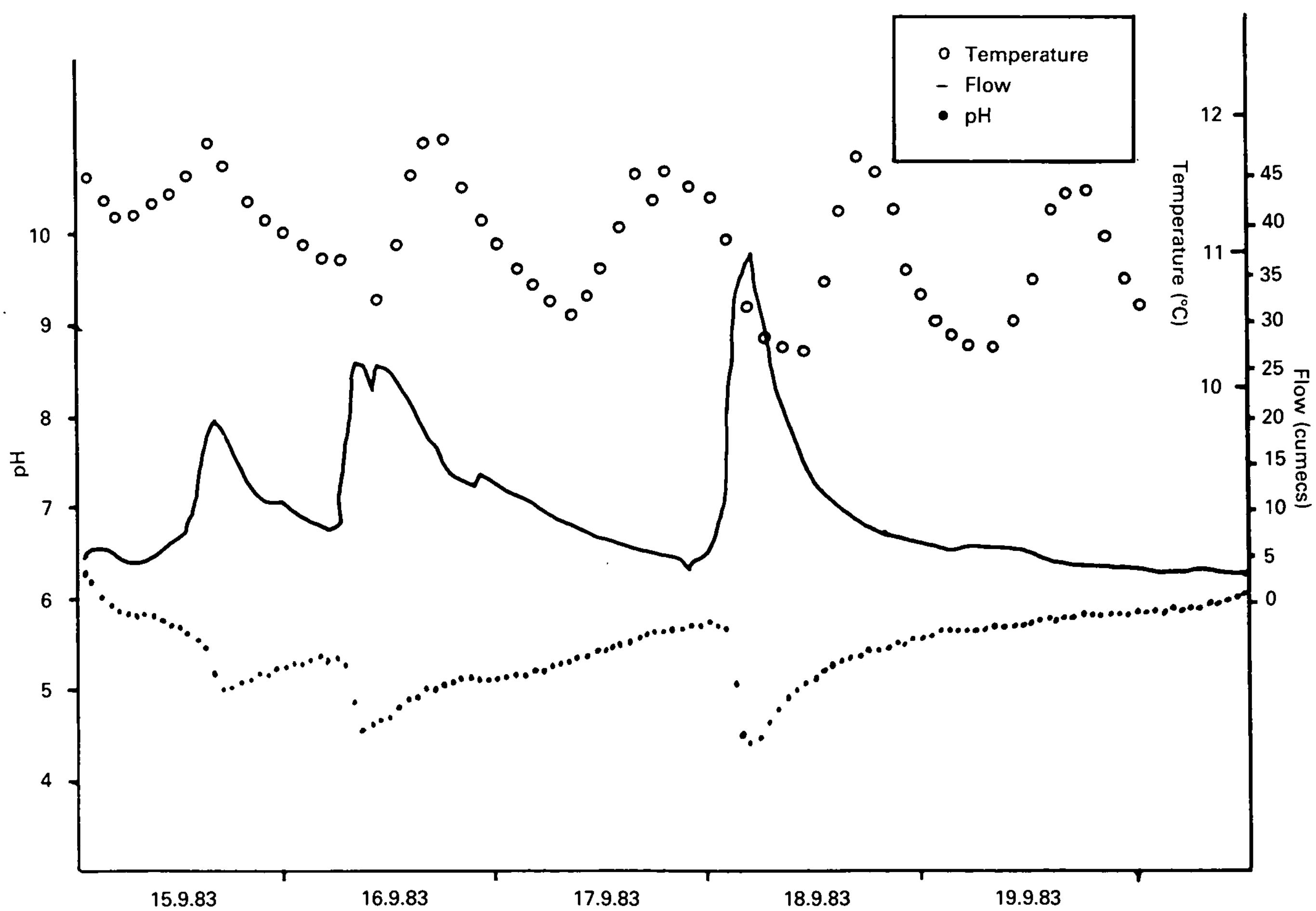

Figure 8. The pH and flow rates of the River Esk at Cropple How during the September 1983 fish mortalities

adverse effects on the fishery. However, whilst the reduction in liming could well have contributed to the mortalities of fresh-run fish in 1980 and 1983, it certainly cannot be blamed for the elimination of fish from some of the tributaries as outlined in Section 2.

6 Conclusions

Catchment liming is unlikely to be a panacea for acidification problems in the River Esk. However, it is an option well worth pursuing, as it might well reduce the impact of acid episodes on freshly run fish by raising the calcium concentrations in the river.

Better information on fish movement in the Esk is required, and hopefully will become available in 1985 after completion of a new fish counting weir.

7 Acknowledgements

I should like to acknowledge the help received from numerous colleagues in the North West Water Authority, in particular J F Robinson who organized the bulk of the chemical sample collection, and R F Prigg who was responsible for the biological work. S Bowling was largely responsible for installation of the instrumentation.

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AGRICULTURAL POLLUTION

The role of the Agricultural Development and Advisory Service in pollution problems

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Summary

Pollution problems associated with agriculture are briefly described, with particular reference to the Control of Pollution Act, Part II, Pollution of Water, and to complaints of agricultural odours. Data are presented on the extent of the problems, and sources of information are outlined. The role of the Agricultural Development and Advisory Service in providing impartial and constructive guidance, together with laboratory analysis, in order to obviate pollution is described.

1 Introduction

It is undoubtedly stating the obvious to say that animals produce large quantities of potentially highly

Plate 1. Scientists at ITE's Merlewood Research Station are studying the fate of radionuclides released into the environment by the Sellafield reprocessing plant (Photograph A D Horrill)

Plate 2. British Nuclear Fuel's reprocessing plant at Sellafield, west Cumbria (Photograph J K Adamson)

Plate 3. Sewage treatment plant on the shores of Lake Windermere (Photograph P Ineson)

Plate 4. Holehouse Tarn. Surprisingly, the incidence of antibiotic resistance in bacteria isolated in this remote upland tarn is higher than that of Lake Windermere (Photograph J G Jones)

polluting materials (see Table 1), which have to be disposed of in a manner that is acceptable to all: farmers, water authorities, conservationists, etc. It is probably equally true to say that it is in nobody's interest to have to resort to legal action (except possibly the legal profession!) to control pollution. This paper outlines the role of the Agricultural Development and Advisory Service (ADAS) in helping to achieve a balanced approach to waste disposal and utilization, so that economic considerations and amenity are harmonized. The topic of agricultural pollution is wide-ranging, and this paper can only skim the surface in the hope that it will stimulate awareness of problems and solutions. Further advice is always available from the ADAS offices of the Ministry of Agriculture, Fisheries and Food (MAFF) (see Appendix 1).

Table 1. Typical biological oxygen demand (BOD) values of effluents

	BOD (mg l^{-1})
Domestic sewage	200– 400
Dairy washings	600– 1 600
Cow waste	11 000– 15 000
Silage liquor	30 000– 60 000
Milk	90 000–100 000

2 Pollution affecting agriculture

Whilst much attention is focused on those relatively infrequent situations where agricultural processes have caused pollution, it should also be remembered that agriculture itself can suffer from the effects of pollution, from its own activities, or from outside influences. Examples in the latter category are the pollution of water used for stock drinking or crop irrigation and the spread of animal and plant pathogens in inadequately processed sewage sludge. Chemical contamination of the atmosphere can occur from factory discharges, with disasters such as the Flixborough explosion or radiation leaks having the potential to cause serious problems. At the individual level, litter left by people, or the people themselves, can damage crops, stock and machinery, and pollution by noise, such as the sonic bangs from aircraft, can frighten stock. Contamination of foodstuffs with obnoxious materials can be extremely serious; for example, in recent years the accidental contamination of animal feed with a fire retardant in America caused massive and far-reaching problems. Contamination of land, and subsequent crops, can occur from leakages from landfill sites, tanker spillages, or the uptake of chemicals from spoil heaps that have been returned to agricultural use.

It is not possible to discuss all these subjects in this review. Suffice it to say that ADAS, with its modern analytical services and wealth of knowledge, is well placed to offer impartial advice and to monitor and investigate problems of this sort. Also, because of our involvement with the agricultural community, advisers may be the first point of contact for the farmer and can co-ordinate activities in the event of a major pollution incident.

3 Pollution by agriculture

Agricultural and horticultural processes can pollute. It is intended to concentrate on 2 aspects of pollution in this paper: namely, pollution of water, and agricultural odours. Other forms of agricultural pollution can be aesthetic due to poor building design, noise from housed stock or machinery, dust pollution from activities such as the milling of feed or the smoke and ash from straw burning.

In general, MAFF has a very limited role in the enforcement of the law in relation to pollution problems, and the major legal responsibilities lie with the Department of the Environment, local authorities and the water authorities. The role of MAFF, and in particular that of ADAS within the Ministry, can be summarized as:

- enforcement of certain statutory functions;
- the co-ordination of activities in the event of a pollution incident;
- the giving of advice;
- undertaking research and development to prevent pollution problems.

4 Water pollution

Each year ADAS collates returns from the 10 water authorities in England and Wales on the number of pollution incidents that have occurred during the year and can be associated with agriculture. Data are presented in Table 2 showing, in the opinion of the water authorities, the number of serious incidents of agricultural pollution during 1984 and the cause. The returns from the North West Water Authority cover, in the main, Cumbria, Lancashire, Greater Manchester and Cheshire, and data for the country as a whole are also presented. It can be seen that the main problem areas are inadequate storage capacity for slurry, leakage of silage effluent, and runoff of contaminated water from cattle yards.

Pollution of water by agricultural practices is covered by the Control of Pollution Act 1974, Part II (COPA), which came into force in the early part of 1985. In the Act, specific provision (Section 31(2)(c)) is made for a *Code of good agricultural practice*, produced by MAFF and the Welsh Office, which is aimed at freeing farmers from unreasonable liability whilst conducting normal farming activities. This Code does not condone activities that could cause serious pollution, but it does recognize the fact that agriculture is probably the only industry in which potentially polluting material is spread into the environment as an integral, and beneficial, part. Also, the majority of streams, underground waters and the like are to be found on agricultural land. Much of the COPA is not 'new' but the Act does incorporate legislation from a variety of previous Acts that concern water pollution, and some new categories have been added. Basically, the COPA

Table 2. Number of serious pollution incidents, England and Wales, 1984

Source	North West Water Authority	All water authorities
Slurry stores		
Inadequate storage	71	166
Bursting	6	75
Poor management	0	79
Runoff from solid waste		
Inadequate storage	0	8
Poor management	0	18
Silage effluent		
Inadequate storage	103	165
Leaking silos	18	89
Leaking storage tanks	0	35
Poor management	0	70
Runoff from land	21	77
Runoff from yards		
Cattle	99	328
Pigs	24	100
Poultry	11	14
Failure of treatment systems	5	36
Disposal of sheep dip	2	13
Mineral fertilizers	1	1
Pesticides	3	27
Vegetable washing	0	7
Oil spillage	0	15
Miscellaneous	0	64
Total serious incidents	364	1 387
Total warnings	454	2 828
No. of agricultural holdings	23 000	193 000

requires that planned discharge of waste from agricultural holdings requires the consent of the water authority who may lay down conditions for the operation. Discharges would be from a sewer or drain into water, or into/on to land. It is not the intention of this paper to provide detailed legal definitions, and farmers are encouraged to consult their local water authority. A practice that causes pollution would be an offence but, where a farmer or grower can show that he was following good agricultural practice, this would be accepted as a legitimate defence. Reference should be made to the *Code of good agricultural practice* and the advisory literature from MAFF (Appendix 2) which forms part of it. The topics covered are:

- inorganic and synthetic fertilizers;
- organic manures, slurries and waste waters;
- silage effluent;
- pesticide usage and disposal of unwanted pesticide containers;
- aerial spraying;
- disposal of spent sheep dip.

5 Waste treatment

The treatment of agricultural wastes so that they do not pollute is technically feasible but is not economically justifiable because of the strongly polluting nature of animal excreta and silage effluent. Any process would have to consist of many stages of treatment and would be time-consuming and expensive to operate. However, some treatment may be appropriate for specific purposes. For example, relatively weak effluents (dirty brown water) from yard drainage can be treated in systems such as a barrier ditch, but these systems can be easily overloaded and may not always be acceptable to the water authority. Aeration of slurries will reduce their polluting potential but not sufficiently to achieve a dischargeable end product. However, aeration may be justified to control the odour of farm waste. Anaerobic digestion of wastes to produce methane, and to reduce the odour and strength of wastes, is frequently advocated, as is chemical treatment using mixtures of enzymes and bacterial additives. To date, monitoring of the efficiency of these methods by the staff of ADAS has been unconvincing, and careful consideration should be given to their value in agricultural circumstances. Certain waste, such as broiler litter, can be disposed of by feeding to other livestock, providing it is correctly treated to ensure that it is microbiologically safe.

Overall, it should be stressed that disposal to land is the preferred method of dealing with animal and plant wastes, providing minimum pollution risk whilst having the benefit of returning nutrients to the soil.

6 Public nuisance

Up to now I have dealt predominantly with problems of water pollution, but agriculture can find itself transgressing the laws relating to public nuisance, which are administered by the local authorities. In particular, it is proposed to concentrate on one facet: the problem of agricultural odours.

In a questionnaire to Environmental Health Officers (EHOs) sent out by ADAS, it was found that in the period of April–September 1984 82% of all Boroughs, District Councils, etc, had received complaints of agricultural odours. A typical Council had received complaints about 8 premises during the summer months (see Table 3). All Councils expressed concern about the increasing numbers of complaints. This increase can be attributed to changes in public attitudes, the spread of townfolk into rural areas, and changes in agricultural practices, eg the development of slurry systems rather than farmyard manure, and increasing stocking densities. Unfortunately, solutions are hard to find and prevention of odour development, rather than cure, is far better. Prevention is a combination of 'tactics and techniques'. Tactics aimed at

Table 3. Number of premises causing odour complaints April–September 1984

Most common causes of odour complaint	Type of livestock unit				
	Pigs	Poultry	Cattle	Horses	Sheep
Housing	138	133	34	32	5
Slurry/manure storage	154	57	65	52	1
Slurry/manure spreading	380	153	142	3	2
Swill boiling or food preparation	49	2	1	—	—
Silage	2	2	54	1	1

reducing the chance of complaints include educating neighbours so that they understand the problems; using common sense in selecting the right weather conditions and time of day for spreading; and seeking advice from EHOs and ADAS staff. Techniques of odour abatement include low-level spreading of slurry, aeration of waste, and the use of chemical masking or neutralizing agents. Such chemicals are not always effective, and careful consideration should be given before adopting this approach.

7 Conclusions

It is clear that the problems associated with farm waste are complex involving many issues. However, expertise does exist and advice is available from water authorities, EHOs and, above all, from the Agricultural Development and Advisory Service, who can give impartial and constructive guidance.

Appendix 1. MAFF/ADAS staff with responsibilities for pollution matters

Chief Regional Officer: A Baines (Leeds 674411) – co-ordination of pollution incidents.

Chairman Regional Farm Waste Committee: D Joyce (Leeds 674411) – co-ordination of technical advice and research.

LOCAL REPRESENTATIVES

Divisional Executive Officer: J Bradbury (Carlisle 23400)

Land and Water Service: D Hill (Carlisle 23400)

Divisional Agricultural Officer: D Willey (Carlisle 23400)

Appendix 2. Publications

The following publications, which may be amended from time to time, give detailed information on good agricultural practices.

Copies are available from Ministry of Agriculture, Fisheries and Food (Publications), Lion House, Alnwick, Northumberland NE66 2PF.

Reference book 209. *Fertiliser recommendations 1985–86.* (ISBN 0 11 242709 X) (Also available from HMSO bookshops) £3.60

Reference book 380. *Agricultural Chemicals Approval Scheme. 1985 List of approved products for farmers and growers.* (ISBN 0 11 242720 0) £4.25

Leaflet 441 (1985). *Nitrogen fertilisers*

Leaflet 593 (1984). *Sheep scab*

Leaflet 719 (1984). *Sheep dipping and spraying*

Leaflet 767 (1984). *Farm chemical stores*

Booklet 2077 (1985). *Farm waste management: general information*

Booklet 2078 (1985). *Guidelines for the use of herbicides on weeds in or near watercourses and lakes* £2.50

Booklet 2081 (1986). *Farm waste management: profitable utilisation of livestock manures* £2.00

Booklet 2198 (1984). *Guidelines for the disposal of unwanted pesticides and containers on farms and holdings*

Booklet 2200 (1985). *Farm waste management: advice on avoiding pollution from manures and other slurry wastes* £2.00

Booklet 2272 (1983). *Guidelines for applying crop protection chemicals. Ground crop sprayers for agriculture*

Booklet 2273 (1985). *Farm waste management: the storage of farm manures and slurries* £2.50

Booklet 2390 (1985). *Farm waste management: dirty water disposal on the farm*

Booklet 2409 (1985). *The use of sewage sludge on agricultural land*

Booklet 2429 (1985). *Farm waste management: silage avoiding pollution*

Booklet 2449 (1983). *Guidelines for applying crop protection chemicals – spraying fruit and hops with insecticides and fungicides*

Priced publications where shown

Also:

CAP 414. *The aerial application certificate: information on requirements to be met by applicants and holders.*
Copies available from Civil Aviation Authority, Cheltenham.

The farmer and pollution

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National Chairman Rural Voice, Orton, Penrith

Summary

Farmers in the Lake District feel somewhat beleaguered and maligned. Growing population has led to a revolution in agriculture in order to feed ourselves, and this has led to the farmer increasingly becoming a producer of pollutants, as well as a recipient. The current attitude of the farmer is one of injustice, in that he is readily seen as the polluter, but is often powerless to defend himself against the intrusion of industrial and urban wastes.

In this paper, the nature of agricultural pollution problems and the growing awareness of the pollution of, and by, agriculture are discussed. Changes both in agricultural practices and farmers' attitudes are occurring, to the benefit of the environment.

1 Introduction

In this symposium we are focusing our attention on Cumbria, a large proportion of which is the most sparsely populated land in England. Farmers in the Lake District, the Pennines, the hills that join them, and the valleys that cleave between them, feel today beleaguered and maligned.

For this reason, I would like to broaden this introduction to the wider scene, of which Cumbria is a very small part. It is estimated that some 5% of all the people who have ever lived on this planet are alive today. Not only the population explosion, but also the industrialization of Europe, is a phenomenon of the last 150 years. Having exercised our insatiable capacity to reproduce ourselves, we have had to revolutionize agriculture in order to feed ourselves. All this reflects great credit on the ingenuity of this restless little mammal.

During the last 20 years, man has become increasingly aware (especially in Europe) that he is fouling and destroying not only his own environment, but that of the other creatures who inhabit his planet. Not only, we have realized, does this behaviour make life increasingly less pleasant and less satisfying, but it could lead to it being impossible.

In western Europe, the urban–rural split varies from 10% to 90%. The pollution of our food, water, air, and ears is essentially an urban industrial problem, of too many people and too many chemical and biological processes taking place in close proximity to one another. Not only have industrial and urban wastes spilled out into the countryside, but the thinking, economic processes, and even the structures of urban industrial man have spilled into the countryside, as has every other aspect of our urban industrial culture. Congested urban industrial man confined in the artifice of the town looks to the countryside for his food and his recreation. Both represent an ideal of purity, wholesomeness and unchanging beauty, unsullied by the excrescences of the changing city.

Alas, the rage of urban industrial man seeing agriculture adopting his industrial methods of production, his industrial building techniques, his machines, and then finding that intensification of output creates large quantities of waste to dispose of, and demands control of pests and diseases, which in turn bring their own side effects . . . is the rage of Caliban seeing his own face in the glass.

Whilst the rage of urban man excluded, by perhaps 3 generations, from a countryside which he loves, and in which he finds a beauty for which he has a nostalgic longing, but of which he has no part, . . . is the rage of Caliban not seeing his face in the glass.

There is then a scenario for conflict.

2 Growing awareness of pollution

For some years now I have served on the Confederation of European Agriculture's Committee for the Protection of the Environment. Most of the time of this Committee has been spent on problems resulting from pollution of the countryside, by urban industry and urban settlements. More recently, it has given equal concern to the problems involving agricultural practice throughout Europe, such as animal slurry, fertilizer usage, and insecticides and pesticides. To this end, it is now working towards producing a strategy for agriculture which could be urged upon and accepted by the industry. Major concerns in Europe have been: the impact of acid rain, where Swedish investigations indicate that responsibility rests with most of the industrial areas, including the UK; nitrate pollution, for which both animal manures and nitrogenous fertilizers have some responsibility; and phosphates and heavy metal pollution, which stem both from domestic and industrial sources as well as from agriculture.

European agriculture is alive to the problem, but what about nearer home? Leaders of the industry have been considering, for some time, how best to promote a strategy which essentially eliminates pollution but is at the same time consistent with sound commercial agriculture.

Two years ago, an organization was formed in the UK called RURAL. Last year it had its annual conference entitled 'Tuning inputs to maintain profits'. This conference examined the considerable reductions in the use of sprays and fertilizers which are possible in arable production by simply taking care to use the right amount at the right time. The conference was an example of a new awareness which is by now pervading a significant proportion of the farming community. As agriculture utilizes 80% of the land in this country, farming practices are capable of having a considerable impact and, in turn, farming is widely susceptible to pollution from other sources.

3 Pollution of agriculture

The effects of waste disposal on agriculture include those of sewage, which is either applied to the land as sewage sludge, or escapes from public sewers. The National Farmers' Union (NFU) has drawn the attention of the Royal Commission on Environmental Pollution (1979) to the frequency of occurrences of incidents. These incidents are not only the responsibility of water authorities, but other public bodies are involved, as well as private organizations. Such incidents, particularly where public bodies are involved, do not normally lead to prosecutions, or any publicity, in marked contrast to water authority policy on pollution by agriculture, where a first incident or accident will frequently result in a highly publicized prosecution. Furthermore, the difficulty of farmers seeking redress for such pollution incidents is considerable, for not only must negligence be proven, but proof of the cause of loss is often very difficult to obtain. Farmers argue that this is an unfair position financially and that the distortion in the public mind resulting from the prosecution of farmers creates an image of the farmer as polluter which is inaccurate and unfair.

In addition, industrial spoils and workings are a cause of concern, and are blamed for heavy metal contamination of agriculture in some areas. Dangers from the heavy metals in sewage sludge finding their way into crops, as well as the risk of dangerous pathogens, are pointed out by the Agriculture and Food Research Council (Royal Commission on Environmental Pollution 1979).

Acid rain, which is regarded as less of a problem in the United Kingdom than in many parts of Europe, is blamed on urban and industrial emissions.

4 Pollution by agriculture

Pollution by agriculture includes pollution of watercourses from livestock units, and from fields spread with slurry followed by very wet weather. Nitrates in water are a growing cause for concern, but the NFU contends that farm wastes are not thought to be the major cause of nitrates in UK waters. However, agriculture is contributing to the nitrate content of our waters, especially in arable areas where the accumulation of soluble nitrates in the soil in autumn (when crops have been harvested and nitrates are not being taken up in growth) can be considerable. To put the contribution of applied nitrogen into perspective, the NFU points out that nitrogen contained in organic matter in the soil exceeds by a factor of 150 the amount supplied as fertilizer each year. The problem comes more from the increased arable acreage. Nevertheless, in some areas, nitrogen accumulations in underground waters represent something of a time-bomb with a fuse of perhaps 20 years. The submission of the Ministry of Agriculture, Fisheries and Food (MAFF) to the Royal Commission on Environmental Pollution (1979) suggested that a reduction in nitrate levels would be less costly to achieve through nitrate removal by water authorities than by widespread restrictions on agriculture.

Straw and stubble burning is a nuisance which does not directly affect Cumbria, but it seems that agriculture will resist a total ban on this practice because of the cleansing value of the burn. Developments in this area include more uses for waste straw and a reduction in burning for each field to a minimum level necessary for the effective control of pests. Again, agro-chemicals have not caused a great deal of complaint in Cumbria but their more widespread use in arable areas has been a matter of concern from several standpoints.

5 Farmers' attitudes and pollution control

In Cumbria, which is mostly grass with a large concentration of dairy and beef units, the high rainfall provides a water supply to other parts of the region, and pollution of watercourses is perhaps a major concern.

Speaking personally as a farmer, and I think that this applies to most of my colleagues in Cumbria, I cannot speak too highly of the staff of the North West Water Authority (NWWA) who have at every level always been most helpful and thorough.

However, in official farming circles, there is concern that a policy of vigorous prosecution, especially for first-time offenders, could be leading to an alienation of farming opinion towards the NWWA. If the Authority could more effectively combine the role of 'policeman' with positive encouragement to farmers in the anticipation and prevention of pollution, then a more constructive relationship leading to long-term improvements in pollution control could be achieved.

This role could take the form of realistic advice on design and material appropriate to agriculture, and financial support for the purpose of improving water quality.

That advice would normally come from MAFF, and here there may be a problem, as there is little formal relationship between the Ministry of Agriculture and water authorities. MAFF and water authorities should work more closely together to provide concerted advice and assistance to the individual farmer, who would know that the recommendation he is receiving has water authority approval. (The Welsh Water Authority has acted by appointing Farm Liaison Officers.) Farmers welcome advice from water authority staff. The difficulty can be that water authority advice, based on standards for public installations, tends to embody such a high standard of environmental protection as to make it economically unacceptable. The economic sensitivity of MAFF offices and the pollution control awareness of water authority offices need to illuminate one another. Perhaps training programmes arranged by the water authority for MAFF officers, and *vice versa*, would be a step forward.

Farmers have welcomed the Minister's announcement on the 2 May 1984 of the re-introduction of a grant for waste disposal facilities on farms with more than 40 cows, but this, like some other schemes, suffers from the necessity of prior approval. There is a strong case for raising and extending support for pollution control, both in terms of advice and capital assistance.

6 An outlook for rural Cumbria

Farmers in Cumbria are a dedicated and law-abiding section of the community who readily respond to leadership. It has been interesting to observe this characteristic in the way they have responded to the changing priorities of society in respect to conservation. Faced with a support system and capital incentives which are orientated entirely towards increased production, farmers have, nevertheless, at considerable financial cost to themselves and in response to the changing priorities of society in the countryside, responded to the call for more effort in the field of conservation by setting up the Farming and Wildlife Advisory Group and taking up conservation schemes on a wide scale. A few years ago perhaps 20% were convinced of the need, now I suspect it is over 50%. There will always be back-sliders who will let down any group, and I suggest it is upon them, and them only, that the full rigours of the law should be visited.

What of the future? Agriculture is changing rapidly and will continue to change. Limits on production, first milk, then other commodities, will lead to a reduction of pressure on installations. The end of growing prosperity, and perhaps a fall in output, will mean less nitrogen, less slurry, and an easing of pressure. The landscape may begin to change, more trees, more non-farming enterprises, altogether less pressure from farming. At a time when the farmer is under great pressure which can only get greater, is this not an opportunity for those who share his concern for his environment to extend more firmly and recognizably a hand of friendship and co-operation and to temper the role of the policeman.

7 Reference

Royal Commission on Environmental Pollution. 1979. *Seventh report: agriculture and pollution.* London: HMSO.

The Cumbria environment – an overview

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Summary
The relationship between Cumbria and other administrative units in Great Britain is discussed in order to place the county in its general environmental context. The pollutants are then divided into 3 groups which operate on different scales as far as overall assessment is concerned. These groups are: general (eg acid rain), agricultural (eg pesticides) and local (eg quarrying). The environmental impacts are also separated into 3 groups which require separate treatment, ie environmental resources, wildlife conservation and amenity. The overall impact of the complex series of pollutants and their interaction with the environment require simplification through the process of modelling, in order to predict impacts through the county as a whole. A model is therefore proposed using the ITE land classification system, by which the relative importance of the pollutants could be assessed.

1 Introduction

The main purpose behind the paper is to emphasize that a framework is required to enable objective statements to be made, rather than a reliance upon intuitive judgements. An introduction to the Cumbrian environment is given first, followed by a discussion of the pollutants and leading finally to a proposed method for assessing relative impacts.

The counties as they appear on the map of Britain today are the result of a combination of geographical, historical, socioeconomic and, finally, administrative factors. Whilst they are not therefore defined by environmental criteria, they are very widely used for comparative purposes in studies where ecological factors are involved. Many counties contain widely different ecological zones which in some cases are closely interlocked, whereas in others they act as separate systems. Thus, wide lowland valleys in the uplands are integrated with the hill land, whereas in other cases a distinct lowland area has little contact with a mountain district nearby. The use of counties therefore presents an ecologist working on planning problems with some difficulties as, invariably, it is necessary to work with county boundaries because advice needs to be given within administrative units. The heterogeneous nature of many counties does make comparison difficult, but it is essential to place a county in its overall context in general environmental terms, as well as for planners to appreciate regions with similar problems to their own. Finally, the impact of pollutants must be considered within counties because adminiistrative decisions are made at this level.

In order to demonstrate the affinities of Cumbria, an analysis was carried out using data for land use in a similar manner to that described by Bunce (1984). Data were drawn from all the administrative units in Britain, ie counties in England and Wales and regions in Scotland. The analysis first separated the units into 2 main groups – those with predominantly lowland or southern land uses, ie arable and grass, as opposed to those with upland or northern characteristics, ie pasture or moorland. Within the upland series, the units were ranked according to the weightings attached in the computer (Table 1). Cumbria occupies a central position amongst this upland series, but is the most upland county in terms of land use in England and Wales. Thus, its planning patterns have in some respects more in common with Scotland than with the south. At first it was surprising that the Western Isles appeared as a close neighbour but, although the region

Table 1. Relationship between Cumbria and other regional administrative units

North Yorkshire	Units with a relatively high proportion of productive land
West Yorkshire	
Gwynedd	
Northumberland	
Dumfries and Galloway	
Grampian	
Durham	
Powys	
Cumbria	
Western Isles	
Strathclyde	
Shetland	
Tayside	
Borders	
Central	
Highland	Units with a very limited proportion of productive land
Orkney	

is not as mountainous as the Lake District, its northerly situation results in a similar matrix of moorland and productive land.

A feature of all these northern units is their heterogeneity. However, as the above analysis indicates, their affinities may be assessed according to the balance of land uses present within them. It is therefore necessary to examine the more detailed composition of the county. To this end, a variety of statistics are available on crops and broad grassland types from the statistical tables produced by the Ministry of Agriculture, Fisheries and Food (1984). A more detailed breakdown of the grassland aand moorland categories, as well as other ecological information on their distribution, is given by Bunce and Smith (1978). For the present purpose, a useful general survey of the major balance of environments within the county is given in Table 2. The surprising feature is the high proportion of intensively managed land, almost 50% – a figure which is confirmed by comparable MAFF statistics. At the outset of the preparation of this paper, it had been assumed that pollutants associated with intensive agricultural use would be minimal in Cumbria because of its upland nature. However, the above figures do not confirm this assumption, and emphasize the importance of objective assessments.

2 *The pollutants*

The variety and significance of the various pollutants are described elsewhere in the proceedings but, in order to define their overall impact, it is necessary to group them for analytical purposes, as shown in Table 3. General pollutants occur over large areas and therefore need consideration at the broadest possible scale, ie at the scale of a whole kilometre square, as specified below. An essential feature of impact analysis is that even these widespread pollutants need modification by individual site factors. Any system of impact assessment needs a framework whereby both scales can be considered together – the basic reason for the modelling process proposed below. The second group are the agricultural pollutants, which operate at a level involving significant areas, say over 80%, of the kilometre squares. Their separation from the third group of local impacts is arbitrary with, for example, silage being relatively localized whereas sewage, on the contrary, is often more widespread. However, the separation provides a convenient framework for the analysis of systems, and separate impacts need to be specified in any modelling exercise. In addition, there are certain unique point sources of pollution, whose origin is known and which require quite separate studies – as typified by the British Nuclear Fuels plc site at Sellafield.

The Table has been separated into 3 columns because the impact of pollutants is quite separate and the groups are in many cases independent. The environmental category includes renewable resources, such as soil, which may be affected reversibly, or irreversibly, by pollutants. Wildlife needs a separate category, partly on theoretical and partly on aesthetic grounds. Although the 2 aspects are often associated, they may be independent; for example, erosion may lead to loss of agricultural land but may not significantly affect wildlife populations, whether of plants or animals. Amenity invariably concerns visual features

Table 2. Comparison of estimates of principal land uses from the GB and Cumbria survey, the background to which is explained in the text

	GB survey %	Cumbria km^2	Cumbria %
Cultivated	26.6	2399	33.7
Inbye	18.0	1230	17.3
Upland	31.6	2475	34.8
Other	23.7	1008	14.2

Table 3. Separation of pollutants into 3 broad categories and suggested disaggregation of impact areas, with principal coincidences

	Environment (resource)	Wildlife	Amenity
	General (at 1 km^2 level)		
Acid rain	+	+	
Industrial	+	+	+
Specific chemicals	+	+	
Erosion	+		
	Agricultural (forestry)		
Eutrophication (including slurry and fertilizers)	+	+	+
Herbicides	+	+	+
Pesticides	+	+	+
Silage	+	+	+
	Local		
Waste disposal		+	+
Sewage	+	+	+
Quarries			+
Waste reclamation	+		+
Verge spraying	+	+	+
Garden sprays		+	
Litter			+

and is therefore harder to define, often being dependent upon perception. For example, fertilizer bags may have no pollution effect, although they are visually intrusive. Separate impact statements are, therefore, required for each of these categories.

3 A method for impact assessment

Although very detailed information is available about the way pollutants act, as can be seen from the proceedings of this conference, there is no study of Cumbria as a system. The work carried out at the ITE Merlewood Research Station on land classification techniques provides a framework whereby such an assessment can be made. An outline for a possible procedure is given below which could form the basis of future work.

The report by Bunce and Smith (1978) classified all the one kilometre squares in Cumbria into 16 strata, termed land classes, on the basis of environmental data. From these classes, a relatively small number of samples, in this case 48, were drawn as representa-

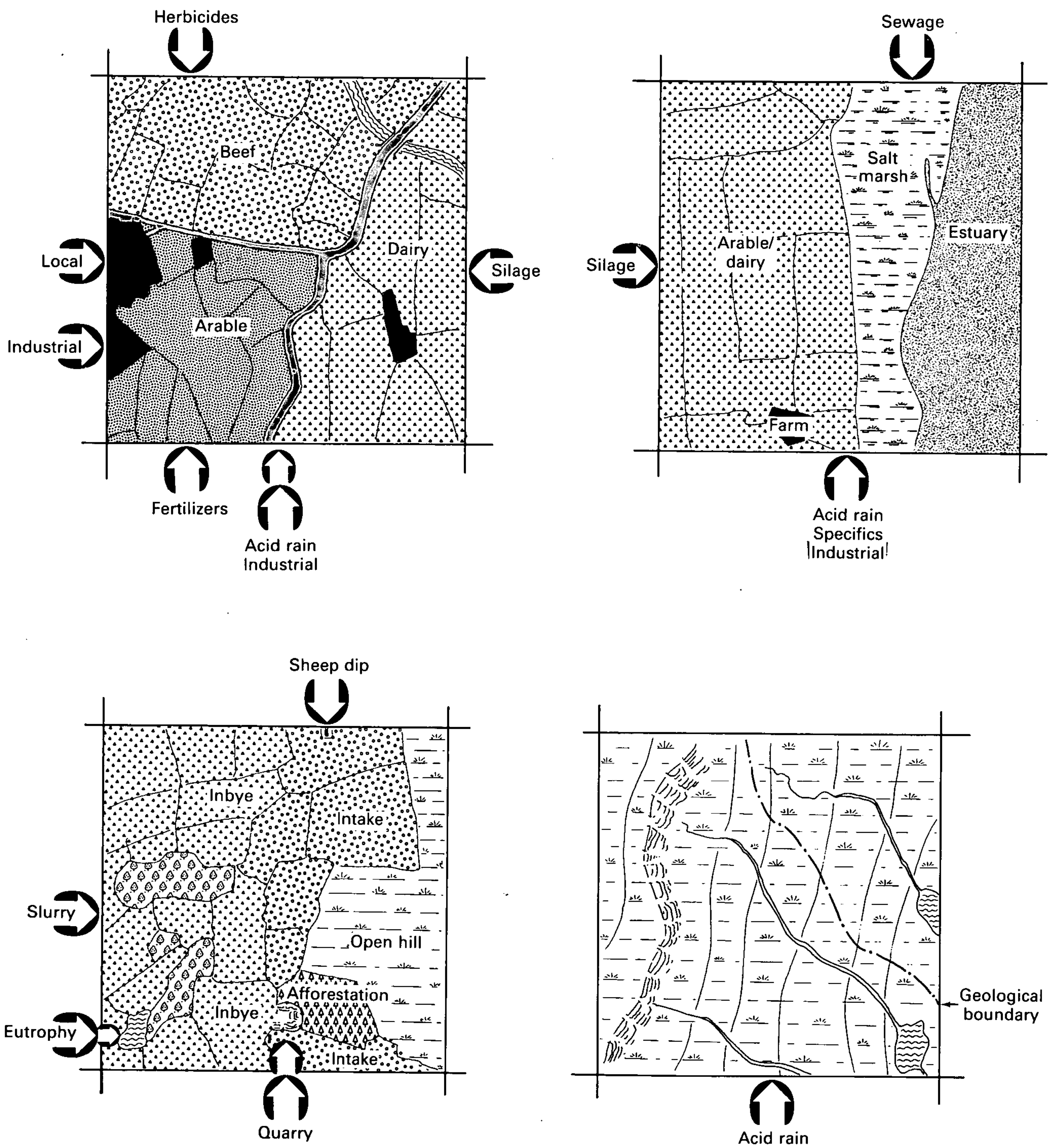

Figure 1. Representative 1 km squares drawn from land classes 1–4, 5–8, 9–12 and 13–16 respectively, demonstrating the contrasts between likely impacts of pollutants in different environments

tive of Cumbria. The survey was primarily concerned with vegetation, and detailed studies were carried out in each of these squares. However, in the subsequent development of the system to Great Britain, interest was extended to land use (Bunce 1984), and the results showed its applicability for data of this type. The further development of the sampling procedure to incorporate estimates of potential land uses in a study of land available for wood energy plantations (Mitchell *et al.* 1983) and subsequent modelling of changes in rural land (Bunce *et al.* 1984) led to a re-examination of the data collected in the Cumbria survey. A rapid exercise was carried out delineating the categories shown in Table 2, and the county predictions were compared with those made from the national data base. The Table shows that the figures are comparable and that the initial series of squares provides a reasonably representative series for the environments of the county – although the accuracy of predictions could be increased by enlarging the number of samples.

The principle of using a sieving technique to progressively identify units of land with defined combinations of criteria could be adopted. Thus, for example, the impact of acid rain on a square might be affected by the distribution of different soil types. An examination of the various pollutants in each of the squares shown in Figure 1 and a consequent estimation of their impact can be made. The estimates for the individual squares can then be combined to obtain mean figures per land class, which can in turn be converted to county figures, as shown by Bunce and Smith (1978). Different parts of the county identified by the land class will have different impacts, as shown in Figure 1.

The use of this approach is important in that high levels of impact may coincide on the same units of land, in which case the effects are dependent. On the other hand, some impacts may occur in different areas, in which case the effects will be compounded to cover a larger area overall. The breakdown of pollutants and areas of impact given above is essential to enable the ecological effects to be partitioned from those concerned with primarily visual changes. The advantages of using the present series of squares is that a considerable amount of information is already available, eg on vegetation, soils and hedgerows, so that repetitive data collection is avoided. Also, a wide range of programmes is already available for manipulating the data and carrying out the modelling process. A further advantage is that co-operating agencies can use the same framework, ensuring that the areas of land concerned are identical. Furthermore, additional data can be added as required. In each case, the impact is identified with an actual area of land, so that field measurements can be incorporated as required. Areas shown as having an intense impact can be studied further, and particularly sensitive areas identified. Many impact assessment studies have shown the importance of varying the initial parameters, so that the sensitivity of the system can be assessed to such changes. Otherwise, there is a risk that the results are dependent on a single variable, which if inadequately measured can alter the whole final assessment.

4 Conclusion

The relative intensity of pollutants varies widely, and their complex spatial interaction with the natural environment means that it is virtually impossible to make intuitive assessments of overall impacts at county level. It is therefore necessary to develop models which, although simplifications of reality, can be used to provide an environmental impact assessment for the county. The accuracy of such models can be increased as finance and the importance of the impact dictate.

5 References

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RADIONUCLIDE POLLUTION

Radioactivity in terrestrial ecosystems

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Summary
The types, sources and possible fate of radionuclides released into the Cumbrian environment are discussed. The difficulties associated with this type of environmental monitoring are outlined, and related to the research programmes currently being undertaken at the ITE Merlewood Research Station.

1 Introduction

The activities of man invariably change our natural environment, often in a physical way, by operations such as building, mining, quarrying, and farming. Materials are added to systems both as a supplement to those present naturally or, in some instances, in the release of entirely new materials and elements. Included in these materials are large amounts of low-grade energy released in the form of heat. To some extent, natural systems have an in-built resilience to the addition of energy and materials, yet at a certain point changes begin to take place which cause concern. It is these effects which the public associate with pollution.

Many pollutants are familiar and have reality: people can smell sulphurous fumes, they know car exhausts are dangerous, sewage is unpleasant to see and smell, pesticides and herbicides are familiar everyday items, even if they do have to be treated with some care. On the other hand, radioactivity is not detectable by the human senses. The general public associate radioactivity strongly with atomic weapons, and, indeed, for many this context was their first introduction to a knowledge of the subject. Often people are totally unaware of the different types of radiation and the intrinsic levels present in the environment due to primordial radionuclides deposited when the earth was formed. For instance, an average person contains about 4.44 kBq (kilobecquerel) of naturally occurring potassium-40 (Eisenbud 1973) and, consequently, is emitting about 475 fairly energetic gamma rays every second. It is known that radiation can induce cancers as well as genetic effects, and there is much doubt concerning the minimum dose needed to cause such effects. Indeed, as stated in the Royal Commission on Environmental Pollution report (1976), it is often assumed that there is no threshold value and the effect of radiation is directly proportional to the dose, down to the lowest doses and dose rates. It is facts such as these, and the lack of everyday knowledge, which create a greater sense of alarm concerning radioactivity than that associated with many other pollutants.

2 Radionuclides in Cumbria

The sources of radiation to which the general public are exposed are summarized by Hughes and Roberts in their 1984 review, published by the National Radiological Protection Board (NRPB). Their diagram (reproduced here as Figure 1) shows the sources of radioactivity to which the members of the general public are exposed. The majority of sources are natural and account for 87% of the total, with a large proportion (11.5%) of the remainder being accounted for by medical exposures.

In Cumbria, we are particularly concerned with the 0.1% accounted for by nuclear discharges. The NRPB point out that liquid discharges from the British Nuclear Fuels plc (BNFL) site at Sellafield contribute a major portion of the population dose attributable to radioactive wastes.

Considering the problem as it applies to Cumbria, when the Windscale works were originally sited on the Cumbrian coast, it was probably assumed that the small amount of radioactive effluent discharged into the Irish Sea would become dispersed and diluted within its basin, and eventually pass out into the ocean. However, this predicted pattern of events has not proved as simple as it first appeared.

Emission takes place from the plant as airborne releases and liquid discharges. Airborne releases take place from the stacks on the site and are essentially ventilation air from the process plant. The main component of these releases is the inert gas krypton-85 which originates as a fission product, other materials being in low to nearly undetectable amounts. By far the largest environmental releases are discharged to the sea as low-level liquid waste from the fuel element storage ponds, the reprocessing plant, the laboratories and the Calder Hall power plant. It is worthwhile considering the materials contained in this effluent as described in the annual report (BNFL 1984) on radioactive discharges for 1983 (Table 1). The effluent contains a mixture of radioactive elements which produce all 3 types of radiation: alpha, beta and gamma. The radioactive elements present, of which 28 are listed, range from those already naturally present in the environment, such as cobalt and zinc, to elements never before existing in nature to any extent, such as plutonium and technetium. The half-lives range from a few weeks to thousands of years.

When this mixture of elements and compounds is

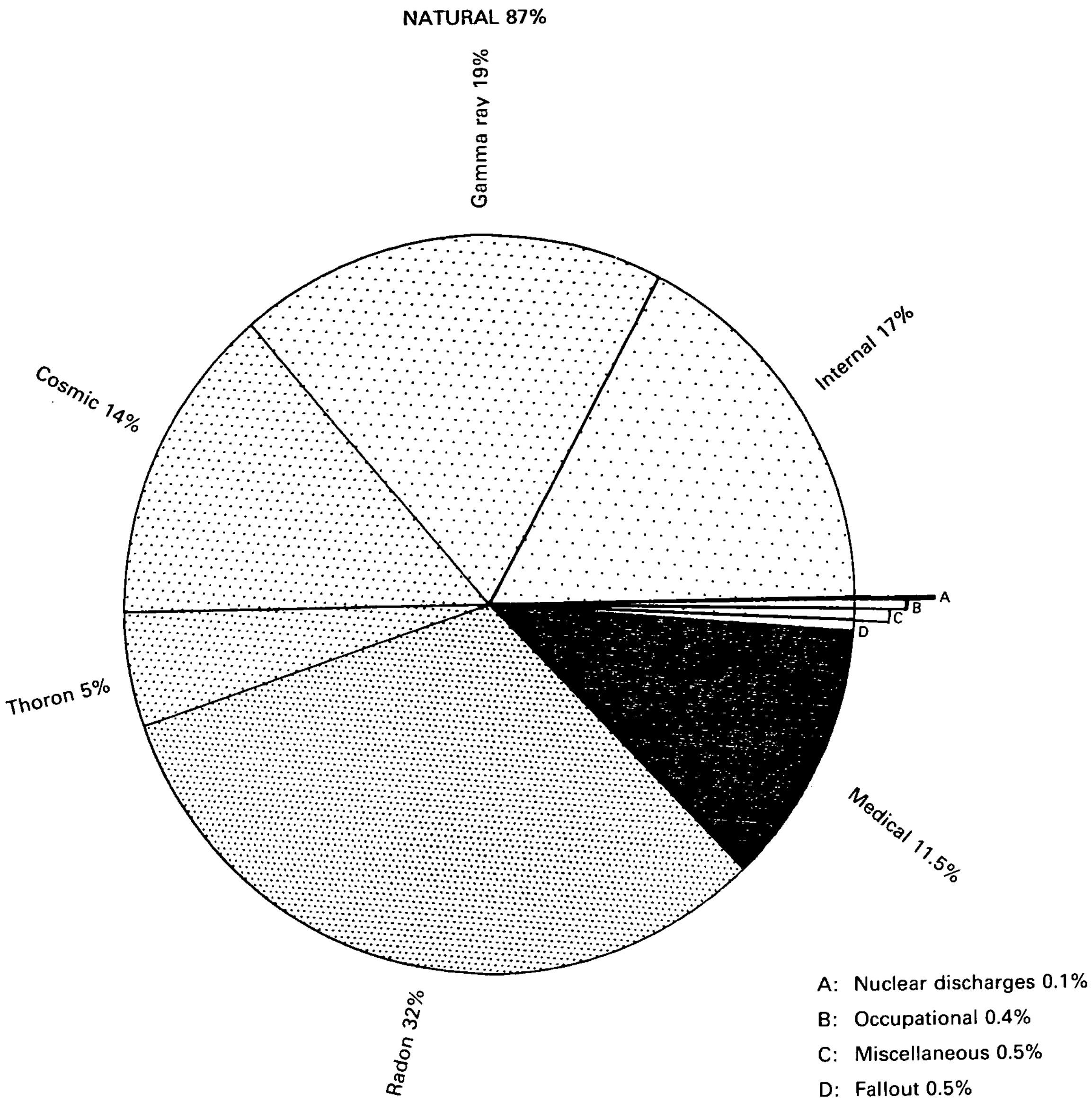

Figure 1. Sources of radiation to which the general public is exposed (source: Hughes & Roberts 1984)

Table 1. Radionuclides discharged by the Sellafield pipeline in 1983

	TB_q		TB_q
Cobalt-6	1.7	Neptunium-237	0.3
Zinc-65	<0.1	Plutonium-238	2.9
Strontium-89	<8.5	Plutonium-239+240	8.7
Zirconium-95	211.4	Americium-241	2.2
Niobium-95	385.1	Curium-242	0.4
Technetium-99	4.4	Curium-243+244	0.1
Ruthenium-103	18.5	Tritium	1831.1
Silver-110	<0.2	Sulphur-35	0.8
Antimony-125	17.6	Manganese-54	<0.2
Caesium-134	89.2	Iron-55	1.1
Caesium-137	1200.2	Nickel-63	1.1
Europium-152	<0.2	Iodine-129	<0.2
Europium-154	<0.5	Promethium-147	24.9
Europium-155	<0.6	Plutonium-241	330.9

released into seawater, a complex set of reactions takes place, which result in the majority of the radioactivity becoming tightly bound to the fine sediments (Hetherington & Jeffries 1974). Offshore of the plant is a large deposit of fine sediments, and recent work has shown that, contrary to original views, these sediments are not being significantly added to by sources such as other sea bed deposits, coastal erosion or material from rivers. Indeed, they are being extensively stirred up and reworked both mechanically and by animal life. The deposits are, in fact, serving as sources of material for deposition in the estuaries of the Irish Sea, such as at Ravenglass, the Solway and Morecambe Bay. Radioactivity is thus being concentrated and returned landwards.

A second pathway (Cambray & Eakins 1980) is indicated by the fact that plutonium of Windscale origin can be detected up to 10 km inland from the coast. It is postulated that, in a very thin micro-layer on the sea surface, radioactive substances are being concentrated and later released by the bursting of bubbles to form aerosols which can be carried inland by the prevailing winds.

Thus, instead of an elimination of radionuclides into the sea, we have mechanisms which are returning these substances to the land, sometimes concentrating them in environmental materials. The purpose of the work carried out at Merlewood is to study the fate of these radionuclides when returned to the land. We need to know how these substances behave when they enter the terrestrial system, the factors that control their movement, any possible accumulation points in the system, and, of course, the quantities which find their way back to man, both in his food and his surroundings.

3 Radionuclide research at ITE Merlewood Research Station

I would like to outline briefly the problems the ecologist faces when trying to understand the processes involved in radionuclide transfer, and mention specifically some of the work in progress at Merlewood on Cumbrian systems.

There are many schemes representing the movement of radioactivity in ecosystems. A typical one is illustrated in Figure 2. The first problem is that of defining the source, which is a combination of natural, industrial emissions and bomb-test fallout. It is comprised of aerosols both dry deposited and washed out by rain, solid particles moved by wind and mechanical means, and gases diffusing through and being blown by the atmosphere. As a first stage, we need to know a great deal concerning the chemical and physical form of these inputs and the manner in which they interact with the many types of surfaces on which they impinge.

In the simplest of models, we can have a source, some form of resistance pathway and a destination. In general, a progressive dilution takes place as one passes along the chain. However, when biological factors are taken into account, this simple picture no longer holds. Well-illustrated examples exist, such as the series of reactions which convert inorganic lead compounds into biologically active methyl-lead in the environment and the progressive build-up of the radionuclide technetium in the trunks of forest ecosystems. The dilution effect may be reversed particularly when elements or compounds are essential to biological growth, and concentration in parts of the ecosystem can result. Deposition in particular tissues may take place, a classic example being the build-up of organochlorine pesticides in fatty tissue.

Returning to our ecosystem model, we then have to consider the complications introduced by multiple pathways. For instance, materials may enter a plant either directly by way of deposition and absorption through the leaf surface, or they may be deposited on the soil surface, pass through the soil system, be

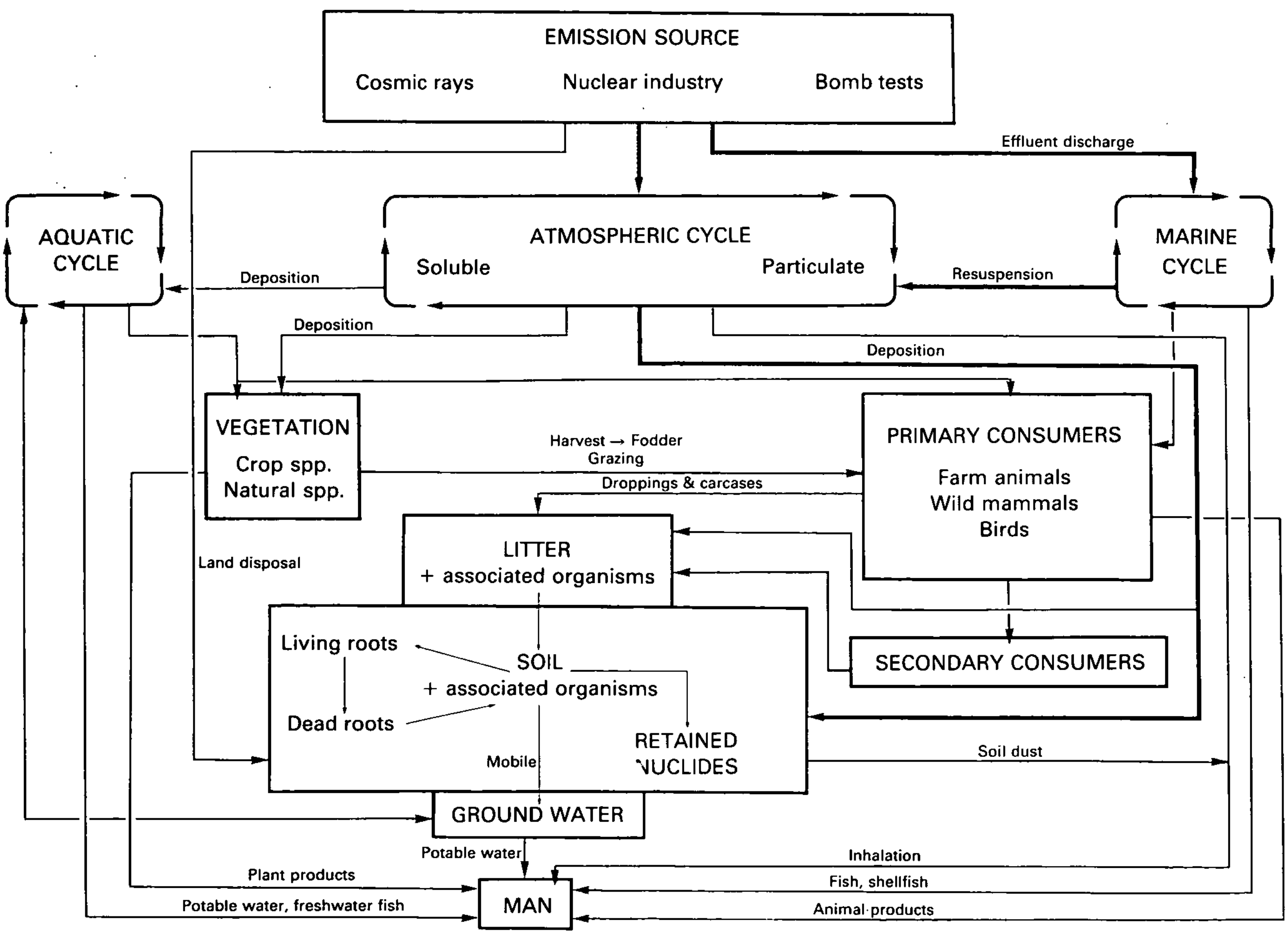

Figure 2. Diagram showing the pathways of radionuclides through the terrestrial environment, from source to man. The thicker lines denote the major routes

captured by the roots, and hence pass into the leaves. In any investigation, we have to be aware of the multiple pathways which exist in ecosystems. There is also the consideration of the different levels within any system, eg the series of food chains leading from the simplest unicellular biota via higher plants and animals to man. There would seem to be 2 possible ways in which these chains could operate. In the classic case of pesticides, there is a progressive build-up through the food chain to the top carnivores, such as the birds of prey. Alternatively, when the concentration factor is less than one, a progressive dilution of the pollutant takes place, particularly if it is a non-essential component of the diet.

A final complication encountered when undertaking studies in the natural environment is the inherent variability found in the systems and in the individuals. This variability is often combined with spatial and temporal fluctuations on both a large and small scale. Despite many attempts, it is not possible to classify biological systems and individuals into distinct units. The biologist has to accept that systems (and in many cases species) intergrade, and sharp boundaries do not exist. As a result, the ecologist has to take many samples in order to obtain reliable figures, and answers are often presented with large degrees of uncertainty, or as probability figures. These results never satisfy the man in the street, as he wants a simple yes/no answer every time.

I would finally like to outline the work programme at Merlewood. We have obviously had to select components of the terrestrial environment for study, and our work can be divided into 5 subject areas: the distribution of radionuclides in saltmarshes; the ingestion of radionuclides by sheep; the role of estuarine birds in the inland transfer of radionuclides; the dynamics of radionuclides in natural and agricultural systems; and plant uptake of radionuclides.

3.1 Distribution of radionuclides in saltmarshes

The saltmarshes and estuarine areas contain by far the largest deposits of radioactive materials and, indeed, these areas must in some respects be regarded as a secondary source of transfer to the inland systems. Concentrations of radionuclides fall dramatically at the tideline over a very short distance (*c*10 metres). For instance, in the Ravenglass area, concentrations of caesium-137 fall from an average of 16 798 Bq kg^{-1} in the surface silts of ungrazed saltmarsh to 40.0 Bq kg^{-1} in the pasture fields immediately behind. These values compare with a range obtained from control sites, such as the Humber and Portsmouth areas, of between 2 and 35 Bq kg^{-1}. The National Radiological Protection Board quote a Generalised Derived Limit (GDL) for soil of 3000 Bq kg^{-1}. It can be seen that, once the tidal limit is reached, levels of contamination are in the order of 1% of the GDL for that element. The deposition of radionuclides in saltmarshes can be related both to tidal immersion, half-life and the form of any vegetation present. In general, short half-life radionuclides such as niobium (35 days) and zirconium (65 days) show a simple deposition pattern related to the amount of tidal immersion. Long-lived material such as americium-241 (458 years) develop complex deposition patterns related to tides, vegetation density and vegetation form (Horrill 1983). For instance, under a bushy shrub of sea-purslane (*Halimione portulacoides*), over 5 times the concentration of americium-241 was found compared with the open mudflats, due to the trapping of particles by the plant.

3.2 Ingestion of radionuclides by sheep

Sheep are a common grazing animal in Cumbria both on the coastal plain and on the high fells. It is therefore appropriate to undertake studies on uptake by these animals. It became apparent during the studies how important the behaviour of the animals and the management practices of the farmer were in determining uptake, and also how seasonal fluctuations in radionuclide levels have to be taken into account. The biological half-life of caesium-137 in an animal is less than one month (Coughtrey & Thorne 1983), and sampling must be carefully matched with periods of food intake, if accurate transfer factors are to be calculated. The mean value for fresh muscle tissue for 3 animals from the coast was 42 Bq kg^{-1} of caesium-137, with a corresponding value for their 3 lambs, in September, of 71 Bq kg^{-1}. These values compare with a GDL for mutton and lamb of 10 000 Bq kg^{-1}. The higher concentration in the young animals is of interest, and further work is in progress to see if this is due either to the mother's milk being a readily absorbable source of caesium or to the young animal being a more efficient accumulator of radionuclides.

3.3 Estuarine birds and radionuclide transfer

If the estuarine areas are regarded as large reservoirs of radionuclides, then the possibility exists that coastal bird populations may act as vectors carrying radionuclides. A secondary interest is the fluctuation in numbers and breeding failures of the bird populations. It has been suggested, totally without evidence, that radionuclides may be the cause of these effects. Merlewood studies are therefore designed to answer these questions. Analyses of many samples of faeces and the tissues of the birds themselves have been carried out, and a joint study on behaviour is in progress with Durham University. Indeed, radionuclides are detectable in the faeces of birds feeding in the estuary, and reflect the place and feeding habits of the bird species. However, only 3 species (black-headed gull (*Larus ridibundus*), greylag goose (*Anser anser*) and starling (*Sturnus vulgaris*)) move from estuary to land to any extent, and the small number of birds and the low concentrations in the faeces indicate that amounts carried inland are very low indeed.

In the breast muscle of the birds, only the 2 isotopes of caesium (^{134}Cs and ^{137}Cs) were detectable and the concentrations were in the order of 70–110 Bq kg^{-1}

fresh weight, with an extreme range of 10–600 Bq kg^{-1} fresh weight. Very little activity, if any, was found in eggs from the Drigg Nature Reserve, less than 1 Bq kg^{-1} of caesium-137 being present in gull eggs, whilst crow eggs from the Eskmeals areas were lower than our limits of detection.

It is difficult to compare these sites with other areas at the moment, but studies in the USA have shown that waterfowl on disposal ponds can have up to 27 000 Bq kg^{-1} fresh weight of caesium-137 in their tissue with no apparent ill effects (Halford *et al.* 1981), whilst the GDL for eggs and chickens are 4000 and 10 000 Bq kg^{-1} respectively.

3.4 Radionuclides in natural and agricultural systems and plant uptake

Studies of radionuclides in natural and agricultural systems and on their uptake by plants can be conveniently brought together. The work aims to investigate the manner in which radionuclides pass through the terrestrial systems, to see if there are any accumulation points and to determine the driving and controlling mechanisms. This is a longer-term project and obviously depends greatly on the goodwill of landowners and farmers in permitting us access to their land. We are sampling a wide range of soils, vegetation and farm crops, as well as obtaining information on farming practices and management.

Initial results indicate that low levels of radionuclides are detectable in the inland systems, and we are concentrating our work on caesium-137 and the plutonium isotopes. Figure 3 shows some initial results for barley samples taken at increasing distances from the Sellafield plant ranging from 0.5 km to 14 km. Caesium-137 concentrations range from 44 Bq kg^{-1} dry weight to just above the level of detection of 0.26 Bq kg^{-1}; the GDL for grain is 1000 Bq kg^{-1}.

I would like to discuss one problem which has emerged from this work, ie soil contamination. The soil is the greatest reservoir of radionuclides. Movement through many soils is slow and the radionuclides accumulated over many years are still in the upper few inches of the profile. This material is resuspended by wind, rain and animals, and tests have shown that much of the radioactivity recorded is stuck to the

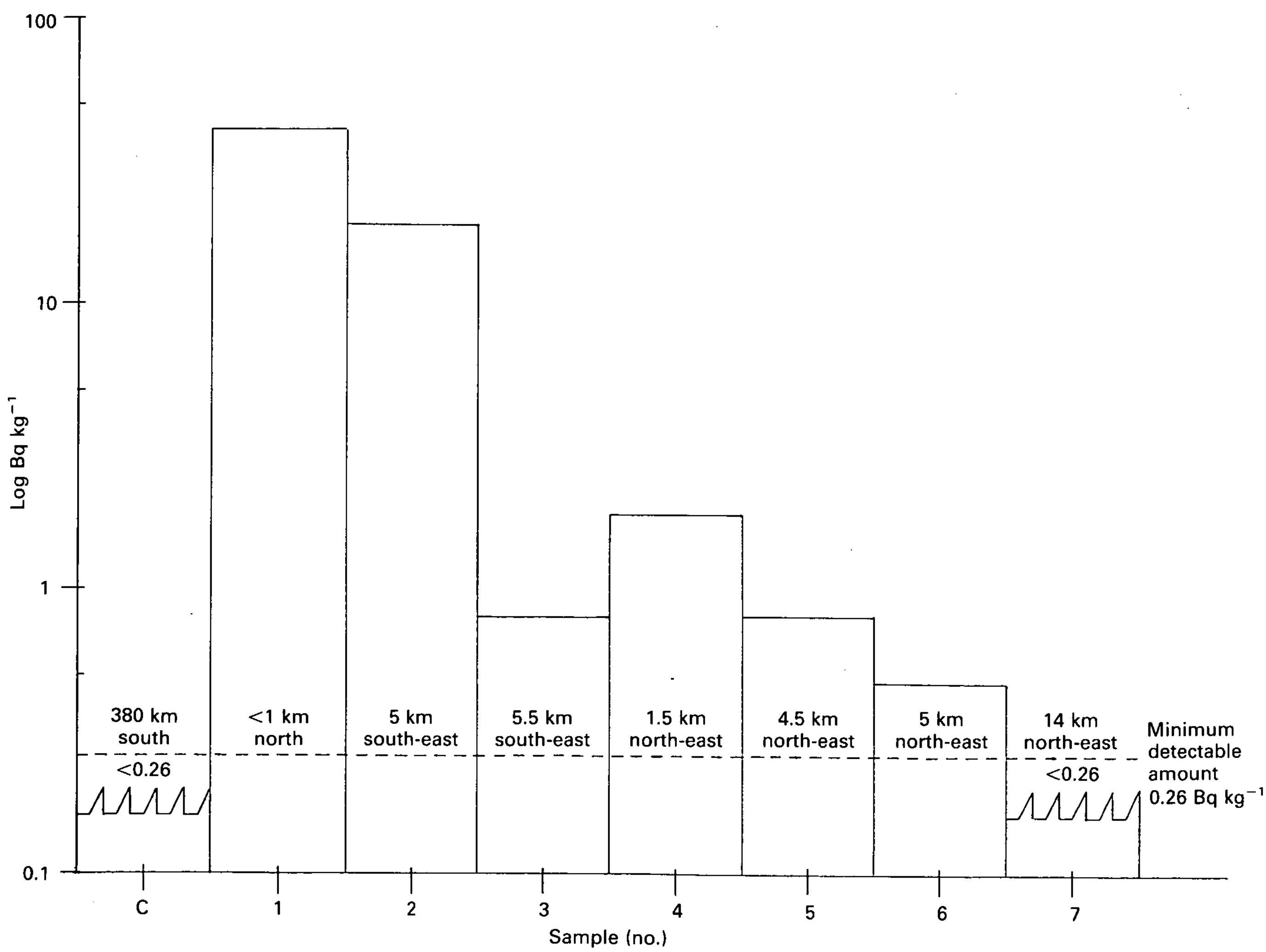

Figure 3. The levels of caesium-137 found in barley grown at varying distances from the Sellafield works. Sample C was a control taken from Taunton, Somerset

outside rather than within the plants. I suspect the same is true for barley, due to dust thrown up by the combine harvester.

We therefore need to know a lot more concerning the uptake by plant roots, in order that we can partition plant contamination into internal and external components. The internal component will be much more available for uptake by animals and man. We also need to know how the soil reservoir responds to environmental and man-made change, in case radionuclide materials fixed in the soil become remobilized and pass either into plants or to water systems.

To summarize, our research programme is designed to look at the fate of radionuclides entering sections of the environment. This information is needed both to identify and quantify the main radionuclide transfer routes to man, and will also help identify key points in the terrestrial system of Cumbria in case of accidental release.

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Radionuclides in Cumbria: environmental issues in the international context

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Summary
Radioactive pollution from the British Nuclear Fuels plc (BNFL) site at Sellafield (Windscale) has attracted concern within the scientific community internationally, but response from British scientists working in the field has been more muted. The responsible UK authorities have claimed that foreign conditions are not comparable and that, in radiological protection terms, the level of concern is not justified. This claim is examined in the light of international experience of reprocessing technology and accepted principles of radiological protection. It is concluded that there is no basis for the UK claim to special conditions and that the Cumbrian situation, unique as it is, reflects policy choices first made in the 1950s and continually reaffirmed in the face of mounting international criticism. The environmental issues are considered with regard to the health implications for Cumbrians, and broader perspectives in the quality of life.

1 Introduction

In 1955, at the UN Conference on 'Peaceful uses of nuclear energy', the international scientific community were first informed of a 'deliberate experiment' in Cumbria, which had taken the form of discharges of radioactive liquid effluent by pipeline into the Irish Sea (Dunster 1956). These experimental discharges were intended to elucidate the fate in the environment of a cocktail of radioisotopes with widely differing chemistries. Elsewhere, in nuclear weapon states which were also developing reprocessing plant for the large-scale production of plutonium (specifically the USA, USSR and France), a more cautious approach prevailed, namely to develop plant which would utilize maximal effluent treatment. Although this contrast of approaches must have been known to scientists involved in the UK nuclear programme, it was not widely discussed until the present controversy over discharges, with its international implications. This paper examines the development of concern for the environment in relation to the science and the politics of the developing controversy. Its aim is to place the response of the UK regulatory authorities in the broader context of international environmental standards, and to address the question of risk to the local population in Cumbria.

2 The historical context of plant development and discharges to the marine environment

Reprocessing began on a small scale in the early 1950s with the uranium from 2 plutonium piles on-site. It increased in scale to accommodate both the military and civil energy programmes, and new plant was built in 1964. Discharges increased steadily in this period, but it was the early 1970s which saw the largest increases in the 2 categories: alpha emitters (eg isotopes of plutonium and americium, also known as actinides), and beta–gamma emitters (caesium-137 is an important example). The actinide discharges arose from treatment of accumulated wastes from the military operations, and the caesium was largely due to the failure to foresee hold-ups in pond storage of Magnox fuel, which corrodes rapidly, and the consequent lack of adequate pondwater treatment systems.

Details of these discharges, their radioecology and the controversy surrounding their effects have been documented elsewhere (Hunt & Jefferies 1980; Stott & Taylor 1980; Taylor 1982). Serious concern within the scientific community about environmental effects first arose in 1975, when V T Bowen, a leading marine geochemist based at Woods Hole Oceanographic Institute, and a specialist in the radioecology of fallout plutonium, warned the UK government of potential problems from the uniquely high levels of discharge. The controversy heightened at the Windscale Inquiry in 1977, when Prof E P Radford, a senior specialist in radiation epidemiology and Chairman of the US Academy of Sciences Committee on the Biological Effects of Ionising Radiation (BEIR Committee), voiced his concern for the residents of the Ravenglass estuary and coastal region where plutonium levels were enhanced. (See Stott & Taylor (1980) for a summary of Radford's evidence to the Public Inquiry.)

3 The development of discharge policy in relation to environmental science

The patterns of discharges can be seen in Figures 1 and 2 for both alpha and beta–gamma emitters. The major contribution from americium-241, plutonium isotopes and caesium-137 is highlighted. The full range of nuclides is not considered here, as caesium and the actinides serve to illustrate the relation of radioecology to discharge policy. Caesium and plutonium/americium represent 2 ends of a spectrum in terms of behaviour in the environment: caesium behaves conservatively in seawater, concentrates in biota, is evenly distributed in tissues and emits a penetrating radiation. As a consequence of these properties, its behaviour in the environment is reasonably predictable and is largely determined by currents and mixing properties of the surrounding seas. Moreover, with a half-life of 30 years (it will all but disappear in 300 years), it will not be subject to long-term bio- or geochemical cycles. In contrast, americium and plutonium behave quite differently in the marine environment: they are in the main removed rapidly from the water column and bound to sediments, and thus are not immediately concentrated in human food chains; they are alpha emitters, a short-range radiation that can only cause biological damage if incorporated either by ingestion or inhalation (plutonium-241 is a beta emitter, but decays with a half-life of 14 years to americium-241). However, the actinides do have long half-lives (plutonium-239 is an extreme at 24 000 years), and may thus be subjected to long-term biological and geochemical cycles.

The discharge profiles are dominated by caesium-137 and americium-241 peaking in the early 1970s. The former results from inadvertent errors rather than conscious decisions, as admitted at the Inquiry in 1977 by BNFL in the face of sharp criticism from the Isle of Man Local Government Board and Cumbrian fisheries organizations. At that time, a commitment was made to reduce the discharges, and this reduction is evident from the graphs. However, as will be seen from the map in Figure 3, the caesium-137 has dispersed widely and is readily measurable as far afield as Greenland and Scandinavia. This dispersal has given rise to a low-level contamination of fish stocks throughout the Irish and North Seas, and has drawn strong objections from the Nordic Council of Environment Ministers and the Irish government. Following representations on behalf of Greenpeace, the Paris Commission (a regional convention on land-based discharges) requested the UK to adopt more stringent discharge

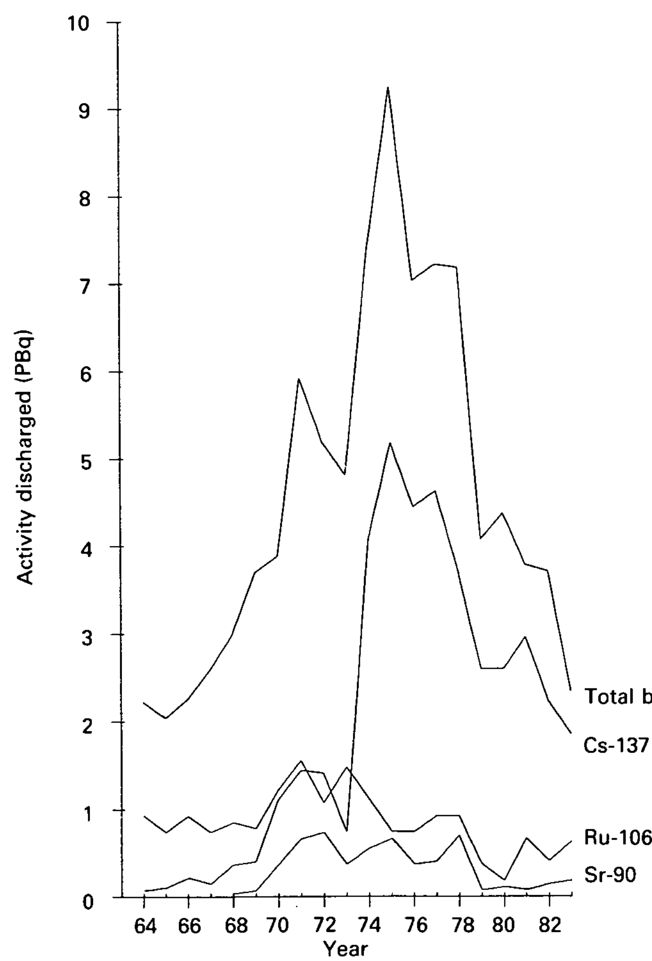

Figure 1. The annual discharge of selected beta and gamma emitters from Windscale, 1964–83

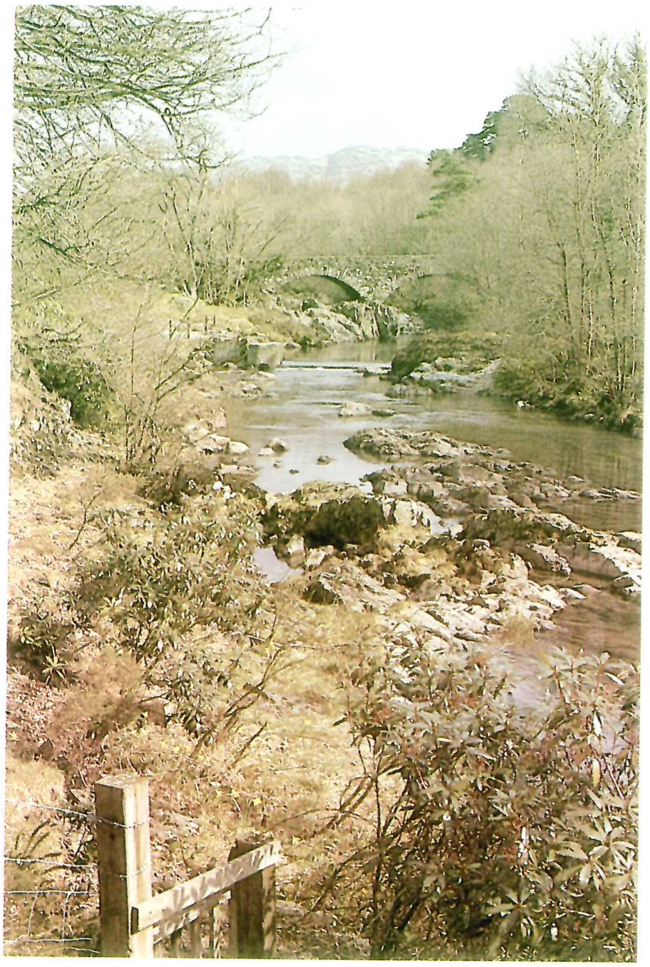

Plate 5. A fish counter at Duddon Hall, where the North West Water Authority is studying the links between fish deaths and river acidity (Photograph D H Crawshaw)

Plate 6. Power stations are a major source of the oxides of sulphur and nitrogen. As well as being air pollutants in their own right, these gases are the precursors of acid rain (Photograph P Ineson)

Plate 7. Loading a muck spreader with broiler waste for land spreading (Photograph D A Joyce)

Plate 8. Good quality landfill sites for the disposal of domestic waste are in short supply in Cumbria (Photograph P Ineson)

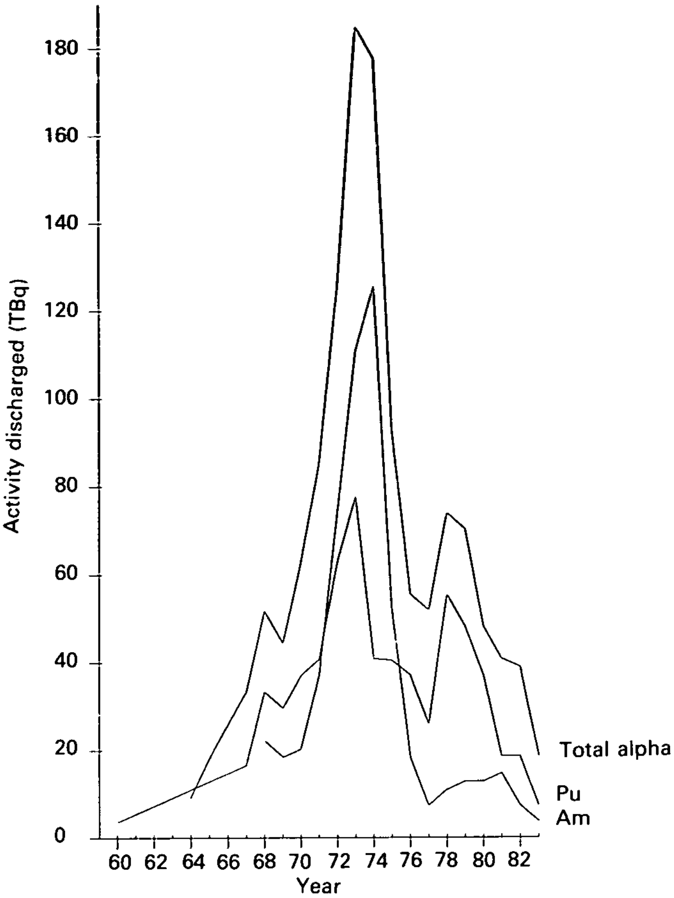

Figure 2. The annual discharge of alpha emitters from Windscale, 1960–83
Pu: plutonium-238, -239, -240
Am: americium-241, not including decay from Pu-241

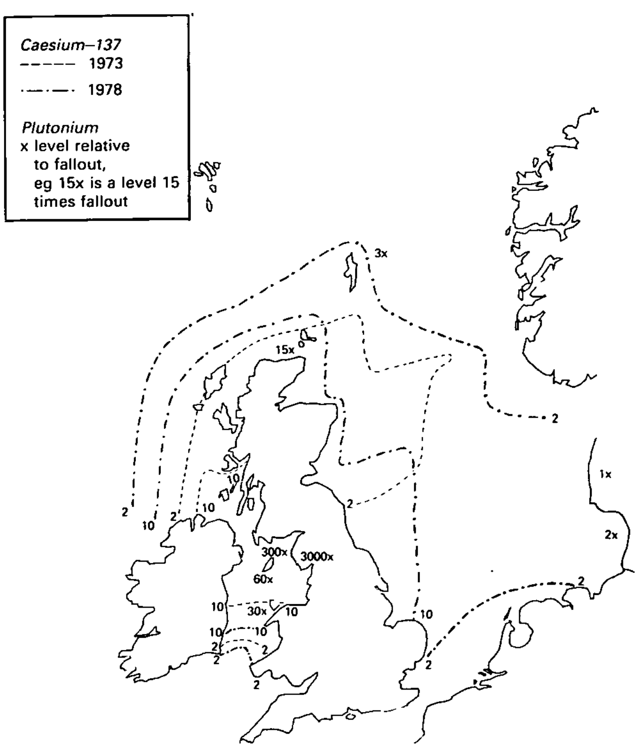

Figure 3. The spread of caesium-137 (pCi l^{-1}), 1973–78, and of plutonium levels relative to fallout (1975)

controls (Taylor 1983, 1984). In the latter case, the collective health detriment was a key factor in the Greenpeace submission, and is dealt with more fully below.

In the case of the actinides, discharges are the result of conscious management decisions and reflect the UK doctrine on environmental quality standards, rather than emission controls as practised elsewhere in the European Communities. Substances known to be toxic can be discharged if it is thought that the environment will disperse or isolate them in such a way that a hazard to human health, or the environment, is avoided. In the case of radioactivity, regulatory practice is strongly influenced by a dose-effect model that has some degree of international acceptance (even staunch critics are only arguing about an order of magnitude uncertainty), together with a supposed 'acceptable' dose limit formerly often presented as a 'safe' limit. In its simplest form, this would mean 'no dose, no effect' and thus, unless alpha emitters are ingested or inhaled, their presence in the environment would not be a hazard to man. There are no internationally recognized standards for damage to marine biota, and it is assumed that lethal effects would be localized and hidden by replacement from adjacent areas. As noted, the actinides are rapidly bound to sediment, and this characteristic led the authorities to promulgate a Limiting Environmental Capacity (LEC) based upon models of marine food chains to man and the dose limit recommended by the International Commission for Radiological Protection (ICRP). The Ministry of Agriculture, Fisheries and Food (MAFF) first calculated an LEC of 2664 TBq yr^{-1} discharge (which would approach the dose limit) and duly authorized 148 TBq yr^{-1} of total alpha discharge to provide a suitable safety factor. This figure was revised in 1970 to 222 TBq yr^{-1} to allow certain accumulated wastes from military operations to be discharged. The majority of this activity is held by offshore sediment, but 5% of the plutonium is in a mobile state due to valency differences, and disperses along with the caesium-137. This dispersal is mapped in Figure 3, which shows the concentrations in relation to fallout from weapons tests. As can be seen, in the context of that background, plutonium levels are significantly enhanced as far afield as Denmark, and, considering the public disquiet that resulted from weapons fallout, it is not surprising that this dispersal has also caused strong reaction from foreign governments.

Elsewhere, operators were more circumspect with regard to the actinides: the USA and USSR adopted an effectively 'zero' discharge policy, and the first French reprocessing plant built at Marcoule (in the 1950s) discharged only 0.2 TBq between 1967 and 1978, whilst processing over 10 000 tonnes of Magnox fuel for military purposes, making it directly comparable with Windscale/Sellafield. The plant at Cap de la Hague, across the Channel, although discharging more beta–gamma than Marcoule or US plant, making use of marine dispersal, nevertheless kept actinide discharges to under 2.2 TBq in 10 years, compared to Windscale's 925 TBq in the same period.

It should thus be clear that, by the time of the Windscale Inquiry in 1977, certain overseas plant had established virtual zero discharge to the marine environment of actinides and most longer-lived beta–gamma emitters, such as caesium-137 and strontium-90. However, operating data from US and USSR plant, and Marcoule were not available to the Inquiry. Intended West German and Japanese discharge targets for similar-scale plant were available, showing, again, the availability of virtual zero control at no apparent extra cost (targets for actinides were expressed in megabecquerels). Evidence on discharge control technology, its availability and cost has accumulated slowly, and often through the research of the Political Ecology Research Group. The first indications were presented to the Windscale Inquiry in 1977, to the Radioactive Waste Management Advisory Committee in 1982, and finally in some detail to the Paris Commission in 1984 (Taylor 1982, 1984). This research has demonstrated that:

i. the technology for virtual zero discharge existed at the time of the Magnox II (1964) design and probably before that;
ii. the technology did not add significantly to the capital cost, if incorporated at the design stage;
iii. the technology was available to BNFL almost certainly in the 1960s, and certainly before the design of THORP via United Reprocessors (Germany/France/UK companies).

Thus, the contention often made that Windscale discharges were due to out-dated technology does not survive scrutiny. As far as the actinides are concerned, the marine discharges were the result of management decisions to discharge these substances, with a full knowledge of their biological toxicity (established by animal experiments where kilobecquerel body burdens were leading to fatal bone tumours in dogs), and persistence in the environment.

4 The regulatory context

As noted above, the rationale for these discharges, which would clearly lead to some exposure via food chains (predictably for caesium-137), was based upon a supposed 'acceptable' limit. In the 1950s, this limit had been defined as an upper limit of 5 mSv, or more than 100% natural background. The wording of the regulations changed with time, coming to emphasize this limit as the lower line of totally unacceptable doses. Below this limit, doses were not necessarily acceptable, and were subjected to the As Low As Reasonably Achievable (ALARA) principle, taking into account economic and social factors. No clear guidance for practical implementation was given by the ICRP. The promulgation of dose standards by ICRP, based upon a risk factor of 10^{-2} per Sievert, was not without criticism (Wynne 1978; Radford 1981). ICRP is a self-selected body, drawn from the Congress of Radiologists, and Wynne (1978) contrasted ICRP's compounding of social and economic judgement with the US practice of separating scientific risk estimates (National Academy of Sciences 1980) from regulatory limits (US Environmental Protection Agency).

Whereas ICRP has found more or less international acceptance for its limit for workers in the industry, its relevance to public exposure has been questioned. In most of Europe, the upper limits for public exposure are defined at between 0.3–0.6 mSv yr^{-1} (Scandinavia, Germany, Holland), in the USA at 0.25 mSv and Japan 0.05–0.25 mSv, depending upon the installation. Wynne (1978) has noted the UK's reluctance to redefine ICRP standards, and commented upon the preponderance of former Windscale safety managers on the ICRP committees, as well as on UK government advisory (National Radiological Protection Board) and regulatory (Health and Safety Executive) agencies. In defence, the UK authorities argue that they do require BNFL to exercise ALARA, with a target of 10% of the ICRP limit, and that this flexible arrangement is equivalent to the more definitive standards elsewhere.

Indeed, the UK authorities have insisted that, of ICRP's recommendations, the ALARA takes precedence over the upper dose limit. This contention can be examined by perusal of plant performance elsewhere, not only with respect to effluent control, but also exposure of surrounding populations. US data show individual exposures of less than 0.01 mSv via ingestion (riverine ecosystems), and projected West German data have similar targets. Evidence by UK experts to the Norwegian Royal Commission in 1978 (Norges Offentlige Utredninger 1978) showed that 0.14 mSv yr^{-1} was a reasonable target.

These figures refer to maximally exposed individuals. In the environs of Windscale, such exposures have averaged 1.3 mSv yr^{-1} over the past 10 years, and ranged up to over 3 mSv. However, if ALARA is the most restrictive rule, then the collective dose rather than the individual dose is the criterion for assessment. This figure is the sum of all the small doses and is usually calculated from the average dose to individuals for each region affected, however small that dose may be. In most cases, it will be 1/100–1/1000th of background levels or less, and individual risk is obviously exceedingly low. Nevertheless, collective dose is not seen as an objective measure of human detriment as, for example, can be calculated in terms of cancer or genetic defects by applying the known risk factors. Rather, it is a measure for comparing options and optimizing control. To this end, monetary values have been placed on the doses, and range from £50 per person-rem (1 rem = 0.01 Sv) (MAFF) to $1,000 (US EPA), with NRPB having suggested a sliding scale and a cut-off at very low doses. How far, then, has the UK applied ALARA, taking account of the social and economic factors?

It is clear from Figure 3 that Windscale contamination has reached international waters and can be measured over a wide area in seafood catches. If one applies risk factors to the man-rem doses, then future health impacts are to be expected: 20–150 fatalities throughout northern Europe over several generations (Taylor 1982). In the US, all Environmental Impact Statements express these future impacts in terms of cancers/severe genetic defects over a time period, whereas in the UK the impact is simply expressed in man-sieverts. If US EPA costings were adopted, then approximately $300 million of health detriment would be accounted, about half outside the UK.

In this respect, we may compare the 1978 ingestion doses from Marcoule in 1978 at 19 person-rems with that of Windscale in 1978 at 38 000 (see Table 1).

Table 1. Comparisons of Windscale with other reprocessing plants

	Liquid discharges (Ci) alpha	Liquid discharges (Ci) beta–gamma	Maximum annual dose off-site (mrem yr^{-1})
Hanford, USA			
1972	4	500	0.5
1975	0.13	5	0.5
1981	'0'	'0'	'0'
Marcoule			
1967–78	0.4		—
West Germany			
Project	0.4	0.4	0.5
Windscale			
1970s maximum	4 800	250 000	350

1978 Total collective dose from liquid pathways at all OECD nuclear stations

Units: Person-rem (1 rem = 0.01 Sv)

Windscale	38 000
The rest	7 000
Cap de la Hague	44
Marcoule	19

The 3 dates for Hanford refer respectively to (i) the last year of operation, 1972; (ii) estimates for restart of the old plant modified after EPA rulings on effluent control; (iii) projected new plant, Environmental Impact Statement

It would appear that BNFL and the UK authorities have only considered the social and economic factors pertaining to the Windscale workforce and local economy when considering optimization, and at no point have they considered the ready availability of alternative plant (although they are now committed to such consideration with respect to THORP). No studies of the social and economic impact of the widespread contamination have been carried out, although it is evident that this impact may have been significant following the alarm at the 1983 releases. The UK authorities have readily agreed that factors which cannot be quantified, relating to aesthetic perceptions of environmental quality, as well as the public aversion to radioactive contamination irrespective of dose level, should be considered in discharge authorizations, but no clear procedure for doing so has been developed.

5 Potential health hazards, present and future

The widespread dispersal of the contamination necessarily reduces the individual risk, and this factor has been used as a defence in response to public alarm. Even at the relatively high doses prevailing locally in Cumbria, where a few tens of people (mostly shellfish consumers) receive a 100% increase over background, no statistically observable health effects would be expected. To gain a perspective, if the population of south-west Cumbria were all exposed to the ICRP limit of 5 mSv each year for a lifetime (70 years), at equilibrium the excess cancer incidence would reach 2% or 6 extra cases on the 300-or-so annual expectation. Leukaemia and bone cancer deaths would be expected to show a 15% excess (National Academy of Sciences 1980). Between 1975 and 1978, cancer deaths varied from 262 to 339 per year and leukaemias between 3 and 8. Clearly, even at these levels of exposure, it would require decades of data and careful analysis to demonstrate any effect.

As a result of the Yorkshire TV inquiries (prompted by PERG's earlier warnings relating to general practitioners' records), it is now known that a 10-fold excess of childhood leukaemias occurs close to the plant, and a 5-fold excess in some coastal communities. These figures were confirmed by the Independent Advisory Group (1984), but were not, so far as environmental science and radiobiology can ascertain, attributable to the discharges from Windscale. In NRPB's assessment for the Black Inquiry, it was estimated that if, pessimistically, all normal leukaemia incidence was caused by background radiation, then doses would have to have been 40 times higher than they are computed to have been. The Group did not rule out undocumented releases or exposure pathways, and, although they appear unlikely, it recommended that more work be done on the exposure levels during infancy.

The 40-times safety factor may not be all that it seems. It is quite possible that background leukaemia levels may be caused by natural alpha emitters in bone rather than penetrating radiation. In this case, it becomes relevant to establish the percentage increase over such natural levels that could occur, particularly in the foetus or infant.

With regard to the present excess of childhood leukaemias, the marine plutonium is not a prime candidate, partly because its return to the coastal environment is relatively recent, and the excess deaths occur over a 30-year period. However, 40% of the dead children were either *in-utero* or suckling at the time of the 1957 fire, when, as disclosed only in

1983, significant quantities of the alpha emitter polonium-210 were released to the atmosphere. The radiobiology of this substance is relatively poorly known. With regard to the 1957 fire, our own work (Taylor 1981), later confirmed by NRPB (Crick & Linsley 1983) and extended by Urquhart (1983), showed that thyroid cancers would be expected over a wide area but at statistically undetectable levels (see Figure 4).

With regard to future hazards, there are, in our view, 2 major sources, each surrounded by uncertainty. One relates to the potential for a major atmospheric release as a result of fire or loss of coolant to various installations on-site. The 1957 fire serves as a reminder of the trans-national implications of atmospheric as well as marine discharges. There is not space to report the lengthy debate on hazard potential and consequences. The Parker Inquiry chose not to present all of the data to the public for fear of 'unnecessary' alarm, having been assured by BNFL that the risk of such a major release was negligibly small due to the very high standard of safety in design, engineering, construction and operation of the site; however, details may be found in the Gorleben International Review (1979), from which Figure 5 is drawn.

The other area of uncertainty relates to the long-term implications of the 1000 TBq of actinides that have accumulated within a few kilometres of the Windscale pipeline, adsorbed to sediment, but now subject to various processes of redistribution which were not predicted at the time of discharge. It should perhaps have been obvious that sediment would be subject to movement by currents. Less obvious, and still not completely elucidated, are mechanisms which are now known to resuspend marine plutonium and transport it to the terrestrial environment. Levels in the marine and terrestrial food chains are still very low, yet they are beginning to bring forth surprises. In 1977, we suggested that transfer models were simplistically based on laboratory studies with inorganic plutonium: plutonium in biological systems could easily display the variability associated with other metal complexes. Furthermore, the MAFF consumption models were also rather loosely documented. Recent research by MAFF and NRPB in these areas has led to some significant changes. First, organically bound plutonium is transferred 500% more efficiently than inorganic plutonium, and as much as 100 times more for suckling mammals. Second, the proportion of shellfish in the local diet has been revised. Thus, the dose profile for the 1980s looks very different from that of the 1970s. Plutonium now accounts for 70% of the dose to the critical group, compared to 10% previously (see Figure 6). The current maximally exposed individual (in the local fishing community) receives 3 times the average annual lifetime dose recommended by ICRP and IAEA, and about 12 times the US EPA limit for which a plant such as Windscale would be licensable. Such public exposures occur nowhere else in the world.

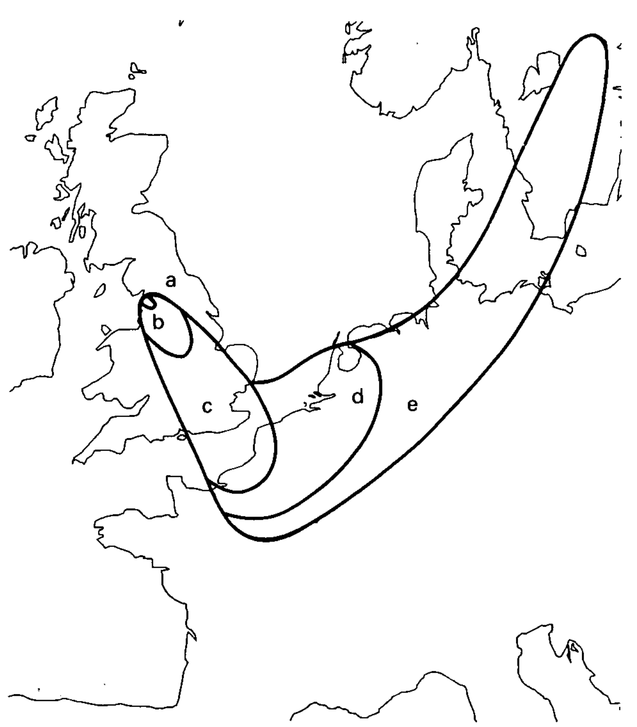

Figure 4. The path of radioactive deposition following the Windscale fire in October 1957
a area of milk ban for several weeks
b 1000+ Ci-days m^{-3}
c 500–1000 Ci-days m^{-3}
d 100– 500 Ci-days m^{-3}
e 10– 100 Ci-days m^{-3}
(Note 1 Ci ≡ 37 GBq)

Furthermore, whereas in beta–gamma radiation equivalents, a twice background level may not be cause for alarm (it occurs regularly from one geographical location to another), these doses have been reduced to 'equivalents' by complex formulae related to the effectiveness of alpha radiation and organ sensitivities, based, in our view, on extremely sparse human data bases. Considering that the critical group's doses are now primarily bone doses from alpha emitters, the situation does not now compare favourably to normal environmental exposures. Overall, the bone is receiving 12 times the usual total environmental dose, and nearly 50 times the naturally occurring alpha radiation dose of approximately 0.24 mSv yr^{-1}. These data refer to adults. The situation for the foetus and infants is not known with certainty, and the Independent Advisory Group (1984) called for more research in this area. Clearly, suckling infants will not also be avid shellfish consumers, but during infancy they will be subjected to various inhalation and ingestion pathways in the home and outside, where resuspended plutonium and americium are now widespread.

It may well be that the action of environmental processes over time will be to bury the actinides in deep sediments, or to disperse them at increasingly

Figure 5. The projected extent of significant radiation-induced health damage following a major loss of containment accident at the Windscale reprocessing plant
a 1 Sv lung dose (1–10/10 000 deaths in the population)
b 0.1 Sv in 30-year cumulative dose (evacuation considered at this level)

lower concentrations: there is no evidence of mechanisms which might exacerbate the present situation, and discharges will not now be licensed at anything like previous levels. If there is a hazard, it will be a combination of hitherto unsuspected sensitivities of human tissues to alpha radiation, and the complexities of food chain transfers regulated by long-term biological and geochemical cycles in the coastal environment. Whilst the situation is not as alarming as some might suggest, it does demand careful monitoring and assessment to provide an early warning of significant harm. In this regard, it is perhaps salutary that the health statistics relating to childhood leukaemia, whatever the cause, were generated not by the appropriate authorities but by a television documentary team.

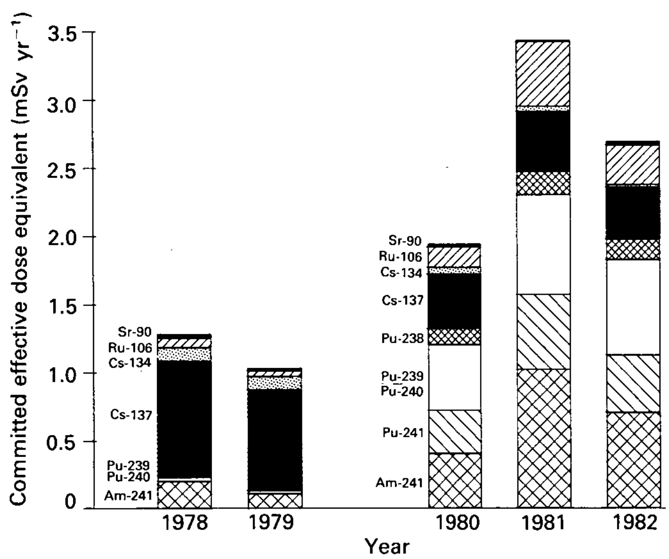

Figure 6. Individual radiation exposure due to consumption of Irish Sea fish and shellfish consumers in the local fishing community (the critical group). Note that the increased dose between 1979 and 1980 is due to an upward revision of the gut uptake factor for plutonium and of the proportion of shellfish in the diet of the critical group (source: MAFF 1967–85)

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The report of the Black Advisory Group and the implementation of its recommendations

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Summary
In November 1983, the government set up an independent Inquiry to look into the recently published claims of an increased incidence of cancer in the vicinity of the British Nuclear Fuels plc site at Sellafield. This inquiry was chaired by Sir Douglas Black. The report of the Inquiry concluded that the mortality in the whole of west Cumbria was near to the national average, but that this finding did not preclude the existence of local pockets of high incidence. In particular, the studies available to the Group did show that the incidence of lymphoid malignancy in young people under the age of 15 in Seascale and the mortality from leukaemia in those under 25 years in former Millom Rural District, which includes Seascale, were above the expected level. When estimates of the average doses of radiation received by members of the public living in the area were calculated, these doses seemed to be insufficient to explain the observed excess.

The Group, therefore, gave a qualified reassurance to the people who were concerned about a possible health hazard in the neighbourhood of Sellafield. However, the Group also stressed the *uncertainties* with regard to both the available epidemiological data and the estimation of radiation doses.

The Group made 10 recommendations for further work, which were accepted by government, and progress on their implementation is described.

1 Introduction
In November 1983, Yorkshire Television (YTV) showed a programme which alleged that there might be a link between discharges of radioactive material from the British Nuclear Fuels plc (BNFL) Sellafield site, and the incidence of leukaemia and other cancers in children and young adults in Seascale and other coastal villages in west Cumbria. As an initial rapid assessment of the epidemiological data suggested that the pattern of cancers in the area might indeed be somewhat unusual, the Department of Health and Social Security was asked by the Department of the Environment to set up an independent Inquiry with the following terms of reference.

> To look into the recently published claims of an increased incidence of cancer in the vicinity of the Sellafield site:
> 1. examine the evidence concerning the alleged cluster of cancer in the village of Seascale;
> 2. consider the need for further research;
> 3. make recommendations.

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The Minister for Health asked Sir Douglas Black, a past president of the Royal College of Physicians, to head the Inquiry, and he asked 6 experts in relevant fields to assist him in his investigations. I was appointed Medical Secretary to the Group and asked to assist by obtaining any relevant information from government departments and other sources. The Group first met on 22 November 1983. It was asked to report as soon as possible, and Sir Douglas suggested at the first meeting that it might be reasonable to aim to report by the end of 6 months. Within such a timetable, it was not possible for the Group to institute and complete research itself, and the Group therefore had to rely heavily on data already collated by workers in relevant fields. However, it is probably worth pointing out that the terms of reference recognized this limitation to the Inquiry by asking for advice on where further research was indicated. Thus, the Group at all times, and the Department of Health and Social Security since the Group reported have seen the Inquiry more as the first part of the investigation rather than the final word on this topic.

The Group visited Cumbria to talk to local medical staff and general practitioners and also to visit the BNFL site at Sellafield in January 1984. In all, the Group met 16 times, and in addition several sub-groups met. As work progressed, it became obvious that there was a need for some estimation of the doses of radiation received by members of the public in the area around Sellafield. The Group asked BNFL to make available to the National Radiological Protection Board (NRPB) all relevant data on discharges to enable NRPB to prepare several reports assessing the doses received by members of the public in west Cumbria, and especially by the young people in Seascale village. Because these doses were calculated by extrapolating from the discharges themselves and from environmental monitoring data, they were necessarily indirect estimates of dose, so the Group also asked NRPB to take their whole body monitor to Seascale and to perform direct measurements of radiation exposures of members of the public. The Group realized that these measurements could only be of the gamma emitter caesium-137, because of the limits of sensitivity of the monitor. Nevertheless, it found these direct measurements of human exposures very valuable in validating at least one aspect of the dose estimation procedure.

The Group was able to consider an impressive number of epidemiological studies on the incidence of cancer in Cumbria submitted by independent scientists. It is not possible to go into the details of all of these studies in this paper, but they did, in general, confirm that the incidence of lymphoid malignancy in young people under the age of 15 in Seascale, and the mortality from leukaemia in those under 25 years in former Millom Rural District, which includes Seascale, were above the expected levels. However, when the studies were widened to include larger geographic areas, such as Copeland District or west Cumbria as a whole, the excess disappeared.

2 Conclusions of the epidemiological data

In its report, which was published on 23 July 1984 (Independent Advisory Group 1984), the Group concluded that mortality from childhood cancer in the whole of west Cumbria was near to the national average, particularly for cancers other than leukaemia. However, this conclusion did not preclude the existence of local pockets of high incidence, and in this connection 2 studies were of particular relevance.

In a study of 675 electoral wards in the Northern Children's Cancer Registry, it was found that Seascale had the third highest lymphoid malignancy rate during 1968–82 in children under 15 years of age, the excess being entirely due to an increased incidence of leukaemia in the area (Table 1). If the data on the 675 electoral wards were used to calculate the Poisson probability of obtaining the incidence for each electoral ward, and the electoral wards were then ranked according to their Poisson probability, then Seascale had the smallest Poisson probability of all of the electoral wards. In other words, it was the village with the rate most unlikely to have occurred by chance (Table 2).

When the Group looked at the geographical distribution of those electoral wards with the highest incidence of lymphoid malignancy in west Cumbria, there did not appear to be any tendency for these electoral wards to be situated near to Sellafield or on the west coast of Cumbria. In addition, although the incidence of lymphoid malignancies in Seascale was increased 16-fold over the expected level, this 16-fold increase, in fact, was caused by 4 cases of leukaemia. While 4 cases of leukaemia represent 4 tragic deaths, in a statistical sense there must be considerable uncertainty attached to evidence for an excess incidence relying on such a small number of cases. For these and other reasons, it was not possible to exclude the possibility that the excess incidence of lymphoid malignancies in Seascale had occurred by chance rather than subsequent to some external event.

3 The estimated radiation exposure of the population

Because any unusual cancer incidence in the population seemed to be confined to those under the age of 25, the Group asked NRPB to concentrate on this group in their dose estimates. NRPB based their calculations upon monitoring data, habit survey data, and data on gut transfer factors for the various radionuclides that were available. The calculations necessarily involved the use of models which made assumptions about the most significant exposure routes and about the sites of the sensitive cell for leukaemia induction. In their studies, NRPB assumed that the most sensitive cell was the red bone marrow stem cell lying within the skeleton. NRPB calculated the average radiation dose that would be received by 7 'birth cohorts' of young people living in Seascale from the time that they were conceived until 1980 or the age of 20 years, whichever was the earlier. These dose estimates then had to be converted into risk estimates for the induction of leukaemia. The risk estimates commonly used for the induction of leukaemia from radiation are largely based on acute exposures, such as those received by the Japanese at Nagasaki and Hiroshima. The Group felt that it was inappropriate to apply these risk estimates to the chronic exposure to very low levels of internal radiation, such as were likely to be received by the population of Seascale. However, we are all exposed to some continuous low-level radiation dose from natural background, and the Group made use of these known exposures to calculate a risk estimate for the induction of leukaemia, based on an assumption that leukaemia in young people under 20 years of age in

Table 1. Ranking of lymphoid malignancy incidence rate per 1000 children – top 10 of 675 electoral wards in Northern Region (source: Independent Advisory Group 1984)

Ward rank order	Number of cases	Child population	Rate/1000 children	Poisson probability	Ward incidence/ regional incidence
1	2	144	13.88	0.003622	22.82
2	1	97	10.30	0.057317	16.94
3*	4	411	9.73	0.000134	15.99
4	1	165	6.06	0.095528	9.96
5	1	172	5.81	0.099373	9.55
6	1	174	5.74	0.100468	9.44
7	1	184	5.43	0.105925	8.93
8	1	189	5.29	0.108641	8.69
9	1	198	5.05	0.113510	8.30
10	1	203	4.92	0.116203	8.09

*Seascale

Table 2. Ranking of all lymphoid malignancy by Poisson probability of rate per 1000 occurring by chance – top 5 electoral wards in Northern Region out of 675 wards (source: Independent Advisory Group 1984)

Wards ranked by Poisson probability	Number of cancers	Population 0–14 years	Poisson probability	Rate/1000 children	Ward incidence/ regional incidence
1*	4	411	0.000134	9.73	15.99
2	4	976	0.003239	4.09	6.73
3	2	144	0.003622	13.88	22.82
4	4	1207	0.996788	3.31	5.44
5	4	1353	0.010003	2.95	4.85

*Seascale

England and Wales is entirely due to the dose of background radiation received by the red bone marrow. This assumption is extremely conservative (ie it over-estimates the risk), but the Group felt it was justified to make this assumption to ensure that the risk from the calculated doses to young people in Seascale was not under-estimated. Using the risk factor calculated in this way, the number of additional deaths that would be expected to occur from leukaemia in this age group in Seascale from the additional estimated dose of radiation that they received from their date of birth up to 1980 or up to the age of 20 was calculated. The maximum number of deaths from leukaemia ,expected to occur was 0.1 for the period 1950–80.

In fact, 4 deaths had occurred at Seascale during this period from leukaemia. Therefore, these calculations of doses received by the young people in Seascale and the estimates of risks of leukaemia subsequent to these doses did not support the view that the radiation released from Sellafield was responsible for the observed incidence of leukaemia in Seascale.

However, it should be stressed that there are unavoidable uncertainties in the dose estimation carried out in this situation, and the Group did stress this fact and that other models could be used to calculate dose. The report also stated that it is impossible to establish for certain the environmental levels of radiation around Sellafield 20 or 30 years ago, and the possibility that unplanned discharges, not detected by the monitoring programme but delivering a significant dose to humans via an unsuspected route, cannot be excluded.

4 Conclusions of the report

To summarize, the Group found that there were uncertainties with regard to both the available epidemiological data, and to the radiation dose estimate data. The combined effect of these uncertainties was that, perhaps not unexpectedly, no firm conclusion could be reached on any possible relationship between the incidence of leukaemia in Seascale village and its proximity to the BNFL site at Sellafield. The Group felt that it was important to put the epidemiological data into a correct perspective, and so concluded that they had found no evidence of any general risk to health for children or adults living near Sellafield when compared to the rest of Cumbria. They therefore felt able to give a qualified reassurance to people who were concerned about a possible health hazard in the neighbourhood of Sellafield. However, the Group also made 10 recommendations covering epidemiological, radiation protection and organizational matters in the interests of enhancing public safety. The government accepted all 10 recommendations made by the Black Advisory Group, and the professional Division in which I work within DHSS is responsible for co-ordinating the implementation of these recommendations.

5 Implementation of the recommendations

The first 4 recommendations were for more detailed epidemiological studies to try to reduce the uncertainties in the data considered by the Group. These 4 studies have already been commissioned by the Office of the Chief Scientist in the Department of Health and Social Security and are in progress. The first recommendation was for a case control study which included all cases of lymphoma and leukaemia occurring in those up to 25 years of age and born since 1950 in west Cumbria. It is hoped that this study will provide information on the possible significance of factors such as parental occupation, coastal residence, and possibly food consumption patterns, in relation to the incidence of leukaemia and lymphoma in the west Cumbria area.

The second recommendation was for a study of cancer incidence and mortality in all children born since 1950 to mothers resident in Seascale. This study will enable children born in Seascale but moving elsewhere in the country to be included in the statistics, and so will make more complete the study of children who have resided in Seascale at any time.

The third recommendation was for a study of cancer incidence and mortality in children who attended schools in Seascale. The aim of this study is similar to that of the second recommendation, ie to enable children who were resident in Seascale for a few years to be included in the study. As it is hoped that it will be possible to trace children who resided at one of the local boarding schools, there is also the possibility, within this recommendation, of following up a completely different group of children from those who have already been studied in the YTV programme data and the data considered in the Black report.

Finally, the data from the Children's Cancer Registry, which was mentioned above, are being reanalysed in more detail. The original study allocated the children to electoral wards according to place of residence at diagnosis; the new study will also allocate the children according to electoral ward at time of birth. The original study used 1981 census populations for the estimated number of children at risk in all years from 1968 to 1982; the new study will use 1971 and 1981 census populations, as appropriate. In addition, the age range of the study will be extended from 0–14 to 0–24 years so that it is more comparable with other studies and with the YTV data. Finally, the North West Region will also be analysed with the Northern Region data.

Other recommendations dealt with improving the ways in which the doses received by members of the public are calculated. These recommendations were more general than the first 4 recommendations and the Department has held meetings with experts to advise on the most important project work to be done in this area. Work on direct measurement of levels of radionuclides (especially the alpha emitters) in post mortem tissues from the Northern Region is already being undertaken by NRPB in collaboration with local physicians and pathologists. In addition, the Department of the Environment is finalizing a contract for studies using a mobile whole body monitor to provide information on the levels of gamma emitters in members of the population in the Northern Region and throughout the United Kingdom. Advice on the best way to proceed on some of the more basic research required is being sought from the Medical Research Council.

Other recommendations dealt with the discharge authorizations, and are the responsibility of the Ministry of Agriculture, Fisheries and Food, and the Department of Environment, rather than the Department of Health and Social Security. From 1 January 1985, BNFL's radioactive liquid discharge authorization has been varied so as to prohibit the discharge of particulate matter and solvent, and to impose short-term limits on quantities of radioactivity discharged. More rigorous requirements are envisaged in a new authorization for Sellafield liquid discharges to reflect the coming into operation of new plant in 1985. Further reductions in the radioactive discharges from the Sellafield site are anticipated, especially when BNFL complete a floc precipitation plant in the early 1990s.

The 2 remaining recommendations (nos 5 and 10 b-d) are less straightforward to implement but are being carried forward as quickly as possible. Recommendation 10 b-d concerns the need for a designated body with significant health representation to enable decisions with regard to the control of permitted discharges to take account of all relevant factors. Implementation of this recommendation will involve important organizational changes within government. Recommendation 5 refers to improved central co-ordination of the monitoring of small area statistics. This recommendation refers to epidemiological data relevant to industrial sites, in addition to those concerned with nuclear materials. The DHSS has held several meetings with other relevant government departments to disuss the way forward on these recommendations and ideas are currently being formulated. A government response can be hoped for soon. These areas are regarded as of great importance and are being taken forward as rapidly as possible.

The work of the Advisory Group and the commitment given by the government to implement its recommendations reflect the increasing attention being given to the possibility of some adverse health effects of low levels of environmental pollutants, whether physical or chemical in form. The fact that the Advisory Group was unable to reach definitive conclusions was due in part to the problems associated with the interpretation of epidemiological data when they relate to relatively small numbers of people living near a potential source of pollution. Distinguishing between a chance occurrence of a cluster of cases of a given disease and an excess due to an underlying cause is often not possible because the number of cases and the size of the population at risk are too small. Conversely, if the size of the study population is increased, then the chance of observing any adverse effect may also be diminished because the study population is then diluted with those living further from the source and likely to be less exposed to any potential hazard. In addition, where only a single area (such as Seascale) has an elevated incidence and all surrounding areas have incidences which approach the average, it is not possible to exclude the possibility that the excess incidence has occurred by chance. The Black report highlighted these problems in its recommendation on small area statistics which dealt with hazards in general, and did not confine itself to the effects of radioactivity.

In this presentation, I have only been able to touch very briefly upon the large amount of work undertaken by researchers in this field and the detailed considerations given to the problem by the Black Advisory Group. It is always frustrating when no clear answer emerges from thorough consideration of a large collection of data. It is to be hoped that the results of the studies in progress at present and being planned for the future will help to clarify the situation.

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Monitoring for environmental radioactivity around Sellafield

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Summary
The monitoring programme for environmental radioactivity, carried out by British Nuclear Fuels plc around their plant at Sellafield in west Cumbria, is described in some detail. The results are discussed briefly. Levels of radioactivity in the environment are falling as discharges have been reduced, and the resulting doses to the public are within the limits recommended by the International Commission on Radiological Protection. The resulting doses are also small in comparison with those which result from the presence of naturally occurring radionuclides in the environment.

1 Introduction
The Sellafield site of British Nuclear Fuels plc (BNFL), situated on the north-west coast of England in the county of Cumbria, consists of a reprocessing plant, fuel plants and the world's first nuclear power station, Calder Hall. An extensive environmental monitoring programme is carried out. The Company also operates a low-level solid waste burial site at Drigg (about 6 km south of Sellafield), and this operation is also included within the environmental monitoring programme.

The reprocessing and reactor operations carried out at Sellafield entail the discharge of radioactive waste materials to the environment in the form of low-level liquid waste to the Irish Sea, down a pipeline of about 2.5 km length, and low-level gaseous and particulate wastes via the ventilation systems of the process areas and laboratories. Filters or scrubbers are used, where necessary, to reduce the radioactivity content of this effluent before it is discharged to the atmosphere. Authorizations to discharge have been granted by the UK government for both liquid and gaseous effluents, and are kept under review. The authorization to discharge liquid effluents was last modified with effect from 1 January 1985 and a further major revision is expected in mid-1986.

The burial of low-level solid waste at Drigg is also controlled by an authorization. All 3 authorizations control, directly or indirectly, the amounts of waste discharged or buried, and require BNFL to take and analyse appropriate environmental samples. Representatives of the authorizing government departments also carry out a wide range of parallel sampling and monitoring of the environment.

The activity discharged from Sellafield into the environment includes a variety of actinides, fission products and activation products. The main actinides of interest are isotopes of plutonium and americium, and fission products of interest include caesium-137, strontium-90 and ruthenium-106.

It has been the policy of BNFL to reduce discharges of radioactivity into the environment wherever this is reasonably practicable. The discharges of radioactivity into the marine environment are more radiologically significant than other discharges, and an indication of the efforts made to reduce discharges since the formation of BNFL in 1971 can be gained from Figures 1 and 2. Figure 1 shows the discharges of total beta radioactivity from 1971 to 1984. The reduction since the mid-1970s reflects introduction of methods to reduce radioactivity in water purged from fuel storage ponds. Further improvements are expected as a consequence of the introduction of new treatment plants during 1985. Figure 2 shows the discharges of total alpha radioactivity over the same period. The reduction reflects measures which have been taken to treat the more important effluent streams. Again, new treatment plant introduced during 1985 is expected to produce a further significant improvement.

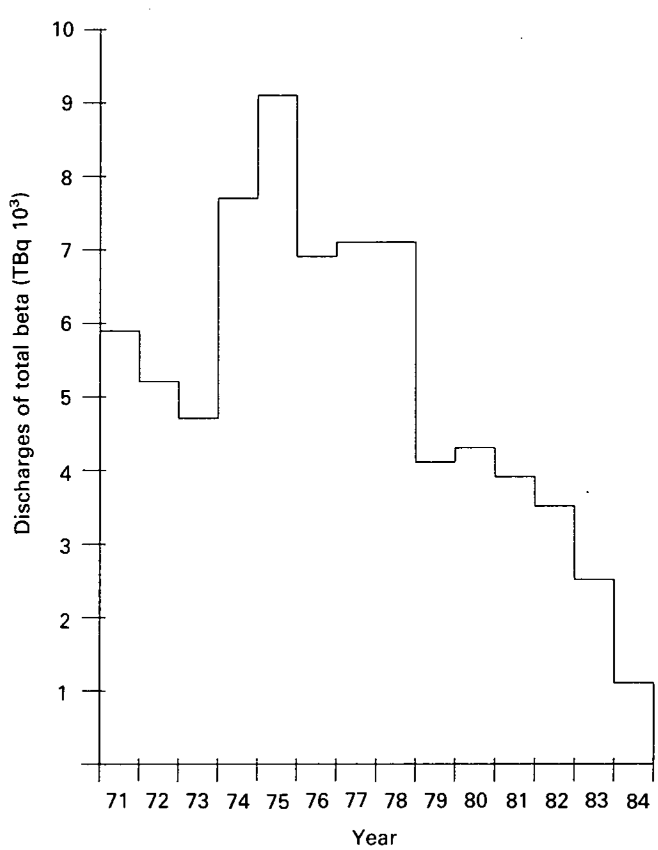

Figure 1. Discharges of total beta radioactivity to sea from Sellafield, 1971–84

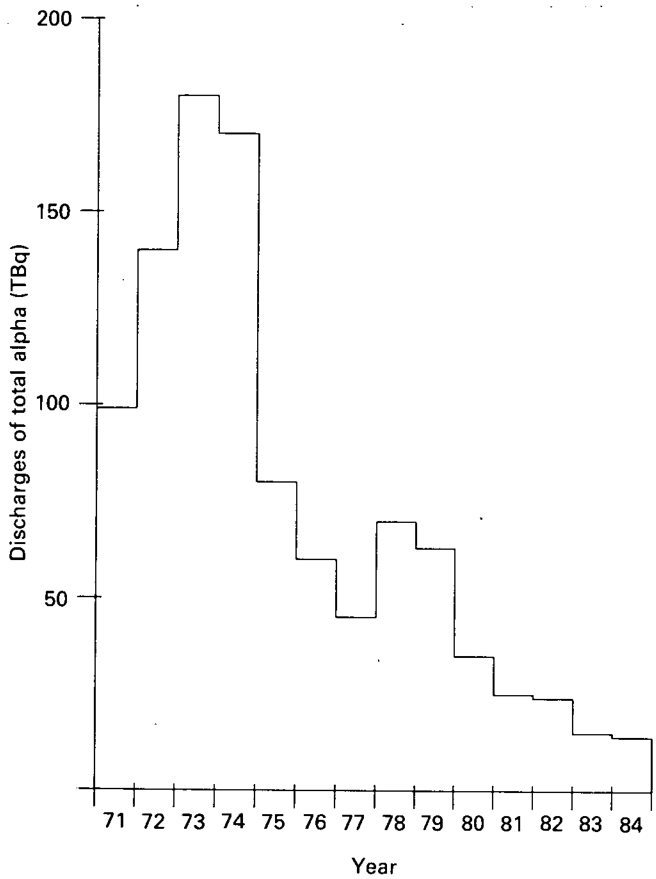

Figure 2. Discharges of total alpha radioactivity to sea from Sellafield, 1971–84

Improvements above and beyond those achieved during 1985 are expected when a further major effluent treatment plant is introduced in the early 1990s, at a cost (capital and operating) in the region of £250 million. The aim of this plant is to reduce annual average discharges to about 0.7 TBq (terabecquerels) of alpha radioactivity, and 300 TBq of beta radioactivity. The overall progress and forward programme for reductions in effluent discharges from Sellafield are reviewed in the *Sixth annual report* of the Radioactive Waste Management Advisory Committee (RWMAC 1985).

It is against this background that the BNFL environmental monitoring programme is conducted. The primary aim is to evaluate the maximum radiation exposures which may be experienced by members of the public, for comparison with the recommendations of the International Commission on Radiological Protection (ICRP), the National Radiological Protection Board (NRPB) and RWMAC. The programme also produces information on the relationship between levels of discharge and levels of radioactivity in the environment, which is used to evaluate the effects of planned future discharges. The change in levels of radioactivity in the environment as discharges are reduced is, of course, of particular interest.

There are many ways in which, having been released to the environment, these isotopes can expose man to low levels of radiation. In looking at these ways, it is convenient to consider marine and land-based pathways separately.

2 Marine pathways

Effluent released from the pipeline into the Irish Sea is dispersed by tidal action and currents. Some isotopes remain mobile within the seawater (eg caesium-137), whereas others are readily adsorbed by silt particles (eg plutonium and ruthenium-106). Certain isotopes are ingested or adsorbed by marine flora and fauna, depending on their chemical nature, and may enter the food chain. The quantity of radioactive material taken up by any particular species will depend, among other things, on its habitat and feeding habits. Eventually, radionuclides will pass along food chains and be found in marine species eaten by man. Of particular interest in the waters and shores around Sellafield are fish such as plaice, cod and whiting; crustaceans such as crabs, lobsters and scampi; and molluscs such as mussels and winkles. Radionuclides will become concentrated in the edible parts of these species, and will thus become a source of radiation exposure to the consumer.

Certain radionuclides are also readily adsorbed by silt, which may then be deposited in the inter-tidal regions of local beaches, harbours and estuaries, exposing people who frequent these areas to gamma radiation from nuclides such as caesium-137 and ruthenium-106. In addition, resuspension of the silt may cause exposure to individuals who might inhale particles.

Many marine materials that concentrate radionuclides are not consumed by man, but may be useful indicators of, for example, changes in dispersion patterns. This role is particularly true of certain seaweeds. One such seaweed, *Porphyra umbilicalis*, was collected from the Cumbrian coast some years ago and sent to south Wales where it was used to make a local delicacy called laver-bread. Although *Porphyra* is no longer collected locally in significant quantities for this purpose, it remains useful as an indicator material and its collection remains a statutory requirement. A summary of the main marine pathways of interest is given in Figure 3.

3 Land-based pathways

Gaseous effluent released to the atmosphere from Sellafield is dispersed and the airborne material provides a source of low-level exposure either directly from the cloud or from inhalation of the material. Ultimately, the airborne material is deposited on exposed surfaces such as soil and vegetation and provides a pathway to man, for example via milk from livestock which has grazed on the vegetation. A further possible source of exposure is from surface water runoff, which then forms part of a drinking water supply. A general summary of land-based pathways is

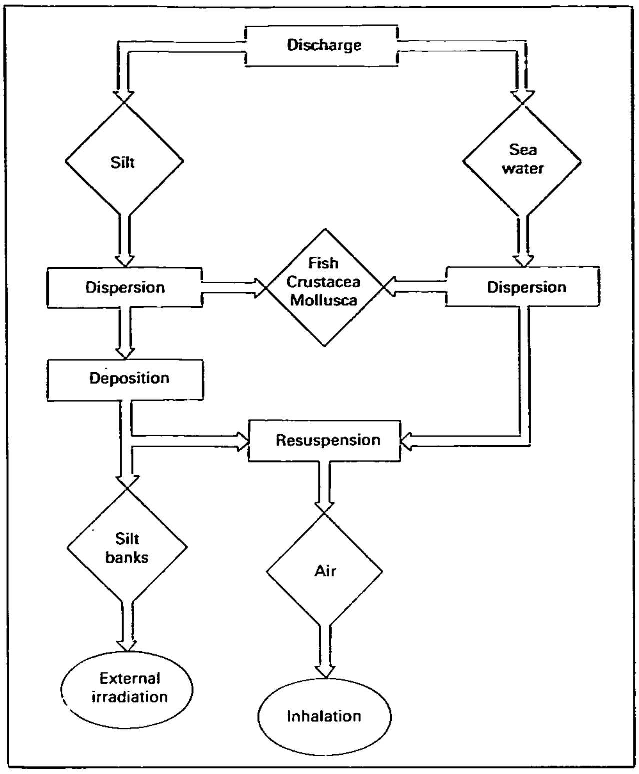

Figure 3. Principal exposure pathways – the marine environment

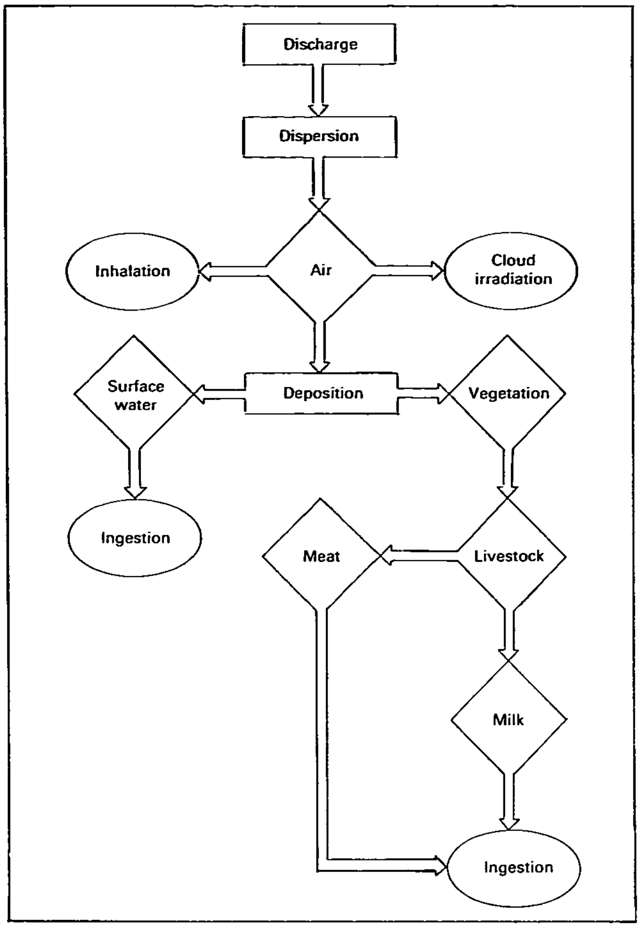

Figure 4. Principal exposure pathways – the terrestrial environment

given in Figure 4. Not all the pathways shown are necessarily of significance at Sellafield.

4 Important pathways and 'critical groups'

The number of possible pathways by which man may be exposed as a result of discharges to the environment from Sellafield is large, although in most cases the exposure due to a particular pathway or group of pathways is insignificant. It is possible to identify those pathways which give rise to the most significant exposure and, for each of these, the group of individuals most highly exposed. Such a group is known as a critical group.

The critical groups for marine pathways are defined by the Fisheries Research Directorate of the Ministry of Agriculture, Fisheries and Food (MAFF). Its staff carry out periodic surveys into the seafood consumption and occupancy habits of the local communities to identify those individuals most highly exposed, and to estimate consumption rates or occupancy times representative of that group of individuals. The regular sampling of animal and plant species representative of those eaten by the group, and the radiation monitoring of areas of silt on which they spend time then form the basis of an environmental monitoring programme. The determination of the quantities of radioisotopes present in these samples, coupled with critical group consumption rates, thus allows the estimation of radiation doses to members of critical groups. The identification of critical groups for land-based pathways is not usually based on detailed habit surveys but on certain maximizing assumptions. For example, in the case of milk, it is assumed that the most highly exposed individual would be an infant living on a farm local to Sellafield and feeding entirely on milk produced at that farm. The milk consumption rate assumed is recommended by MAFF.

5 Marine monitoring

The important marine pathways have already been identified as external irradiation from occupancy of exposed areas of silt and consumption of local fish, crustaceans and molluscs. The monitoring programme is largely based on a statutory programme, last reviewed and modified with effect from 1 January 1985, the details of which have been published and the results of which are reported annually by BNFL (1985). BNFL also carries out some monitoring beyond the requirements of the statutory programme, and the Ministry of Agriculture, Fisheries and Food carries out a parallel monitoring programme, the results of which are also published annually (Hunt 1985).

A major part of the programme consists of a series of measurements and samples taken from the beaches and inter-tidal areas of the Cumbrian coast.

Gamma radiation surveys are carried out over certain areas of exposed silt, on a monthly or quarterly basis, along the coastline from Maryport to Walney. Areas of silt in Whitehaven harbour and the Ravenglass estuary are of particular interest, and the critical group for this pathway has been defined as boat-dwellers in Whitehaven harbour. Radiation measurements are made using a hand-held radiation monitor one metre above the silt. On extensive areas of silt, readings are taken and recorded at regular intervals along, say, a river bank, whereas on beaches where only small sporadic areas of silt may be present a reading is taken over each area. Samples of silt are also taken for more detailed analysis, as are samples of shore seawater. Mollusc samples (mainly mussels and winkles which are consumed by the critical group) are collected monthly from several coastal sites. The specimens are 'picked' at low tide and sufficient are obtained to ensure a sample of a few hundred grams of flesh. Sand and other debris are rinsed off the winkle and mussel shells with seawater during collection, and at Sellafield the molluscs are quickly prepared as if for consumption, in a manner recommended by MAFF. The edible flesh can then be removed from the shells prior to radionuclide analysis. The reasons for sampling the seaweed *Porphyra umbilicalis* have been described previously. Samples for analysis are obtained from 4 coastal locations between Braystones and Walney, where it grows in patches on rocks. It is usually blackish brown or reddish in colour, producing flat, lobed growths. The monitoring locations for inter-tidal areas are shown in Figure 5. The remaining major component of the programme is the sampling of other marine foods from offshore.

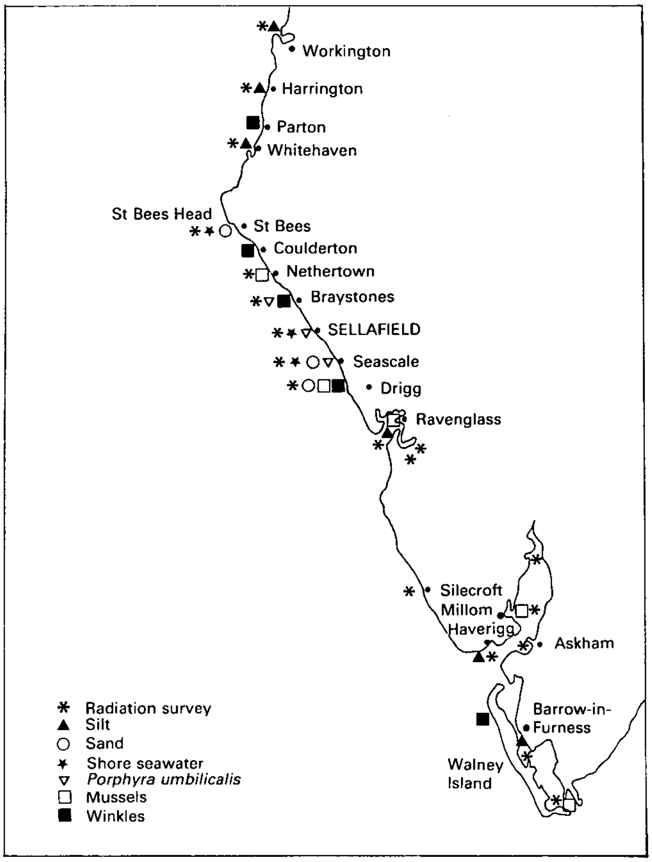

Figure 5. Statutory environmental monitoring around Sellafield works. Marine shoreline sample positions

The Company owns a trawler, the RV 'Seascan', based at Whitehaven harbour, which fishes for the main species consumed by the critical group, namely cod and plaice. From time to time, samples of other species such as whiting, sole and herring are obtained, and cod and plaice landed commercially at Ravenglass and Whitehaven are also purchased regularly. A typical sample consists of a few kilograms of edible fish flesh, which are analysed at Sellafield for the appropriate radionuclides. The sampling concentrates on areas close to the shore between St Bees Head and Selker, as shown in Figure 6. Crustacean samples (mainly crabs, lobsters and scampi) are also obtained, mainly from local commercial suppliers, although some are caught by the 'Seascan'. These samples are again brought to Sellafield for radionuclide analysis of the edible parts.

6 Land monitoring

The important land pathways have already been identified and, as can be appreciated, much of the effort and expense in the land programme goes on milk sampling. Milk is collected from a number of farms every 2 weeks, a sample having been placed in a bottle by the farmer at each milking over the 2-week period. The farms sampled include 7 within 2 miles of Sellafield, and another 4 between about 2 and 4 miles from the site, chosen to provide a reasonably uniform directional coverage. Analysis for important radionuclides such as caesium-137 and strontium-90 is carried out on each sample, and, for less important nuclides, on 6-week bulked samples. A sample from the milking on the day of collection is also taken from each farm and analysed for radioiodine. Samples of milk are taken from 2 farms about 25 km from the site to establish 'background' levels of activity. Finally, milk is regularly sampled from the local Milk Marketing Board dairy.

In addition, milk is sampled from a farm adjacent to Ravenglass estuary to cover the cattle grazing on pastures washed by the tide and on which may have been deposited low levels of radioactivity from the effluent discharged to the Irish Sea. Milk samples are also taken from a farm adjacent to the Drigg disposal site. Milk sampling locations are shown in Figure 7.

A small number of samples of meat, potatoes and local vegetables are also collected each year.

In order to monitor the inhalation pathway, a number of air sampling devices provide samples from points on the site perimeter and in the surrounding area up to about 10 km from Sellafield. Locations sampled fur-

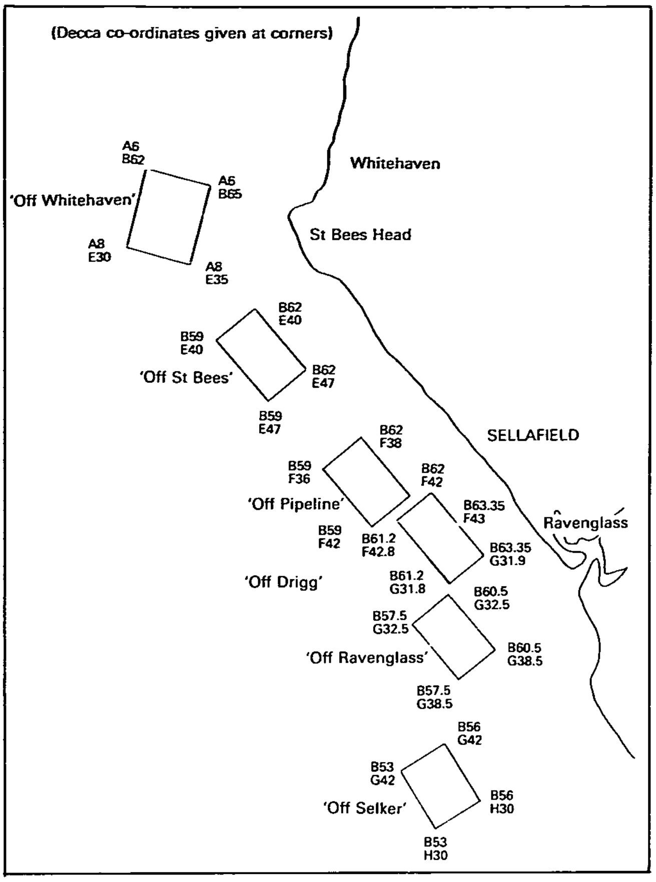

Figure 6. Offshore sampling areas for fish and crustaceans. The Decca co-ordinates are given at the corners of the blocks

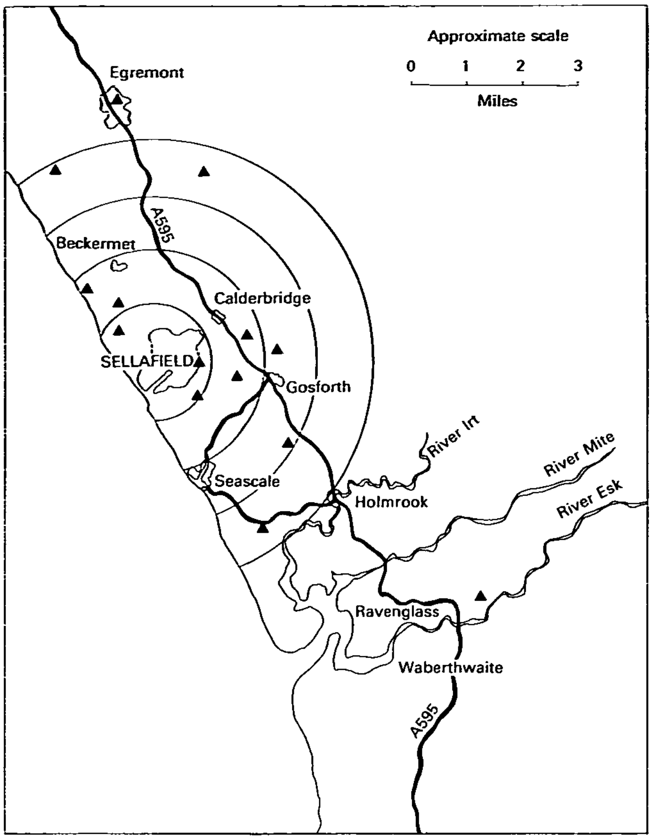

Figure 7. Environmental monitoring around Sellafield works. Farms supplying milk samples are shown (▲)

ther from the site include local inland population centres (Beckermet, Calderbridge, Holmrook), together with coastal locations (Ravenglass, Seascale, Braystones, St Bees) which will reflect the effects of any resuspension of marine material. Pumps capable of pulling up to 100 m^3 air h^{-1} through a large filter paper are used to monitor the very low levels of airborne radioactivity. The sample papers are bulked periodically for radionuclide analysis. Air sample locations are shown in Figure 8.

Two rivers, the Calder and the Ehen, flow into the sea at Sellafield and samples are regularly taken at several locations either once or twice a month. The sample consists of a spot sample taken in a plastic bottle to confirm that the very low levels of radioactivity in the rivers have remained unchanged. The lower reaches of these rivers are not a normal source of drinking water. The works' sewer, which discharges to the sea, is also sampled on a continuous basis. A stream which carries drainage from the Drigg site is sampled automatically every hour, and the samples bulked weekly for analysis. Local water supplies are also sampled regularly, both from lakes and reservoirs and from the tap.

7 Costs

The programme involves the collection of about 10 000 environmental samples per year, and the declaration from those samples of about 100 000 results for the concentrations of individual radionuclides. In addition, a large number of individual direct measurements of gamma radiation is made.

The survey and sampling work is carried out by a group of about 25 staff from the Safety and Medical Services Department at Sellafield, who also record, interpret and report on the results of all the measurements and analyses. The programme is managed by professional health physicists. The analysis of samples is carried out by a specialized branch of the Analytical Services Department at Sellafield.

Overall, the survey programme costs in excess of £0.5 million per year to run. A large fraction of this cost is taken up by the detailed radiochemical analysis of samples. Taken together with the additional technical work which is done to enable predictions to be made of the effects of future discharges, the total budget of the Environmental Protection Group at Sellafield is about £1 million per year.

8 Results

Detailed results of the BNFL monitoring programme are published annually (BNFL 1985), as are the results of the parallel programme carried out by the Ministry of Agriculture, Fisheries and Food.

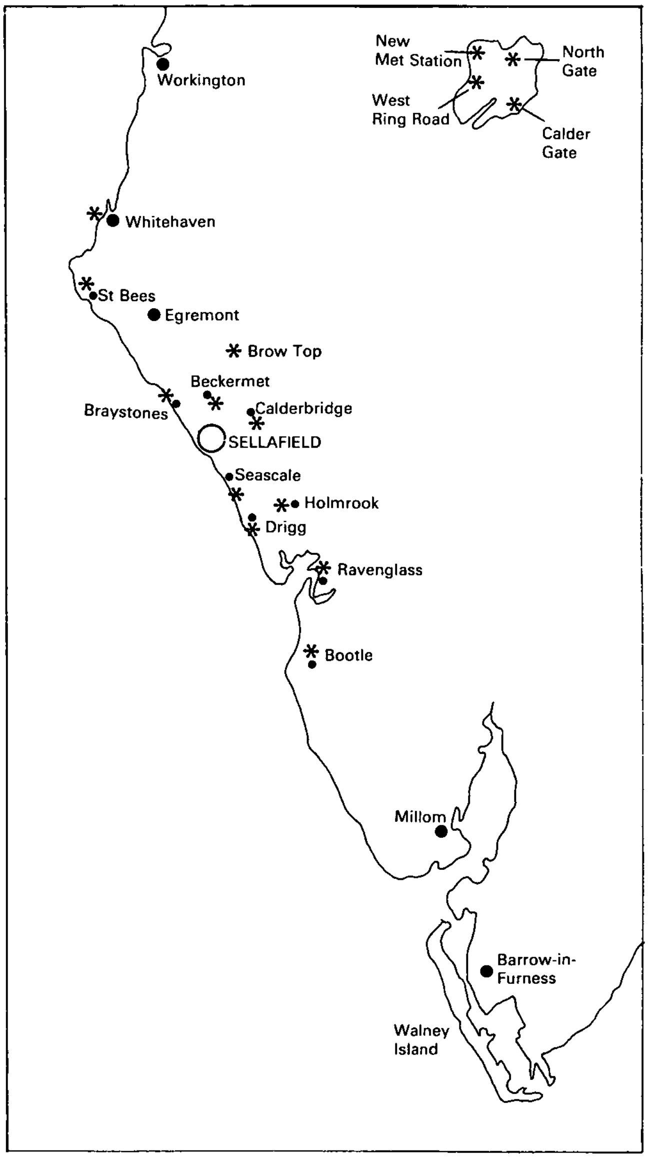

Figure 8. Environmental monitoring around Sellafield works. The installed district air sampling points are shown (*)

Radiation doses to which members of the different critical groups are exposed are, in general terms, as follows:

High rate consumers of marine foods	*c*2 mSv yr^{-1}
Exposure to gamma radiation from sediments	*c*0.5 mSv yr^{-1}
Inhalation of air	*c*0.05 mSv yr^{-1}
Consumption of milk	*c*0.05 mSv yr^{-1}

The consumption of meat, offal and local vegetables is estimated to have a similar or lower significance to the consumption of local milk, although exposure at the 'critical group' levels in these cases is inherently less likely than for milk.

It should be emphasized that these doses apply to the extreme cases, ie the 'critical group' for each pathway, and are not additive. For example, the marine food consumption is based on large quantities of local seafoods, particularly winkles, where the consumption rate assumed is 16.5 kg (2½ stone) yr^{-1}. Radiation doses to the general population of west Cumbria are, of course, very much lower.

These doses can be compared to the limits recommended for radiation exposure of the public by the ICRP (1985) of 5 mSv in any year, and 1 mSv yr^{-1} averaged over a lifetime.

The levels of radioactivity in the environment are falling steadily as discharges have been reduced. Because of this reduction, and because doses to the high-rate seafood consumer group have only exceeded 1 mSv over the last few years, it is anticipated that lifetime doses will be maintained well within the 1 mSv yr^{-1} average, even for this most highly exposed group (RWMAC 1985; Hunt 1985).

The radiation doses due to Sellafield discharges may be placed into perspective by comparison with the doses due to natural radioactivity. The average radiation dose to the UK population due to naturally occurring radioactivity is 2 mSv yr^{-1}, with a range from 1 mSv yr^{-1} to 100 mSv yr^{-1} (Hughes & Roberts 1984). The high upper values in this range are due to the accumulation of the naturally occurring radioactive gas radon in houses. Radon levels are higher in areas where the local rocks contain a relatively high proportion of uranium. Recently, it has been reported that the average radiation dose to people living in Cornwall, due to radon gas, is 7 mSv per year (Matthews 1985). This figure is, of course, higher than the dose to the average member of the public in Cumbria due to discharges from Sellafield by a factor of more than 100.

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Radiation and radioactivity in the United Kingdom and Cumbrian environment

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Summary
All persons are exposed to natural and artificial sources of radiation. Radiation from natural and artificial sources is identical in type and effect. On average, 87% of the radiation dose to members of the UK population comes from natural sources; 13% comes from artificial sources, mainly from medical uses of radiation; only about 0.1% comes from the disposal or discharge of radioactive wastes. Some population groups in Cumbria are exposed to radiation as a result of the discharge of radioactive waste from the British Nuclear Fuels plc (BNFL) site at Sellafield. The groups receiving the highest radiation doses are those that consume locally produced marine foodstuffs. The total radiation dose received by persons who also receive significant doses as a result of Sellafield discharges lies well within the range of doses received from natural sources by persons living elsewhere in the UK.

1 Introduction

Radioactivity is a natural phenomenon that has always been present in the environment, and mankind has always been exposed to natural sources of radiation. Radioactive material and radiation are also produced artificially for use in medicine, industry and science, and as a by-product of the generation of electricity by nuclear power. The radionuclides (radioactive varieties of elements) that are produced artificially are frequently different from those that occur naturally in that they are radioisotopes of chemical elements that do not exhibit radioactive forms in nature. The radiations emitted by artificial radionuclides, eg alpha particles, beta particles and gamma rays, are identical in behaviour and effect to those emitted by naturally occurring radionuclides.

Exposure to radiation is measured in terms of effective dose equivalent or committed effective dose equivalent, referred to in this paper simply as dose or committed dose. These quantities take account of the type and potential for harm of different types of radiation to different body organs. They allow exposures to diverse sources of radiation to be combined or compared.

Exposure to natural sources of radiation is mostly unavoidable. More control is possible over exposure to artificial sources. In particular, the discharge of radioactivity into the environment is controlled and subject to limitations imposed by government agencies. The limitations are imposed with 2 aims: first, to ensure that the total dose, to all persons at all times, that is expected to arise as a result of the discharge should be kept as low as can be reasonably achieved, economic and social considerations being taken into account; second, to ensure that the dose to any individual member of the public resulting from all such discharges does not exceed the appropriate annual dose limit recommended by the International Commission on Radiological Protection (ICRP).

In this paper, I briefly review the sources of radiation to which members of the public in the UK are exposed, with emphasis on environmental radioactivity sources. I then consider the special factors affecting the Cumbrian environment, particularly the discharges of radioactivity from the BNFL installation at Sellafield.

2 Sources of radiation exposure in the UK

2.1 Natural sources

The National Radiological Protection Board has recently issued a report which reviews the exposure of the UK population to all sources of ionizing radiation (Hughes & Roberts 1984). It shows that approximately 87% of exposure to the UK population is due to natural sources of radiation. The major components of exposure to natural sources are cosmic radiation, external irradiation from terrestrial gamma rays, internal irradiation from natural radionuclides in diet, and exposure to radon and thoron. The average annual doses from each of these components are shown in Table 1.

Table . 1 Summary of the average annual doses to members of the UK population from all sources (source: Hughes & Roberts 1984)

Source	Average annual dose (μSv)	Percentage of total
Natural		
Cosmic	300	14
Terrestrial gamma	400	19
Internal irradiation	370	17
Radon	700	32
Thoron	100	5
Artificial		
Medical	250	11.5
Occupational exposure	9	0.4
Miscellaneous	11	0.5
Fallout	10	0.5
Radioactive waste disposal	2	0.1
Total (rounded)	2150	100%

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Cosmic radiation consists of very energetic elementary particles and photons which originate mainly outside our solar system. As they penetrate the atmosphere, these particles and photons undergo complex reactions and their energy is gradually absorbed so that the dose decreases as altitude decreases. The dose also increases slightly with latitude, but over the UK the annual average dose due to cosmic rays at sea level varies by only 10%.

All rocks and soils contain traces of long-lived naturally occurring radionuclides and their daughters. Radiation will be received from those radionuclides that emit penetrating gamma rays, notably potassium-40 and certain daughters of uranium and thorium isotopes. Doses depend mainly on surface geology and may vary by a factor of 2 or more from place to place in the UK. The dose will be affected by local artefacts such as roads and buildings which will provide some shielding, but most building materials also contain traces of radioactivity so that the dose received indoors from terrestrial gamma rays is, on average, slightly higher than that received outdoors.

Natural radionuclides that are present in rocks and soils will also be present in foodstuffs and water supplies, and will give rise to internal irradiation. The largest component of internal irradiation in the diet comes from potassium-40, a long-lived naturally occurring isotope which constitutes 120 parts per million of the stable element. The level of potassium in the body is under metabolic control so that the dose from potassium-40 is relatively constant in all persons. Smaller internal doses are received from radionuclides in the uranium and thorium series, notably lead-210 and polonium-210, and from radionuclides produced by the action of cosmic rays in the atmosphere, such as carbon-14.

An important and variable source of internal irradiation is exposure to radon and thoron and their radioactive daughters. Radon and thoron are radioactive noble gases and are produced in most rocks, soils and building materials by the decay of radium-226 and thorium-228 respectively. Radon and thoron readily diffuse through solids along minute airways and enter the atmosphere. The concentration of radon and thoron in outdoor air is usually low as they are rapidly dispersed, but in buildings the concentration may build up. The immediate decay products of radon and thoron are solid radionuclides with short half-lives, which will attach to dust particles in the air and, when inhaled, will irradiate the lung. The air concentration of radon and thoron in a building will depend mainly on the concentration of radium-226 and thorium-228 in underlying soils and rocks and the design of the building, principally the ventilation rate and the underfloor structure. Very large variations in indoor concentrations of radon have been measured. Individual dwellings have been found in which the estimated radiation dose to the occupants was up to 100 times the national average.

2.2 Artificial sources

Approximately 13% of exposure to the UK population is due to artificial sources of radiation. This category includes additional exposure to natural sources of radiation brought about by industrial and technological practices. The largest contribution is that from medical exposures. The annual average doses to the UK population from medical and other artificial sources of radiation are also shown in Table 1.

Medical exposure, occupational exposure and some elements of miscellaneous exposure are not relevant to the discussion of environmental radiation, so are only noted briefly here. The doses from medical sources include doses from conventional X-rays, radiodiagnostic tests, radiotherapy by high-energy beams and radioactive implants and dental radiography. Clearly, some members of the population may receive no medical irradiation, while some patients undergoing radiotherapy receive very large doses. Similarly, occupational exposure is confined to a limited population, principally those employed in the nuclear industry and in underground mining. Exposure to miscellaneous sources includes exposure arising from the use of certain consumer products, notably older-style watches and timepieces luminized with radium. However, the major contributions in this category are doses to aircraft passengers from cosmic rays and doses to the population from coal-fired power stations.

The combustion of coal in a power station results in the emission of fly ash into the atmosphere. The ash contains, in a more concentrated form, the naturally occurring radionuclides that were originally present in the coal. Internal irradiation of the population occurs through the inhalation of ash and through the incorporation of radionuclides from deposited ash into foodstuffs. The radionuclides contributing most of the dose are lead-210 and polonium-210.

Artificial radioactivity is spread throughout the world as a result of nuclear weapons tests in the atmosphere which were carried out mainly in the late 1950s and early 1960s. Much of the radioactivity was initially injected into the upper atmosphere, from which it is transferred slowly to the lower atmosphere and then to earth. This process and the material are known as fallout. The radionuclides in fallout may be inhaled or ingested in foodstuffs, thus giving rise to internal exposure, principally from carbon-14, strontium-90 and caesium-137. External exposure is received from ground deposits of gamma ray emitting nuclides, principally caesium-137. Measurable levels of strontium-90, caesium-137 and plutonium fallout are still present in the atmosphere, although the current annual average dose from fallout in the UK is approximately 8 times less than the annual average received in the UK in the early 1960s from this source.

Artificial radioactivity is discharged to the environment from nuclear installations and to a lesser extent from some research, defence, medical and industrial establishments. The principal discharges which lead to exposure of the public in the UK are discharges to air of radioactive gases and particulates from operating nuclear reactors, discharges to air during nuclear fuel reprocessing, and discharges to sea of low-level liquid wastes produced during storage and reprocessing of nuclear fuel. These sources contribute 0.1% of the annual average dose to the UK population, and most is due to discharges from the BNFL installation at Sellafield in Cumbria.

3 Sources of radiation exposure in Cumbria

3.1 Variations due to natural and climatic influences

The average radiation dose received from natural sources by a member of the public in Cumbria is probably slightly higher than the UK national average, because the local igneous rocks contain higher levels of natural radionuclides than those found in sedimentary rocks over which the bulk of the UK population dwells. As a result, the average external dose due to terrestrial gamma rays is slightly higher, and a larger proportion of dwellings than usual is liable to have concentrations of radon and thoron above the national average.

The principal mechanism by which fallout from nuclear weapons tests is deposited on the ground is by entrainment in rainwater droplets, so that the level of deposited fallout is roughly proportional to annual rainfall. Hence, in Cumbria, the level of external irradiation from ground deposits and of internal irradiation from fallout radionuclides in locally produced foodstuffs may be somewhat higher than the national averages.

3.2 Discharges from the Sellafield installation

BNFL is authorized to discharge limited amounts of radioactivity to sea and air from the Sellafield installation. The discharges are managed with the twin aims of ensuring that the doses received by all persons are as low as reasonably achievable and that no individual exceeds the dose limit recommended by the ICRP. The ICRP currently recommends that no member of the public should receive a dose or committed dose in excess of 5000 μSv within any year from non-medical artificial sources, and also that the dose rate averaged over a normal lifetime from such sources should not exceed 1000 $\mu Sv\ yr^{-1}$. The NRPB has recently published a report which assesses the radiation exposure of members of public in west Cumbria as a result of discharges from the Sellafield installation (Linsley *et al.* 1984).

In terms of activity released and of estimated radiation dose to the population, the most important discharge from Sellafield is the discharge of liquid waste to the sea via a pipeline from the site. The principal radionuclides discharged via the pipeline are tritium, caesium-137, isotopes of plutonium and americium-241. Tritium, a radioactive isotope of hydrogen, is very rapidly dispersed and because of this, and because of its radiological properties, the radiation dose from it is negligible. Caesium-137, which remains soluble under most conditions, is also dispersed by the sea currents. However, caesium is preferentially taken up by fish, so that persons consuming fish caught in the Irish Sea are exposed to internal radiation from this source. It is estimated that, in 1980, a few hundred people who regularly consumed fish caught in coastal waters near Sellafield were receiving committed doses in a year from caesium-137 equal to about 10% of the current ICRP annual dose limit for members of the public, namely 5000 μSv; that is, they were receiving an annual dose from caesium-137 similar to the annual dose that they receive from the natural body content of potassium-40. More recent data show that current committed doses from caesium-137 in this population are considerably less. A much larger population in Cumbria and north-west England, who consume fish with lower average concentrations of caesium-137, caught further out in the Irish Sea, will receive much lower doses.

A proportion of caesium-137 and other gamma ray emitting fission products discharged to sea become associated with or attached to marine sediments. Some of the contaminated sediment is deposited on inter-tidal mudflats and beaches, where it forms a source of external exposure to those using the areas. On stony and sandy beaches near Sellafield, the average dose rate at one metre height is typically twice that found from terrestrial gamma rays. Above inter-tidal deposits of fine silt found in estuaries and enclosed harbours, such as at Ravenglass and Whitehaven, the dose rate may reach 10 or 20 times that due to terrestrial gamma rays. In assessing radiation doses from this source, allowance must be made for the period of occupancy. A few individuals who live on boats moored in Whitehaven harbour are estimated to receive annual doses of rather less than 10% of the ICRP dose limit from this source; that is, they receive doses from this source that are about equal to the national average dose from terrestrial radionuclides. Holidaymakers and locals who use the beaches for recreational purposes will receive very much lower doses.

Plutonium isotopes and americium-241 discharged from Sellafield also tend to become associated with marine sediments. These radionuclides do not emit significant amounts of penetrating radiation, and therefore are not a source of external exposure. However, if they are retained in the body, they deliver a relatively high dose per unit activity to the tissues in which they are incorporated. Currently, it is estimated that the highest exposure to individuals that occurs as a result of Sellafield discharges is due to the consumption of molluscs (mainly winkles and mussels) which tend to absorb or entrap plutonium isotopes and americium-

241 from the marine sediments. A few persons who consume unusually large quantities of local winkles have been identified. It is estimated that the committed dose in a year to these people is slightly less than 50% of the ICRP annual dose limit; that is, they receive committed doses from a year's intake of molluscs about equal to the UK annual average dose from all sources. Molluscs are not harvested commercially on the Cumbrian coast and the consumption of local molluscs is confined to a rather small population whose habits are liable to change from year to year.

The average measured concentrations of plutonium isotopes and americium-241 in soil and air in west Cumbria are higher at coastal locations than at inland locations, indicating that these radionuclides are from a maritime source. Recent studies have shown that fine sediment contaminated with these radionuclides may be injected into the atmosphere at the surf zone and transported inland by the wind. The resulting inland air concentrations vary with weather conditions, but activity from this source may be detected in soil up to 10 km inland. Committed doses to the local population from the inhalation of plutonium isotopes and americium-241 during a year can be estimated from concentrations of these radionuclides in air to be less than 1% of the ICRP annual dose limit. Plutonium and americium are only poorly taken up by plants and animals so that their concentrations in foodstuffs produced locally, although higher than elsewhere in the UK, do not give rise to appreciable doses.

Some radionuclides are discharged to air from the Sellafield site, principally gaseous emissions such as argon-41 and carbon-14, aerosols of fission products such as strontium-90 and caesium-137, and minor amounts of plutonium isotopes. These radionuclides are dispersed downwind from the site. Persons living nearby will be exposed to external irradiation from gamma ray emitting nuclides in the air, notably argon-41, external irradiation from accumulated ground deposits of gamma ray emitting nuclides, notably caesium-137, and internal irradiation from inhalation of radionuclides, particularly isotopes of plutonium. However, the total committed dose in a year from all these sources, even to a person living within 1–2 km of the site is estimated to be less than 1% of the ICRP annual dose limit.

Carbon-14, which is discharged mainly as carbon dioxide and is therefore taken up by plants during respiration, and ground-deposited radionuclides, such as strontium-90 and caesium-137, may enter the food chain, and are present in locally produced foodstuffs. The actual doses that are received by the local population are uncertain because foodstuffs produced near Sellafield are distributed widely and may be mixed with foodstuffs from other sources. It is estimated that a person whose total supply of meat and vegetables came from farms within 2–4 km of Sellafield would receive an annual dose less than 0.1% of the ICRP annual dose limit.

Table 2 summarizes the average doses estimated to have been received during 1980 by various population groups in Cumbria and north-west England, as a result of discharges from Sellafield; it also shows estimated doses to members of the critical group for each pathway, ie to the group of persons who are liable to be most highly exposed through that pathway. It should be noted that some persons may be members of more than one critical group; for example, those

Table 2. Summary of average doses (in 1980) to population groups in west Cumbria from Sellafield discharges (source: Linsley *et al.* 1984)

Pathway	Exposed population group Size	Location	Annual dose[1] (μSv) Average individual	Critical group[2]
Mollusc consumption	~100–500	Within 10 km of site and 1 km inland	~300	2500 (<10)
Fish consumption	1–2 million	NW England	~50	500 (<500)
External dose on inter-tidal areas	~10 000–100 000[3]	Coast from Solway to Barrow	<50	450 (<10)
Inhalation of resuspended marine material	~200 000	Within 10 km of coast, Solway to Barrow	~2	25 (<50)
Inhalation and external irradiation from discharges to air	~15 000	Within 10 km of Sellafield	~3	225 (<50)
Terrestrial foodstuff consumption	NK[4]	i. Within 10 km of Sellafield	<5	160 (<50)
	NK[4]	ii. Near the Ravenglass Estuary	NK[4]	400 (<10)

[1]Annual dose or committed dose from intakes in 1980 to an average member of each population group and to a member of the critical group
[2]The figures in brackets are estimates of the critical group size
[3]Includes holidaymakers
[4]Not known because of uncertain distribution of local foodstuffs

associated with the local fishing communities near Sellafield may consume molluscs and fish. The highest individual doses are those that arise from the consumption of molluscs, but the population group that is affected is small in number. The highest collective dose (ie the total dose to all persons receiving a dose from a particular source) comes from the consumption of fish, but Table 2 over-estimates the current annual dose as discharges of caesium-137 from Sellafield, and concentrations of caesium-137 in locally caught fish, have declined since 1980. Doses from the other pathways are likely to decline slowly in the near future, because they arise mainly from levels of radionuclides that have accumulated in the environment over several years.

In considering the radiological importance of the doses received as a result of discharges from Sellafield, it is to be noted that the doses are generally comparable with or much smaller than those received from natural sources. No group is exposed at rates in excess of the maximum limits recommended by the ICRP. However, even though doses to individuals are generally low, the most important criterion in managing future discharges is that doses to all persons should be kept as low as reasonably achievable, social and economic factors being taken into account. The application of this principle, together with consideration of the proximity of the doses received by the critical group to the ICRP dose limits, has contributed to the decision to install new equipment at Sellafield to reduce the discharge to sea of radiologically important radionuclides.

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INDUSTRIAL POLLUTION

Water quality and sources of pollution – Duddon Estuary, Walney Channel and Morecambe Bay

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Summary
The water quality of the Duddon Estuary, Walney Channel and Morecambe Bay is reviewed, and the major sources of pollution are identified. Water quality is generally very good, although there are some areas of lower quality, but these areas are not causing serious problems. Sewage contamination of molluscan shellfish is a problem, but it can be largely overcome by shellfish cleansing tanks, at a cost to the fisherman.

1 Introduction

The legal responsibility to control the discharge of effluents to the area rests with the North West Water Authority (NWWA) mainly under the Clean Rivers (Estuaries and Tidal Waters) Act 1960 until January 1985, and from then onwards under Part II of the Control of Pollution Act 1974.

Sea Fisheries Committees (SFCs) have limited pollution control powers by byelaws made under Section 5(1)(c) of the Sea Fisheries Regulation Act, 1966. Only non-Water Authority sewage discharges and industrial discharges outside 'controlled waters' (specified in the Clean Rivers (Estuaries and Tidal Waters) Act 1960) can be controlled and there are only 6 in the Lancashire and Western Sea Fisheries Joint Committee (L&WSFJC) District, all in Wales. This byelaw power is due to be repealed when Part II of the Control of Pollution Act 1974 is fully implemented.

Virtually all the water quality surveys in recent years on the estuaries of the area have been carried out by NWWA, in conjunction with the L&WSFJC, and in some cases with Lancaster University and local industry. A comprehensive water quality data set is available for the Heysham area from a 2½-year study by Evans (1979).

2 River inputs

The River Lune provides easily the greatest contribution to the freshwater flow into Morecambe Bay, accounting for nearly 50% of the total. The Rivers Kent and Leven are the next largest, being of similar size and accounting for about 30% of the total between them. The remaining 20% is distributed between the Rivers Wyre, Crake, Beela and Keer. The River Duddon has a similar flow to that of the Kent (Figure 1).

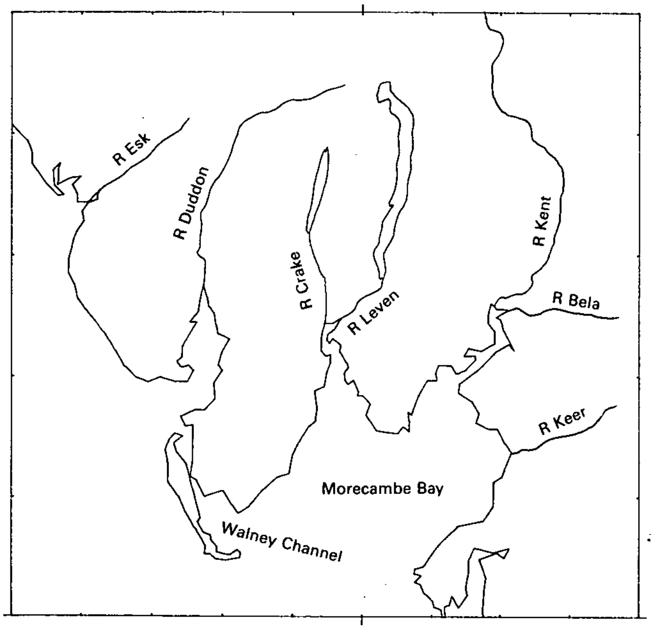

Figure 1. Map of southern Cumbria showing the location of the principal rivers referred to in the text

The major river inputs are sampled monthly as part of the Department of Environment (DoE) Harmonised Monitoring Programme, or as part of the NWWA internal 'key point' monitoring programme, which is effectively an extension to the DoE programme. Detailed water quality and associated flow data are therefore available for the Rivers Kent, Leven, Wyre, Lune and Duddon.

3 Nitrogen and phosphorus inputs

The nitrogen and phosphorus inputs to the estuaries are a good indicator of the polluting loads that they receive, and these loads are detailed in Table 1. The figures have been broken down into contributions from rivers, sewage and trade. The 'rivers' contribution includes any sewage and trade effluent discharged above the tidal limit and input from significant estuary tributaries. The 'sewage' and 'trade' contributions refer to any discharges direct to the estuaries (or small tributaries).

The 'river' inputs, particularly of nitrogen, derive almost entirely from diffuse runoff from agricultural activities, including the leaching of nitrates from fertilizers applied to the land. These contributions amount to 76% of the nitrogen discharged to Morecambe Bay. The large nitrogen contribution from the River Lune is rather surprising for a Class 1A river. Nearly all of this amount is in the form of nitrate rather than ammonium, and thus presumably derives from the leaching of fertilizers.

There is a marked seasonal fluctuation in the nitrogen loads, with the Morecambe Bay figure varying from 2–4 tonnes day^{-1} in summer to 20–30 t day^{-1} in winter.

The phosphorus loadings are quite different from those for nitrogen because sewage is the largest contributor.

4 Water quality of the individual estuaries

In the estuaries classification of the National Water Council scheme, all of the estuaries are in Class A, except the Walney Channel (north and south), the Wyre and the west side of the Kent Estuary, which are all Class B.

The only significant data on the water quality of Morecambe Bay itself are those of Evans (1979), who obtained approximately fortnightly samples at 30 min before high water about half a mile offshore on the edge of the Heysham Channel over a period of 2½ years. The water quality found was generally very good, particularly once an ammonium discharge from the Imperial Chemical Industries plc installation, near Heysham, ceased.

Between 1975 and 1977, L&WSFJC sampled a transect of stations between the Duddon and Fleetwood as part of their Offshore Water Quality Survey. Water quality was generally very good.

Stage 1 of the Central Electricity Generating Board (CEGB) Heysham Power Station discharges 4300 Ml day^{-1} of chlorinated cooling water and Stage 2 will discharge an equal volume when it becomes operational. There will be a 0.5°C temperature rise in the surrounding area, but it was predicted that the temperature rise for Morecambe Bay as a whole

Table 1. Inorganic nitrogen and phosphate – phosphorus loading to Morecambe Bay, Walney Channel and Duddon Estuary

Estuary	Nitrogen (kg day^{-1}) Rivers	Sewage	Trade	Total	Phosphorus (kg day^{-1}) Rivers	Sewage	Trade	Total
Duddon	170	38	0	208	9	13	0	22
Walney Channel – north	0	0	8.5	8.5	0	0	10.5	10.5
Walney Channel – south	0	424	0	424	0	141	0	141
Leven	1353	128	329	1810	27	43	129	199
Kent	1969	482*	0	2451	110	160*	0	270
Lune	4312	411	314	5037	162	81	1	244
Wyre	1484	310	472	2266	60	89	2	151

*Includes Morecambe and Heysham outfall discharges should be 0.1°C or less. The discharges of radioactive material from the power station are quite low and monitoring has shown that they are swamped by the material deriving from the British Nuclear Fuels plc (BNFL) site at Sellafield. Monitoring is being carried out by the CEGB, the Ministry of Agriculture, Fisheries and Food (MAFF) and by the local council under a county-wide scheme.

As the Wyre and Lune Estuaries are, strictly speaking, outside the scope of the conference, nothing more will be said about them. In any case, as they both discharge near to the mouth of Morecambe Bay on the southern side, it is unlikely that they have any direct effect on the Cumbria side of the Bay.

4.1 Kent Estuary

There are no large-scale water quality problems in the estuary but some quite serious local problems exist, particularly in the Grange-over-Sands area where discharges of crude sewage are made on to the foreshore. This is the area in Class B referred to earlier. Stage 1 of an improvement scheme is under construction at present at a cost of £2 million, with a further £1.3 million to be spent in Stage 2. When finished, the scheme will pump the sewage to a treatment plant near Humphrey Head where there will be an effluent discharge of good quality. The sludge produced will be disposed of to land.

The River Kent is a good salmon river, although not quite in the same class as the Lune.

4.2 Leven Estuary

The estuary is of good quality, except the tributary known as Carter Pool which is of Class C quality due to continuous discharge by Glaxochem Ltd of pharmaceutical effluent, and an ebb discharge of Ulverston town sewage. There is also an ebb discharge of high biological oxygen demand (BOD) waste from the Glaxo works at Hammerside Point, which has been shown to be well dispersed and diluted by the surveys carried out by NWWA and L&WSFJC.

Between 1977 and 1980, salmon fishermen complained of declining salmon and sea trout runs, and estuary fishermen complained of declining catches of flounders, cockles and other species in the Leven. They attributed these declines to the effect of the effluent discharged by Glaxochem. NWWA and L&WSFJC carried out joint surveys of the fish in the Leven Estuary and also in the Kent Estuary. No evidence was found to support the view of declining catches of salmon and sea trout, and variations in flounder and cockle catches were attributed to variations in the channels and sediments.

4.3 Walney Channel – south

The Walney Channel is really a tidal inlet rather than an estuary as it has only a very small freshwater input. At low water, it is separated by a bar from the northern half of the channel. It does receive a number of crude or partially treated sewage discharges, the largest of which is from Barrow-in-Furness. Some of the discharges include low concentrations of toxic metals derived from trade effluent. Water quality surveys have shown elevated coliform counts in the channel, and slightly elevated ammoniacal nitrogen concentrations, but there is no significant oxygen sag. Monitoring of shellfish from within the channel by the local authority Environmental Health Department has shown toxic metal levels to be a little above background levels.

4.4 Walney Channel – north

The northern part of the Walney Channel drains into the outer part of the Duddon Estuary, and thus needs to be considered separately from the southern part. There are only small sewage discharges to the area, but there are 2 large trade effluent discharges to the part of the area known as Scarth Hole. The discharges are from Bowater Scott Corporation Ltd and British Cellophane Ltd factories. The former effluent is a warm, neutral discharge containing suspended paper fibres, which is piped to just above the low water mark; the latter, however, is a hot, highly acidic effluent containing inorganic and organic sulphides and suspended organic matter.

Until September 1977, the British Cellophane effluent was discharged *via* a short pipe to the foreshore, but since then it has been piped to Scarth Hole with a diffuser sited in the deepest part of Scarth Hole. Surveys in this area up until 1976 had shown poor water quality, with low pH, high BOD and low dissolved oxygen saturations. Subsequently, greatly improved water quality has been found in Scarth Hole, although sulphide levels are not as low as might have been expected. The Bowater Scott effluent has a high phosphate content and that is shown in the phosphorus input figure in Table 1.

4.5 Duddon Estuary

The Duddon Estuary has no significant trade effluent discharges, and thus the major discharges to the estuary are of sewage from Askham (crude) and Millom (settled). The estuarine water quality is thus very good.

5 Molluscan shellfish contamination

The health hazards associated with the consumption of molluscan shellfish are well known. Bivalve molluscs are efficient filter feeders that concentrate particulate matter and associated micro-organisms from the large volumes of water that they pump through their gills. Because molluscs thrive in sewage-polluted waters, it is not surprising to find that large numbers of micro-organisms, including pathogenic bacteria and viruses, can occur within their shells. Thus, in Morecambe Bay, cockles and mussels are often found to have significant levels of *Escherichia coli* (10–30 *E. coli* ml^{-1}) even when not in the vicinity of a sewage discharge, while near sewage discharges these levels can be in the range 100–400 *E. coli* ml^{-1} or even greater.

Under the Public Health (Shellfish) Regulations 1934, District Councils may prohibit the sale for human consumption of shellfish taken from shellfish beds contaminated by sewage. However, if the shellfish are relaid in clean water, subjected to sterilization by steam or to a cleansing process, then they may be sold for human consumption. Whilst relaying in clean water is not usually a practical proposition, steam sterilization is commonly used for cockles and cleansing by the chlorination or ultra-violet light methods for mussels and oysters. A tank has recently been built at Morecambe for cleansing mussels by the ultra-violet method.

Unfortunately, the application of these Regulations has been very inconsistent, so that, while virtually all the shellfish beds in the area are covered by the so-called 'closing orders', in any one area only one type of shellfish may be covered. For example, the order covering the Hest Bank to Arnside area only deals with cockles, the order covering the Leven Estuary deals with cockles and mussels, the order for the Duddon only covers the lower half of the estuary and only deals with mussels, while another order bans the taking of cockles from within a 200 yard radius of the Askham sewage pipe.

Cleansing is an additional cost to the fishing industry, imposed upon it by the sewage disposal practices of the whole community. It really is about time that there was legislation to produce an efficient comprehensive system for dealing with sewage-contaminated shellfish beds, and to assign responsibility for the provision of cleansing facilities.

6 Conclusions

The water quality of the Duddon Estuary, Walney Channel and Morecambe Bay is generally very good, although there are some areas where improvements are needed. Sewage contamination of molluscan shellfish is a problem which can be largely overcome by cleansing, but the cost of installing cleansing tanks has undoubtedly hindered the development of the mussel fishery in particular.

7 Acknowledgements

The author wishes to thank D Crawshaw (NWWA) for providing much of the water quality data and the Lancashire and Western Sea Fisheries Joint Committee for permission to publish this paper.

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Man's influence on the lakes of Cumbria

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Summary

The lakes of Cumbria attract tourists, and this attraction has formed the basis of a major industry. It has also influenced the quality of water in the lakes either directly or indirectly. This paper is not an attempt to produce a comprehensive catalogue of 'pollution incidents' or other effects of man on the lakes; such a catalogue would be boring and would offer few solutions. Instead, I have chosen 2 events from the past, the discharge of sewage into Grasmere and the construction of the A66 at Bassenthwaite, and asked 'What can we learn from these experiences?' I then attempt to identify problem areas for the future based on experience elsewhere in the world and ask 'With hindsight, can we make a better job of tackling these problems?' The potential problems chosen are the effect of motor boating on Windermere and the incidence of bacterial antibiotic resistance in water used by the public for bathing.

1 Introduction

A lake in balance with its catchment exhibits some degree of stability, evolving on a fairly long timescale in response to the weathering of rocks and the changes in catchment use brought about by man, such as the cutting down of forests and the increase in area of land devoted to agriculture. During the summer months, our lakes stratify; in other words, the surface water warms up to around 20°C whereas the deeper water remains at 6–8°C. The transition with depth from warm to cool water is relatively sharp and the 2 waterbodies do not mix until the cooler weather and higher winds of autumn overturn the lake. The 2 parts of the lake have different functions. The surface water receives light and supports the growth of algae, and, as these plants, and other material brought into the lake, settle out into the deeper zones, they are decomposed by bacteria. The process of decomposition consumes oxygen, and in many of our richer lakes all the oxygen in the deep water zone is exhausted.

Man can influence these processes in many ways but usually does so by alteration of either the inorganic or organic inputs to the lake. By inorganic inputs, I mean compounds such as nitrates, phosphates and sulphates found in fertilizers and sewage effluents. The organic inputs include the carbon compounds found in sewage effluents, the fuel waste from motor boats and the discharge from certain industries such as paper mills. In many instances, the effects of such effluents are obvious but on other occasions, where chronic low-level pollution is involved, an understanding of long-term trends is required, if the impact is to be assessed with any accuracy. Long-term research programmes are therefore essential.

Before turning to the case studies mentioned above, I would like to demonstrate how long-term research at the Freshwater Biological Association (FBA) can play a part in management of fresh water in Cumbria.

Among the complaints heard most frequently about waterbodies are those which express a general concern and which are often the most difficult to answer satisfactorily.

'The water is not as clear as it used to be.'
'The fishing has gone off, far fewer fish are caught nowadays.'
'It's not been the same since the sewage effluent was piped into the lake.'

In Cumbria, the FBA has been involved not only in keeping long-term records of fish populations (Kipling & Le Cren 1984), but also in the management of fish stocks (Kipling & Frost 1972) to improve fishing. Other studies have shown how sea trout population structure has not changed in 50 years (Elliott 1985), although it is influenced periodically by droughts. It is essential to understand this background natural variability before we risk using relatively few observations to judge the impact of some potential pollutant.

Another example of the use of FBA's long-term records has been in the evaluation of the water quality of Esthwaite Water. A report by Talling and Heaney (1983) to the Nature Conservancy Council has formed the basis for management proposals for the removal of phosphorus from Hawkshead sewage effluent, which eventually discharges into the lake. The assessment of 'water quality', 'nutrient status', 'pollution load', 'man's impact' is only as precise as the question being asked. Thus, general questions will often result in unsatisfactory answers, whereas more specific questions about particular nutrients or pollutants are more likely to be resolved. The case studies described below fall into both categories.

2 The effect of sewage effluent on Grasmere

In the summer of 1971, the village of Grasmere was converted from septic tank to mains drainage with sewage treatment at an activated sludge plant. The effluent was discharged into the River Rothay, the main inflow of the lake. The main effect on the lake was that the rate of oxygen loss in the deeper water almost doubled, the phosphorus level in the lake increased significantly, and the ammonium level in the River Rothay increased by between 10- and 100-fold (Hall *et al.* 1978; Jones *et al.* 1980a). During this period, there was an observable increase in the numbers of water plants in the lake. The conversion of the village to mains drainage for public health reasons, had, therefore, affected the nutrient loading of the lake. When septic tanks were in use, their contents were removed elsewhere for treatment and, during use, any excess effluent escaped into the soil, where nutrients were removed before they reached the lake. The discharge of the effluent from the treatment plant into the River Rothay ensured its direct passage into the lake. After much local pressure, and several meetings with FBA, the North West Water Authority decided to divert the effluent and discharge directly at a deeper point in the lake. Thus, it was argued that the impact of the effluent would be confined to the depths of the lake. Direct discharge into the lake started in 1984 and, as expected, immediately caused a greater oxygen loss from the deeper water (Figure 1). The continuing effect of the change in discharge is being monitored by FBA.

Several points must be made about the treatment of sewage effluent at Grasmere. The North West Water Authority did not commission the sewage treatment plant, they inherited it, along with its attendant problems. Sewage treatment, particularly by the activated sludge process, is essentially a continuous process dependent on a more or less constant supply of sewage. Such a treatment system was chosen because it could be housed in a small building which was in keeping with the surroundings in the heart of the Lake District National Park. The alternative scheme would have been a much more extensive, and probably malodorous, trickling filter plant. Needless to say, the supply of sewage is far from constant at Grasmere, and therefore such a small plant was unlikely to be adequate. At weekends, and Bank Holiday weekends in particular, the population of Grasmere may double or treble, with attendant excessive consumption of alcoholic beverages and deep-fried food. The increased liquid flow in the sewerage system is therefore also carrying an additional load of fat and grease. Plans for improving treatment at Grasmere now include extra holding capacity at the plant to cope with peak demand.

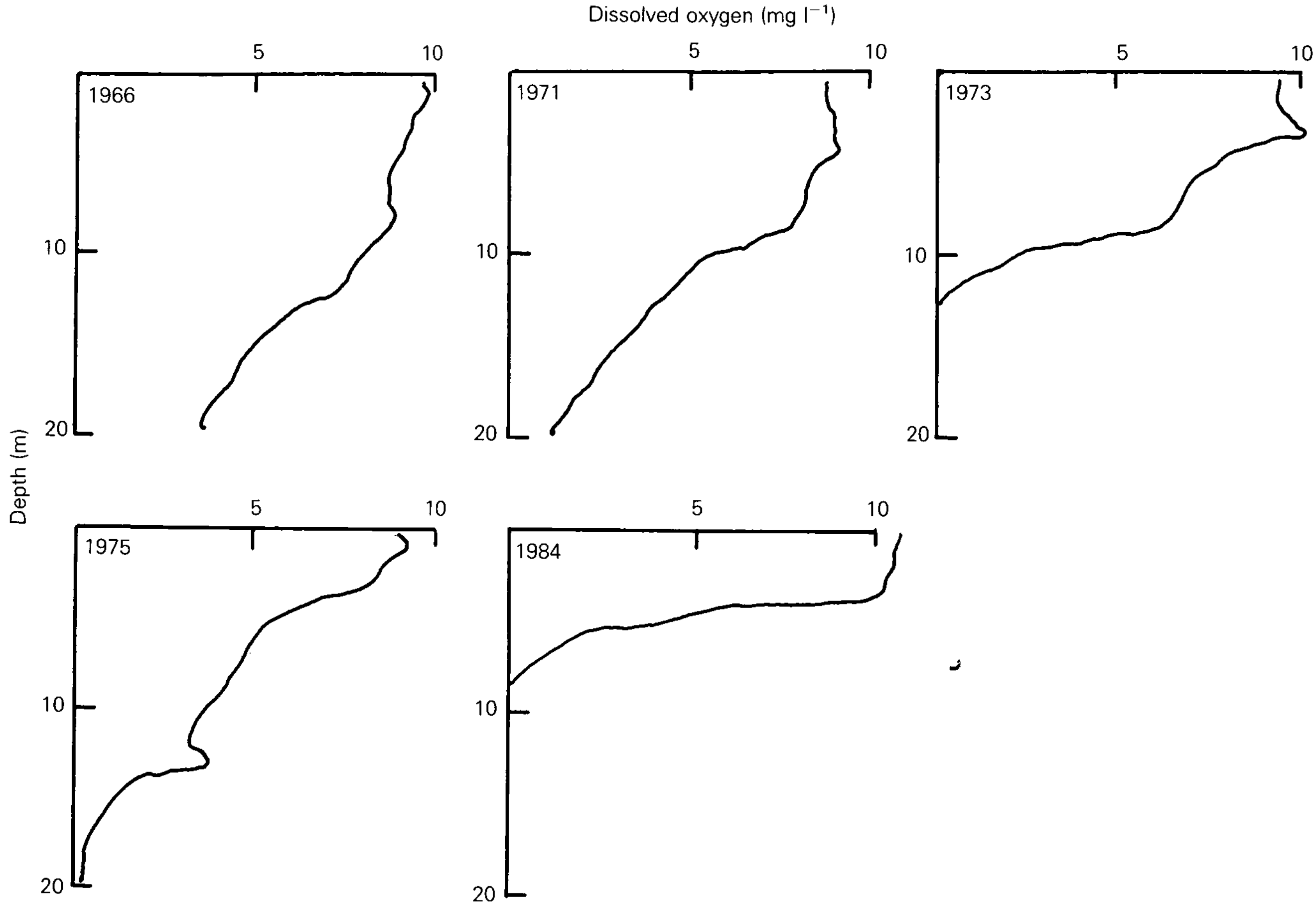

Figure 1. Oxygen concentrations in the water of Grasmere during August in years before (1966), during (1971) and after (1973, 1975) the conversion of Grasmere to mains drainage. In 1984, the treated sewage effluent was diverted and discharged directly to the lake (source: Hall et al. *1978; Hall, unpubl.)*

During the debate which surrounded these events, local pressure groups alleged that there had also been a marked increase in the quantity of water plants in the lake since the treatment plant had been commissioned. However, older residents of Grasmere recalled periods in the past when plant growth had been much more extensive. In this instance, quantitative long-term records were absent, but the value of consulting people who had lived in the area for several decades was evident. Grasmere has extensive shallow areas and is therefore vulnerable to excessive plant growth and silting. It should be monitored with care in the future. Should the present solution prove to be unsatisfactory, then the more expensive options of a more complete treatment at Grasmere or piping the effluent to Ambleside will have to be considered.

3 The effect of road construction on Wythop Beck
During 1976 and 1977, new sections of the A66 road were opened along the shores of Bassenthwaite Lake. Furnace slag and limestone had been used as hard core during the road construction and, at times, the lake water had become turbid. Guidelines for construction indicate that furnace slag should not be used on acidic sites or where the water table is likely to be high. Yet these are precisely the conditions prevailing at the northern end of Bassenthwaite, particularly in that part of the catchment which includes the lower drainage basin at Wythop Beck. The result was that large quantities of sulphide leached in highly alkaline water from the roadside drainage ditches of the A66 into Wythop Beck, and caused mortalities in the fish population. Five years later, one drainage ditch was still discharging water containing more than 200 μmol l^{-1} of sulphide (Figure 2). This concentration is 1000-fold greater than that required to cause a mortality of 50% of a trout population during a 4-day exposure. Fortunately Bassenthwaite Lake is relatively shallow and possesses a large catchment area in relation to its volume. Its flushing rate is therefore relatively rapid, and there is little evidence of permanent adverse effects on the lake itself (Jones *et al.* 1982). While such incidents are clearly avoidable, there may be occasions when treatment of inorganic pollutants such as sulphide must be undertaken. Under such circumstances, it is worth noting that many bacteria exist which are capable of converting inorganic as well as organic compounds into relatively harmless products. Indeed, the situation at Wythop Beck might have been worse had not a population of *Thiothrix* developed in the stream. *Thiothrix* is a filamentous bacterium which can convert sulphide into

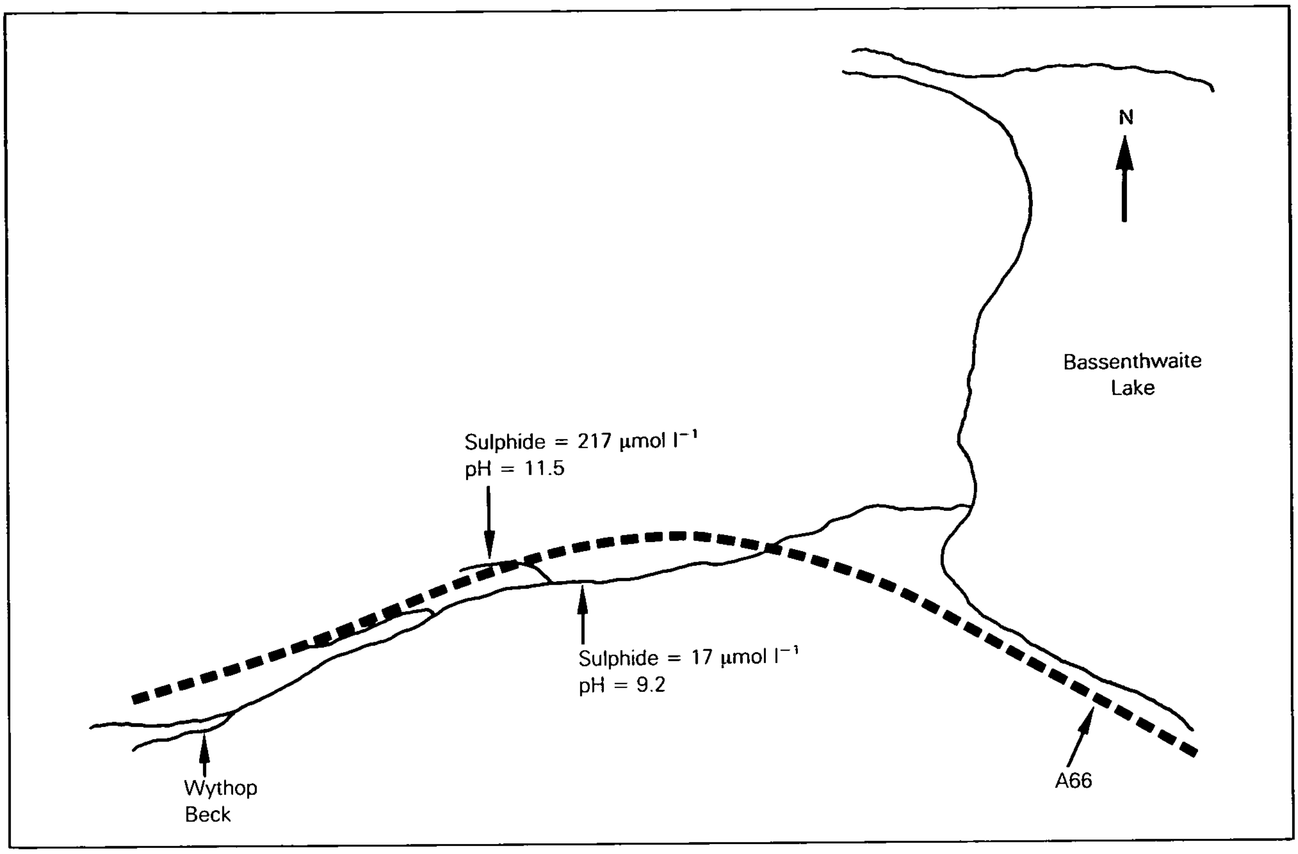

Figure 2. The effect of road drainage on sulphide levels in Wythop Beck. The 4-day 50% lethal dose for trout is 0.2 $\mu mol\ l^{-1}$ sulphide (source: Jones et al. *1982)*

elemental sulphur and deposits this harmless form as globules within its cells (Jones *et al.* 1982). Such organisms form the basis of the new biotechnology, a large part of which is devoted to the problem of disposing of man-made wastes and to environmental decontamination. Government agencies and the biotechnology industry are becoming increasingly aware of the fact that we have barely begun to exploit the vast potential of the bacteria which exist in the natural environment. A significant proportion of the microbiological research in FBA is devoted to the use of novel techniques developed at the laboratory for the isolation of such organisms.

4 The effect of motor boating on Windermere

With the closure of other lakes in Cumbria to high-speed motor boating, there is increased pressure on Lake Windermere. Apart from disturbance and over-crowding (which are already evident), what effect will the increased input of partially combusted 2-stroke fuels and other oil products have on the lake? We regularly receive requests for information from water undertakings who wish to allow motor boating on reservoirs but do not know what effect it will have on 'water quality'. The effects of petroleum hydrocarbons on waterbodies are many, but in this instance we are faced with a good example of the problems associated with chronic low-level pollution. The questions we must answer include the following. Do the petroleum hydrocarbons come from the motor boats? Is their rate of input such that the lake is unable to cope? Are they being concentrated as they pass up the food chain, possibly reaching toxic levels? To answer only the first of these questions will require an extensive study of Lake Windermere, including many expensive analyses. It will be necessary to determine what proportion of the petroleum hydrocarbons actually come from the motor boats. The few studies available are on lakes in North America, and these studies suggest that the contribution from boats can vary between 5% and 50% of the total input (Jones *et al.* 1980b). Other inputs can include sewage effluent, inflowing rivers, road runoff, atmospheric deposition and accidental spills. Although our national and European agencies have shown no interest in this problem, German authorities have now banned boats with engines larger than 10 horsepower from a major European lake. This ban was based, in my opinion, on inadequate scientific evidence, and is currently the subject of appeal to the European Court. Clearly, we must not repeat this mistake, but at the same time we must accept that the alternative will be an expensive scientific investigation.

5 The quality of water for public bathing

Lake Windermere was recently described by the then District Medical Officer for South Cumbria as a cesspit. The statement was incorrect, but unfortunately it received more publicity than the retraction which followed soon afterwards. There is no doubt that both the public and local authorities are rightly concerned about the public health dangers associated with swimming in our lakes. A monitoring programme was called for, but I would argue that in many instances the money would be better spent in stopping the sources of pollution than in paying scientists to conduct expensive surveys of our lakes. The public and their elected representatives are well aware of the point sources of pollution; their unsightliness and offensive odours are sufficient reason for demanding a solution. The announcement by the North West Water Authority that it intends to stop all overflow discharges between Lake Windermere and its treatment plant is therefore particularly welcome.

These measures will not, however, totally remove the possibility of public contact with sewage-contaminated water. Unfortunately, the medical profession is unable, as yet, to provide us with figures for a minimum infective dose. This information might be obtained by experiment or extensive surveys to correlate swimming and the incidence of gastro-intestinal disorders. The FBA has proposed that the Department of the Environment and the Department of Health and Social Security should consider funding such a survey. Although it would be costly, it might provide a greater level of sophistication in our care of amenity water.

There is increasing concern about the incidence of antibiotic resistance in the natural environment, and the possibility of its transfer to potentially pathogenic bacteria. The FBA will shortly be publishing research which shows that the incidence of antibiotic resistance is higher in Lake Windermere and remote upland tarns than in sewage effluent. I would like to emphasize, at this point, that such a resistance may merely reflect a natural lack of susceptibility among the bacteria of our lakes. It is only when such a resistance is shown to be transferable that we should be concerned about its effect on our lakes. At present, we have no evidence to this effect, although we shall continue to examine the possibilities of such transfers.

6 Acknowledgements
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Industrial pollution – prevention and control

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Summary
This paper briefly explains the more important legal constraints that water authorities use in controlling pollution, including the recently introduced Control of Pollution Act 1974, the Dangerous Substances Directive for List I and List II substances, and the Freshwater Fish Directive issued by the Commission of the European Communities (CEC), which member states are obliged to enforce. It then proceeds to explain the policies adopted by the North West Water Authority (NWWA) for surface water quality in the region, and the short-term and long-term objectives embodied in those policies.

The implications for those industries wishing to discharge their waste either direct to a watercourse or to the North West Water Authority's foul sewerage system are discussed, and the arrangements for local liaison and consultation are given.

1 Introduction
Almost all of Cumbria lies within the area of NWWA,

with a very small portion at the eastern side being in the adjacent Northumbrian Water Authority area. Industry is generally centred on the larger towns and on the western coastal strip and, although in the context of this paper it is true to say that the major industry in the county is based on agriculture, there is sufficient other industry present to make it clear that pollution problems can exist – especially if allowed to go uncontrolled.

Within the last 9 or 10 months, the various Acts which had provided the main framework for water pollution control in England and Wales for over 30 years have gone, and they have been replaced by an all-embracing and comprehensive piece of legislation called the Control of Pollution Act, which makes provision to control not only water pollution, but waste disposal, atmospheric pollution, pollution by noise and certain aspects of public health.

2 The changing legislation

Part II of the Control of Pollution Act is now being implemented. The Act establishes new, and extends existing, controls and its impact on industry will be substantial. The provisions of the Act make it an offence to discharge solid or liquid matter to 'relevant' waters, which include rivers, canals, enclosed waters in lakes or ponds, estuaries, the sea out to 3 miles offshore and certain specified underground waters.

Other important constraints on the way pollution is controlled are contained in directives issued by the European Communities Commission (1976). First, there is the Dangerous Substances Directive which requires member states to reduce pollution in both fresh and saline waters caused by the families or groups of dangerous substances specified by the Commission. This list of substances, which is the subject of a communication to the National Water Council (NWC), is extremely long. However, the Commission has established a first list, known as List I, of certain individual substances selected mainly on the basis of their toxicity, persistence and bioaccumulation, and it is the declared intention that these must be eliminated. Daughter directives have already been issued for mercury and cadmium.

The second list of substances, known as List II, contains substances which are known to have a deleterious effect on the aquatic environment but which can be confined to a given area and the effects of which depend on the characteristics and location of the water into which they are discharged.

As a first step towards fulfilling its obligations under this directive for the List II substances, national water quality standards have been established for lead, chromium, zinc, copper, nickel and arsenic which correspond to the environmental quality objectives which will most frequently be applied in the UK. Unlike those for List I substances, quality objectives and corresponding quality standards are to be set nationally rather than at Community level. It is for water authorities to establish the uses for which a particular body of water may be suitable and, hence, to define the environmental quality objectives. The water authorities will then determine discharge emission standards in the form of consent conditions, and will enforce them by using the Control of Pollution Act.

The second CEC directive (European Communities Commission 1978) which influences how pollution is controlled relates to the fresh waters needing protection or improvement in order to support fish life. Under this directive, certain waters have been designated as fisheries which require protection, and the quality of the water within these designated rivers is specified so that a satisfactory environment for the balanced development of freshwater fish is maintained.

3 North West Water Authority objectives

Quite early on in the life of the newly created water authorities, NWWA developed their philosophy and set about defining objectives for improving surface water quality for inland waters within the area (North West Water Authority 1978). In 1979, it adopted a policy for river water quality. The long-term aims of the policy are to restore and protect the river water quality of the region. The short-term aims are to prevent deterioration of the present situation and, as far as capital is available and local needs exist, to improve river water quality.

These objectives are related to and defined by the river classification system detailed in the NWC classification, which is shown in Table 1. This system sets out the water quality criteria for each river class and the potential uses for the water. On this basis, the following long-term objectives have been adopted (North West Water Authority 1983).

1. Existing Class 4 and Class 3 rivers to be improved to at least Class 2 where practicable.
2. Existing Class 2 rivers to be improved to Class 1A or 1B where reasonably practicable.
3. Existing Class 2 rivers, where it is not reasonably practical for improvement because of diffuse sources of pollution, should be maintained in their present classification.
4. Existing Class 1A and Class 1B rivers should be maintained in their present class.

More recently, the Authority has developed a tidal water quality policy and, although estuaries and tidal waters have a different but similar classification system (see Table 2), the short- and long-term policies are in line with those described above for rivers. The long-term objective would be attainment of at least Class B for all estuarial waters currently in a lower classification.

Table 1. Suggested classification of river quality

River class	Quality criteria	Remarks	Current potential uses
	Class limiting criteria (95 percentile)		
1A	i. Dissolved oxygen saturation greater than 80%. ii. Biological oxygen demand not greater than 3 mg l^{-1}. iii. Ammonium not greater than 0.4 mg l^{-1}. iv. Where the water is abstracted for drinking water, it complies with requirements for A2** water. v. Non-toxic to fish in EIFAC terms (or best estimates if EIFAC figures not available).	i. Average BOD probably not greater than 1.5 mg l^{-1}. ii. Visible evidence of pollution should be absent.	i. Water of high quality suitable for potable supply abstractions and for all other abstractions. ii. Game or other high-class fisheries. iii. High amenity value.
1B	i. DO greater than 60% saturation. ii. BOD not greater than 5 mg l^{-1}. iii. Ammonium not greater than 0.9 mg l^{-1}. iv. Where water is abstracted for drinking water, it complies with the requirements for A2** water. v. Non-toxic to fish in EIFAC terms (or best estimates if EIFAC figures not available).	i. Average BOD probably not greater than 2 mg l^{-1}. ii. Average ammonium probably not greater than 0.5 mg l^{-1}. iii. Visible evidence of pollution should be absent. iv. Waters of high quality which cannot be placed in Class 1A because of high proportion of high-quality effluent present or because of the effect of physical factors such as canalization, low gradient or eutrophication. v. Class 1A and Class 1B together are essentially the Class 1 of the River Pollution Survey (RPS).	Water of less high quality than Class 1A but usable for substantially the same purposes.
2	i. DO greater than 40% saturation. ii. BOD not greater than 9 mg l^{-1}. iii. Where water is abstracted for drinking water, it complies with the requirements for A3** water. iv. Non-toxic to fish in EIFAC terms (or best estimates if EIFAC figures not available).	i. Average BOD probably not greater than 5 mg l^{-1}. ii. Similar to Class 2 of RPS. iii. Water not showing physical signs of pollution other than humic coloration and a little foaming below weirs.	i. Waters suitable for potable supply after advanced treatment. ii. Supporting reasonably good coarse fisheries. iii. Moderate amenity value.
3	i. DO greater than 10% saturation. ii. Not likely to be anaerobic. iii. BOD not greater than 17 mg l^{-1}*.	Similar to Class 3 of RPS.	Waters which are polluted to an extent that fish are absent or only sporadically present. May be used for low-grade industrial abstraction purposes. Considerable potential for further use if cleaned up.
4	Waters which are inferior to Class 3 in terms of dissolved oxygen and likely to be anaerobic at times.	Similar to Class 4 of RPS.	Waters which are grossly polluted and are likely to cause nuisance.
X	DO greater than 10% saturation.		Insignificant watercourses and ditches not usable, where objective is simply to prevent nuisance developing.

Note
(a) Under extreme weather conditions (eg flood, drought, freeze-up), or when dominated by plant growth, or by aquatic plant decay, rivers usually in Classes 1, 2 and 3 may have BODs and dissolved oxygen levels, or ammonium content, outside the stated levels for those classes. When this occurs, the cause should be stated along with analytical results.
(b) The BOD determinations refer to 5-day carbonaceous BOD (ATU). Ammonium figures are expressed as NH_4.
(c) In most instances the chemical classification given above will be suitable. However, the basis of the classification is restricted to a finite number of chemical determinands and there may be a few cases where the presence of a chemical substance other than those used in the classification markedly reduces the quality of the water. In such cases, the quality classification of the water should be downgraded on the basis of the biota actually present, and the reasons stated.
(d) EIFAC (European Inland Fisheries Advisory Commission) limits should be expressed as 95% percentile limits.

* This may not apply if there is a high degree of re-aeration.
** CEC category A2 and A3 requirements are those specified in the CEC Council directive of 16 June 1975 concerning the quality of surface water intended for abstraction of drinking water in the member states.

Table 2. National Water Council classification of estuarial quality

1 The points awarded to each area under the headings of biological, aesthetic and chemical quality in Table C1 are summed, and the area classified according to the following scale.

Classification	Number of points	Description
Class A	30–24	Good quality
Class B	23–26	Fair quality
Class C	15–9	Poor quality
Class D	8–0	Bad quality

2 Classification of an estuary is summarized according to the length in each class. The length of an estuary is normally measured along its centre line from the landward limit to the seaward limit of the survey. Where the classification is different from one side to the other, the length of estuary affected is allocated proportionally between the different classes.

TABLE C1 – ALLOCATION OF POINTS FOR ESTUARY QUALITY

Biological quality (scores under a, b, c and d are summed)	Points awarded if the estuary meets this description
a. Allows the passage to and from fresh water of all relevant species of migratory fish, when this is not prevented by physical barriers (relevant species includes salmonids, eels, flounders and cucumber smelts, etc).	2
b. Supports a residential fish population which is broadly consistent with the physical and hydrographical conditions.	2
c. Supports a benthic community which is broadly consistent with the physical and hydrographical conditions.	2
d. Absence of substantially elevated levels in the biota of persistent toxic or tainting substances from whatever source.	4
Maximum number of points	10

Aesthetic quality (one description only is chosen)	
a. Estuaries or zones of estuaries that either do not receive a significant polluting input or which receive inputs that do not cause significant aesthetic pollution.	10
b. Estuaries or zones of estuaries which receive inputs which cause a certain amount of aesthetic pollution but do not seriously interfere with estuary usage.	6
c. Estuaries or zones of estuaries which receive inputs which result in aesthetic pollution sufficiently serious to affect estuary usage.	3
d. Estuaries or zones of estuaries which receive inputs which cause widespread public nuisance.	0

Chemical quality (one value only is chosen)		
Dissolved oxygen exceeds a saturation value of:	60%	10
	40%	6
	30%	5
	20%	4
	10%	3
	below 10%	0

Table 3 gives the lengths of river in each class in Cumbria. It shows that the length of non-tidal river that needs to be brought up to the minimum acceptable standard of Class B is 109 km, which is only 3.8% of the total length of the classified stretches. It is also clear from this Table that only 6 km of tidal rivers need to be brought up to this standard, representing 2.3% of the total of estuaries in Cumbria.

Table 3. The lengths (km) of rivers in Cumbria assigned to each of the river water quality classes

i. Non-tidal rivers					
River class	1A	1B	2	3	4
Length (km)	2365	414	121	70	39
ii. Tidal rivers					
River class	A	B	C	D	
Length (km)	215	48	6	0	

4 Industrial effluent disposal

Industry disposes of waste waters in 2 ways – either by discharging direct to a watercourse or by discharge to a sewerage system for treatment at works operated by this Authority. It is, in fact, the policy of the Authority to persuade industry to connect to the foul sewer wherever possible, and in such cases a charge is levied to cover the costs in accepting and treating the waste.

For those industries continuing to discharge direct to river, there will be cases where attainment of the long-term objectives will require the installation of additional treatment plant by the industry concerned to produce the effluent standard required, just as this Authority would need to install extra treatment at its own sewage works.

In the case of industry discharging to sewer, when additional sewage treatment is installed, so costs to industry rise, as for consumers generally. It is not possible to quantify the additional costs to industry because each process is different and the needs of the receiving waters and the standards required can be different. Thus, each industrial discharge is dealt with individually, using the overall guidelines which have been described previously.

However, it is of very great importance that industry should be in step with this Authority in its efforts to improve river water quality in the area, and that both the Authority and industry should work closely together in planning how best to achieve these improvements.

5 Local liaison arrangements

The Authority has a small team of River Inspectors who work from their homes, who are part of the local community and know its particular problems, and who are assigned to Districts based on river catchments.

Each District has a Senior River Inspector who organizes the day-to-day workload of the Inspectors under his control. These are the people very much at the sharp end of things, who bear the brunt of public complaints and who will probably be the first contact an industry will have with this Authority. The administrative centre for these Inspectors in the north is in Carlisle, and there is a radio network system so that they can make contact, or be contacted, as required.

It is the Inspector's job to maintain regular liaison, and to foster good relations, with the industrialists in their area, to get to know their manufacturing processes and to familiarize themselves with the problems which might affect effluent discharge, and hence water quality. It is also their job to get involved in discussions, at a very early stage, whenever an industry intends to expand production or change process, so that the question of consent conditions and the implications can be fully explored before detailed designs are completed. This involvement will result in consents being tailored so that pollution is avoided and yet, hopefully, without being unnecessarily restrictive on the industrialist. It is important therefore to regard the local River Inspector as an ally in whom the industrialist can confide and to whom he can turn for advice and assistance in any problem he might have relating to an effluent discharge.

6 Conclusions

Environmental protection means getting rid of or preventing unacceptable damage wherever practicable and reducing risk. It does not mean that we should never discharge the waste of our society into the environment. Our aim must be to set goals of environmental quality which take account of the uses we wish to make of particular environmental resources, and of the feasibility and cost of achieving these goals. The North West Water Authority has adopted a policy which will mean that the rivers in the region will eventually reach a minimum acceptable standard. This Authority cannot tackle this task alone, and many other bodies from the public, private and voluntary sectors have essential roles to play.

However, it does not mean that we will not move progressively towards higher goals, taking advantage of technical advances, but it does mean that we will give top priority to tackling the worst problems vigorously and to restoring as much of the environment as possible to an acceptable quality in the best achievable timescale.

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The risks of pollution associated with waste disposal in Cumbria

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Summary

1. A wealth of derelict land exists in Cumbria, although much of it has the potential to cause pollution by the tipping of domestic and industrial wastes.
2. The use of this derelict land is likely to continue into the foreseeable future.
3. Care is needed in the selection of sites and, for those selected, appropriate techniques must be adopted for their preparation and operation in order to minimize their impact on water resources.
4. Care must also be adopted in the re-use of waste materials, again with the aim of minimizing the impact on water resources.
5. As a general rule today, the co-operation of the waste disposal authority and private developers is gained in achieving the above aims. It is certainly the aim of this Authority not to permit the development of sites that will give rise to the problems described. I would like to think that this view is shared by the waste industry in Cumbria.

1 Introduction

Approximately 1.5 million tonnes of wastes are produced annually in Cumbria consisting of a variety of waste products (Table 1). Almost all of the household and commercial wastes are disposed of at landfill sites operated by the County Council. Similarly, by far the greatest proportion of industrial wastes, demolition and construction wastes, together with smaller quantities of medical, veterinary wastes and sewage sludges, use landfill for disposal.

In order to minimize environmental damage, the disposal of waste on landfills is controlled by legislation, namely the Control of Pollution Act 1974, Part I, Waste on Land. This Act is administered by the waste disposal authorities which for England and Wales are the County Councils. The legislation provides that all sites have a licence which controls many aspects of environmental concern in the operation of a site – aesthetic appearance, wind-blown litter or dust, mud on roads, noise, vermin and odour. The water authorities are required by statute to be consulted in order to provide protection of water resources.

Table 1. Summary of wastes arising in Cumbria in 1979

General category of waste	Tonnes
Household and commercial	230 000
Industrial	297 215
Medical, surgical, veterinary	2 875
Mine and quarry	538 000
Construction and demolition	415 000
Sewage sludge	36 000
Old vehicles	167
Total	1 519 257

The aim of this paper is to explain where and how wastes are disposed of, with an illustration of the risks of pollution by a number of examples from Cumbria.

2 The risks of pollution

Cumbria has a wealth of minerals including coal, iron ore, non-ferrous ores, slate, limestone, hard rocks (for aggregates), sand, gravel and a variety of building stones. Their extraction has created areas of derelict land, generally with quarries. The need to return this derelict land to better use has traditionally meant that these quarries have provided the principal source of waste disposal sites. Similarly, some sites exist on marginal land where there is again a demand to restore to better agricultural use. However, mineral extraction will continue and increased pressure to restore these sites, coupled with the relatively cheap development of waste disposal compared with other methods, means that landfill will continue into the foreseeable future.

Many of these sites are below the water table; others are fissured (eg sandstone and limestone) or are porous (sand and gravel), thus allowing easy movement of water and presenting a high risk of water pollution, if developed without protection measures for waste disposal purposes.

It is often incorrectly assumed that it is the 'toxic' wastes that are the principal causes of water pollution. In fact, such wastes (now defined as those considered to present a danger to life) only represent a small proportion of the total amount of wastes arising, particularly in Cumbria, and their movement and disposal are very strictly controlled by regulations. By far the greatest potential to cause pollution derives from the disposal of domestic, commercial and other industrial wastes.

Water from rainfall or ground water movements infiltrates the landfills and dissolves those substances which are soluble and those formed during the chemical and biochemical processes occurring within the decaying waste mass. Vegetable matter, waste food, and even paper and cardboard undergo decay, releasing organic compounds and ammonium into solution. Metal objects, such as tin cans, corrode, releasing dissolved metals into solution. The water within the landfill therefore becomes contaminated, although the strength and amount vary greatly depending on the hydrogeology of the site and the chemical and physical conditions within the landfill. In freshly tipped areas, the leachate can reach concentrations equivalent to approximately 100 times that of crude domestic sewage, although, typically, it is in the order of 20 times that of crude sewage (Table 2). The problem of leachate generation is particularly marked in Cumbria owing to the high rainfall. About one-third of the county has rainfall approximately twice the national average, with some areas having rainfall exceeding 4 times the national average. Consequently, the refuse soon achieves saturation and free-draining leachate can very rapidly move out of the site and cause pollution, unless controlled or removed off the site for treatment.

Table 2. Results of analysis of 2 samples of leachate from recently emplaced and 'aged' domestic wastes (all units except pH are mg l^{-1})

	Recently emplaced wastes	Aged wastes
pH	7.1	7.1
Chemical oxygen demand (COD)	11 600	125
Biological oxygen demand (BOD)	7 250	5
Total organic carbon (TOC)	4 440	40
Ammoniacal nitrogen	340	40
Oxidized nitrogen	<0.5	2
Orthophosphate	0.2	<0.02
Chloride	2 100	225
Sulphide	460	—
Iron	160	0.1

3 *Effects of pollution*

The leachate generated is organic in nature, and is thus degraded in the stream by bacteria and other micro-organisms. This process depletes the oxygen content, altering the chemical and biological quality and, in extreme cases, resulting in the asphyxiation of fish. Typically, it gives rise to the filamentous or slimy gelatinous growths referred to as 'sewage fungus' on the stream bed. It must be emphasized that extremely low concentrations (less than 1 mg l^{-1}) of certain low molecular weight sugars resulting from the breakdown of paper can give rise to these growths, particularly in swift-flowing highly oxygenated conditions typical of many upland Cumbrian streams. Several pollution problems below Cumbrian tip sites have manifested themselves in this way.

Inorganic matter such as iron will settle and blanket the bed, choking weed growth, which in turn eliminates organisms upon which fish can feed. Discoloration also results, creating the typical rusty (ochre) appearance similar to problems below mine drainage discharges.

Toxic matter, such as ammonia and some heavy metals (eg lead and copper) may kill stream life directly. Taste and odour problems may result if, for example, the stream is used as a source of water supply.

Ground water pollution differs from that of surface water because it cannot easily be observed, and the relatively slower rate of movement of pollutants through the ground water to an abstraction borehole or spring will probably mean that, once pollution is detected in the borehole, a large block of aquifer (ie a water resource bearing rock) will have been contaminated. Such contamination may well have been occurring for a period of years and rehabilitation of the aquifer may be technically impossible or require considerable expense, resulting in the permanent loss of a water resource.

4 *Pollution problems in Cumbria*

To illustrate the problems, I have selected 2 cases in Cumbria where pollution has occurred from sites used principally for domestic and commercial wastes.

The first is Flusco Quarry, a former limestone quarry near Penrith. Pollution was first detected at a spring in a limestone fissure at a farm about 1.5 km distant from the site. Tracing work revealed the tip to be the cause. The degree of contamination of ground water, bearing in mind the distance between the site of origin and the site of emergence of pollution, was therefore likely to be extensive and certainly use for future supplies is doubtful. The stream, a tributary of the River Petteril, and the main river itself showed signs of gross pollution, being coated with sewage fungus and iron ochre staining. At some points, the stream was black and smelt strongly of hydrogen sulphide. Pollution on this scale is not easy to resolve and a 'last resort' approach using chemical treatment (hydrogen peroxide) has been applied at the spring discharge. This measure is particularly successful in controlling the extent of fungal growths and the sulphide problem. However, there remain localized ochrous deposits and the ammonia still causes a change in the classification of the river from National Water Council Class 1B to 2 (see Hughes (1986) for details of the river classification system).

It must be noted, however, that the ground water pollution still continues.

The second example concerns a gravel quarry, Peth Quarry, at Longtown, near Carlisle. In this case, the coarse gravel remaining at the site and extending outside of the quarried area has allowed the rapid movement of leachate to the adjacent stream and the

Border River Esk shortly after commencement of filling at the site. Fungal growths were profuse and extended a considerable distance downstream of the main river, and this problem was a source of complaint by anglers and the general public for several years. An almost irretrievable pollution problem resulted as it was not possible to intercept ground water or leachate. Again, as a last resort, hydrogen peroxide dosing was used to treat the stream chemically. This measure was partially successful in controlling the fungal growths in the main river, but 3 years on from the closure of the site the pollution continues.

These problems can be avoided by careful site selection and, for those that are selected, by adopting suitable techniques to minimize leachate generation. Additionally, it is possible to treat leachates which do result or to remove them from the site altogether for treatment at this Authority's sewage treatment works.

5 Recycling and re-use of materials

Considerable discussion has taken place relating to the recycling and re-use of waste material in the belief that this is an otherwise wasted resource, and partly in the belief that pollution would be minimized. However, the removal of the recyclable components, eg glass and metals, would still leave those components responsible for causing pollution.

Incineration may be considered as an alternative but this method is extremely costly, eg 4–5 times more costly than landfill. Even then, the bulky items and the residual ash can comprise about 30% of the original weight of refuse and still require to be disposed of by landfill. It is clear therefore that landfill will continue to be the principal means of waste disposal. It follows that, if pollution is to be avoided, then careful site selection must be adopted and operational techniques used in the preparation and operation of the site to minimize leachate production.

Some mineral extraction and industrial processes have given rise to above-ground spoiling of land. I refer, for example, to the colliery spoil heaps and slag banks to be found in the Barrow-in-Furness and Workington areas. The following example demonstrates the care that is required in considering the re-use of these materials.

Blast furnace slag had stood at Workington for many years without causing pollution. It was chosen as a foundation material in the construction of the new A66 Keswick to Workington trunk road. The streams draining land where this material had been used in order to stabilize the ground in peat bogs began to show signs of pollution, smelling strongly of hydrogen sulphide and becoming covered with bacterial growths identified as the hydrogen sulphide-oxidizing bacterium *Thiothrix*. Few migratory fish entered these streams as the level of sulphide was above that known to produce avoidance reactions in salmonids. The slag contained appreciable quantities of sulphide and sulphate, and the cause was believed to be attributable to the interaction between the sulphide and sulphate and the acid ground water in the peat. Since investigation of the problem, slag has not been used in areas below the water table in peat, and further problems have not arisen.

The lesson to be learned is that care is required in investigating the properties of waste materials, and in selecting sites where apparently harmless waste materials appear to have a useful role.

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Responses of plants to sulphur dioxide and oxides of nitrogen pollution

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Summary
SO_2 and NO_x are the main primary pollutants produced by combustion processes, and the evidence that combinations of these pollutants can influence the growth of plants is presented here.

There is currently insufficient information to evaluate the effects of SO_2 and NO_x on vegetation in Cumbria, yet the influx of cars and the proximity of major conurbations mean that Cumbria is potentially exposed to the same problems that are developing elsewhere.

1 Introduction

SO_2 and NO_x are the main primary pollutants produced by combustion processes. Most fossil fuels (coal, oil, natural gas) contain sulphur which is oxidized on combustion to give SO_2. The fuels may also contain some nitrogen, but this is not the main source of NO_x. The heat of combustion causes N_2 and O_2 from the air to combine to produce nitrogen monoxide (NO) which is subsequently oxidized in the atmosphere to nitrogen dioxide (NO_2). The ratio between NO and NO_2 in polluted atmospheres is very variable, which is why it is convenient to refer to this form of pollution as NO_x.

Until comparatively recently, SO_2 was regarded as the major air pollutant of widespread concern in industrialized countries. In the 1950s, however, NO_x began to attract attention in the United States because it acts as a source of ozone, which is very toxic to animals and plants. NO_2 can react with O_2 to give O_3+NO, and, because the NO is subsequently re-oxidized to NO_2, ozone formation can be a continuing process from a given amount of NO_x in the atmosphere. Ozone formation is, however, less rapid in cooler climates, and it was first thought that it would not be a serious pollution threat in western Europe. Then, in the unusually hot summer of 1976, alarming levels of ozone were recorded; for example, in southern England the concentrations exceeded 200 ppb, more than 5 times the natural level. Since that time, more attention has been paid to ozone pollution in many parts of Europe, and there is no doubt that concentrations damaging to plants occur from time to time (Ashmore *et al.* 1980).

The attention given to NO_x as a source of ozone has led to a realization that it may also be important as a toxic pollutant in its own right. NO_x emissions have been increasing steadily since the 1940s, and have continued to rise in recent years when emissions of SO_2 have been falling (Barrett *et al.* 1983). Although there are some concentrated local emissions of NO_x (such as nitrogenous fertilizer factories), the sources that are mainly responsible for the continuing upward trends are widely distributed (eg motor cars). This wide distribution means that only the most remote regions in western Europe are likely to escape significant pollution from NO_x. There is increasing concern about NO_x in areas, such as the Black Forest, where the density of cars is high in summer, and which are not located far from major centres of population (Lichtenthaler & Buschmann 1983).

It is not possible to say whether SO_2 and NO_x are likely to be causing damage to vegetation in Cumbria, because there is insufficient information on their concentrations in the atmosphere. However, the speed with which pollution injury to forests in Germany has developed over the last decade suggests that a close watch should be kept on the situation in the Lake District. The increasing influx of cars, and the proximity to major conurbations such as Merseyside and Greater Manchester mean that Cumbria is potentially exposed to the same problems that are developing elsewhere.

In this paper, we shall summarize some of the evidence that combinations of pollutants, particularly NO_x and SO_2, influence the growth of plants. Our knowledge is still very sketchy, but we are beginning to understand some of the basic processes involved.

2 Fumigation studies with SO_2 and NO_2

Most of the research into effects of pollutants on plants conducted up to 1970 had been performed with single gases, and there was a substantial amount of information on the effects of SO_2 alone. From the results of these studies, some scientists had concluded that SO_2 was unlikely to constitute a threat to vegetation, except in a few heavily polluted areas. However, because most sources of SO_2 also produce NO_x, the effects of the 2 pollutants together were studied and it was discovered that greater-than-additive effects can occur. Some of the results of research in the 1970s were reviewed by Mansfield and Freer-Smith (1981).

From the most recent investigations, we have begun to obtain information of the kind which will ultimately enable us to understand the complex phenomena that determine effects seen in the field.

1. It has been possible to produce good dose–response relationships from fumigations under

controlled conditions. The data in Figure 1 show the results obtained in a recent study of smooth meadow-grass (*Poa pratensis*) (Whitmore 1985). A smooth curve of this kind can only be achieved by treating plants of uniform age in a carefully controlled environment. Nevertheless, we have good reasons to believe that the basic character of these responses, *viz* growth stimulation by low doses and a sharp turnabout to inhibition as the dose increases, is the same for different plant species growing under different conditions. For example, Freer-Smith (1985) found growth stimulation in silver birch (*Betula pendula*) exposed to 3000 ppb days, but large inhibitions (eg 25–50% reductions in leaf area) in 7000 and 9000 ppb days of SO_2+NO_2.

2. We have learned to expect different effects under different environmental conditions, and out-of-doors this means that responses may change at different times of year. A pollution dose that is toxic to plants under slow-growing conditions may stimulate growth under more favourable conditions. Figure 2 shows that growth inhibitions which occurred in smooth meadow-grass in winter were followed by a marked recovery in spring and summer. However, flowering was much reduced in the plants exposed to SO_2 and SO_2+NO_2, probably because they were so much smaller than the controls at the time of flower initiation in March.
3. Although SO_2 and NO_2 often seem to act synergistically in causing damage, they do not always do so, and sometimes the responses are additive or less-than-additive. In a long-term experiment such as that in Figure 2, responses change so much as time progresses that it is not possible to make concise statements about the precise nature of the combined action of the 2 pollutants.

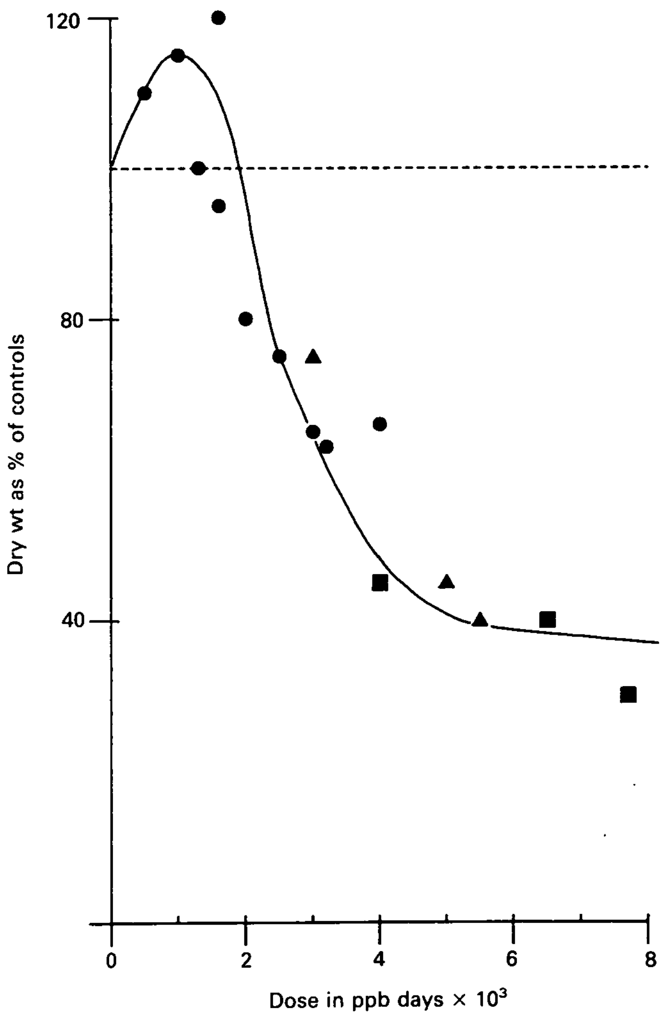

Figure 1. Dose–response curve showing effects of SO_2+NO_2 mixtures on growth of smooth meadow-grass. The results of several experiments under similar conditions are included. Dose is defined as concentration in ppb × days of exposure. Concentrations were 40 ppb (●), 70 ppb (▲) and 1000 ppb (■) applied for periods between 4 and 50 days (Example of calculation: 40 ppb SO_2 + 40 ppb NO_2 for 20 days = 1600 ppb days)

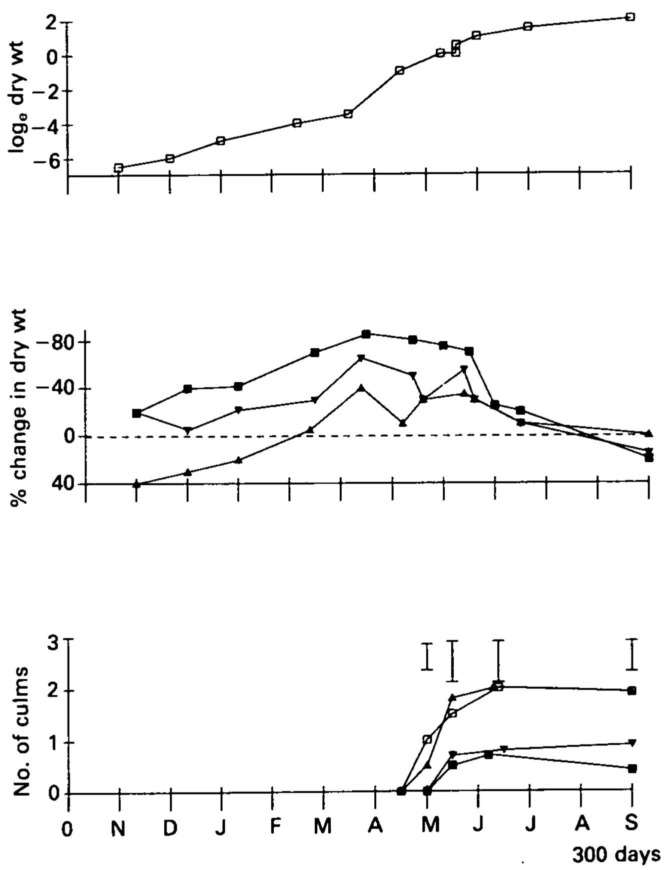

Figure 2. Effects of exposure to 62 ppb SO_2 (▼), 62 ppb NO_2 (▲) or 62 ppb SO_2 + 62 ppb NO_2 (■) on growth and flowering of smooth meadow-grass. Plants were exposed from germination in October 1980 to September 1981. The upper graph shows dry weight changes for the controls (□), these being for the whole plant until May and thereafter for the shoots only. The vertical bars indicate least significant differences (P<0.05) in numbers of culms (eg flower-heads)

4. In the case of woody plants, the changes in response that occur during long fumigations suggest that cumulative effects may be of utmost importance in the field. Figure 3 shows that, for small-leaved lime (*Tilia cordata*), there were no reductions in growth during the first year of exposure, but marked reductions in the second year. With downy birch (*B. pubescens*), however, inhibitory effects were seen clearly in the first year and were of increased magnitude in the second. Further information on the responses of broadleaved trees is provided by Freer-Smith (1984, 1985).

3 *Effects of SO_2 and NO_2 in the field*

It will be clear from the foregoing paragraphs that effects under field conditions are very difficult to predict because of the multiplicity of factors that can influence the response of a given species, and also because different species may respond differently to the same apparent dose.

Dose–response studies like that in Figure 1 suggest that growth *stimulation* as a result of exposure to SO_2+NO_2 may often occur in rural Britain. It is important to recognize that increases in growth are not always desirable. It is not difficult to explain such growth stimulation effects, because both sulphur and nitrogen are important nutrients in plants and their supply often limits growth. Uptake of SO_2 and NO_x into leaves provides soluble forms of the 2 elements which are usable in normal metabolism. However, it is well known to agriculturists that the time of supply of mineral nutrients is important, and that stimulation of growth at certain times of year can have deleterious effects. Increased supplies of nitrogen are often found to induce 'soft growth', ie new growth which has low resistance to biotic and abiotic stresses. Greater infestations by insect pathogens are documented for plants growing in atmospheres polluted with SO_2 and/or NO_2 (Port & Thompson 1980; Dohmen *et al.* 1984). Increased nitrogen can reduce tolerance of frost, drought and heat in various kinds of plants (Levitt 1972). SO_2 has recently been shown to reduce frost resistance in grasses and cereals (Baker *et al.* 1982; Davison & Bailey 1982).

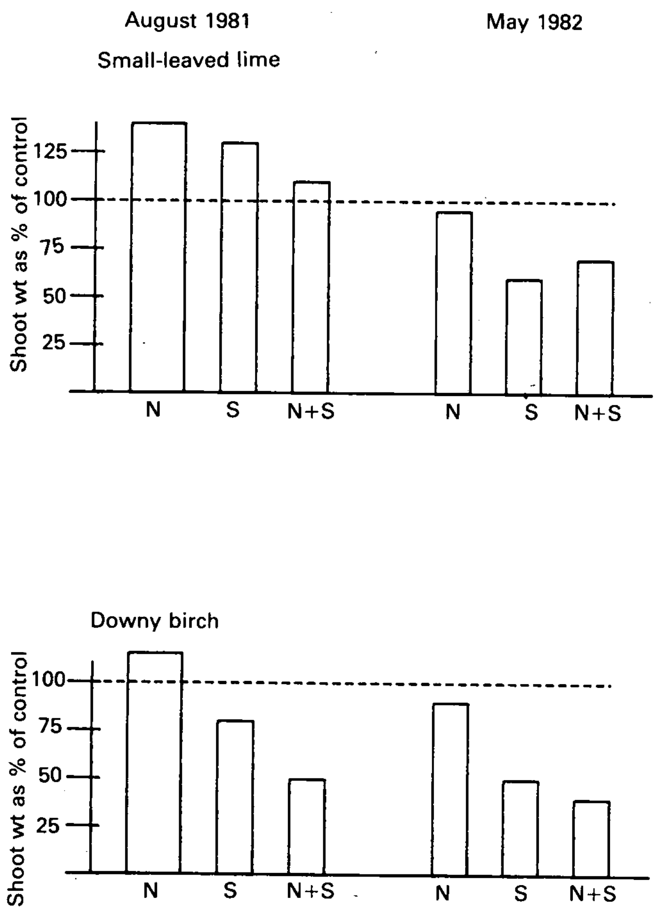

*Figure 3. Effects of 62 ppb NO_2 (N), 62 ppb SO_2 (S) singly and in mixtures (S+N) on the shoot dry weights of 2 deciduous trees. They were exposed for 2 years and the effects shown (% of controls) were in the first growing season of exposure (August 1981) and in the spring of the following year (May 1982). Significant differences: *$P<0.05$, ***$P<0.001$*

Thus, it is hazardous to regard the effects of low doses of pollution as 'beneficial' when assessing the need to control emissions (Central Electricity Generating Board 1984). Doses which produce growth stimulations in short-term experiments may have serious consequences in the field because of interactions with other factors. We must be fully aware of these possibilities in balanced discussions of emission control policies.

4 *Acknowledgement*

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The role of the local authority Environmental Health Officer in industrial pollution control

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Summary
The paper seeks to describe the role of Environmental Health Officers in advising District Councils in:
1. the enforcement of statutory controls over pollution;
2. assisting planning authorities in controlling or preventing nollution through the application of development control policies;
3. liaising with other bodies or organizations with interests or responsibilites in pollution control;
4. acting as a pressure group either through local authority associations or professional institutions in seeking to influence national government in pollution control policies;
5. assessing and monitoring environmental health risks.

1 Introduction
The power and influence of local authorities acting through their Environmental Health Officers (EHOs) play an enormous part in minimizing pollution problems in their localities. Power lies in the many controls exercised by the enforcement of legislation and influence in the democratically elective nature of local authorities, with their attendant duty of care to the public they represent.

Pollution has been defined as the introduction by man into the environment of substances or energy likely to cause hazard to human health, harm to living resources and ecological systems, damage to structure and amenity, or interference with legitimate uses of the environment (Royal Commission on Environmental Pollution 1984).

The EHO is concerned with the first part of this definition and his role can be described as 'to take the necessary measures to deal with the physical factors in the environment which threaten health in its widest sense'. Enforcement of statutory controls is the basic activity, but improvements achieved result largely from persuasion and education.

Scientists have made the distinction between 'contamination' and 'pollution', the former being used to describe situations in which substances are believed to be harmless or not present in sufficient quantities to produce damage. In practice, neither the EHO, the general public, nor the legislation draws such distinctions. The individual who complains about cooking odours demands abatement in just the same way as the individual experiencing toxic fumes from a chemical works. Again, noise, which is dealt with under the Control of Pollution Act and is the single most common pollution complaint received by local authorities, stands apart because it virtually has no lasting effect on the physical environment or wildlife.

2 The principal pollution problems dealt with by EHOs
The principal sources of industrial pollution may be grouped as follows:
1. discharges to the atmosphere of smoke, grit and dust, oxides of sulphur, the products of chemical processing, the products from incineration of waste materials, radioactive waste, offensive odours, noise, and toxic materials from certain industrial processes;
2. discharges to land of agricultural wastes and toxic materials;
3. discharges to water of sewage, toxic wastes, and agricultural chemicals.

3 Statutory controls used by EHOs
In order to deal with the problems identified above, the EHO enforces 3 principal Acts of Parliament, together with a host of associated regulations and codes of practice. The Acts are the Clean Air Act 1956/68, the Public Health Act 1936 and the Control of Pollution Act 1974.

For almost 30 years local authorities have had to be notified under the provisions of the Clean Air Act of the proposed installation of any furnace in any trade premises. Authorities have had to be satisfied that such furnaces are capable of being operated smokelessly, that adequate grit and dust arrestation equipment is fitted in appropriate cases, and that waste products are discharged at such a height as will cause adequate dispersal of those products. All non-domestic chimneys are subject to emission control levels of dark and black smoke, and industrialists can be required to provide means to carry out grit and dust measurement of discharges. Controls also exist over the burning of waste products in the open air, including the burning of cables in scrap metal recovery.

Whilst the Act achieved remarkable results in its principal objective of reducing visible smoke pollution, it did little (and neither was its aim) to solve the problems of sulphur dioxide emissions other than through its chimney height controls, which were determined largely by the sulphur content of the fuel used. The advent of natural gas and the explosion in oil prices reduced this problem, but there are already signs of a return to the use of coal in industry which is expected to accelerate as gas supplies diminish. Sulphur dioxide is, of course, one of the principal causes of the 'acid rain' problem. Some authorities have tried to control sulphur dioxide emissions by specifying the use of low-sulphur fuels, but this measure is difficult to enforce.

The Public Health Act 1936 contains provisions for abating statutory nuisances. Such nuisances are prescribed and include, for example, any dust or effluvia caused by any trade, business, manufacture or process which is prejudicial to health or a nuisance to the inhabitants of the neighbourhood. Odour problems can be dealt with under this provision but objectively measuring odour and defining standards of acceptability make this an extremely difficult problem to resolve. The same Act makes provision for the protection of drinking water supplies from pollution likely to be prejudicial to health. Commission of the European Communities (CEC) directives coming into operation this year will lead to the need for more quality control of drinking water.

The Control of Pollution Act 1974, Part III, deals with noise, and contains provisions relating to the abatement of noise nuisance, the creation of noise abatement zones, the control of noise at construction sites, and the use of loudspeakers in public. Noise complaints now form the largest group of complaints received by EHOs.

4 Administrative controls used by EHOs

These are the control mechanisms used by EHOs and they influence decision-making by other enforcing agencies, either within District Councils or in outside bodies.

Within District Councils, the EHO is heavily involved in the application process for development permission and seeks to have such applications refused or made subject to conditions, where there is likely to be an adverse environmental health impact from the proposed development. In environmental health terms, the planning process seeks to maintain the *status quo* and, although proving a valuable power in controlling new development, it does nothing about existing environmental disasters. An additional disadvantage is that the enforcement of planning conditions is time-consuming and cumbersome. Nevertheless, the system is an important control mechanism in preventing environmental deterioration.

In the field of air pollution control, the EHO works closely with the HM Air Pollution Inspectorate who deals with industrial pollution problems at industrial operations which present special technical problems not capable of being dealt with under the Clean Air Act, and which are dealt with under alkali, etc, works regulations. There is also close co-operation with the water authorities over river, inland and coastal water pollution problems of mutual concern.

One must not forget the power and influence which local authorities, as democratically elected bodies, can bring to bear on problems over which they have no direct statutory involvement, but which they cannot ignore because of their concern for the public they represent. EHOs act as their professional advisers in these matters. Typical examples at local level are the formation of liaison committees with industries, with the object of stimulating environmental improvements through argument and persuasion. At national level, local authority associations are an extremely powerful pressure group in the seeking of new powers to control problems.

Similarly, the Institution of EHOs as a professional body seeks to persuade government to enact legislation of environmental health importance. Local authorities also have the power and resources to commission independent scientific assessments of potential environmental health hazards.

5 Assessment of environmental health hazards in Cumbria

With the possible exception of emissions from the British Nuclear Fuels plc site at Sellafield, industrial environmental pollution is localized and rarely likely to cause acute or chronic ill health throughout the county. Since the demise of the heavy industries of the west coast, the sum total of sulphur emissions from the remaining industrial plant has an insignificant effect upon the general atmospheric level.

Environmental noise is highly unlikely to cause hearing loss, but nevertheless it is responsible for stress. Odour has never been associated with clinical illness, but recipients find it unacceptable and some find certain odours quite nauseous.

Grit and dust emissions are usually of too great a particle size to cause lung disease, but are considered to be an unacceptable nuisance. Asbestos fibre emissions to the atmosphere from stripping operations or from accidental fires in buildings containing large quantities of asbestos are dangerous, with the possibility of long-term cause of asbestosis to near neighbours. Stripping operations are very closely controlled either by the EHO or the Health and Safety Executive. Fire prevention is the only cure for the second hazard.

Bathing in polluted waters is not thought to give rise to serious disease, although there is some evidence that milder disease of the digestive system can occur (Royal Commission on Environmental Pollution 1984).

The consumption of drinking water contaminated by the agricultural industry, whether it be animal faecal matter or fertilizer, pesticides or herbicides, presents risks to the many consumers of the non-public water supplies in Cumbria.

6 Pollution monitoring in Cumbria

Some monitoring of suspended smoke and sulphur dioxide is carried out in Cumbria, the results of which form part of a national survey identifying long-term trends in air pollution levels.

Independent surveys of water pollution in the Solway, and of air quality in the vicinity of a major works manufacturing sulphuric acid have been commissioned by the Environmental Health Department. Radioactivity in silt prior to dredging operations has been investigated, and regular monitoring of some west coast beaches for radioactivity is routinely carried out, independently of the authorities with statutory duties in these matters. Some of the popular bathing beaches and inland waters are routinely monitored, although none are designated 'Euro beaches' which are subject to statutory controls.

7 Pollution from the industries of Cumbria

On casual acquaintanceship, Cumbria may be thought to be pollution-free; this is true for large parts of the central areas, but closer examination reveals that Cumbria has as wide a range of polluting or potentially polluting industries as other counties, albeit perhaps on a smaller scale.

First, consider the agricultural industry which can cause pollution in drinking water as well as in amenity water, in addition to odour problems. Fortunately, in Cumbria, the industry is perhaps unique in the absence of straw burning, and so is not responsible for visual air pollution.

Second, there are the traditional industries where steam-raising plant and other furnaces still have to be monitored and controlled to prevent smoke, grit, dust and acid smut emissions. Dust emissions from cement silos, drying plants, limestone quarrying and open-cast mining also occur, as do odour emissions from printing works, natural gas operations, chemical works and animal rendering works. Noise emissions are a problem from a variety of factories.

Third, the leisure industry gives rise to noise problems from activities such as music at discotheques and power boating, and extends to ice-cream vendors' chimes and aircraft associated with parachuting. All are becoming less acceptable as people's expectations of a quiet environment rise. Odours arising from the catering trade are also much less tolerated than hitherto.

8 The future role of the Environmental Health Officer

Certain aspects of the duties of the EHO will not change and he will continue to monitor and control emissions of smoke, dust, noise and odour. More codes of practice can be expected to control noisy activities, and better techniques to measure odour and to define acceptable levels are needed. For example, monitoring of the atmosphere will increase following the draft CEC directive on the air quality standards for nitrogen dioxide. More work will be needed on the monitoring of drinking water supplies, especially to prevent such pollutants as nitrates, pesticides and herbicides.

Despite medical evidence to the contrary, the public finds bathing in polluted waters to be wholly unacceptable, and more work will have to be carried out in identifying the problems and persuading government to allocate resources to remedy the situation. Local authorities rather than water authorities are felt to be the most appropriate authorities for identifying and monitoring bathing waters.

More contentiously, I envisage greater involvement in radioactivity monitoring, including the transport of nuclear materials. I detect a lack of trust by the public in both the industry itself and the statutory regulatory agencies who are seen as remote and uncaring of local feelings. Included within this monitoring there should be detailed investigation into all cases of leukaemia, to ascertain if there are any environmental causes. Local authorities are seen as the true representatives of the public to whom they are not only available but accountable, and already some of the Cumbria District Councils are becoming more involved in radioactivity monitoring.

Increasing involvement with obtaining and providing information on emissions will become more necessary if public suspicions grow as a result of the lack of information. Hopefully, this involvement will avoid entrenched positions, with industry, authorities and pressure groups within the community adopting more open attitudes and tolerance.

The views expressed in this paper are the author's own and do not reflect the views of South Lakeland District Council or any other of the Cumbria District Councils.

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Appendix II: The international system of units for radioactivity

The International system (SI) units are a consistent set of units for use in all branches of science. Certain special unit names have been adopted for SI units used in connection with radioactivity.

The SI unit of *activity* is the becquerel (symbol Bq) which is equal to one nuclear transformation per second.

The SI unit of *dose equivalent* is the joule per kilogram (J kg^{-1}). This is called a Sievert (symbol Sv).

There is a standard set of prefixes used with SI units and these include the following.

Factor	Prefix	Symbol	Factor	Prefix	Symbol
10^{18}	exa	E	10^{-3}	milli	m
10^{15}	peta	P	10^{-6}	micro	μ
10^{12}	tera	T	10^{-9}	nano	n
10^{9}	giga	G	10^{-12}	pico	p
10^{6}	mega	M	10^{-15}	femto	f
10^{3}	kilo	k	10^{-18}	atto	a

In order to be able to convert between SI units and non-SI units, the following relationships need to be known.

Physical quantity	SI unit	Non-SI unit	Relationship
Activity	Becquerel (Bq)	Curie (Ci)	1 Bq = 2.70×10^{11} Ci = 2.70 pCi 1 Ci = 3.7×10^{10} Bq = 37 GBq
Dose equivalent	Sievert (Sv) 1 Sv = 1 J kg^{-1}	rem	1 Sv = 100 rems 1 rem = 0.01 Sv

Examples

50 μCi = 1.85 MBq
5 mCi = 185 MBq
1 Ci = 37 GBq
1000 Ci = 37 TBq

Editor's note added in proof

There has always been considerable debate concerning the 'acceptable' annual radiation dose limit of 5 mSv, as referred to by several of the authors in this book. This debate has been intensified by the recent Chernobyl nuclear power station accident, and it is increasingly obvious that this limit is in need of downward revision. Readers are advised to keep this in mind whilst considering the information presented in the radionuclide section of the book.

Staff at the ITE Merlewood Research Station have been closely monitoring the input of radionuclides to Cumbria from the Chernobyl accident, and a report will be published in due course.

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