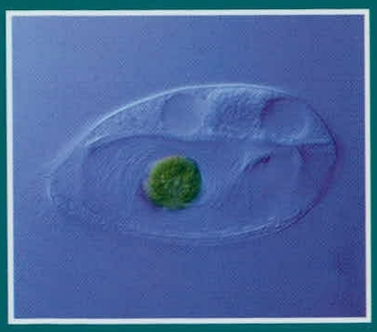

Institute of Freshwater Ecology

Annual Scientific Report 1996-97

Centre for Ecology and Hydrology

Natural Environment Research Council

Institute of Freshwater Ecology Mission Statement

The Institute's mission is:-

"To conduct research of the highest quality and to develop integrated theory for the science of fresh and estuarine waters. This research will be conducted at the species, population, community and ecosystem levels and will include investigations of the genetic, physiological and behavioural mechanisms by which organisms interact with their environment. Research will also be undertaken into the biological, chemical and physical components and processes which control aquatic ecosystems, especially the mechanisms of response to natural and anthropogenic change. The Institute will study the dynamics of interactions between terrestrial and freshwater ecosystems, and the control of the chemical composition and physical structure of water bodies and their retention and transport of soluble and particulate material. The information gained will be used to develop strategies for the sustainable management, conservation and exploitation of freshwater systems at national and global levels.

The Institute will also collect, validate and manage relevant environmental data in the furtherance of its research programme and will act as an international resource of expertise and information. It will continue to develop its programme for long-term, multidisciplinary research, undertake commissioned research on behalf of its customer base, provide training of the highest quality and maintain its international reputation. The Institute of Freshwater Ecology will collaborate with the component Institutes of the Centre for Ecology and Hydrology, the Freshwater Biological Association and other organisations to ensure achievement of these aims."

Front Cover Illustrations:

Large photograph – *A television crew recording Institute fish biologists and divers placing synthetic grass mats in Haweswater, Cumbria, to aid spawning by the endangered fish schelly.*

Small photographs – *The ciliated protozoon* Lembadion magnum *trapping a planktonic microalga.*

– *Blea Water, Cumbria, a high altitude (483 m) corrie tarn, one of two sites to which schelly eggs have been introduced.*

– *Experimental work in progress in the IFE fish ponds.*

– *A plant community typical of a nutrient enriched river.*

Report of the Institute of Freshwater Ecology 1996-97

Centre for Ecology and Hydrology

Natural Environment Research Council

Contents

Director's Introduction

Professor Alan Pickering
Director.

The science programme has flourished at a time of great change and this report summarises some of the exciting research undertaken during the past 12 months.

1996/97 heralds a significant change in the annual reporting arrangements for the four component Institutes of the Centre for Ecology and Hydrology. This report, the Institute of Freshwater Ecology Annual Science Report for 1996/97, will focus on the *scientific* achievements of the Institute and the role it has played in the overall research programme of CEH. The CEH Annual Report for 1996/97 complements the four Institute Annual Science Reports and presents an overview of the scientific programmes, the interaction of CEH with NERC and other organisations, financial information and output/performance indicators. Details of the other Reports can be found at the end of this document.

During the year, plans for the new CEH Core Strategic Programme were finalised for implementation in April 1997. The ten Programme Areas are each subdivided into Projects and Issues and each new piece of scientific research undertaken at the IFE is now allocated to an appropriate Programme/ Project/Issue (the PPI number). The development of the new structure has involved a great deal of work by staff at all levels and has, I believe, not only laid the foundations for future strategic planning but also engendered a spirit of greater communication and collaboration between the component Institutes. The IFE Annual Science Report is organised according to the Core Strategic Programme and details of some of the scientific achievements are reported for eight of the ten Programme Areas. Further details of the IFE contribution to the CEH Core Strategic Programme can be found in Appendix 7.

Many of the important scientific questions underpinning the sustainable management of the natural (and not-so-natural) environment lie at the interface of the different scientific disciplines. By way of an example, to understand and predict freshwater quality requires a knowledge of key hydrological pathways and processes, the influences of geology, soil type and catchment land use, the impact of atmospheric pollution and, not least, the biological processes occurring in the freshwater environment itself. CEH is uniquely placed to provide a multidisciplinary approach to such problems and this Report highlights some of the interactions between the IFE and other CEH Institutes in tackling (and solving) complex environmental problems.

This type of approach is exemplified by some of our work in *Programme 1 – Soil and Soil-Vegetation Interactions.* Investigations of the potential effect of climate change on the decomposition of organic matter in upland catchments has involved close cooperation between scientists at the IFE's Windermere Laboratory and colleagues at ITE's Merlewood Research Station. Process-based models have been developed which simulate, realistically, the observed effects obtained from experimental studies and field observations. The non-linearity of the relationships between soil temperature and moisture and the production of dissolved organic matter in the soil leachate are important factors in predicting the impact of future climate change scenarios on carbon cycling.

The IFE input to *Programme 3 - The Urban Environment* is very limited at the present time but a survey, resourced by the CEH Integrating Fund, of the characteristics of urban fresh waters has been completed,

The structure of the programme embraces all national concerns for the aquatic environment.

outlining the downstream impacts of the urban environment. It is expected that work on urban fresh waters will increase as part of the URGENT Thematic programme.

As might be expected, a significant component of the overall IFE research effort is in *Programme 4 – Freshwater Resources*. The environments under study include both still and running waters with biological end-points ranging from phytoplankton to fish – both ends of the biological scale being important freshwater "resources". The impact of low winter rainfall on the subsequent spring phytoplankton bloom in lakes is a timely reminder of the relationship between the science of the Institute of Hydrology and the classical limnology of the IFE. Moreover, given the implications of this work in terms of the costs of treatment for potable water supplies, the links with *Programme 8 – Environmental Risks and Extreme Events* are beginning to emerge. The importance of land use on water quality and associated fish populations is illustrated in the research on Loch Leven and on Bassenthwaite Lake, work which has prompted a new collaborative study with IH and ITE, funded by the CEH Integrating Fund, to develop a GIS-based catchment model of phosphorus transport to surface waters. This relationship between the terrestrial and freshwater environment is also explored in our work on river habitats. The performance of freshwater fish under different environmental conditions is clearly of importance as fish are a tangible and valuable resource directly exploited by man. The work described in this report covers growth, schooling behaviour and performance in aquaculture. Finally, the role of migratory fish as vectors of energy and nutrients between marine and fresh waters completes the loop linking primary production, water quality and fish populations.

Several research projects are featured in this Report under *Programme 5 – Biodiversity and Population Processes*. Using aquatic ecosystems as a model, fundamental questions are being asked of the link between biodiversity and ecosystem function. It is shown that in such systems, microbial diversity is inextricably linked with ecosystem function, that traditional concepts such as the value of diversity or the redundancy of species have little meaning at this level and the hypothesis is developed that most microorganisms are ubiquitous and cosmopolitan in distribution. Some aspects of microbial diversity are demonstrated in the differences between molecular and phenotypic techniques for describing protozoan diversity and a role (the oxidation of reduced sulphur) is finally found for the world's largest bacterium. Collaboration with IVEM has been vital in some of the research on microbial diversity, one 'spin-off' to the IFE being the intriguing observation that ingestion of virus-infected bacteria by protozoa causes the virus to replicate and disperse from the protozoan faecal pellets. Future work in this area might belong more appropriately to *Programme 6 – Pest and Disease Control and Risk Assessment for GMOs*. Under the issue of biodiversity in rivers, the historical reasons behind the dramatic decline in fishery diversity in lowland rivers are reviewed and food availability at a critical time is shown to be an important factor. Conservation of fish diversity is also addressed in a programme to save the schelly, one of the rarest UK freshwater species.

Under *Programme 7 – Pollution*, this IFE Annual Science Report describes some of the factors which must be taken into consideration when developing an emergency response model to disasters such as the Chernobyl accident. This research, under the Issue 'Radionuclides', complements other collaborative work between radio ecologists from the IFE's

River Laboratory and ITE's Merlewood Research Station, funded through the CEH Integrating Fund.

As part of the LOIS programme and in collaboration with IH, a detailed study of river chemistry during storm events has demonstrated the hysteresis of nutrient concentrations. A model, based on this work, has been developed to enable future comparisons of diffuse and point sources during high flow conditions. This work forms part of the IFE contribution to *Programme 8 – Environmental Risks and Extreme Events* but also has strong scientific links with several other programme areas.

One of the most interesting aspects of global climate is the growing awareness of the importance of changes in the major oceanic currents (eg the *El Niño* effect in the South Pacific). Work at the IFE, originally in collaboration with colleagues in the marine scientific community, has elucidated some of the links between changes in the latitudinal position of the North Atlantic Gulf Stream and the thermal stratification of freshwater lakes. In this Report we show how regional climate is influenced by the Gulf Stream and the consequences that this has for nutrient remobilisation and phytoplankton production in Esthwaite Water. The work forms part of *Programme 9 – Global Change* but also has very strong links with related work on this water body under Programme 4. This is an important area of research which may well have implications for terrestrial ecology.

Underpinning all the above research is *Programme 10 – Integrating Generic Science*, which includes facilities for the development of techniques, instrumentation, data handling systems and reference collections. This work is essential to the success of the rest of the Core Strategic Programme and, therefore, there are very strong links between work in Programme 10 and Programmes 1-9. Examples of IFE progress in this area include new arrangements for the Culture Collection of Algae and Protozoa, novel instrumentation for data collection in lakes and rivers and a demonstration of the value of well-designed databases for the analysis of long-term data sets.

It should be apparent to the reader that one of the themes that I have chosen for this Director's Introduction to the IFE Annual Science Report for 1996/97 is the importance of collaboration between the component Institutes of CEH to tackle complex environmental questions at the interface between scientific disciplines. However, this ought not to hide the value of the role of the higher education sector in contributing to the overall research programme of the IFE. Details of the work of the 40 PhD students working with the IFE, from 18 different UK universities, can be found in pages 49-51 of this Report. Furthermore, the strong international links between IFE scientists and colleagues across the globe are referred to during the main text and also under pages 51 and 52, which describes the staff and their external activities.

To summarise, 1996/97 has been a year of major scientific achievement for the IFE in many areas of environmental research. The work described in this Annual Science Report is just a *selection* from a wide range of activities but is one which illustrates the breadth of our science across the new CEH Core Strategic Programme. The Report focuses on science *per se* (with the CEH Annual Report addressing many of the more socio/political aspects of research institute activities) and is, I believe, a fitting testimony to the high quality of IFE research, to its relevance for the solution of practical, environmental problems and to a highly-motivated and innovative staff.

The research programme addresses many issues of international importance.

The Relationship between the Institute of Freshwater Ecology and the Freshwater Biological Association

Directors' Introduction

Upholding the tradition for excellence in freshwater science.

Much of the tradition and the basic approach to research in freshwater ecosystems has its origins in the Freshwater Biological Association. Founded in 1929, the Association quickly established a reputation for high quality environmental research with pioneering studies in the fields of plankton and fish population dynamics, invertebrate ecology and palaeolimnology. Since 1965, the research programme of the Association has been funded through the Natural Environment Research Council.

In 1989, the NERC assumed responsibility for the management of the majority of the staff and the facilities of the FBA when it created the Institute of Freshwater Ecology. The IFE has subsequently maintained and developed this reputation for high quality ecological research in fresh waters. The functions retained by the FBA (through a formal Agreement with the NERC) were those of servicing the active membership of a learned society, a continued fulfilment to the science in the form of its Scientific Publications series and a general brief to promote research into fresh water as a fundamental resource. The charitable status of the Association allows it access to additional sources of funding which, in turn, provides excellent opportunities to support post-graduate training. In addition, through its community of Research Fellows (Post-doctoral Fellows and Honorary Senior Research Fellows), the Association has maintained an ongoing contribution to the development of aquatic ecology in the UK.

During the past year, the terms of the 1989 Agreement between NERC and the FBA have been the subject of review and, where appropriate, renegotiation. Although, as we write, the final Agreement has not been concluded, the Directors of the IFE and the FBA are confident that the final document will be to the mutual advantage of both organisations and will set the framework for future co-operation and collaboration, thereby upholding a national core capability in limnology and freshwater ecology. Sharper definition of the aims and objectives of the Association will assist in its research programme/training prioritisation but it can only do this with the co-operation of IFE scientists and by reference to the CEH Core Strategic Programme.

The months ahead will be crucial to the developing relationship between the two organisations and both Directors are dedicated to the ideal of close collaboration, driven by a belief in the importance of carrying forward a firm base of freshwater science in the UK. In the context of this belief, it is

pertinent to make reference to the scientific progress from the FBA during the past year, to illustrate the complementary nature of the research programmes from both organisations.

Nowhere is this better demonstrated than by the publication of a book on tropical limnology, the culmination of four years' intensive work on the interrelations of physical, chemical and biological dynamics in such systems. The relevance of this synthesis to research reported on in the 1995/96 IFE Annual Report on Lake Tanganyika will be there for all to appreciate. Similar evidence of the complementarity of expertise can be seen in the important contribution made by the FBA to the identification of planktonic organisms from Priest Pot, as part of the IFE Integrating Fund project on microbial biodiversity.

An equally fruitful area for collaboration has been the interface between aquaculture and the freshwater environment. FBA research on the use of changes in the structure of fish otoliths to detect environmental stress has been partially validated using fish reared under aquaculture conditions. It is now being applied to a fish population from Seathwaite Tarn, an acidic water which has been the site for a major field experiment by the IFE to develop neutralisation techniques via nutrient enrichment. Antibiotic resistance in bacteria, resulting from antimicrobial agents used in aquaculture, is the subject of a further IFE/FBA link, as is the field of fungal infections in fish and research to find an alternative fungicide to malachite green. The FBA has been instrumental in providing known, characterised *Saprolegnia* cultures to the IFE for this work. Staying in the area of fish biology, fundamental FBA research on the biology of coarse fish (including work on shoaling behaviour) is of clear and direct relevance to the IFE work on coarse fish populations in southern chalk streams and the lowland rivers of eastern England and several joint scientific papers from both organisations have recently been published.

An important component of the IFE research programme is concerned with the use of aquatic macroinvertebrates as indicators of river quality, an approach which has resulted in the development and application of the biological quality assessment procedure RIVPACS. In an interesting new development in this broad area, the FBA is examining the bacterial gut flora of a typical macroinvertebrate, *Gammarus pulex*, with the objective of using changes in the gut flora as indicators of environmental stresses such as pH change or metal pollution. This work is at an early stage but is yet another example of the coordination between the research programmes and further evidence of the benefit to both organisations of a mutually-beneficial, close working relationship. As Directors, we will do all we can to achieve this relationship during the coming years.

The relationship is dedicated to close, mutually beneficial achievements in freshwater research.

Prof A D Pickering
Director,
IFE

Prof C S Reynolds
Acting Director,
FBA

CEH is undertaking ten NERC Core Strategic Programmes which provide a science base that underpins both national and international requirements in the terrestrial and freshwater sciences. The ten component programmes cover a wide range of topics. They are also dynamic and can be changed to incorporate new and emerging environmental issues.

CEH Core Strategic Programme

1: Soils and Soil–Vegetation Interactions

This programme is designed to improve our understanding and ability to model key soil processes controlling the transformations of materials within soils and the flux of water through the soil–vegetation–atmosphere continuum.

2: Land Use Science

This is aimed at promoting an integrated approach to land use science that is applicable to the wide range of user community requirements. The programme's themes will be developed to provide the basis for large-scale, long-term analytical studies of major land use change.

3: The Urban Environment

This relatively new programme aims to extend the interdisciplinary knowledge base and to understand the key environmental patterns and processes in urban situations and particularly change due to human activities. This knowledge is required to plan more sustainable urban environments.

4: Freshwater Resources

Increasing demands on freshwater resources have resulted in the need for a scientific basis for the effective strategic and sustainable management of freshwater resources. This programme will address this by integrating CEH research in the areas of water quantity, water quality, and the ecological aspects of freshwater systems.

5: Biodiversity

Aimed at improving our understanding of microbiological and biological resources at a range of spatial scales. The research considers the underlying processes and resulting functions, and directs knowledge to the sustainable management of biodiversity.

6: Pest and Disease Control and Risk Assessment for GMOs

The primary aim of this programme is to undertake research in the provision of novel pest and disease control strategies whilst addressing any possible risk to the environment. The use of molecular biology is essential to maintain a novel and progressive approach to the themes of pest control and animal disease control.

7: Pollution

This programme is aimed at developing a better understanding of generic processes such as atmospheric transport, fluxes of pollutants and the fate of pollutants, in order to predict more accurately the likely impacts on environments and organisms.

8: Environmental Risks and Extreme Events

This research programme will develop understanding of how environmental extremes affect mankind and the natural environment, developing quantitative, predictive tools to describe these effects, and contributing to mitigating measures.

9: Global Change

This programme will help to reduce uncertainty in the magnitude of global change and its impacts. The research is focused on improving the accuracy of global change predictions through measurement programmes, the development of scaling-up methods and models, and the identification of ecosystem responses.

10: Integrating Generic Science

Programme 10 has been designed to provide a research framework for those areas of CEH science which underpin the nine other programmes (eg providing the data and technological support), as well as conducting its own fundamental research.

The following section of this Scientific Report describes research which is currently being carried out in eight of the ten programmes by the Institute of Freshwater Ecology. Further details of the projects and issues that make up each of the ten Core Strategic Programmes are listed in Appendix 3 of the CEH Annual Report.

Water passing through soils gains and loses solutes by chemical and biological processes. IFE research into these exchanges aims to understand and predict their effects on the chemical compositions of surface waters in the UK uplands.

Programme 1 Soil and Soil-Vegetation Interactions

Climatic effects on the output of dissolved organic matter from upland soils

The wet and cold conditions in the British uplands mean that dead plant material breaks down slowly and incompletely. Soils accumulate large stores of organic matter, which is microbially and chemically converted to complex organic molecules. Some of these pass into solution, move through the soil and into surface waters.

The mobile organic matter contributes to the overall carbon budget of the soil-water system. It binds and transports metals, including radionuclides, buffers waters against changes in acidity, and absorbs light. It also presents a problem to water treatment engineers, requiring removal before water is suitable for domestic and industrial supply.

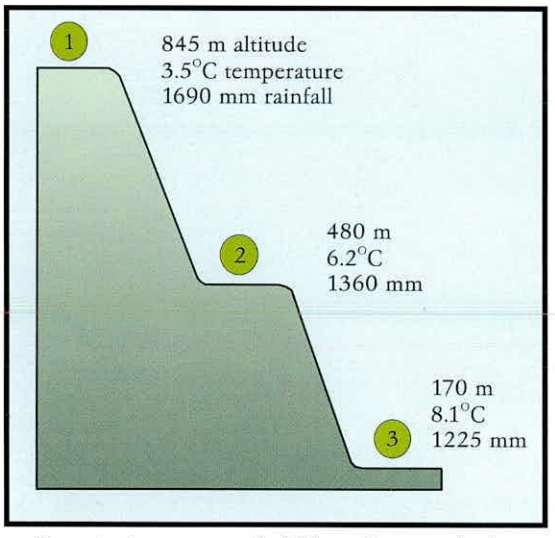

Figure 1. Arrangement of a field experiment to simulate climate change. Heights above sea level, mean annual temperature and mean annual rainfall are shown. Columns of soil located at sites 1, 2 and 3 were monitored for dissolved organic matter in their drainage water.

As part of a project within the TIGER Community Programme, the effects of changing climate on the leaching of dissolved organic matter (DOM) from upland soils were investigated. The study also involved scientists from CEH's Institute of Terrestrial Ecology (ITE), the NERC Radiocarbon Laboratory, and the Universities of Bristol and Reading. Fieldwork was carried out at Great Dun Fell, in English Nature's Moor House Reserve

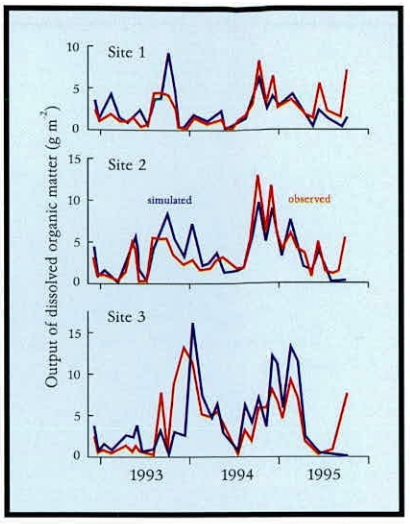

Figure 2. Observed (red) and simulated (blue) outputs of dissolved organic matter from the soil columns.

Upland soils may export more dissolved organic matter should the climate become warmer and drier.

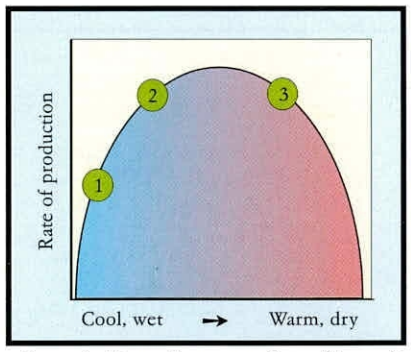

Figure 3. Dependence on soil conditions of the production rate of potentially-soluble organic matter. The relative positions of sites 1, 2 and 3 are shown.

in the northern Pennines, and at Newton Rigg College. Soil cores from the top of Great Dun Fell were transferred to sites of lower altitude, thereby simulating a change to warmer, drier climatic conditions (Figure 1).

In collaboration with ITE staff, drainage waters from the columns were collected over a period of three years, and analysed for a variety of solutes including dissolved organic matter (DOM). By combining solute concentrations and drainage volumes the amounts of DOM leaving the soils under the different conditions were calculated.

Of the three soil types studied, an organic-rich peaty gley responded most. Warming and drying doubled the export of DOM, but the increase did not continue significantly beyond site 2 (Table 1).

Site	gDOM m^{-2}
1	81
2	136
3	136

Table 1. Outputs of dissolved organic matter (DOM) from a peaty gley soil during the period November 1992 – September 1995

Three main processes are considered to govern the amount of DOM leached from soils. The first is the production of organic matter with the potential to dissolve; this process is sensitive to soil temperature and moisture content, and therefore to climatic change. Second there is the dissolution process itself, which depends upon a number of simultaneous chemical reactions, involving the organic matter itself, aluminium, acidity and the surfaces of the soil solids. Third is the movement of water through the pores of the soil, and its diffusive exchange with less mobile water.

These processes have been represented in a computer model (CHUM-C2), which calculates the volume and chemical composition of soil leachate on the basis of rainwater inputs and soil properties. By adjustment of key parameters, reasonable simulations of soil column behaviour were achieved. Figure 2 shows observed and calculated outputs of DOM from the peaty gley soil for the duration of the monitoring period. The modelling shows that organic matter production leads to a build up of potentially-mobile material during the summer, and that this is leached from the soil mainly during autumn, leading to the observed seasonality.

The modelling results suggest that the rate of production of organic matter with the potential to dissolve depends non-linearly on soil temperature and moisture content. If conditions are initially cold and wet, then warming and drying increase the production rate. However, the rate then slows again when warming and drying pass a certain level. This explains why the increased export of DOM (Table 1) does not continue from site 2 to site 3. The average conditions at the three sites are indicated in Figure 3.

Urban areas provide employment, housing and social contact but they consume resources, generate waste and pollution, destroy habitats and are prone to environmental hazard and decay. The CEH Urban Environment Programme is designed to understand the key environmental patterns and processes in urban environments, their responses to change (especially those resulting from man's activities) and to make this knowledge base available to those with responsibilities for urban planning and development. The ultimate objective is urban sustainability.

Programme 3 The Urban Environment

Figure 4. Near-natural urban stream environment.

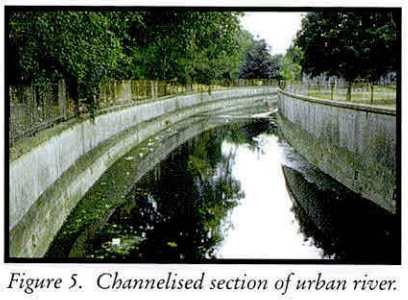

Figure 5. Channelised section of urban river.

The characteristics of urban fresh waters

Over 90% of the UK population lives in conurbations, which cover 10% of its land area. Half of the world's six billion people will probably be living in cities by the year 2000. This pressure on the environment demands closer study and development of management strategies for both terrestrial and aquatic resources. As part of a CEH Integrating Fund initiative involving ITE and IoH, the IFE are examining the environmental characteristics of urban fresh waters.

The urban stream environment can range from near natural conditions (Figure 4) to grossly modified channels with heavy pollution loads (Figure 5). Urbanisation has major effects on the flow characteristics of urban waterways which in turn will affect substratum characteristics and habitat availability and diversity, with knock-on effects on the instream biota. This situation may be exacerbated by increased pollution levels from point and diffuse sources.

The project started in October 1996. Since then effort has been directed to collation of information from the literature, and that held by the Environment Agency and the Scottish Environmental Protection Agency, and examination of the macroinvertebrate data from urban sites sampled in the 1990 National River Water Quality Survey.

Preliminary results from 134 sites covering a wide range of conditions indicate that environmental quality is significantly worse downstream of urban areas than within them. This suggests that at least for running waters the effects of urbanisation extend well beyond the urban boundary.

Future work will extend the data set and develop a classification of urban fresh water environments which will contribute to the new NERC thematic programme URGENT.

Figure 6. Cladophora *(blanket weed), a filamentous green alga covering the shoreline of Windermere prior to tertiary treatment.*

The Urban Waste Water Treatment Directive and the current status of Cumbrian lakes

The 1991 Urban Waste Water Treatment Directive of the EC requires action to be taken to reduce discharges to sensitive waters under certain conditions. In the English Lake District, Windermere and Bassenthwaite Lake fall within the criteria in that they are both natural lakes receiving waste water from population equivalents in excess of 10,000 and are both showing symptoms of advancing eutrophication with damaging effects on important fish species. In Windermere the Arctic charr, *Salvelinus alpinus*, has been the species in decline whereas in Bassenthwaite Lake the vendace, *Coregonus albula*, is showing clear signs of poor recruitment. Both fish populations are relicts of the last ice age and towards the southernmost limits of their geographical distribution.

Water quality models have been used to develop management strategies for two of the most important lakes of the English Lake District.

Working in partnership with North West Water and the Environment Agency, IFE scientists have parameterised and applied lake water quality models developed under Programme 4 (Freshwater Resources) to advise on the most appropriate management strategies for each lake. The model output highlights the differences between the way in which the two lakes utilise phosphorus, the limiting plant nutrient. In Windermere the growth of planktonic and attached filamentous algae is largely controlled by the external loading of nutrients to the lake. In contrast, biological productivity in Bassenthwaite Lake is strongly influenced by the recycling of nutrients from the lake sediments (the internal flux).

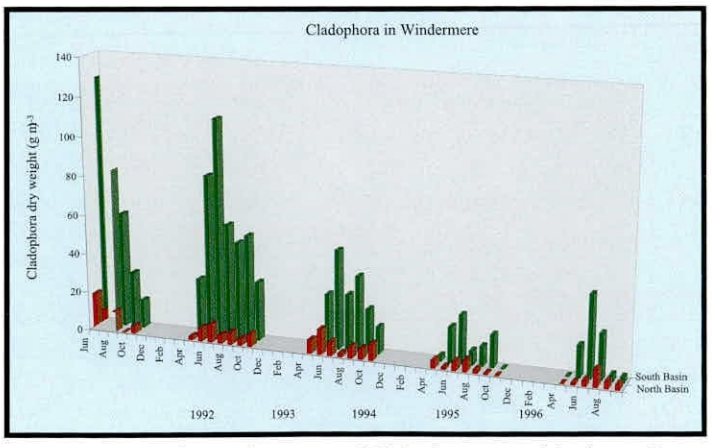

Figure 7. Decline in the amount of Cladophora *around the shores of Windermere following tertiary treatment.*

Tertiary treatment (phosphorus stripping) of the waste water effluents to each lake has been recommended but the predicted rate of recovery is very different, with Windermere likely to show a relatively rapid improvement compared to Bassenthwaite Lake. The predictions for Windermere have now largely been borne out by subsequent events. Tertiary treatment on the main sewage effluents commenced in 1992 and algal water quality has subsequently improved. Anoxia of the hypolimnion now no longer occurs and, in the charr population in the south basin of the lake (the most heavily impacted area), recruitment of young fish has improved markedly. In Bassenthwaite Lake, tertiary treatment was implemented in 1995 but water quality improvements are, at this stage, relatively modest. 1996/97 has seen a reduction in the maximum chlorophyll levels normally observed in the lake but significant algal production is still being supported by nutrients recycling from the sediments during wind-mixing events. Thus, the rate of recovery is compromised by the relative mobility of nutrients accumulated in the lake prior to tertiary treatment. No recovery of the vendace population has yet been observed but the situation is complicated by additional effects of interspecific competition as non-native fish (ruffe, roach, dace, bream) have appeared in the lake.

This programme of work is an example of the value of collaboration between a research organisation (the IFE), the water industry (NWW) and an environmental manager (the EA) to diagnose, using unique long-term data sets, potential environmental problems and to follow this with the design and implementation of practical solutions.