Data and analysis at your fingertips

The value of good quality datasets that are accessible and well organised has never been more apparent. But although there is considerable potential for using environmental datasets to detect change, there are also many pitfalls. The value of continuity in the core staff who develop the science of interpreting environmental datasets of considerable size is well recognized at IH, and the Institute is now reaping the benefit of fostering such work.

The Institute's foundation on experimental catchment research producing high quality water balance data over a long period of time, has resulted in three decades of experience in the collation, computerisation, quality control and archiving of datasets.

This experience has been reinforced in several directions. The five-year research programme which culminated in the publication of the Flood Studies Report in 1975 included a complete volume of computer output of UK flood records. Such time series have been transferred to a succession of mainframe computers and are now accessible through terminals within the Wallingford site or over the JANET communications network to the wider academic world.

Subsequently, when the Water Data Unit was transferred to NERC from the Department of the Environment in 1982, it brought with it the responsibility for national hydrometric record archiving and publication.

More recently there has been an expansion into environmental water quality data handling, of which the Acid Waters Monitoring Network for DoE is one example. Digital mapping of hydrologically related characteristics has led on to the commercial development of the IH Water Information System for advanced graphics workstations. High resolution real time data for river flow forecasting has included handling weather radar data of precipitation fields over 100 km radius areas.

Early on, the Institute recognised the need for handling hydrological data for regions and smaller nations on desktop PC computers. The HYDATA software package for processing, storage, presentation and basic analysis of hydrological data has gained wide international acceptance with the help of ODA support. The World Meteorological Organization has sponsored links between HYDATA and its CLICOM software that meets a comparable climatological data management need.

Control rules for the Barmby tidal barrage on the River Derwent are an integral part of the new operating system for Yorkshire's rivers. The barrage controls the outlet of the Derwent into the tidal Ouse to prevent salt and sediment-laden water entering the Derwent and affecting water supply offtakes.

Les règles de contrôle pour le barrage à marée sur le Derwent font partie du nouveau système de gestion des rivières du Yorkshire. Le barrage contrôle la sortie de la rivière dans l'estuaire de l'Ouse et empêche l'eau salée et chargée de sédiments de se mélanger à l'eau potable.

Specialist Databases

Details of the comprehensive retrieval facilities to make available the data stored in the national Surface Water Archive are given in the annual Hydrological Data UK Yearbooks. Each Yearbook includes sample results for streamflow, catchment rainfalls and river water quality. Indexing covers the 1200 past and present flow gauging stations for which the average record length is now 22 years. Seventeen different computer retrieval options are available; over 130 requests for one or more of these were serviced during this last year, representing heightened interest as the long-running drought focused on southeast England.

The UNESCO International Hydrological Decade and subsequent International Hydrological Programmes gave a major impetus to the collection of river flow data from basins worldwide. The FRIEND project (Flow Regimes from International Experimental and Network Data) sought to utilise these data beyond individual basin boundaries and to apply statistical analysis and flow modelling techniques over wider areas within Western Europe.

The establishment of the FRIEND database involved liaising with over 40 European agencies including national and state hydrological services, water management agencies, research institutes and university departments. The resulting database assembled at IH, as the Project Centre for the study, includes the following three categories:

- river flow and rainfall time series for individual stations;
- gridded topographic, land use and climate data for the European Community;
- numerical indices of catchment and climate characteristics for individual stations, derived from the gridded database.

The FRIEND database holds flow data from approximately 2100 stations from 13 countries in Western Europe, with an average of 18 years of record per station (see Figure 13).

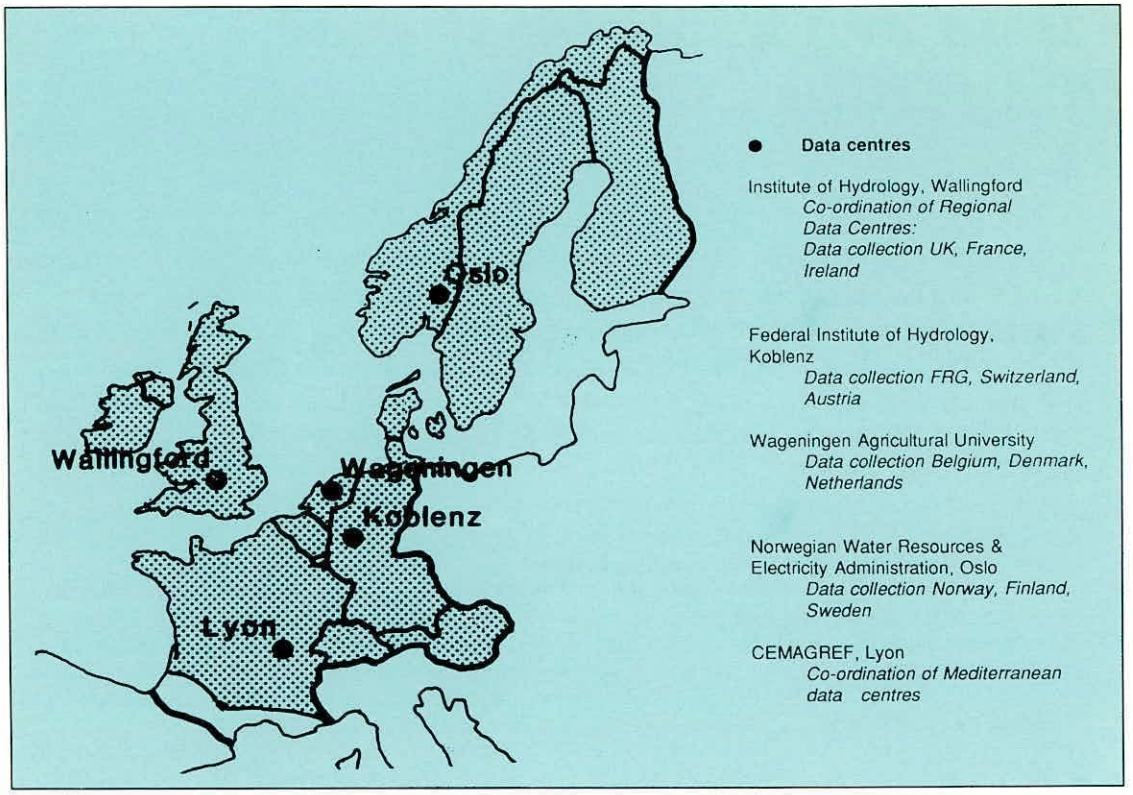


Figure 13 The FRIEND project approach has now spread to five different regions of the world.

L'approche du projet FRIEND s'est répandue à cinq régions différentes du globe.

1991 saw the first printing of the five-volume *Representative Basin Catalogue for Great Britain*. This publication embodies the Flood Event Archive but goes further by producing a computer database of catchment hydrology. An ORACLE relational database system holds the text and data on over 340 British catchments varying widely in size and type. Considerable use has been made of modern computer graphics to display the digital outline of the catchment in its grid reference context and the location of relevant measuring points. Surface Water Archive retrievals are used to demonstrate the calendar range of daily flows and the flow duration curve. A typical eight pages of text per basin includes a catchment description in geographical terms, a list of available maps, all raingauges known to have operated, a flow station description, summary flow statistics, Flood Studies Report catchment characteristics, as well as flood event data. By 'flood event' is meant the entire response hydrograph coupled with the rainfall intensity which caused it. Over 4000 events are held within a versatile management system that crowns 20 years of work in assembling national flood information.

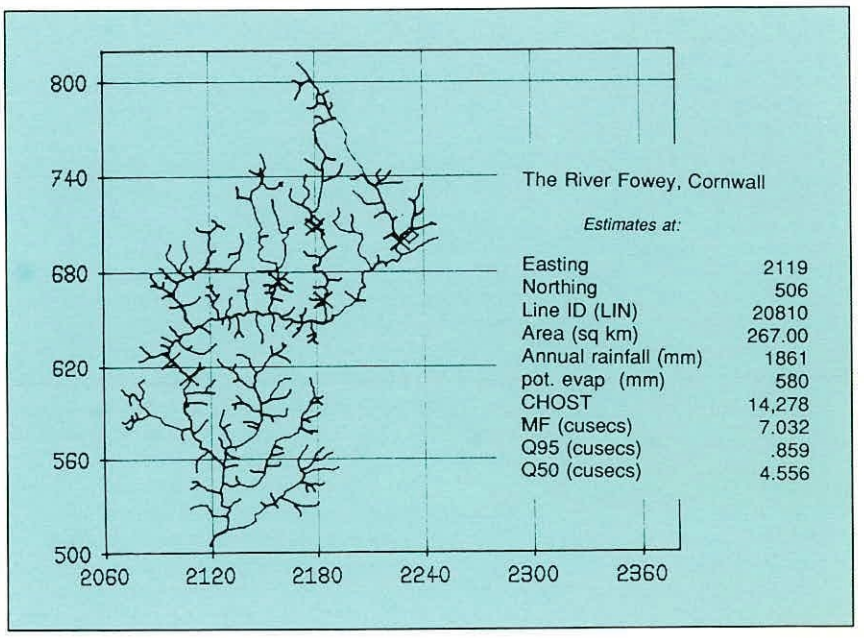
Analysis packages

The need to predict the impact on the environment of climatic or land-use change, or any other man-induced perturbation, is the fundamental target behind most hydrological research. The use of statistical analysis based on historic inputs and outputs from a catchment is an essential technique, the continued development of which occupies a significant part of the Institute's research programme. One recent major advance has been in the automation of low flow estimation.

A new software package MICRO LOW FLOWS allows the rapid and consistent estimation of design low flows at ungauged sites. The major technical achievement is the overlaying of gridded databases of catchment characteristics upon a vectored river network database, such that the user can roam around the screen to access different river reaches. Upon selection of a particular reach, the system displays the estimates generated for that site on a split screen (see Figure 14). In addition, the system can

Figure 14 A typical screen display obtained from MICRO LOW FLOWS

Un écran typique du logiciel "Micro Low Flows"



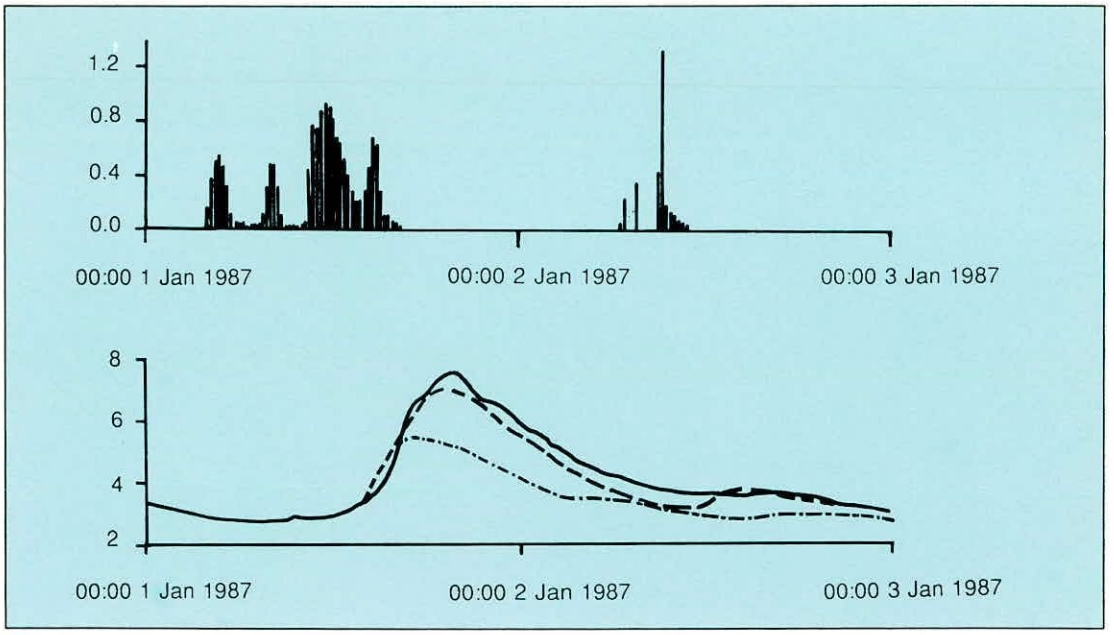


Figure 15 Flow forecast for the River Dove at Kirkby Mills using Church Houses rainfall: the upper forecast assumes perfect foreknowledge of rainfall whereas the lower forecast is based only on observed rainfall up to 12:00 1 January 1987 and a backup rainfall profile after this.

Prévision des débits pour la Dove à Kirkby Mills à partir de la pluviométrie de Church Houses; la courbe supérieure est obtenue en supposant toute la pluviométrie connue, tandis que la courbe inférieure n'utilise des observations de pluie qu'avant le 1/1/1987 à midi et un profile de pluie typique après cette date.

identify and display any additional information regarding upstream abstractions, discharges from reservoirs, or details of gauging stations and spot current metering that may be archived for that reach.

MICRO LOW FLOWS is already in operational use within the South West and Anglian regions of the National Rivers Authority, giving the water industry faster performance in an important functional area.

Integrated systems

The increased availability and power of personal computers and professional software has ensured that rapid storage and retrieval of data is now taken for granted. A limiting factor on the efficient use of databases lies in the choice of database management system with the difficulty of data input from a range of sources and the need to output information to external programs or packages. The Institute's hydrological database system for personal computers HYDATA is a unified system for importing data from telemetry systems, loggers and other databases, and provides flexible methods for exporting data for use in analysis packages. During the year the first of an annual series of workshops on HYDATA was held in Nairobi. This was a first step in developing a homogeneous database throughout southern Africa and was attended by participants from ten different countries.

The Water Information System referred to earlier is the successful culmination of collaboration between IH and the computer firm ICL to produce a four-dimensional database capable of handling all types of water data. This complete system of hardware, software, data and supporting services stores and handles environmental data to produce a range of reports, maps and graphs. Its novel feature is the ability to look at specific features of a river network and their related environmental data at interactive speeds.

An example of advanced systems applications is the River Flow Forecasting System for the Yorkshire Region of the National Rivers Authority, designed and developed by IH under contract to Logica Ltd. Whilst currently configured to make forecasts at over 100 sites in the Yorkshire Region, the design of the system allows reconfiguration to any river network or set of networks without re-coding. At the heart of the system is an algorithm which controls the flow of data required to make forecasts and which selects the model algorithms to be used in their construction. An example forecast exercise is shown in Figure 15.

The future

Under the NERC Corporate Data Policy, IH has accepted the continued responsibility of providing the National Water Archive. At the heart of this valuable resource are the Surface Water and the Experimental Catchments Archives described earlier. Their total size exceeds 700 Megabytes (Mb) and continues to rise at about 30 Mb per year.

A key target is to improve the indexing of all datasets so that they can be browsed by E-mail or be read in hard copy. Better retrieval options will continue to be developed, making use of advanced graphics to get the best from existing laser printer technology. As data requests grow, it is anticipated that there will be a switch to providing these on CD-ROMs as an alternative to tapes or multiple floppy disks; reciprocal Northern American data are already being received in this way.

Environmental impact – a central role for hydrology

Water is essential for all forms of life and plays a crucial part in many of the physical, chemical and biological processes that regulate the behaviour of the earth's environment. There is growing consensus of opinion that human activity is as important as natural events in shaping our environment. Only when the behaviour of the environment is better understood, therefore, will it be possible to make reliable predictions of how human activities may change the environment of the future.

The accuracy of such predictions needs to be improved if national and international bodies are to set and operate controls on development designed to protect the future environment from excessive degradation. Quantitative research into the processes that control the movement of water through all parts of the environment is therefore essential. Hydrology - like meteorology and oceanography - is a key environmental science with a vital role to play.

UK and European legislation requires that the full environmental consequences of specific development and more general development policies are addressed at an early stage in the planning process. Environmental assessment is now viewed as a valuable procedure that can enhance project design, not merely a test that any scheme has to pass in order to satisfy legislation. Identifying hydrological impacts has become an increasingly important part of any comprehensive environmental assessment.

The hydrological impacts of perturbations imposed on an existing water regime as a result of development will therefore be an important aspect of most environmental assessments. It is quite likely that the greatest consequences of a change in flow regime or water quality may not arise directly, but rather from indirect effects upon sub-systems such as, for example, the local groundwater or the ecology of particularly sensitive or marginal habitats.

The work at IH on the assessment of hydrological impacts has evolved in part as a response to environmental legislation, the form and extent of which will continue to change in response to government policy, public pressure and the outcome of ongoing international environmental research programmes. One of our objectives at IH is to ensure that our research participates in and accelerates scientific developments, so that we are ready with responses to the latest legislative developments. The Institute has therefore sustained a programme of applied studies supported by on-going research in hydrological processes to develop appropriate techniques for assessing hydrological impacts within more general environmental assessment. This work is underpinned by comprehensive sets of time-series and thematic data held at IH. Some of the projects are supported by fellow NERC Institutes of Freshwater Ecology (IFE) and Terrestrial Ecology (ITE). IH is an Associate Member of the Institute of Environmental Assessment.

The following sections describe some recent projects and demonstrate the Institute's ability to manage interdisciplinary environmental assessment teams, to participate fully in the development of hydrological science for environmental assessment, and to apply techniques to the solution of practical problems of impact mitigation.

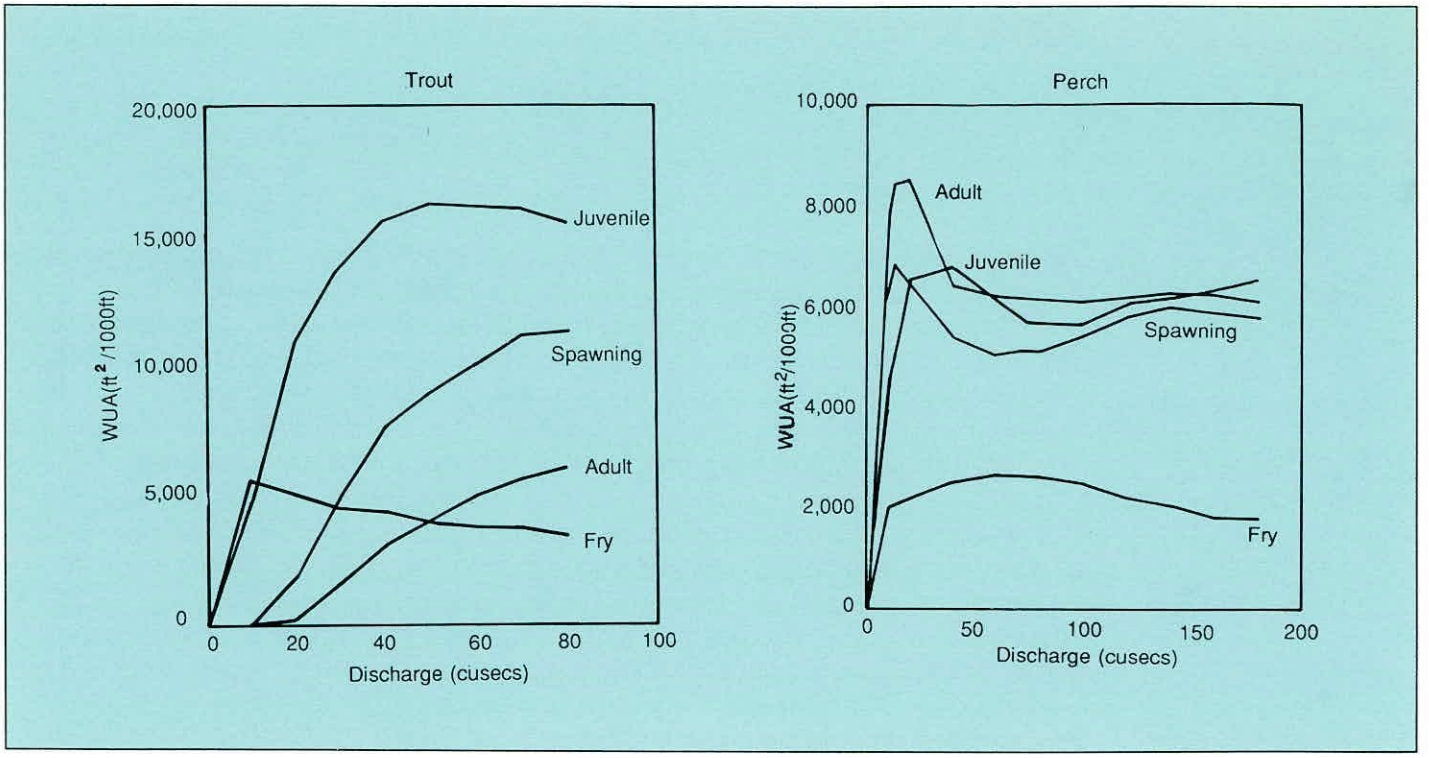
Flow regimes and ecology

The Physical HABitat SIMulation (PHABSIM) model, developed and released on public access by the Aquatic Systems Branch of the US Fish & Wildlife Service, is integral to the Instream Flow Incremental Methodology (IFIM). IFIM is a management model which considers ecological demands when recommendations for flow regimes are determined, and has been widely used in 20 states in the USA. IFIM relates changes in habitat area available to aquatic species to changes in discharge, allowing ecological demands to be expressed in the same terms as other water resource demands.

Following the success of an initial study (published in *IH Report No. 115*), further assessment of the applicability of PHABSIM to UK rivers is in progress, with support from the Institute of Freshwater Ecology, through a three-year R & D commission on 'Ecologically Acceptable Flows' funded by the National Rivers Authority. This work is highly pertinent to the European

The River Blithe, upstream of Blithfield reservoir, a typical stretch of river used in habitat surveys

La rivière Blithe, en amont du réservoir de Blithfield, un bief typique utilisé pour l'étude des habitats



Community requirements and those of the 1989 Water Act for the NRA to set 'minimum acceptable flows' where the PHABSIM model could be a useful tool.

Ten rivers in England and Wales have been selected for the study. The rivers lie in ten different ecological zones, identified by analysis from the IFE RIVPACS database of invertebrate groupings in over 100 sample UK river reaches. In addition to the on-going collection of hydrological data at the ten chosen sites, habitat suitability requirements of selected target fish, invertebrate and macrophyte species are being developed by IFE. The multi-disciplinary nature of this project has highlighted the general need for more integration in the collection of hydrological and biological data, which is essential if ecological demands are to be assessed alongside other water resource demands. Application of the method in such diverse river environments has required the development of new fieldwork techniques which in itself has been a new challenge.

Flow regimes and water quality

Many environmental impact studies centre on the problems of water quality in streams and rivers. The following case study shows how a wide range of different skills were brought to bear on a particular engineering project which had environmental implications.

For generations, the area around Maidenhead, Windsor and Eton has suffered severe flooding. Recently, the Thames Region of the NRA has proposed a major flood alleviation scheme to protect these towns. The scheme involves the construction of a flood relief channel some 11.5 km long and with a capacity similar to that of the main river. The channel will traverse the shallow gravel aquifer enclosed by a loop of the Thames between Maidenhead and Eton.

There is some concern that at times when the channel is not being used to convey flood waters from the river, the seepage of nitrate-rich groundwater into the open channel may pose water quality problems.

The Institute has modelled the effects on water quality of different operating policies on both the

Figure 16 PHABSIM is a tool which enables 'ecologically acceptable flows' to be set for target fish in ecologically different rivers.

PHABSIM est un outil qui permet d'évaluer les "débits écologiquement acceptables" pour des poissons donnés dans différentes rivières.

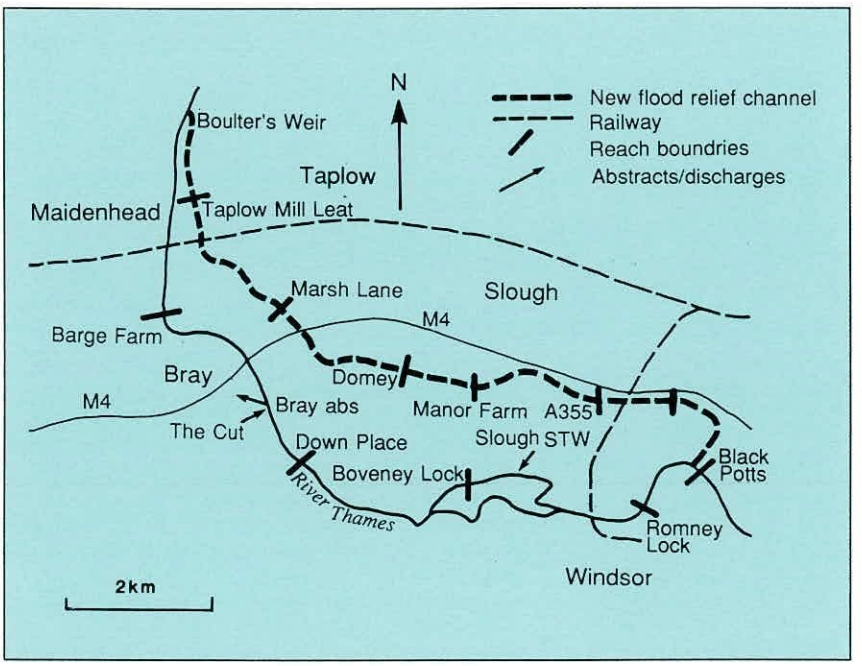


Figure 17 The model structure for the flood relief channel for the Thames at Maidenhead

La structure du modèle pour le canal d'évacuation des crues de la Tamise à Maidenhead

channel and the main river. Groundwater inflows, and the associated water quality, were provided from an existing groundwater model. IH contracted IFE and ITE to provide specialist ecological inputs to the study. The model showed that water quality in the channel would not deteriorate if a regular sweetening flow from the Thames were maintained. During drought periods, however, this might not always be possible as there are navigation interests to satisfy in the main river.

Hydrological studies of wetlands

Many of the UK wetland areas are under threat because of land drainage and other agricultural practices. It is increasingly difficult to achieve a balance between the needs of modern farming and various recreational requirements while also conserving the ecological uniqueness of such regions.

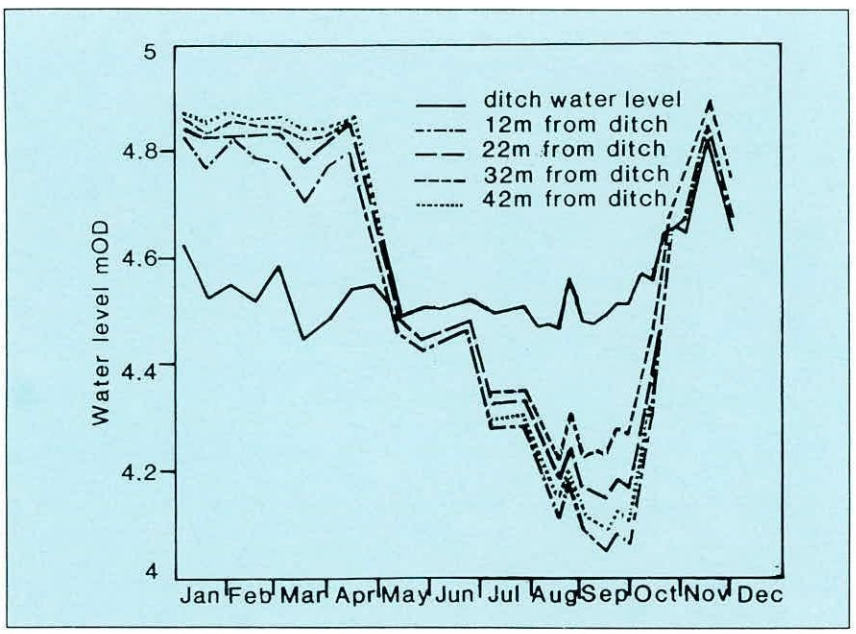


Figure 18 The Sedgemoor study has quantified changes in the pumping regime and established the relationship between water table and the levels in open ditches.

L'étude de Sedgemoor a quantifié les changements en régime de pompage et a établi une relation entre le niveau de la nappe aquifère et le niveau d'eau dans les fossés.

In 1985 IH was commissioned by the Nature Conservancy Council to study the hydrology of West Sedgemoor, a peatland site where water levels are managed by a pumping station in the interests of grazing and hay production. There has been a long-term decline in the conservation value of the area, which is designated as a Site of Special Scientific Interest. The Institute was able to quantify changes in the pumping regime, and established the relationship between water levels in the open ditches dissecting the Moor, controlled by fixed 'penning levels' at the pumping station, and the elevation of the water table in the fields.

Three complete years' data were collected from water level stations on the ditches and from a network of dipwells. A longer sequence of measurements of water level taken at the pumping station showed that there was a gradual fall in the levels in the main drain over the period between 1964 and 1986, presumably in reaction to a perceived decline in ground level and to the needs of agriculture. Ground level within the fields was shown to vary in response to the water table, with a seasonal amplitude of up to 200 mm. This ground movement is caused by a combination of shrinkage of the upper layers of the peat on desiccation, and loss of buoyancy leading to compression of the lower, saturated horizons.

The response of the water table to possible changes in the management of ditch water levels has been explored with a digital model. Despite the maintenance of a high penning level in summer, the water table in the fields experiences a drawdown which is determined almost entirely by climate. There is a considerable inertia in the groundwater body, and changes in the central area of a field take time to develop. The change in groundwater levels resulting from variation of summer or winter water penning levels is always less than the change in ditch level, owing to the delay in the system, but the model demonstrates the importance of very high water levels in winter in restoring the water table in readiness for the summer drawdown.

Alluvial groundwater systems

IH have recently completed an investigation of the possible impact of a nearby gravel extraction and landfill proposal on groundwater levels beneath Burnham Beeches SSSI. The project involved IH groundwater hydrologists in the drilling and monitoring of over 30 wells, together with pumping and permeameter tests.

The fieldwork showed that the area is characterized by a series of partially connected, compartmentalised layered aquifer units within River Terrace Deposits and Reading Beds with groundwater eventually reaching the Chalk aquifer via solution features: one such feature proved to be 25 m below ground level. Hydraulic conductivities in the gravels derived from pumping tests, variable head tests and permeameter tests ranged from 10^{-1} to 10^{2} m d^{-1}, with column drainage tests giving specific yields ranging from 0.05 to 0.2.

Using a computer model developed previously by IH for predicting groundwater changes around gravel pits, the likely alteration of water levels under the Beeches was predicted.

These examples of recent projects demonstrate the Institute's ability to manage interdisciplinary environmental assessment teams, to participate fully in the development of hydrological science for environmental assessment, and to apply techniques to the solution of practical problems of impact mitigation.

Land use change

Land use change remains a dominant area of research in IH with increasing national and international significance. Major changes are taking place in the landscape through afforestation and deforestation in the uplands, and broadleaf afforestation in the lowlands. These, coupled with agricultural changes imposed by altered climates or government policy, means that land use change issues are likely to stay at the forefront of the Institute's research programme.

A notable landmark over the past year has been the publication of results from twenty years of research in upland Wales (at Plynlimon), and ten years of research in the uplands of Scotland (at Balquhidder). New projects have also begun on the impacts of broadleaf afforestation in the UK and erosion processes and quality studies in Nepal.

Changes in land use in the UK have been gathering momentum since the beginning of the century. A variety of causes lie behind the alterations to be observed in the British landscape, such as an increase in forest plantation, principally conifers; the ploughing up of large areas of permanent grassland for arable farming; the large-scale use of fertilizers and agrichemicals; increased urbanisation to meet the needs of a growing population; land drainage for expanding agriculture; and, more recently, the move towards 'set-aside'. Other changes could follow if the view that more forest - particularly using more broadleaf species - should be developed adjacent to urban centres gains wide acceptance.

All these factors impact on the quantity and quality of surface and groundwater regimes and the ecology of an area. For example, the ploughing up of grassland and the establishment of forest stands may initiate sediment disturbance and acidification problems, exacerbate eutrophication and the deposition of atmospheric pollutants; they may also alter the timing and magnitude of peak river flows. It is therefore extremely important to study, understand and appreciate, albeit retrospectively, the reasons for the observed, sometimes detrimental, changes which have occurred so that future developments may be planned accordingly. The following sections describe some examples of studies undertaken at IH to assist in this task.

Automatic weather station in experimental plot within the Black Wood, Hampshire, as part of a study on the effects of lowland broadleaf afforestation

Une station météorologique automatique dans le bois de Black Wood, Hampshire, faisant partie d'une étude des effets de la plantation d'espèces caduques à basse altitude

Water Quantity Studies

The impact of forests on water remains a central theme in hydrological research. The studies carried out in the mid-fifties at Stocks Reservoir in Lancashire indicated that the evaporation from a coniferous plantation was much greater than that from surrounding grass moorland. The implications for water supply and hydroelectric generation were far-reaching and stimulated the initiation of experimental catchment research at the Institute.

The processes controlling water quantity and quality changes are complex and dynamic, and require a multidisciplinary approach. The higher aerodynamic transfer between the surface of forest vegetation and the atmosphere, in comparison with shorter vegetation, allows for the higher evaporation rates of intercepted water (the interception process). Moreover, forests can scavenge atmospheric pollutants which promotes higher deposition rates of pollutants in both the dry form from reactive gases and as particles, and in the wet form as pollutants contained within cloud and mist droplets. In addition, altered flow paths and land disturbance can enhance sediment release and exacerbate the drainage of acid waters.

The Institute established the Plynlimon experiment in Wales in 1968 to assess the impacts of upland forestry on water resources and water quality. Results from Plynlimon (published as *IH Report No. 109*) confirmed the results obtained at the Stocks Reservoir but raised the question of whether such results would apply in other regions, such as Scotland, where vegetation cover differed and where snow and climatic conditions were significantly different. The Balquhidder experimental catchments were thus established to assess whether the results from Wales could be extrapolated to Scotland.

Impacts of afforestation have been followed in two different ways: catchment studies seek to measure the integrated effects of a specific land-use treatment - whether it be afforestation or deforestation - whilst process studies have been directed to identifying, understanding and quantifying the underlying mechanisms.

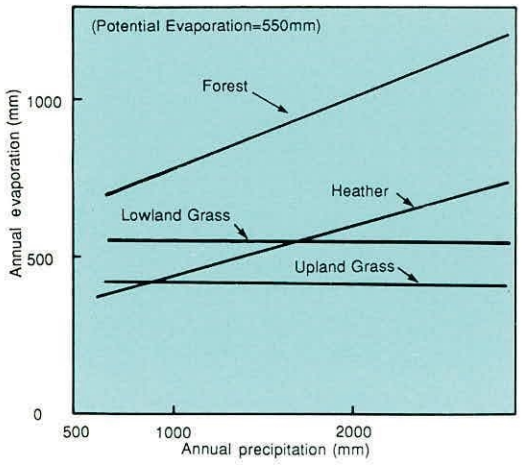


Figure 19 Evaporation estimates for different vegetation types

Estimations de l'évaporation pour différents types de végétation

Perhaps one of the greatest strengths of the combined catchment and process study approach lies in the ability to compare and contrast results which are, to a large extent, derived independently. Indeed, some of the most exciting insights obtained (see *IH Report No. 116*) and new research areas identified from the Balquhidder studies have arisen through trying to reconcile the two approaches.

The increasing windspeed – and to some extent solar radiation – with altitude results in a larger value for 'potential' evaporation as calculated from the Penman E_T formula. This effect is the reverse of that expected from using other mathematical estimation techniques which assume that evaporation decreases with altitude. Lysimeter measurements show actual evaporation from upland grass is considerably less than potential, primarily because the grass is dormant for a considerable fraction of the year. In contrast, measurements of evaporation from heather show it to be equal to or greater than the potential, especially in the high rainfall areas. This has major implications for land-use and water resources. The results of this work have been incorporated into a water-use model for upland vegetation (see Figure 19).

Hydrochemical Studies

With the increasing emphasis on environmental threats and recent predictions of climate change, sites such as Balquhidder and Plynlimon provide a unique opportunity to monitor closely the likely impacts on water quantity and water quality. Such well instrumented and managed sites are providing key baseline data to assess change in the future. Moreover, they provide a testing ground for new hypotheses on ecosystem dynamics, chemical behaviour and hydrological controls and are available to the wider scientific community for process studies and inter-disciplinary research.

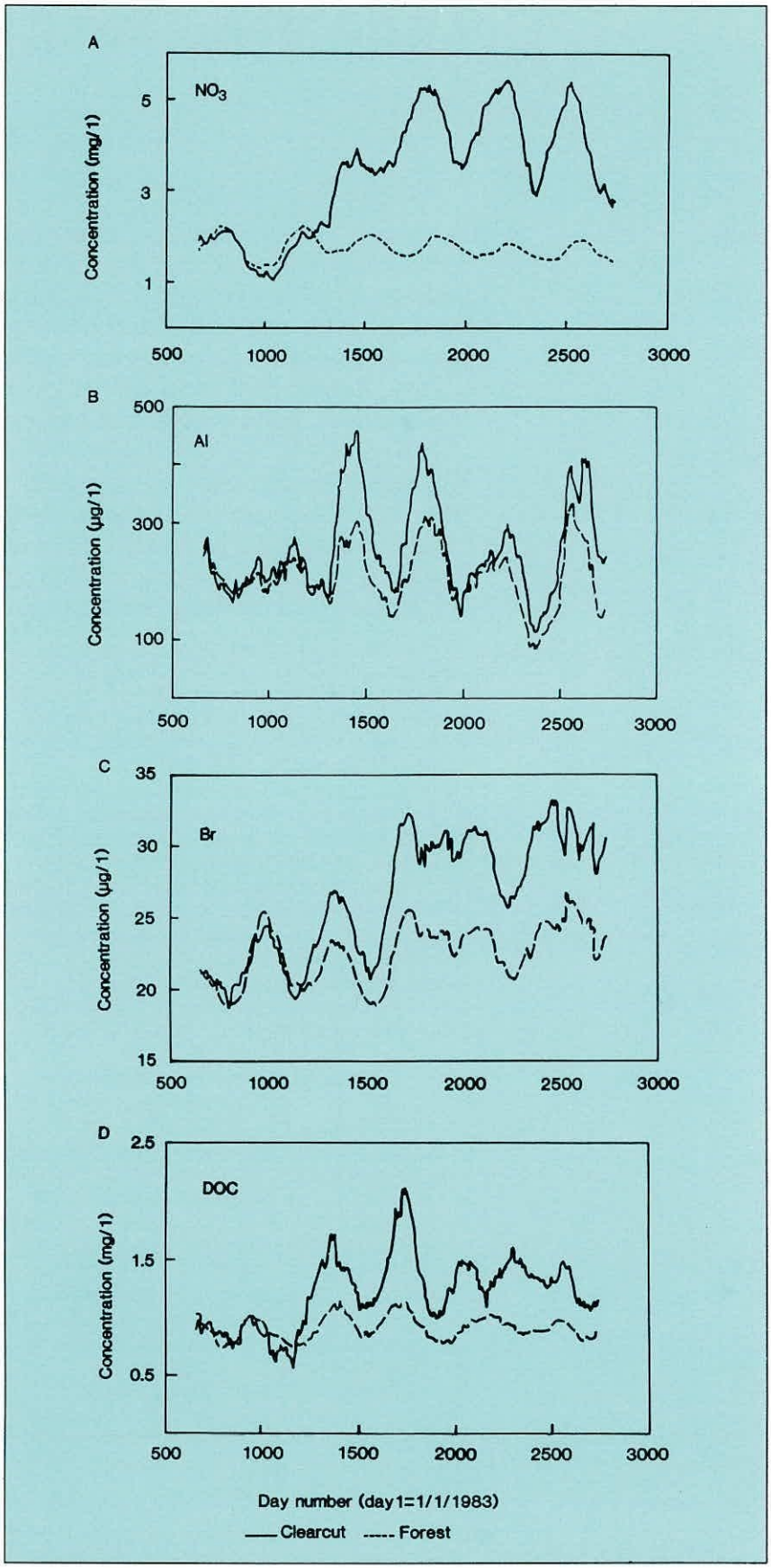


Figure 20 Changes in different chemical determinands from clearcut and forested catchments, Plynlimon, 1983-1990

Variations de différentes composantes chimiques dans un bassin avec forêt et dans un bassin après la coupe forestière, à Plynlimon, entre 1983 et 1990

For example, a major study has been undertaken at Plynlimon to assess the impact of clearfelling on stream water quality. Figure 20 shows the variations in concentration of several key determinands since felling took place. The increase in nitrate levels (shown in A) impacts on acidification processes by decreasing pH and releases toxic metals such as manganese and aluminium (shown in B); increased nitrate exacerbates eutrophication in upland reservoirs. Bromine levels (as shown in C) have similarly increased dramatically and may become a problem for water undertakers because of the potential for the formation of trihalomethanes and haloforms during water treatment processes. The increase in dissolved organic carbon (shown in D) reflects the increased colour content in the streams, again a cause of concern for potable water supply.

Sediment Studies

Over the last two decades, the Institute has steadily built up an extensive data compilation on the impacts of conventional forest practice upon bed-load and suspended sediment transport in upland streams. This information, together with data from other studies, has provided scientific support for guidelines for foresters, the water industry and conservationists. Conventional practices are now being compared with other, more recent techniques thought to reduce impacts upon the fluvial system, such as new ground preparation techniques, buffer zones and a reduction in erosion at source. When combined with water chemistry data, a fuller picture of the effects of clear felling at the other end of the forest rotation is emerging.

The Upper Severn experimental catchment at Plynlimon is the site of two collaborative studies with university research teams. One of these, with the Geography Department of Birmingham University, on bank erosion processes utilises a photo-electronic system to continuously monitor erosion of an upland alluvial river bank for the first time. Records of water discharge, climate and sediment transport are being used in a long-term trial of this innovatory system. In the same reaches, IH is to carry out joint work with the University College of Wales on modification of coarse sediment by pebble abrasion processes. This study links in with laboratory pebble abrasion experiments being carried out in U.C.W.'s Geography Department.

To counter the effects of acid runoff upon fish populations, the National Rivers Authority has been experimenting with the addition of granular limestone to the channel to improve stream habitat at a number of sites in Mid-Wales. The grades of limestone used in these feasibility studies extend from material fine enough to be subject to suspended load transport up to gravel sizes which moves downstream as bed-load. Observation of removal and downstream migration of this material under a variety of flow conditions has indicated the grades of material which are likely to be quickly removed from a given reach and the dynamics and residence time of larger grade injected material. It is hoped that this will provide a management tool, in combination with fishery and water quality monitoring programmes, to indicate the most desirable grades and quantities of limestone necessary to provide significant long-lasting amelioration of stream acidity.

IH is in the second year of a major commission from NRA to investigate the effects of agricultural soil erosion upon watercourses. This study has involved the compilation and analysis of suspended sediment load data from throughout England and Wales, including a new field programme with networks of turbidity monitors and bulk samplers and analysis of existing

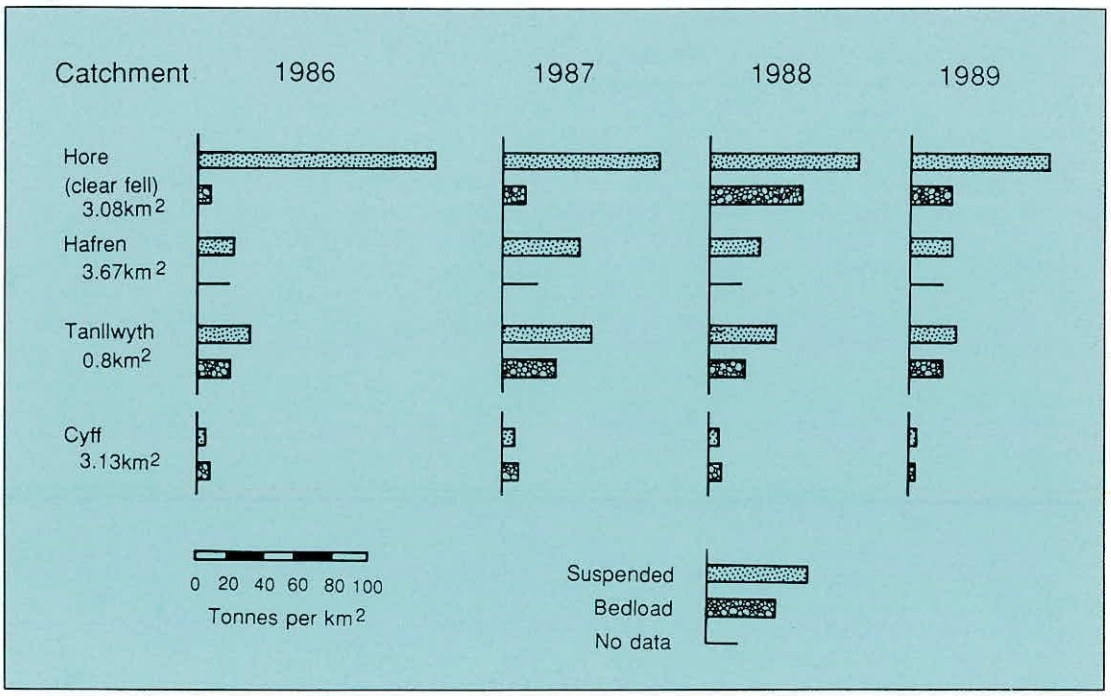


Figure 21 Annual sediment yields from the Plynlimon experimental catchments

Teneurs annuelles en sédiments des bassins expérimentaux de Plynlimon

archive data. Intensive measurements are being carried on six selected catchments to quantify the impact of particulate inputs from field surfaces in to the fluvial system.

Lowland Broadleaf Afforestation

The government is actively encouraging farmers to convert agricultural land to broadleaf woodland. This change is likely to have an effect on both water quality and on water quantity, particularly in drought years.

Two current projects, "The hydrological effects of broadleaf woodland in lowland Britain" and "The impact of broadleaf woodland on groundwater", part-funded by the NRA and the Directorate of Rural Affairs, DoE, are investigating the water use and the effect on water quality of broadleaf trees on two important geological formations in lowland Britain, Boulder Clay overlying the Oxford clay (Old Pond Close, Northants.) and the Chalk (Black Wood, Hants.).

These projects have made detailed water use and quality measurements at the two key sites. The important mechanisms controlling the water use of broadleaf woodland have been identified and a range of water use models calibrated. The measurements show that the trees regulate their water use through physiological controls but the large rooting depth allows them to continue to evaporate when other vegetation would have stopped. Preliminary results from the modelling studies show that in average years the water use of broadleaf forest and grassland is likely to be similar. However, in drought years such as 1976 and 1990, woodland evaporates substantially more water.

Significant increases have been found in the fluxes of solutes reaching the forest floor when compared with those in rainfall above the canopy. Most noticeable are the variations in the solutes arising from sea salt (see Figure 22), particularly when sampled at the edge of the forest plots; these effects are not obvious with other solutes which are recycled with the forest canopy, such as nitrogen. The results from analyses of throughfall samples have been confirmed by hydrogeological studies. Both sets of results suggest increased evaporation and scavenging of sea salts at the forest edge.

The major effect on groundwater quality of replacing agricultural land with woodland is likely to be a reduction of nitrate leaching due to reduced fertilizer inputs. However, the nitrate concentrations in the groundwater beneath woodland are highly variable and high levels (greater than 20 mg l^{-1} NO_3-N) have been found, often associated with small clearings with fallen trees. It is obviously important to consider the complete cycle of forest growth, from establishment through maturity to felling.

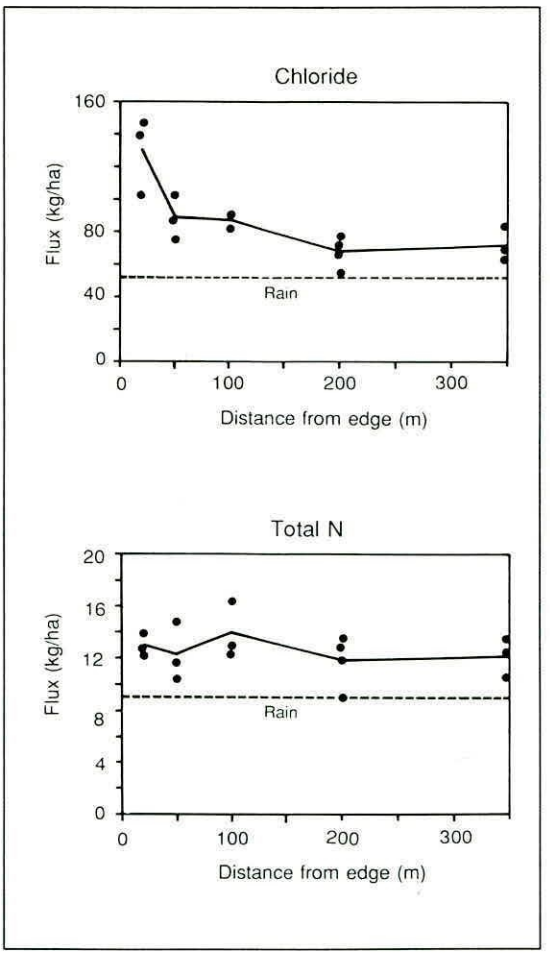


Figure 22 The mean fluxes of chloride and nitrogen reaching the forest floor, from measurements at the Black Wood site. The chloride shows a clear gradient from the forest edge but the nitrogen does not; both, however, show an increased flux when compared with the rainfall.

Les flux moyens de chlorure et d'azote atteignant le sol de la forêt, à partir de mesures effectués au site de Black Wood. Le chlorure varie selon un net gradient à partir de la lisière, ce qui n'est pas observé avec l'azote; cependant les deux flux augmentent avec la pluie.

These results now need generalising and incorporating into models of total catchment output so that the impact of particular afforestation schemes can be assessed. A start has been made, particularly for water use. However, more modelling and field measurements are required to produce estimates for a range of catchment and forest types.

Current research aims to combine our existing data with new measurements and to incorporate these into a management model. This could be used to assess the effects of a major change to or from woodland on the flow and quality of a river and where appropriate on the groundwater. New calibration/verification measurements to include common combinations of geology and species not covered in the current research will also be undertaken and an experiment initiated to investigate more fully the processes (scavenging, interception and transpiration) occurring at a forest edge. This work will capitalise on and expand upon the findings from Black Wood. It will then be possible to apply the methodology to estimate hydrological impacts for a number of selected catchments.