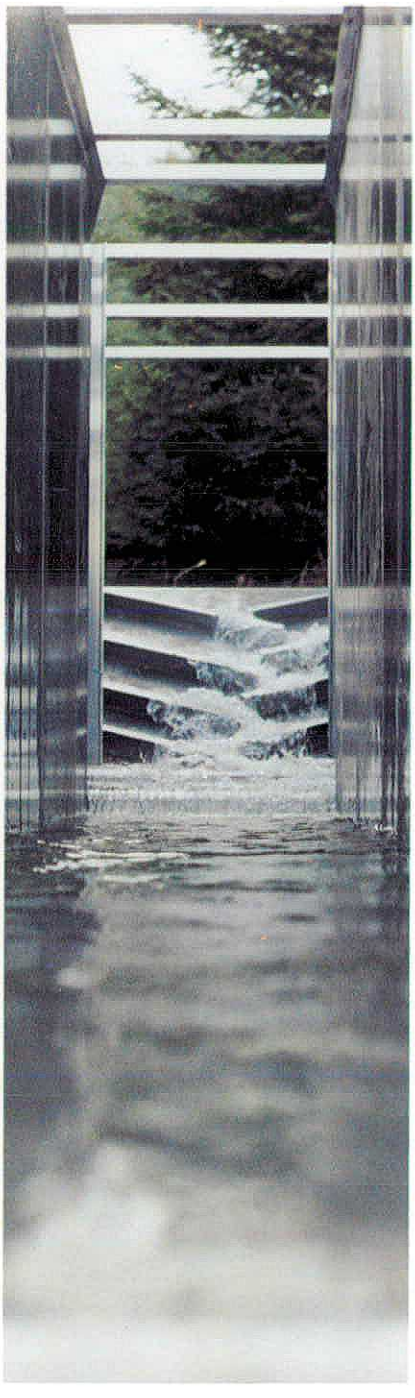
1988 – 1989

REPORT



Institute of Hydrology

Natural Environment Research Council

Foreword

The Natural Environment Research Council produces an Annual Report summarising the activities across the organisation. Such an Annual Report can only provide selected information on the scientific activities of individual Institutes. It is therefore important for each Institute to produce its own Report which gives a full account of its research, its structure and its finances.

The Institute of Hydrology is part of the Terrestrial and Freshwater Sciences Directorate of NERC. The Directorate's in-house capability also comprises the Institutes of Freshwater Ecology (formed in April 1989 from the staff and laboratories of the Freshwater Biological Association), Terrestrial Ecology, and Virology and Environmental Microbiology (formerly the Institute of Virology but renamed in April 1989), the Unit of Comparative Plant Ecology (Sheffield University), the Water Resource Systems Research Unit (Newcastle University) and the Interdisciplinary Research Centre for Population Biology (Imperial College London).

The Institute of Hydrology has continued its vigorous and dynamic commissioned research programme, together with much valuable work done under the Science Budget. Following the retirement of Dr James McCulloch, the founding Director, after 27 years of distinguished service, I would like to take this opportunity to welcome the new Director, Professor Brian Wilkinson. During the year there have also been major changes in the management structure which will strengthen the Institute.

P B Tinker
Director of Terrestrial and Freshwater Sciences
Natural Environment Research Council

Front Cover Illustration: New streamflow gauging structure for water quality studies, central Wales. (Photograph: A C Warwick).

The Natural Environment Research Council

Report of the Institute of Hydrology for 1988/89

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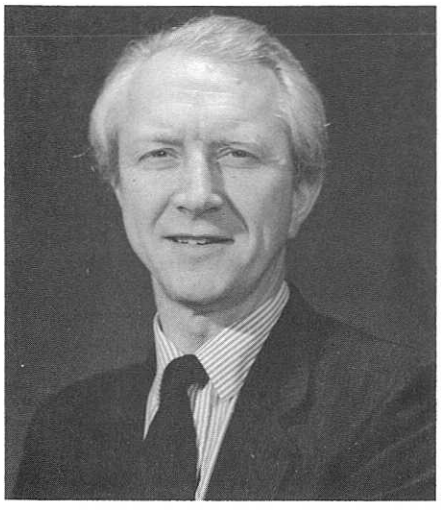


This report covers my first year as Director of the Institute of Hydrology. I am pleased to report that the Institute's research programme continues to reflect that exciting mixture of innovative science and pragmatic problem solving that characterises much of present day hydrological practice. In particular, I should like to highlight the following important developments:

- new types of research have begun on climate change;
- research on water quality has expanded;
- a new computer-based Water Information System has been developed;
- a new management structure has been introduced which is more relevant to the hydrological issues of the 1990s;
- links with other Institutes in the Terrestrial and Freshwater Sciences Directorate have been strengthened, and
- the support for commissioned research at the Institute has continued to grow.

Research initiatives

Due to man's activities over the last two hundred years, the pace of global environmental change has quickened and issues such as pollution, desertification, urban spread, deforestation and global warming are causes for scientific, public and political concern. These problems may well represent the most significant challenge facing the world tomorrow. Knowledge of hydrological processes is central to understanding the causes and to providing solutions to most of these issues.

The development of atmospheric research has been given high priority over the last decade. The hydrology of the continental land masses in such models received only a simple description. However, as concern for global environmental issues grew, attention turned more towards predicting climate change over the land rather than the oceans so that studies of the impact on humanity could be made.

In addition, many regions have experienced rapid changes due to soil erosion, deforestation and irrigation. The need for a better understanding of changing land use and representation in the climate models of the hydrological processes that occur at the land surface is now well recognised. Indeed, the World Meteorological Office (WMO) has given this type of work a high priority in their World Climate Research Programme (WCRP). This research requires collaboration between international teams of hydrologists, meteorologists, soil physicists, plant biologists and scientists with skills in instrumentation and remote sensing. Scientists from this Institute are recognised internationally as one of the leading teams in this respect. Extensive oveseas field studies have been made in climate zones ranging from temperate forest to tropical rainforest and savannah to semi-desert conditions. During the coming year, the Institute hopes to be involved with new hydrological land-surface process studies in forested and deforested areas in Brazil, as well as in an arid area in central Spain and possibly in the boreal forests of north America. These proposals are part of the WCRP Global Water and Energy Experiment (GWEX).

One important aspect of the research is to improve the determination of aggregated hydrological parameters over an area of possibly several thousand square kilometres. Remote sensing research at the Institute has a central role in such studies. These regional parameters are necessary to describe the hydrological components of the General Circulation Models (GCMs) used to predict climate change. A collaborative project (MITRE) between the Institute and the Meteorological Office has been established to improve the representation of surface hydrological processes in the UK climate models.

Much of our hydrological research at the Institute is directed towards improving understanding of physical systems. However, there has been, and will continue to be, a steady growth in our water quality studies. The work on acid rain and the predictive capability of the MAGIC model in relating stream water quality in our uplands to the level of sulphur dioxide emissions from the burning of fossil fuels is particularly noteworthy. We have also completed work on modelling caesium distribution following the Chernobyl disaster.

Our field studies on pesticides have also progressed well. This is an important area of research but data on the movement, metabolism and fate of pesticides are sparse and much remains to be done. During the year we have acquired the physical habitat simulation model (PHABSIM) from the USA and, in association with the Institute of Freshwater Ecology and the Institute of Terrestrial Ecology, we are building up experience in its use on UK rivers.

The National Surface Water Archive (IH) and the Groundwater Archive (British Geological Survey) are managed from the Wallingford site. As well as flow and groundwater level statistics, water quality information is now included in the annual Yearbooks published jointly by the two organisations. For the first time since these statistics were first compiled in 1935, the annual data (1988) have been published in the year following their collection and analysis. Long-term, high quality hydrological data sets of the type held in the National Archives are particularly important in providing an historic baseline against which environmental changes may be measured. The data will become more readily accessible as advanced computing methods are used to recover, manipulate and display them ever more rapidly on a terminal or workstation screen. These are exciting prospects and the Institute's Water Information System (WIS), which will display both spatial and time-series hydrological data, is well advanced.

International activities

The Institute has taken part in many overseas studies in previous years but the need for the international scientific community to collaborate over global and environmental issues was never so urgent as now. During the past year we have been very active in the WMO's Commission for Hydrology in providing the Hydrological Adviser to the UK Permanent Representative to WMO and two rapporteurs to Working Parties on Climate Change and Land-Atmosphere Interactions. IH is also the UK centre for the WMO's Hydrological Operational Multipurpose System (HOMS), a scheme for technology transfer to developing countries.

The Institute has also acted as the host laboratory for the Flow Regimes for Experimental Network Data (FREND) study as a contribution to the UNESCO Third International Hydrological Programme. The project brought together scientists from Belgium, the Federal Republic of Germany, Finland, the Netherlands, Sweden and the UK. The Institute will continue to play an important role in future European hydrological research. We have submitted major research project bids to the European Commission's STEP and EPOCH programmes. These have involved us in partnerships with almost all of the member states; we eagerly await the outcome of our submissions. We also provide office accommodation and assistance to the International Association of Hydrological Sciences publications unit (the IAHS Press) on our Wallingford site. The Institute continues to maintain a wide portfolio of commissioned research projects in support of the work of the Overseas Development Administration.

New Divisional structure and facilities

Providing the proper management support to develop these new research areas adequately has required the reorganisation of the Institute. There are now four science divisions:

Hydrological Processes
Environmental Hydrology
Engineering Hydrology
Applications Research

The Institute of Hydrology has had many distinguished visitors during the year. We were particularly honoured to be visited by and to have the opportunity to present some of our research work to Their Excellencies the President of the Republic of Senegal and Madame Abdou Diouf during their State Visit to the Queen and Duke of Edinburgh.
L'Institute of Hydrology a eu cette année un grand nombre de visiteurs distingués. Nous avons été particulièrement honorés de recevoir la visite de leurs Excellences le Président de la République du Sénégal et Mme Abdou Diouf, durant leur visite d'Etat à la Reine et au Duc d'Edimbourg, et d'avoir l'opportunité de leur présenter une partie de notre travail de recherche.

A small Policy Studies and Information Division has also been established, since our research findings are valueless if they are not disseminated in an effective manner. Our specialist consultancy services continue to thrive, and sales of the Institute's computer software have doubled during the year.

It has also been necessary to improve some of our support facilities. A Local Area Network has been completed. When fully operational this will link 160 personal computers across the site. The chemistry facilities have been expanded to analyse a wider range of organic compounds, particularly pesticides.

There has been a marked growth in staff on fixed-term appointments, in students and in visiting workers, particularly from overseas. The increase in the number of students working at the Institute is especially pleasing. It is an exciting time to be undertaking research in the hydrological and environmental sciences and the ideas, energy and enthusiasm of our younger scientists are vital. However, the increase in numbers has continued to create accommodation problems. These are being solved by the use of temporary buildings. In the longer term a permanent extension to the Wallingford laboratory will be needed.

Brian Wilkinson

Rapport du Directeur

Le présent rapport couvre ma première année en qualité de Directeur de l'Institute of Hydrology (IH). Je suis heureux de pouvoir affirmer que le programme de recherches de l'IH continue de refléter un mélange exaltant d'innovations scientifiques et de solutions pragmatiques des problèmes qui caractérise en grande partie les méthodes pratiques dans le secteur hydrologique de nos jours. J'aimerais en particulier souligner les importants développements suivants:

- *de nouveaux types de recherches sur les changements climatiques ont été mis en oeuvre;*
- *les recherches sur la qualité de l'eau ont pris de l'essor;*
- *un nouveau système informatique relatif aux Informations Hydrologiques a été développé;*
- *les liens avecs les autres institutions au sein du Directorat des Sciences Terrestres et de l'Eau Douce ont été renforcé, et*
- *le support en matière de recherches commandées auprès de l'IH a continué de croître.*

Initiatives en matière de recherches

Du fait des activités humaines au cours des deux cents dernières années, les modifications affectant l'environnement de la planète vont à une allure croissante et les questions telles que la pollution, la désertification, le développement des zones urbaines, le déboisement et le réchauffement du globe, provoquent des inquiétudes sur les plans scientifique, public et politique. Il est bien possible que ces problèmes représentent les plus grands défis auxquels notre monde devra faire face demain. Une bonne connaissance des processus hydrologiques est essentielle à la compréhension des causes et à la solution de la plupart de ces problèmes.

Il a été accordé une priorité de toute première importance au développement de la recherche atmosphérique au cours de la dernière décennie. L'hydrologie des masses continentales dans les modèles de cette nature, a fait l'objet d'une simple description seulement. Toutefois, à mesure que les craintes relatives à l'environnement de la planète sont allées en croissant, l'attention s'est tournée d'avantage vers la prévision des modifications climatiques sur les continents plutôt que sur les océans pour permettre d'en étudier l'impact sur le genre humain.

En outre, de nombreuses régions ont connu des changements rapides du fait de l'érosion du sol, du déboisement et de l'irrigation. Il est désormais généralement admis qu'il est nécessaire de posséder une meilleure compréhension des modifications apportées aux utilisations des sols et de représenter dans les modèles climatiques les processus hydrologiques qui surviennent à la surface de la terre. De plus, l'Office Météorologique Mondial (OMM) a accordé à ce type de travail un haut degré de priorité dans son Programme de Recherches sur le Climat Mondial (World Climate Research Programme - WCRP). Ces recherches requièrent une collaboration entre des équipes d'hydrologues, de météorologues, de géophysiciens, de phytobiologistes et de scientifiques versés dans la pratique de l'appareillage et de la télédétection. Les scientifiques de notre Institut ont la réputation, sur le plan international, d'être parmi les équipes de pointe dans ce domaine. Des études de terrain exhaustives ont été entreprises à l'étranger, dans des zones climatiques allant de la forêt tempérée à la forêt tropicale humide et de la savanne aux conditions semi-désertiques. Au cours de l'année à venir, l'IH espère participer à de nouvelles études sur les processus hydrologiques dans les régions boisées et déboisées du Brésil, ainsi que dans les forêts boréales de l'Amérique du Nord. Ces propositions font partie de l'Expérimentation Hydrologique et Energétique Globale (Global Water and Energy Experiment - GWEX) du WCRP.

Un des aspects importants de la recherche consiste à améliorer la détermination des paramètres hydrologiques agrégés sur une superficie pouvant atteindre plusieurs milliers de kilomètres carrés. La recherche en télédétection de l'IH joue un rôle primordial dans les études de ce type. Ces paramètres régionaux sont nécessaires pour décrire les éléments hydrologiques des Modèles de Circulation Généraux (General Circulation Models - GCMs) utilisés pour la prévision des modifications climatiques. Un projet de collaboration (MITRE) entre l'IH et l'Office Météorologique a été établi pour améliorer la représentation des processus hydrologiques superficiels dans les modèles climatiques du Royaume-Uni.

Une grande partie de notre recherche hydrologique à l'IH vise à améliorer la compréhension des systèmes physiques. Toutefois, nos études sur la qualité de l'eau ont connu et continueront de connaître une croissance régulière. Les travaux entrepris sur les pluies acides et la capacité de prévision du modèle MAGIC, lorsqu'il établit un rapport entre la qualité de l'eau des cours d'eau dans nos régions montagneuses, avec le niveau des émissions d'anhydride sulfureux provenant de la combustion des combustibles fossiles, sont tout-à-fait remarquables. Nous avons également mené à bien la réalisation d'un modèle sur la distribution du césium à la suite du désastre de Chernobyl.

Nos études de terrain sur les pesticides ont également fait de bons progrès. Ce domaine de recherche est un des plus importants mais les données sur le mouvement, le métabolisme et le sort des pesticides sont limitées et il reste beaucoup à faire en la matière. Au cours de l'année qui vient de s'écouler, nous avons fait l'acquisition du modèle physical de simulation de l'habitat fluvial (physical habitat simulation model - PHABSIM) mis au point aux Etats-Unis et, en collaboration avec l'Institute of Freshwater Ecology et l'Institute of Terrestrial Ecology, nous nous familiarisons avec lui en l'appliquant aux cours d'eau du Royaume-Uni.

L'Archive Nationale des Eaux Superficielles (IH) et l'Archive des Eaux Souterraines (British Geological Survey) sont gérées à Wallingford. De même que les statistiques sur les débits et le niveau de la nappe phréatique, des informations sur la qualité de l'eau sont désormais incluses dans les recueils annuels publiés conjointement par les deux organisations. Pour la première fois depuis la première compilation de ces statistiques en 1935, les données annuelles (1988) ont été publiées dans l'année qui en a suivi la collecte et l'analyse. Des séries de données hydrologiques de bonne qualité, recueilles de longue date, du type conservé dans les Archives Nationales sont particulièrement importantes pour fournir un cadre historique par rapport auquel les modifications de l'environnement peuvent être mesurées. Il sera de plus en plus facile d'accéder aux données avec l'utilisation de méthodes informatiques de pointe qui permettent de les rappeler, les traiter et les visualiser encore plus rapidement sur un écran de terminal. Les

perspectives dans ce domaine sont exaltantes et le système d'Information Hydrologique de l'IH (Water Information System - WIS), qui visualisera les données hydrologiques sur les plans, tant spatial que temporel, est à un stade de mise au point avancé.

Activités sur le plan international

L'IH a participé à de nombreuses études outre-mer par le passé, mais la nécessité d'établir une collaboration étroite entre les membres de la communauté scientifique internationale à propos des problèmes écologiques au niveau de la planète, ne s'est jamais fait sentir de façon aussi pressante. L'année dernière, nous avons pris une part active au Comité pour l'Hydrologie de l'OMM en fournissant le Conseiller Hydrologique au Représentant Permanent du Royaume-Uni auprès de l'OMM et deux rapporteurs aux Groupes de Travail sur les Modifications Climatiques et les Interactions Masse Terrestre-Atmosphère. L'IH est également le centre au Royaume-Uni du Souprogramme Hydrologique Opérationel à Fins Multiples de l'OMM (Hydrological Operational Multipurpose System - HOMS), qui est un projet de transfert de la technologie en faveur des pays en voie de développement.

L'IH a également joué le rôle de laboratoire d'accueil pour l'étude des Régimes de Débit pour les Données de Réseau Expérimental (Flow Régimes for Experimental Network Data - FREND) dans le cadre de sa contribution au Troisième Programme Hydrologique International de l'UNESCO. Le projet a réuni des scientifiques en provenance de la Belgique, de la République Fédérale Allemande, de la Finlande, des Pays-Bas, de la Suède et du Royaume-Uni. A l'avenir, l'IH continuera à jouer un rôle important dans le cadre de la recherche hydrologique européenne. Nous avons soumis d'importantes offres de projets de recherche aux programmes STEP et EPOCH de la Commission Européenne. A cette fin, nous avons constitué des associations avec la majeure partie des pays membres; nous attendons avec impatience le résultat de nos offres. Nous fournissons également des bureaux et notre assistance au groupe publications de l'Association Internationale des Sciences Hydrologiques (International Association of Hydrological Sciences - la presse IAHS) dans nos bureaux de Wallingford. L'IH continue de maintenir un large portefeuille de commandes en matière de projets de recherche qui viennent soutenir les travaux de l'Overseas Development Administration (ODA).

Nouvelle structure départementale et installations

Pour assurer un soutien en matière de gestion qui permette le développement adéquat de ces nouveaux domaines de recherche, il a fallu procéder à une réorganisation de l'IH. Nous avons maintenant quatre divisions scientifiques:

Processus Hydrologiques
Hydrologie et Environnement
Hydrologie Technique
Recherche et Applications

Un petit Service 'Études des Lignes de Conduite et Information' a également été établi, les résultats de nos recherches n'ayant aucune valeur s'ils ne sont pas disséminés de manière efficace. Nos prestations d'experts-conseils continuent de prospérer, et les ventes des logiciels développés par l'IH ont doublé au cours de cette dernière année.

Il s'est également avéré nécessaire d'améliorer certaines de nos installations de support. Un Réseau de Secteur Intérieur a été mis en place. Lorsqu'il sera pleinement opérationnel, il raccordera 160 ordinateurs personnels répartis dans nos bureaux. Les installations chimiques ont été agrandies pour permettre l'analyse d'un plus grand éventail de produits organiques, comme les pesticides en particulier.

Personnel nouveau

On a constaté une croissance marquée d'employés permanents, d'étudiants et de travailleurs de passage, venant en particulier de l'étranger. Le nombre croissant d'étudiants travaillant à l'IH est une source particulière de satisfaction. La recherche dans les secteurs de l'hydrologie et des sciences de l'environnement connaît actuellement des jours exaltants, et les idées, l'énergie et l'enthousiasme de nos plus jeunes scientifiques sont d'une importance vitale. Toutefois, l'accroissement des effectifs a continué de créer des problèmes de logement. Ceux-ci sont résolus par l'utilisation de bâtiments provisoires. Mais à long terme, il s'avérera nécessaire de construire une extension permanente au laboratoire de Wallingford.

Brian Wilkinson

Effect of man on the hydrological cycle

Experimental catchments

All human activities have some impact on the environment. The Institute has a long-term interest in the effects on the hydrological cycle of large-scale changes such as land-use change. The best known example of this type of research is the work carried out at the Institute's field station at Plynlimon, mid-Wales. A paired catchment experiment in the headwaters of the Rivers Severn and Wye has been running since 1967, with the aim of assessing the losses of water caused by the change from upland grazing to conifer forest in a region that is important for its contribution to Britain's water supply. Over the years, the Plynlimon station has attracted studies of many other environmental effects, and the network of experimental catchments, each instrumented to investigate particular problems, has grown.

Investigation of the effects of land use demands both intensive and extensive approaches. There is a need to make both detailed point measurements with a high degree of precision and also to draw conclusions and make predictions on the basin scale. The advantages of taking a catchment as an experimental area are its similar spatial scale to the land-use pattern, and the ability to partition the water balance into simple terms, with no surface or subsurface inflow, and all lateral outflow concentrated through a single measuring structure.

The catchment approach demands accurate instrumentation, a thoroughly reliable data collection system and a strict procedure for data processing and quality control, maintained over a long period. As the experiment proceeds, the work entails a continuous programme of checking on instrument calibrations and gauging structure datum levels, the recording of the progress of land-use changes within the catchment, and the tracking of year-to-year climate variations. The Plynlimon data are now collected largely by solid-state data loggers and transferred to a mainframe database after preliminary examination on a desktop computer.

Further progress has been made in the development of within-year evaporation models with a view to improving water resource assessment, particularly in dry years. The main direction here is to investigate the effects of low temperatures and soil moisture stress on grassland transpiration in the uplands. Following concern in recent years about the effects of land use on water quality, the problems of acidification, leaching of applied fertilizers and increased sediment yield have all received attention at Plynlimon. The effects of modern forestry practices are being investigated on two Llanbrynmair catchments, the recently forested Cwm and the grazed Delyn. New gauging structures are being installed to monitor the effectiveness of riparian mires in controlling the flow of excess nutrients and sediment losses from disturbed land. Other hydrometric networks are being upgraded to improve the water quality component, to take the experiment through the canopy closure phase.

Contour ploughing for afforestation in the Cwm catchment, Llanbrynmair.
Travaux de labour pour l'afforestation du bassin versant de Cwm, Llanbrynmair.

A similar pair of experimental catchments on the western side of the Plynlimon range, at Nant-y-Moch, was instrumented to investigate the effects of upland pasture improvement on water quality. These catchments are now operated jointly by the Institute and by the Department of Geography of the University College of Wales at Aberystwyth. Hydrometric expertise has also been utilised in the design and installation of a steep stream flume for the Llyn Brianne acid waters study in South Wales.

The Institute's catchment experiments at Plynlimon and Balquhidder in Scotland have been used as a background to a wide variety of other studies ranging from the development of sophisticated computer models (for example the Institute of Hydrology Distributed Model) to assessments of algal growth and population studies of river invertebrates and salmonid fish. They are also of great advantage to external researchers requiring long-term climate and land-use records, because knowledge has been accumulated within a firm geographical framework, and the Institute has many contacts with university departments within the UK.

Established patterns of agriculture are more tenuous in the British uplands than in the lowlands and far-reaching changes in land use could be brought about by small changes in climate and large-scale economics. The uplands have streams with 'natural' flow regimes controlled only by climate and land use, relatively unaffected by pollution; the long run of data from the catchment experiments and a network of automatic weather stations thus provide a unique background against which the effects of climate change could be recognised.

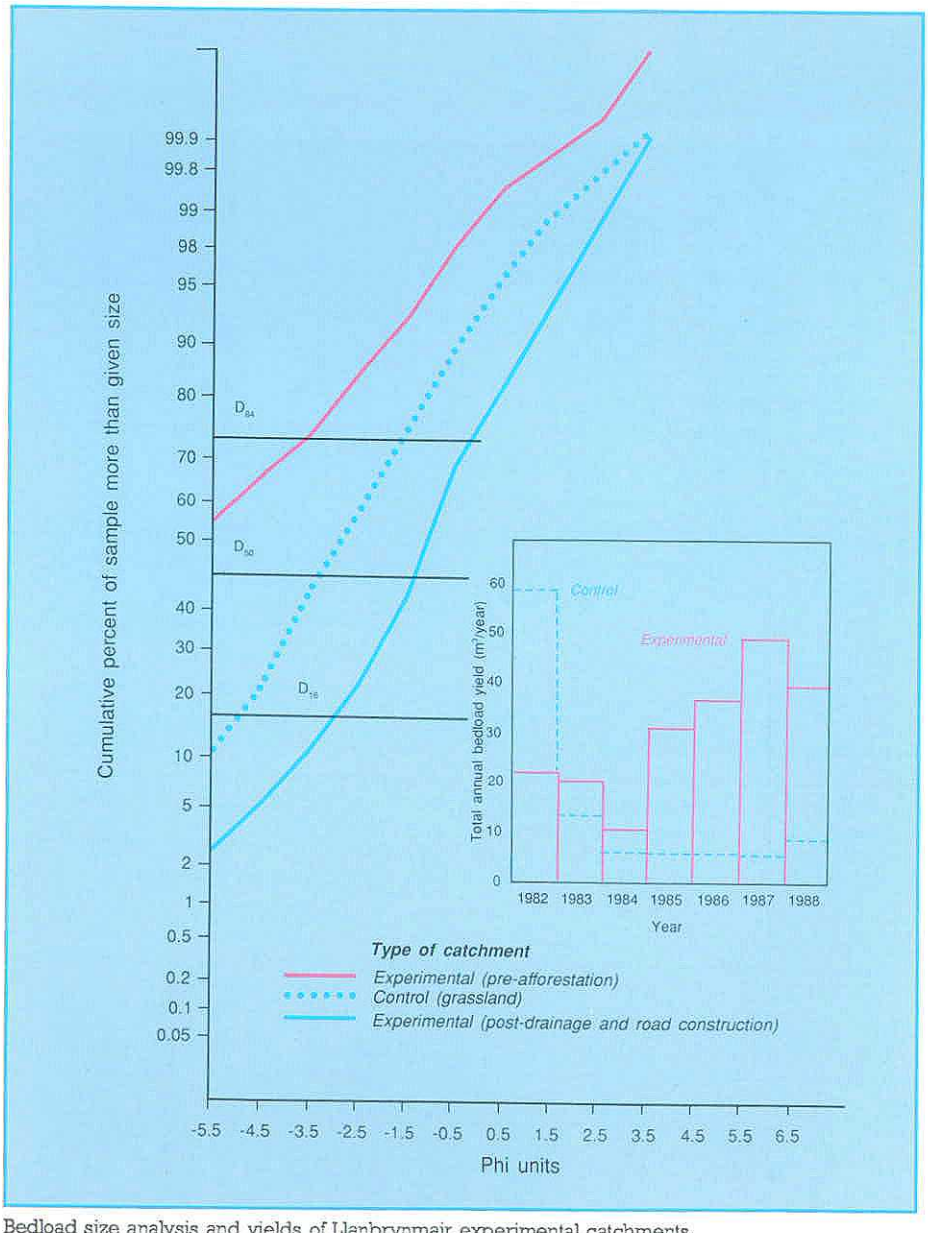
Sediment yields from experimental catchments

Using a number of paired catchment experiments, sediment yields have been studied at each stage of the forest rotation within the Institute's long-running Plynlimon catchment experiment in central Wales. A continuous study of bedload at Plynlimon has indicated a long-term (i.e. over several decades) enhancement in sediment outputs from drained mature forested subcatchments of three to five times that of the nearby grassland catchments. This enhancement relates to the long-term persistent erosion of open forest ditches.

The impacts of afforestation practices have been investigated at Llanbrynmair, also in central Wales, where track-building led to significant increases in bedload yields relative to an un-disturbed rough grassland control catchment. Further increases in sediment yield above those of mature forestry were also apparent in a clear-felling experiment in the Hore (a subcatchment of Plynlimon). Track widening led to an immediate rise in suspended load concentrations by an order of magnitude, while bedload response was initially a fall in yield, resulting from formation of debris-dams in the upper reaches and drains. This was followed by an increase in yields to 5-10 times that of pre-felling. A summary model of sediment yields over the forest rotation has now been developed.

It should be noted that the enhanced sediment yields are lower than in many studies reported elsewhere, particularly in North America, and the data do not relate to the best forest practice now available or put forward in the new Forestry Commission Guidelines. Promising new practices, such as ripping techniques, are now being investigated. The end of the first rotation in many of our upland forests also presents the opportunity to ameliorate long-term persistent erosion. The IH studies have been used as a basis for recommendations to reduce sediment yields from forested catchments which are now being taken up by the water industry, foresters and the Nature Conservancy Council.

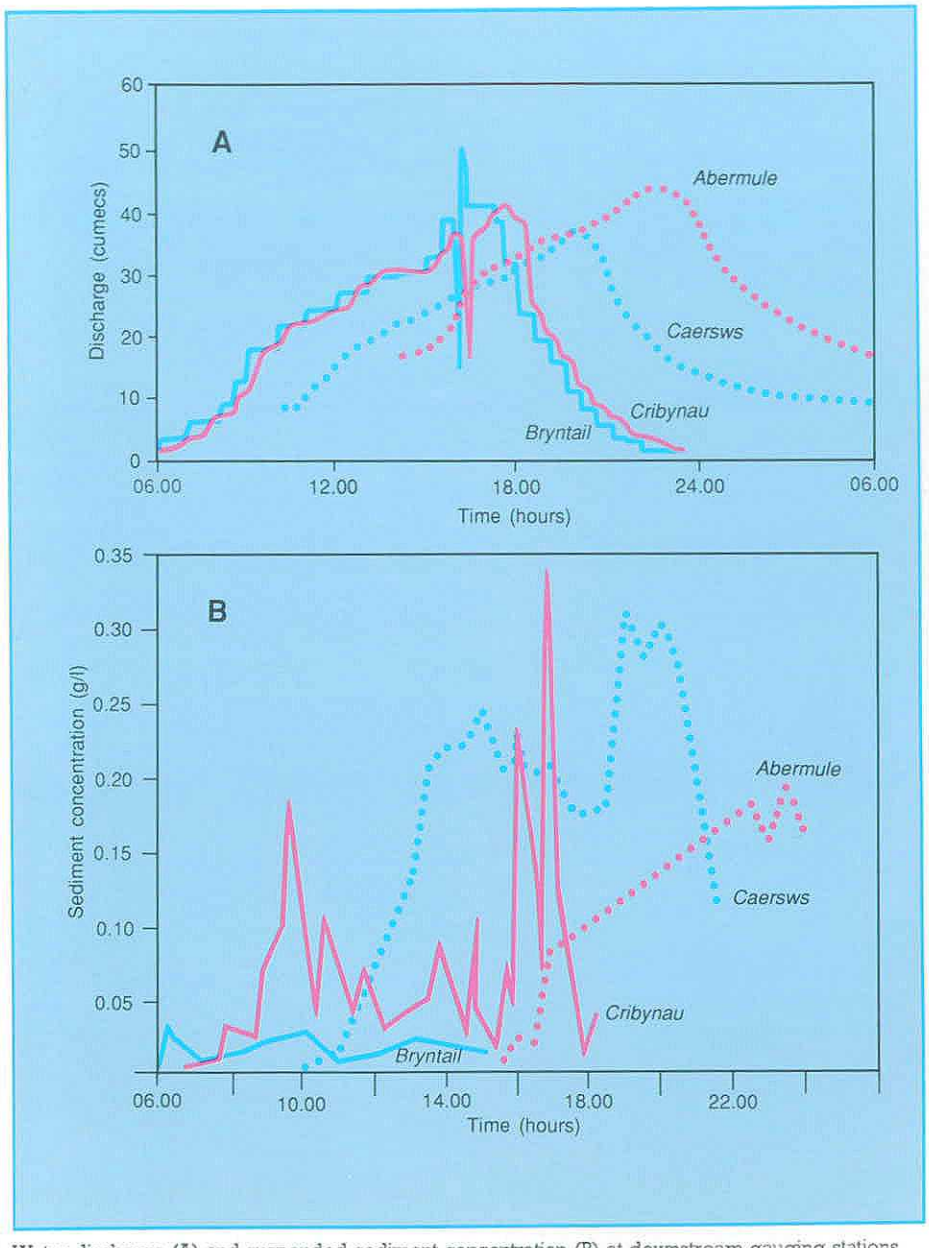
Serious sediment pollution associated with afforestation of 11.5% of the



Bedload size analysis and yields of Llanbrynmair experimental catchments.
Analyse granulométrique et débits du charriage dans les bassins versants expérimentaux de Llanbrynmair.

catchment of Cray Reservoir in the Brecon Beacons, South Wales, provided an opportunity to test the value of direct intervention to halt persistent erosion problems in existing forests.

High inputs of suspended sediment immediately following afforestation in 1981 have resulted in massive additional operational costs. By 1987 it was apparent that the dominant source was one spectacularly eroding drain which had contributed approximately 11 000 tonnes of sediment to the reservoir. Following a joint site visit by IH and Welsh Water, modifications were carried out to the forest drain network, with the cooperation of Economic Forestry Limited, leading to stabilisation of the eroding drain and immediate reduction in sediment pollution back to acceptable levels for water supply.



Water discharge (A) and suspended sediment concentration (B) at downstream gauging stations.
Écoulement de l'eau (A) et concentration des sédiments (B) en suspension aux stations de jaugage aval.

In addition to the use of agricultural catchments as a control for comparison with forestry land-use effects, the paired catchment approach has also been used to contrast rough pasture with improved grassland. Bedload trapping in the Welsh Nant-y-Moch catchments for five years has shown no significant stream sediment transport response to a pasture improvement scheme.

Beach studies

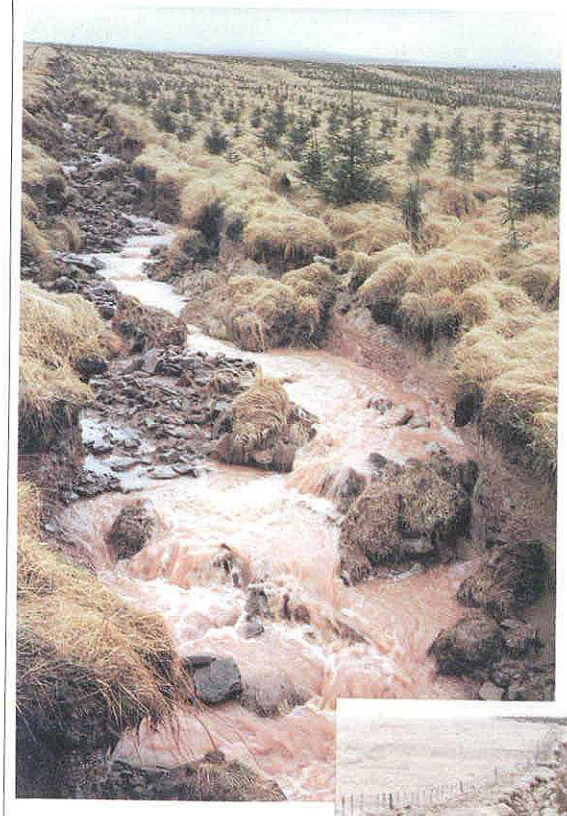
The most direct impacts of man on the fluvial sediment system are in changing flows, sediment availability and channel form. The monitoring of the effects of high discharges from Llyn Clywedog Reservoir upon sediment transport and bank stability has indicated the importance of the duration of high

Removal of sediment from above the Crump weir in the Llanbrynmair.
Enlèvement des sédiments de la zone surplombant le déversoir de Crump dans le bassin versant de Llanbrynmair.

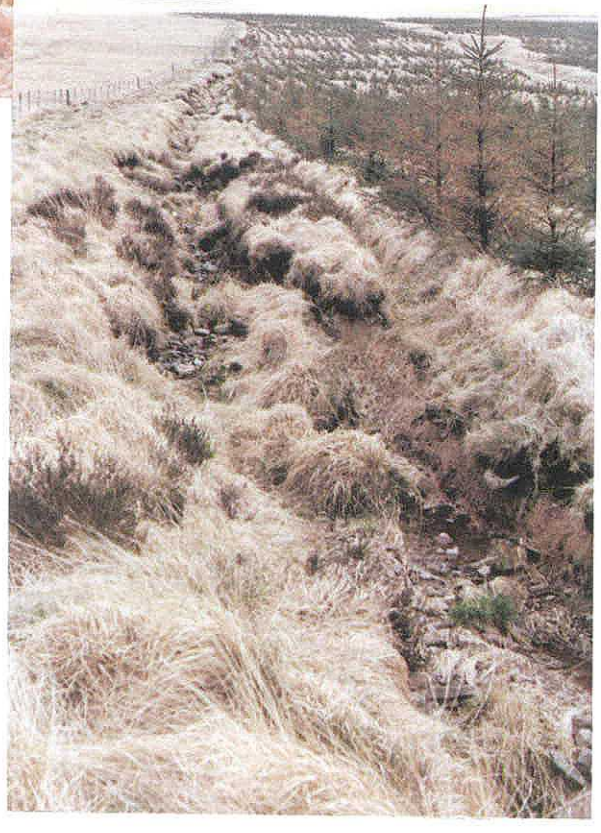
discharges and varying channel impacts through different reaches up to 40 km downstream of the dam. The relative dynamics of the water and sediment waves and in-channel sediment availability were also significant, for example in determining whether erosion or deposition was dominant in any particular reach.

With regard to effects on channel form, a long-term monitoring exercise has been carried out on the River Trannon since the inception of major river channel works in 1979. The initial works have performed badly, with failure of structures originally designed to stabilise the channel, thus endangering the flood protection banks. This led IH and the University College of Wales, Aberystwyth, to investigate fluvial geomorphological reasons for these failures, including long-term channel change and tracer experiments to indicate contemporary bed mobility. Further collaborative work is being carried out with Severn-Trent Water regarding new channel works, more attuned to the sediment dynamics of this river, to combat the possible erosion of flood banks.

A study of the effects of large-scale riparian gravel extraction on the River Tywi in cooperation with Newcastle University and the University College of Wales, Aberystwyth, has been carried out for Welsh Water. This research highlighted deleterious effects on



Eroding forest drain - Cray reservoir 1987.
Erosion d'un drain forestier - Réservoir de Cray 1987.



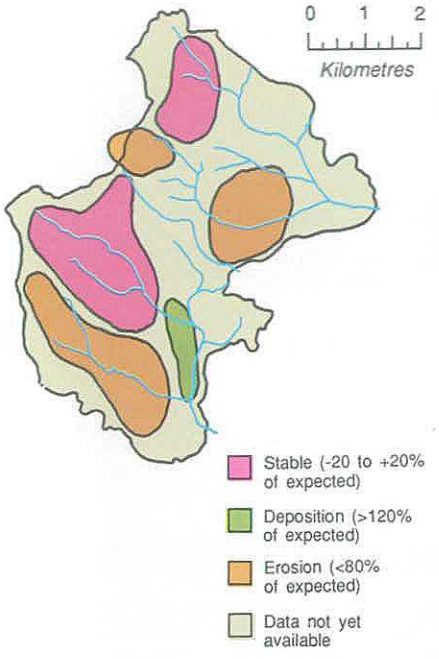
Eroded forest drain - Cray reservoir 1989, now stabilised and grassing over following modifications to the drain network.
Drain forestier érodé - Réservoir de Cray 1989, désormais stabilisé et commençant à être recouvert de végétation à la suite des modifications apportées au reseau de drains.

channel habitat as a result of repeated bed disturbance and removal of bed material at rates higher than the estimated rates of bed sediment replacement. This has led to a review of extraction licence procedures by the Water Authority and District Councils. Another Water Authority has commissioned an investigation of possible effects of riparian gravel extraction on the elevation of manganese and colour levels in water abstracted from a river source for public water supply. This has involved detailed monitoring of downstream variations in channel bed disruption and streamwater chemistry.

Chernobyl-labelled fluvial sediments

Joint work between Liverpool University, the UK Atomic Energy Authority (Harwell) and IH has further clarified the likely sources of fluvial sediment in Plynlimon streams. The use of magnetic analysis techniques in the experimental catchments has been extended in combination with radiometric methods following the nuclear accident at Chernobyl in April 1986. The strong fixation of caesium-137(^{137}Cs) to clay minerals provided an opportunity to study sediment transport through the upland system. Chernobyl-derived debris was deposited on Plynlimon in early May 1986. An extensive network of soil coring sites was established. The deposition of Chernobyl-derived caesium could be distinguished from nuclear weapons fallout because of the characteristic association of ^{134}Cs with ^{137}Cs.

Comparison between the expected distribution of deposition and measured Chernobyl fallout activity in the soil cores indicated zones of soil erosion and deposition in the two years following May 1986. Removal was apparent in the upper Hore and particularly in the lower half of the Hore, Tanllwyth and Cyff catchments, whilst lower parts of the Iago and Gwy down to the Cyff confluence had more than expected activity values, indicating deposition. Hence there is evidence of post-Chernobyl redistribution of topsoil, although some of the losses may be due to vertical and lateral migration of radio-caesium from surface peat in the highest parts of the catchments.



Soil activity zones at Plynlimon in Wales following the Chernobyl disaster.
Zones d'activité pédologiqueà Plynlimon au Pays de Galles après le désastre à Chernobyl.

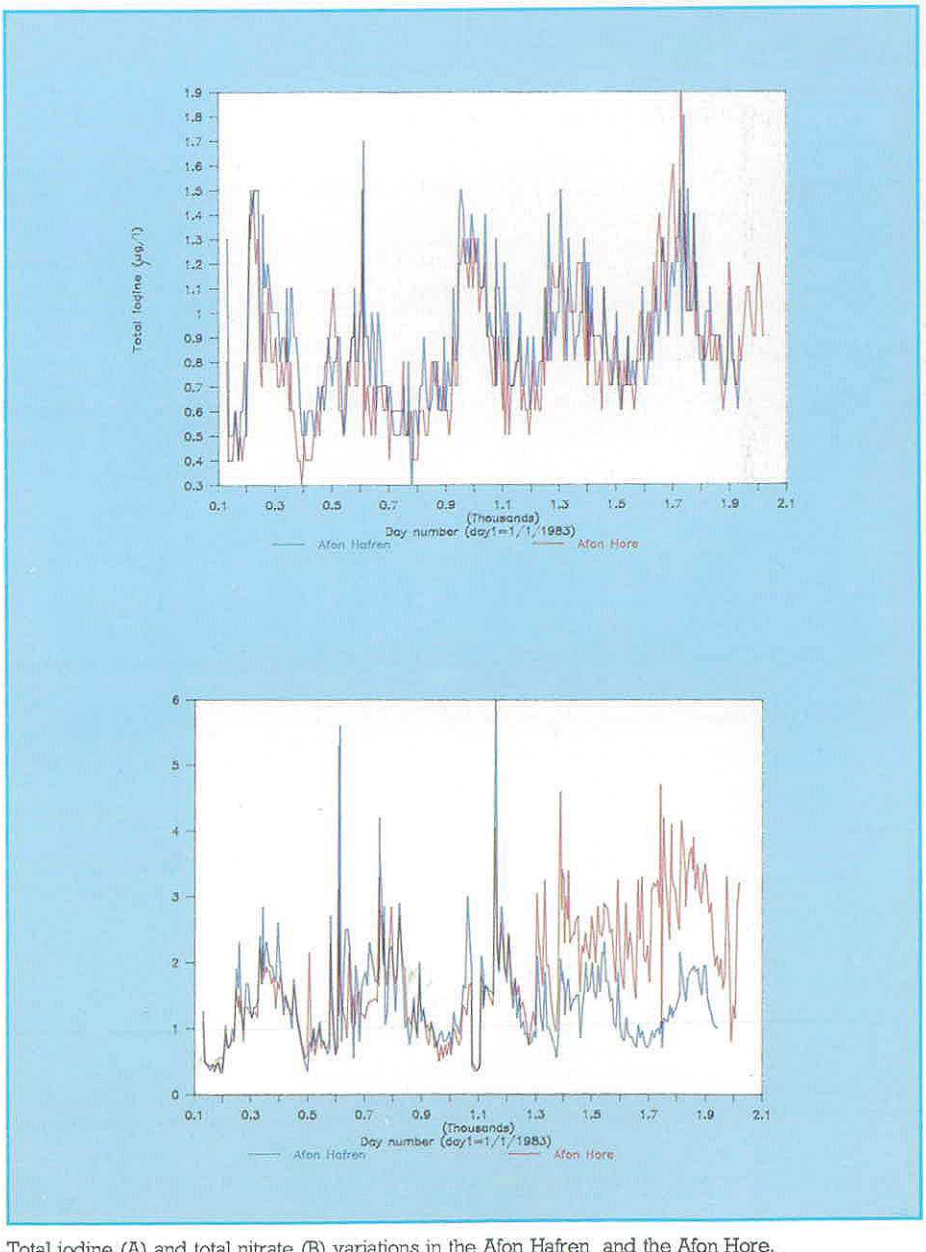
There is also evidence of removal of caesium from the catchments by attachment to the fluvial sediments. Both bedload traps and specially designed suspended-load settling tanks installed in the Plynlimon catchments have a high Chernobyl content. Total caesium activity of 60% in suspended load and 32% in bedload is an indication of the relative importance of topsoil as a source for the different types of transport. This is backed up by magnetic analyses which point to channel and subsurface sources for bedload and surface sources for suspended load. Changes in the caesium budgets have also taken place as a result of clear felling in the Hore. There is preliminary evidence of an enrichment in Chernobyl-derived caesium in the lower Hore catchment in comparison with other parts of the catchments.

Hydrogeochemical studies

The Institute's hydrogeochemical research is centred on studies of the impact of man on streamwater quality. Work focusses mainly on a detailed investigation of major, minor and trace element variations in rainfall, stemflow, throughfall and stream waters in the Hafren spruce forest at Plynlimon in mid-Wales. Here the natural variations in element concentrations are being studied, together with the effects of tree harvesting.

The results for the two main streams in the area, the Afon Hafren and the Afon Hore, show that iodine varies seasonally

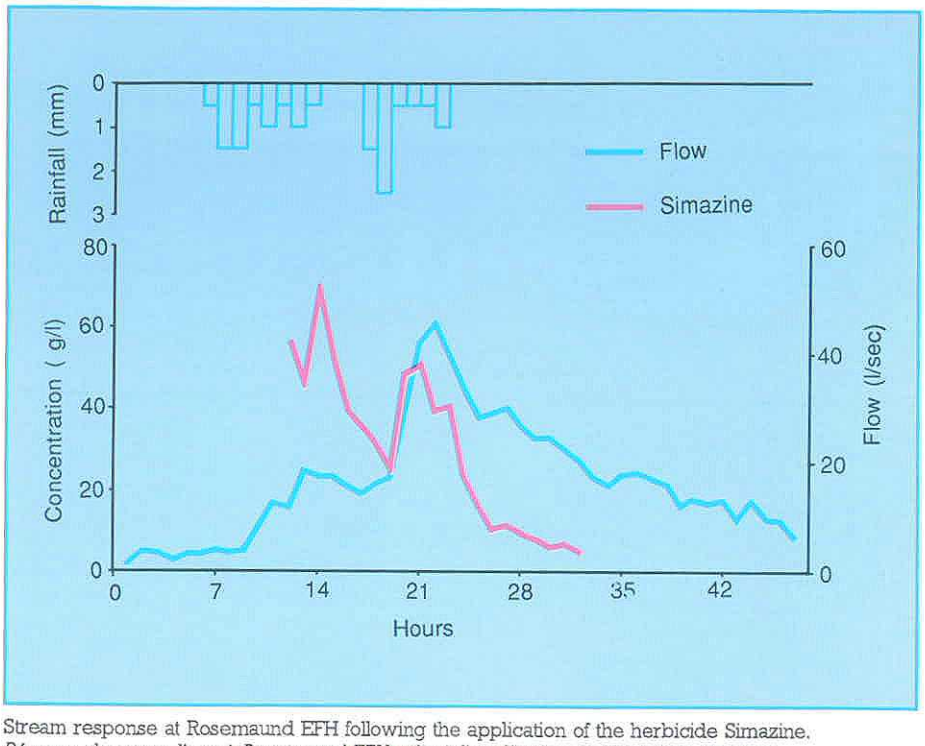
Water quality sampling at Plynlimon.
Echantillonnage de la qualité de l'eau à Plynlimon.



Total iodine (A) and total nitrate (B) variations in the Afon Hafren and the Afon Hore.
Variations de la concentration totale en iode (A) et nitrate (B) dans l'Afon Hafren et l'Afon Hore.

as a result of the seasonal organic matter breakdown processes in the catchments, and also that nitrate concentrations increase with time in the Afon Hore catchment compared with the Afon Hafren because of tree harvesting in the Hore catchment. Seasonal patterns are still observed which result from biological processes occurring in the catchment.

A ten-year programme of water quality monitoring in ten streams and ten lakes throughout the UK has been initiated to assess the long-term impact of acid deposition and reductions in atmospheric emissions of acidic oxide gases. In addition, studies of the impact of broadleaf plantations on groundwater quality in the south of England are being undertaken at Blackwood beech forest near Basingstoke. Here the objective is to identify the importance of forest edges in increasing the scavenging of atmospheric acidic oxide pollutants and in producing chemical gradients.



Stream response at Rosemaund EFH following the application of the herbicide Simazine.
Réponse du cours d'eau à Rosemaund EFH suite à l'application de l'herbicide Simazine.

Pesticide transport to streams

Under existing legislation, water undertakings have powers to control point sources of pollution but not diffuse sources. Recent concern over the contamination of water resources by agricultural chemicals (i.e. pesticides and nitrates) has highlighted just how important diffuse sources of pollution are. It is important therefore that the movement and distribution of these chemicals is quantified within river basin catchments. The Institute has set up catchment monitoring studies on two farms, each of which has a small catchment within its boundaries. These catchments are at the Rosemaund Experimental Husbandry Farm (EHF), run by the Agricultural Development and Advisory Service (ADAS), 8 km northeast of Hereford, and Wilmington Farm, a privately-run farm 5 km west of Bath. At each of these farms records are kept of the applications of pesticides and fertilisers to all parts of the catchments.

Stream samples are taken at fortnightly intervals to assess the background level of contamination in the streams. Stream samples are also taken at hourly intervals during high intensity rainfall events following major applications of pesticides. After an application of 19.2 kg of Simazine to the hop yards, the response of the stream draining the Rosemaund EHF was monitored over the period 16-20 February 1989.

The following pesticides have been found in the streams draining the two catchments:

Mecoprop
Atrazine
Simazine
2,4-D
Dicamba

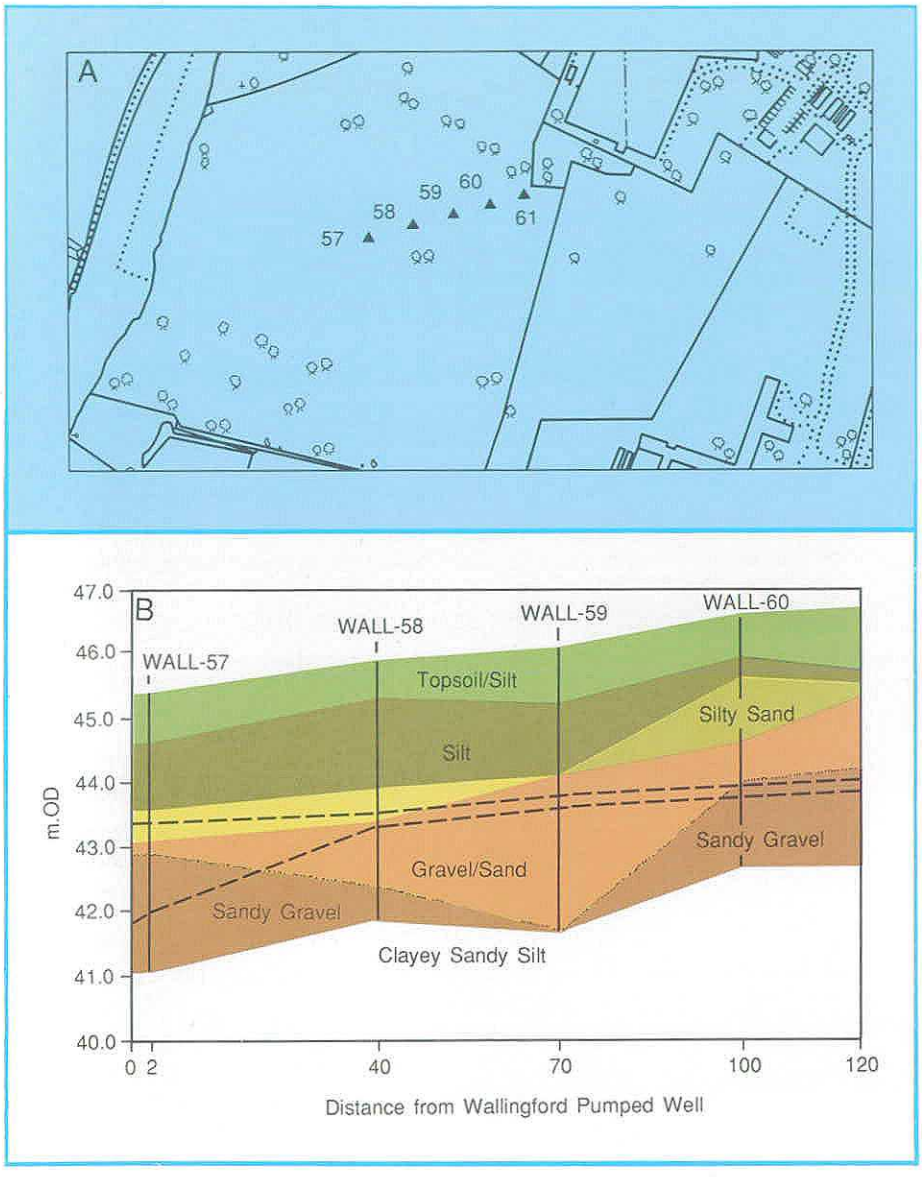
The work at Rosemaund EHF will be expanded to look in more detail at the flow pathways connecting the points of application to the stream.

Use of sulphur hexafluoride as a groundwater tracer

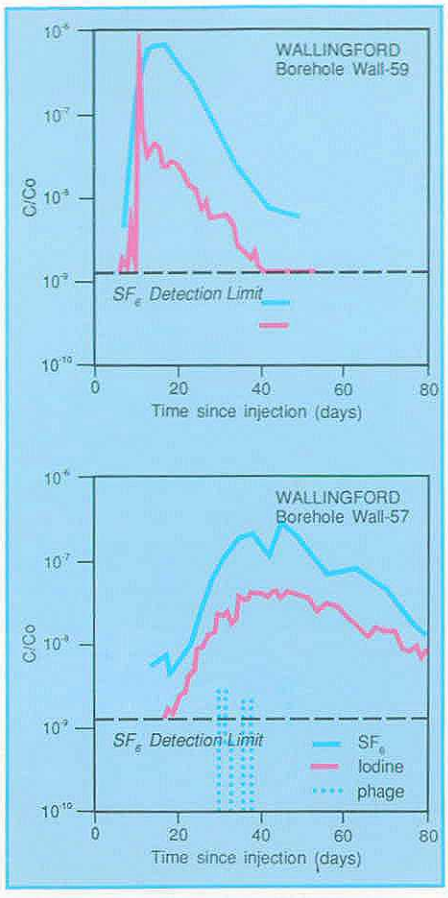
The potential of sulphur hexafluoride (SF_6) as a groundwater tracer is being investigated following its successful use in deep marine conditions.

This chemical is an inert, slightly soluble gas which is analysed with a modified gas chromatograph using an electron capture detector. Its attraction as a tracer is twofold: first, it has no adverse environmental effect, and second, it is detectable at remarkably low concentrations, typically 10^{-13} to $10^{-12}gl^{-1}$. This compares with detection limits for conventional dye tracers of $10^{-9}gl^{-1}$. Unfortunately, there is one potential drawback: SF_6 is poorly soluble and readily de-gasses from water when exposed to the atmosphere. This means that in unconfined aquifers, where the water table is freely connected to the atmosphere, any SF_6 introduced as a tracer may quickly pass out of solution. To establish how serious this problem might be, initial field trials have been carried out in unconfined gravel aquifers with a shallow water table, where direct connection to the atmosphere clearly exists.

The latest and most extensive of such trials was in the Thames valley flood plain at Wallingford, between the Institute and the Thames. A line of five observation boreholes was installed parallel to the line of groundwater flow,



Tracer tests at Wallingford: map of experimental site (A) and cross-section (B).
Essais au traceur à Wallingford: carte d'un site expérimental (A) et coupe transversale (B).



Breakthrough curves for boreholes on the Wallingford site.
Courbes de passage des puits de sondage sur le site de Wallingford.

which at this site is towards the river. A pumping borehole was installed at the end of the line of observation wells to encourage the movement of water towards the river. This created a cone of depression into which all the tracer which had been introduced was drawn. A quantity of SF_6 was injected into the fourth observation borehole from the river, together with three comparative conventional tracers: a dye (Rhodamine WT), a bacteriophage (Serratia) and a chemical (iodine). Samples were taken from each well at regular intervals over a period of 81 days. The results were encouraging, with a peak of SF_6 correlating to the other tracers recorded in every borehole.

Further field tests are planned. The first will be under Karstic conditions and will establish whether SF_6 is a viable tracer where groundwater flow is turbulent and restricted to discrete channels. Other tests are to be carried out in confined aquifers where degassing is not a problem: theoretically the performance of the tracer should improve in this case. Concurrent laboratory experiments are in hand to investigate the impact of various parameters, such as temperature, E_H and pH, upon the tracer, and to determine how different geological materials will affect its performance. Air and water samples from selected sites around the country are also being analysed to establish the natural background levels of the gas.

The work is continuing in collaboration with the University of Bristol. Although more testing and validation is required, the results to date are encouraging and suggest that there is a rôle for sulphur hexafluoride as an effective tracer.

The Institute of Hydrology Distributed Model

The Institute's physically-based rainfall runoff model, the IHDM, has recently been extended to investigate paths of water flow on hillslopes and soil water residence times.

The methodology allows consideration of transient as well as steady state conditions and deals with saturated and unsaturated conditions, both of these features being key aspects of near-surface runoff production.

Darcian velocity fields are derived from a finite element solution of the Richards equation for porous medium flow. Water particles are moved through the region according to their mean pore fluid velocities, taking account of changing Darcian velocities and changing degrees of saturation.

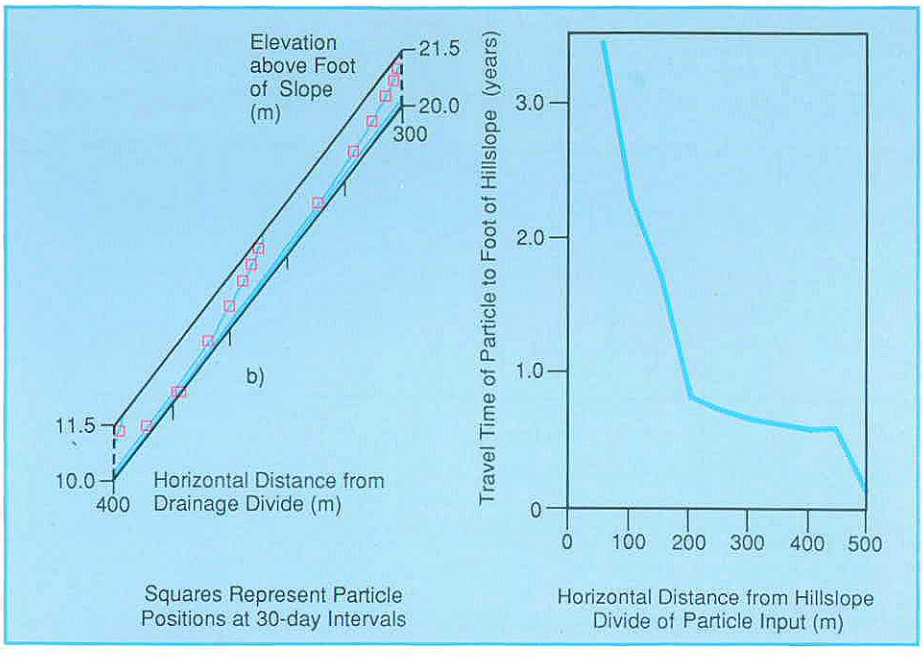
The model is able to show the particle tracks and the widely spaced arrival times at the channel bank of particles introduced on the soil surface at varying distances from the drainage divide.

A basin-wide flow forecasting system

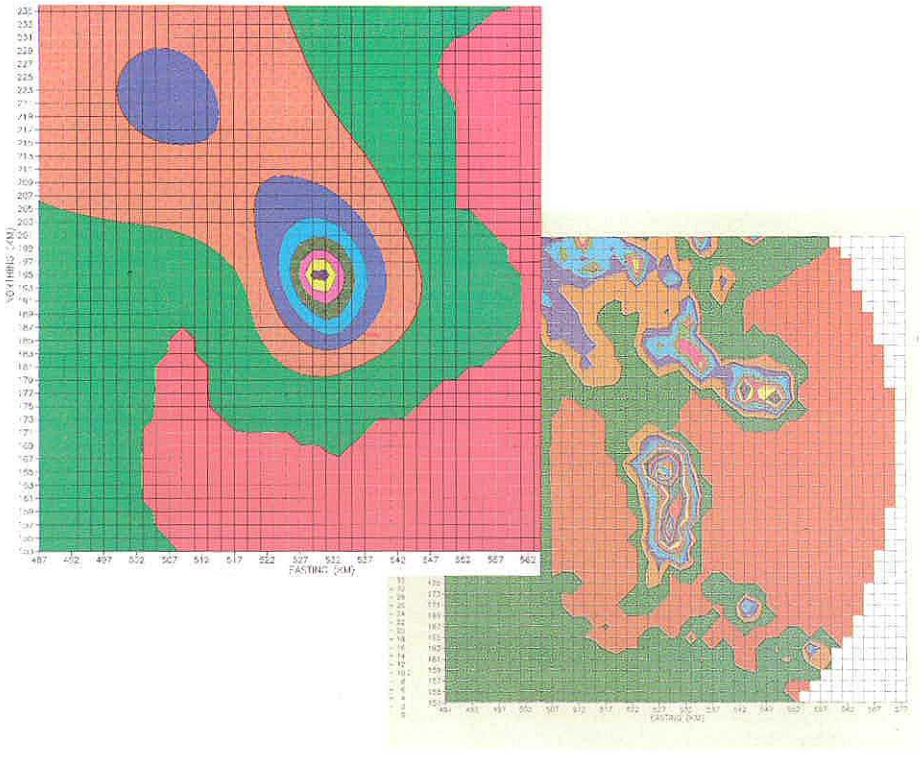
A real-time river modelling system for flood warning, river control, intake protection and drought management is under development for the National Rivers Authority Yorkshire Region in collaboration with Logica Energy and Industry Systems Ltd.

The system's modular design and flexible structure allows the addition of new forecast points, measurement sites and model structures as the need arises. The system is currently being reconfigured to provide flow and level forecasts at 200 sites throughout the 13 500 km^2 area of responsibility of the Yorkshire Region of the National Rivers Authority.

A key feature of the design is an information control algorithm, which uses the river network structure to generate a forecast at a chosen point within the river basin. The modelling modules incorporated within the system represent catchment runoff from rainfall and snowmelt and channel flow in gate-



Sample output from the Institute of Hydrology Distributed Model (IHDM).
Sortie type du Modèle Distribué de l'Institute of Hydrology (IHDM).



Rainfall fields estimated using raingauge data only (left) and radar data (right). The additional information on the detailed structure of this convective event shown on the right provides a persuasive argument for the value of radar.
Champs de précipitations estimés à l'aide des seules données des pluviographes (à gauche) et des données radar (à droite). Les informations supplémentaires sur la structure détailléee de cet événement à convection représentée à droite démontrent de manière persuasive la valeur du radar.

controlled, washland and tidally-affected river reaches. Forecasts are updated using recently telemetered river level measurements via state-correction and error-correction techniques.

The river modelling components form the kernel within a program shell which handles data acquisition and information dissemination tasks. External data will be polled by an independent regional telemetry scheme at 15-minute intervals when the system is being used to support flood warning and control decisions.

The London weather radar local calibration study

A once-in-50-year flood in the London area could cause damage to residential properties approaching £17 million. However, if timely and accurate warning of imminent flooding was available, substantial savings could be made.

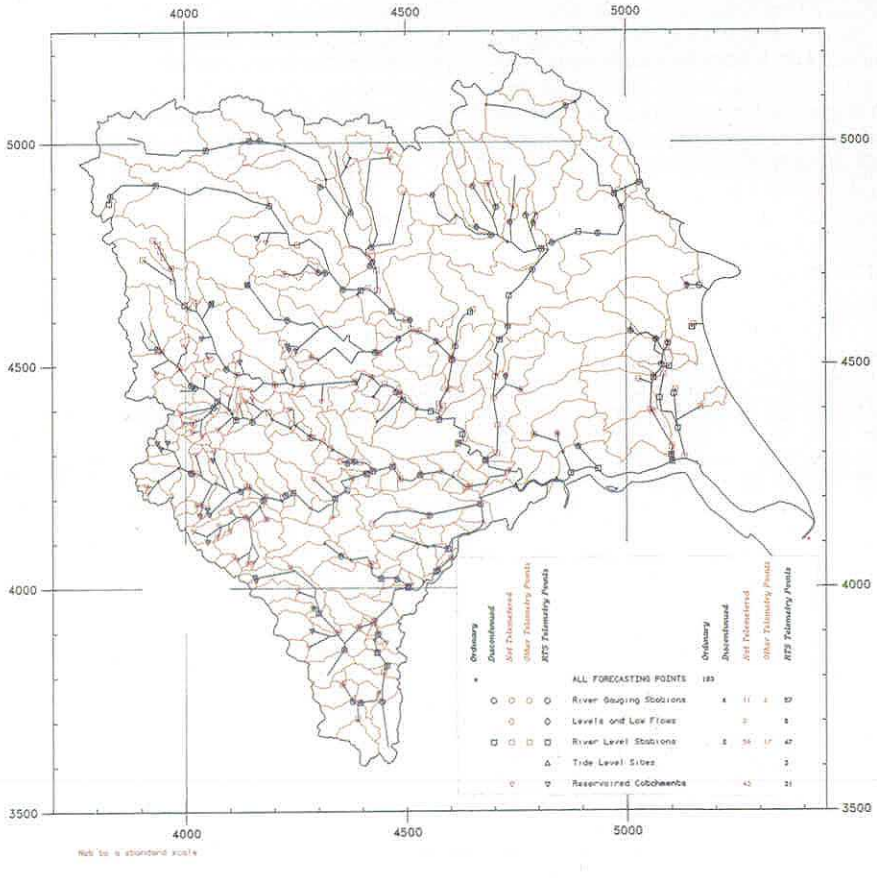
The London weather radar local calibration study was initiated by Thames Water Authority (now NRA Thames Region) in recognition that weather radar data from the Chenies radar serving the London area can contribute to the realisation of these potential savings. Chenies weather radar provides a unique source of information on rainfall variations over London and its surrounding area. This information can be especially valuable for localised summer convective storms which can cause substantial damage but still remain undetected by a conventional raingauge network.

There are unfortunately two serious shortcomings to the Chenies weather radar: it is calibrated using only five raingauges, and the synoptic type dependent domain procedure used introduces temporal and spatial discontinuities in the rainfall estimates supplied.

The main aim of the study was to use the 30 telemetering raingauges available for the London and Lea Valley area as the basis of a regional recalibration procedure. This provides more accurate and reliable estimates of spatial rainfall variations, in particular to assist in flood warning operations. Procedures were developed for the calibration of weather radar based on fitting multiquadratic surfaces to the calibration factor values, conventionally defined as the ratio of raingauge to coincident weather radar grid-square estimates of rainfall.

Based on data from 23 rainfall events, the new procedures provide a 22% improvement in accuracy relative to that obtained by radar without calibration. A remarkable finding of the study was that the radar, even without raingauge calibration, provides better spatial estimates of rainfall than can be obtained using the dense regional raingauge network (30 gauges over about 3600 km^2).

Chenies weather radar, northwest of London.
Le radar météorologique à Chenies, au nord-ouest de Londres.



Model river network indicating forecast points and data sources.
Réseau fluvial modèle indiquant les points où les prévisions sont effectuées et les sources de données.

A new operational system for recalibration of the London weather radar became operational in March 1989. A further procedure for estimating spatial rainfall using raingauges only was implemented in September 1989 to complement the recalibrated product and to replace it in the event of radar malfunction.

Llyn Brianne acid waters project

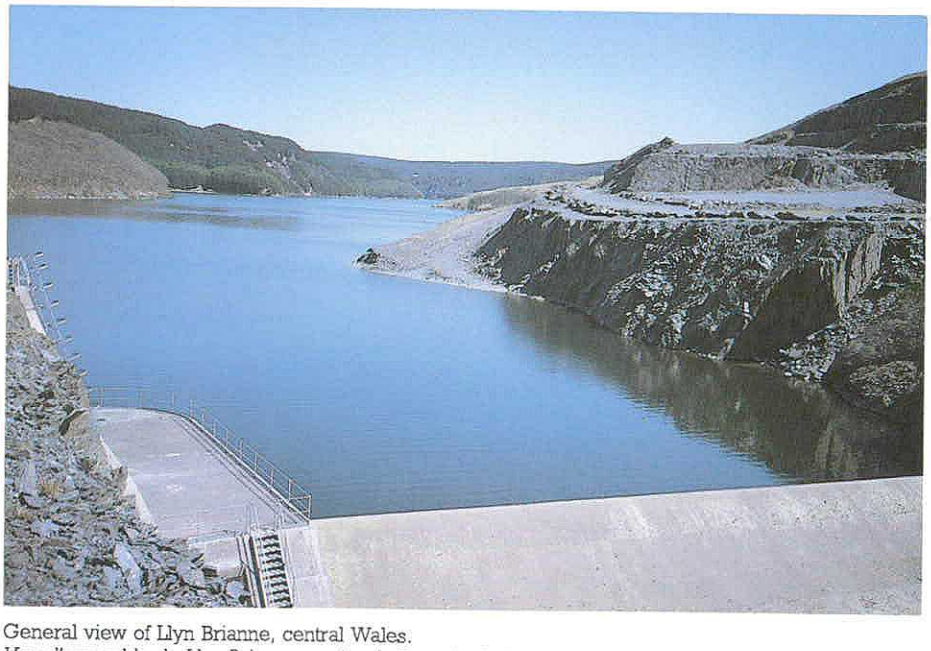
The Institute is collaborating in a major multidisciplinary research programme to examine the causes and effects of streamwater acidity and the impact of a variety of land management strategies on the acidification processes. Funded by the Department of the Environment and the Welsh Office, the project stems from detailed studies carried out by the Welsh Water Authority on water quality in the Llyn Brianne area. In the current programme 14 catchments have been selected for intensive study and instrumentation. Some are acting as controls (mature conifer forest, juvenile conifer forest, oak woodland, unacidified moorland and acidified moorland) with the others used to assess the impact of a range of land management treatments, such as bankside clearance of conifers, standard upland grassland liming and ploughing.

The modelling of the water quality, hydrological and biological data is being carried out by IH. Time series techniques are used to understand basic catchment dynamics by predicting short-term hydrological and water quality responses to storm events. Long-term trends in catchment acidity are also being modelled, including predicted responses to the various land treatments, using the Model of Acidification of Groundwater in Catchments (MAGIC).

Small-scale irrigation systems in Sri Lanka and Zimbabwe

Field trials have been carried out in Sri Lanka to help evaluate a low-cost, low pressure drip irrigation system designed and developed by Wimpey Laboratories Ltd. Efficient use of limited water was essential and IH work has concentrated on soil moisture status and crop response to drip irrigation. Mercury manometer tensiometers and neutron probe soil moisture meters have been used in field reading programmes based on those developed during drip irrigation research in Mauritius. The experimental site in Sri Lanka was at the Maha Illuppallama Research Station in North Central Province, which is the major dry-zone research centre of the Ministry of Agriculture.

Pitcher irrigation: one of the low-cost irrigation methods tested by the Lowveld Research Station, Chiredze, Zimbabwe.
Irrigation à la cruche en terre: une des méthodes d'irrigation à bon marché mises à l'essai par le Centre de Recherches de Lowveld, Chiredze, Zimbabwe.



General view of Llyn Brianne, central Wales.
Vue d'ensemble de Llyn Brianne, centre du Pays de Galles.

The Wimpey Low Head Drip (LHD) system operates under a water pressure of only two metres head, which can easily be generated by using an inexpensive raised storage tank. Distribution is by 'lay flat' plastic hoses and low-head emitters spaced along the crop rows. In the trials, the Wimpey LHD system was compared with locally established ridge-and-furrow irrigation techniques.The principal crops grown were chillies (*Capsicum annum*) and onions (*Allium cepa*), planted in 0.125 ha blocks, with drip lines spaced at 0.7 m.

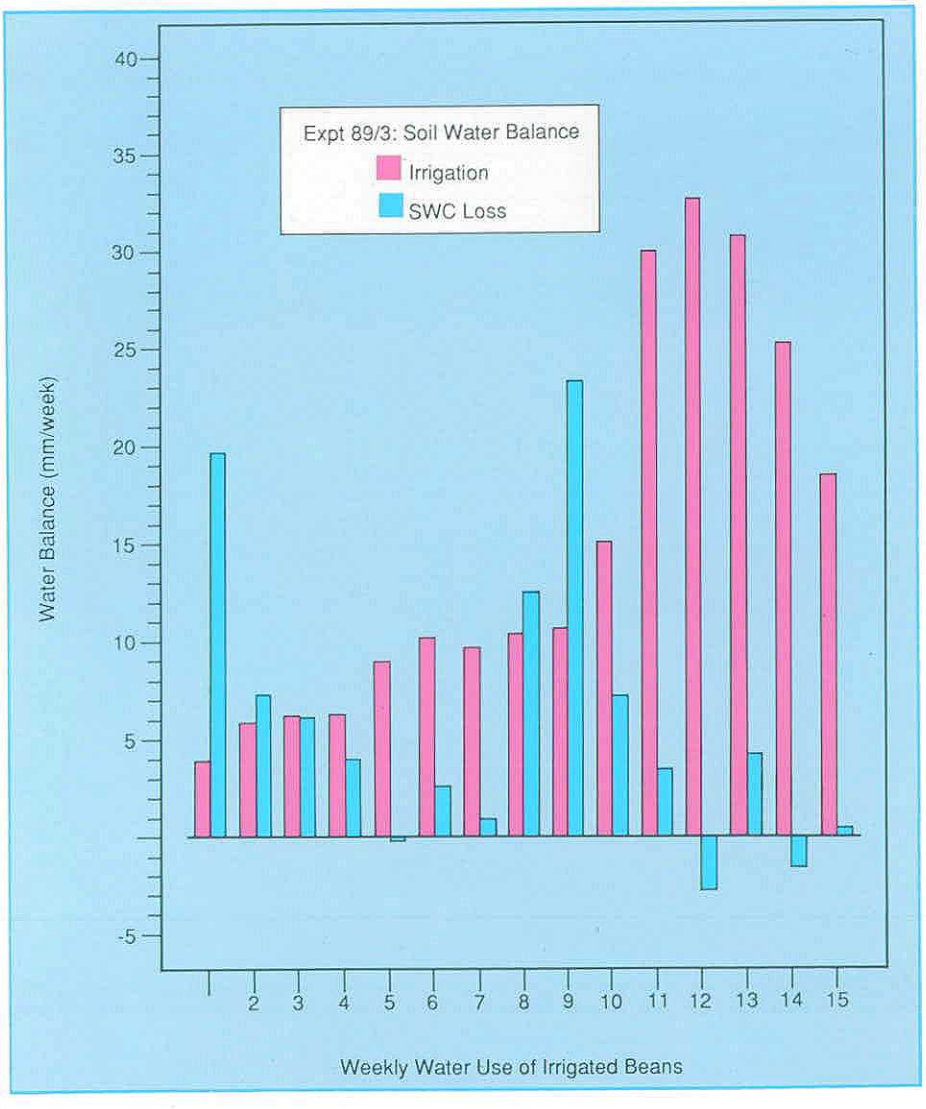
The trials showed that the LHD system produced considerable advantages over the "control" ridge-and-furrow irrigation method in terms of efficiency and water use. Crop yield per unit land area was lower under the drip system, possibly due to the presence of a continuously moist rooting zone within a Red-Brown Earth soil prone to waterlogging, as indicated by the soil moisture

measurements. However, crop yield per unit of water applied - the essential criterion when evaluating irrigation from limited water resources - was significantly higher from the low-head drip irrigated plots than from the traditional ridge and furrow plots. The work in Zimbabwe, like that in Sri Lanka, was linked to the use of radially drilled shallow collector wells developed by the British Geological Survey (BGS). In a trial set up during 1989, six different methods of small scale irrigation are being evaluated at the Lowveld Research Station at Chiredzi in southeastern Zimbabwe with the active cooperation of the staff there. The methods used have been:

a) small unglazed clay pitchers (c 0.6 l capacity)
b) large unglazed clay pitchers (c 3.0 l capacity)
c) subsurface pipe irrigation (clay tiles)
d) subsurface pipe irrigation (slotted PVC)
e) trickle irrigation (in-line emitters)
f) trickle irrigation (spaghetti tubes)

The trial commenced at the end of the period under review, so results cannot yet be reported. However, the combination of the use of mercury manometer tensiometers, neutron probe access tubes and climatic measurements with the agronomic assessment of crop development and yield follows the experimental pattern which was established earlier in Mauritius and Sri Lanka.

Measuring plant heights in the experimental bean crop, Lowveld Research Station, Chiredzi, Zimbabwe.
Mesure de la hauteur des plantes dans le cadre d'un projet expérimental de culture des haricots, Centre de Recherches de Lowveld, Chiredzi, Zimbabwe.



Weekly water use of irrigated beans.
Utilisation hebdomadaire d'eau pour l'irrigation des haricots.

Drip irrigation research in Mauritius

The major cooperative research effort between the Institute and the Mauritius Sugar Industry Research Institute (MSIRI) on the drip irrigation of sugar cane has continued, although the Institute of Hydrology's last resident staff member involved in the study left Mauritius towards the end of 1988. Continuing research has included evaluation of the index tensiometer technique for scheduling irrigation.

Maize and groundnut both responded well in intercropping trials with cane, and plant studies indicated that physiological processes were influenced by water stress, contributing to a loss of sugar productivity.

Land surface water balance

Vegetation and climate modelling

A high priority of climate research is to try to understand how the atmosphere and the vegetation on the surface can interact to affect climate. A particular problem is to determine how changes in vegetation, such as deforestation in the humid tropics or the degradation of grazing land in the dry tropics, may produce feedback effects which act to change the climate by, for example, reducing the cloudiness and rainfall. Global climate models have the capability to estimate the effects of these changes, but if such modelling experiments are to produce realistic predictions it is essential that the representation of the land surface - both before and after the modelled change - be as accurate as possible. This can only be achieved by calibrating the parameters in the models' land surface representations against actual data of the energy partition, aerodynamic roughness and radiative properties of the relevant surfaces. The Institute has a programme of research aimed at collecting such data from key areas of the world.

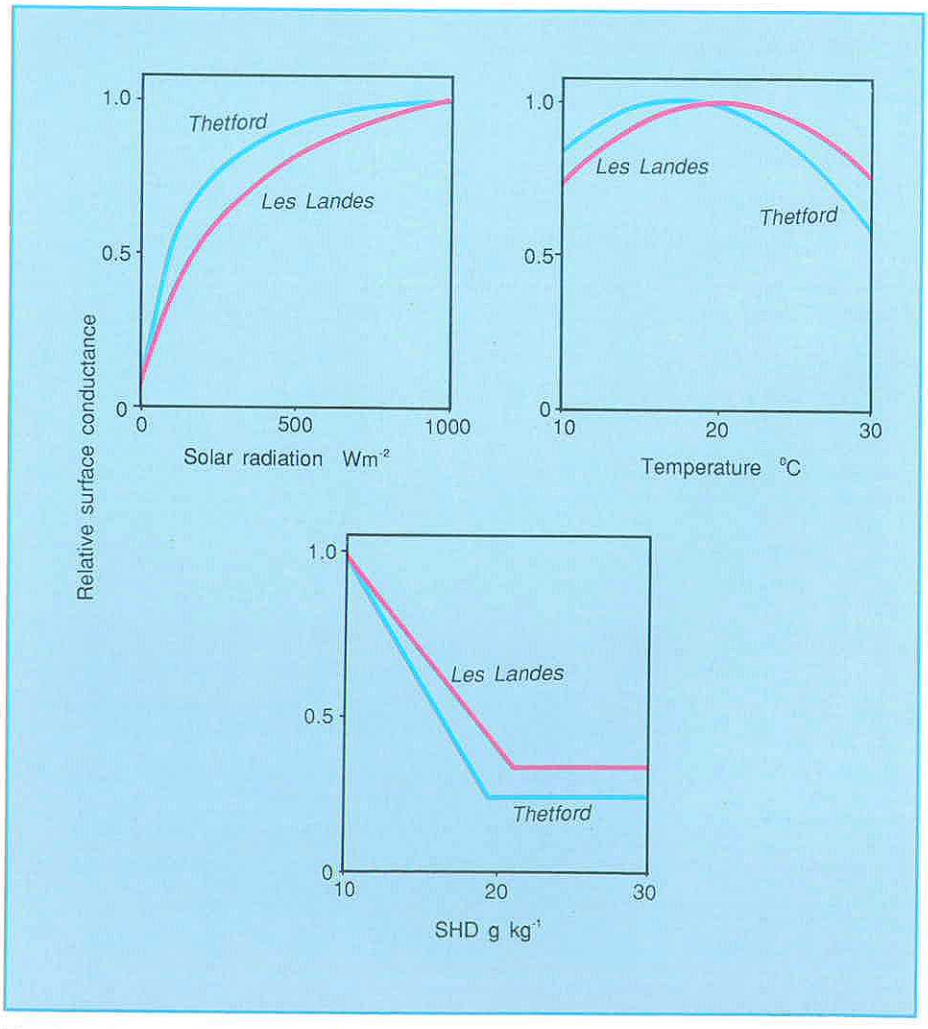
Amazonian rain forest

Between 1983 and 1985 a micro-meteorological experiment was carried out in collaboration with the Brazilian national institutes for Amazonian research (INPA) and space research (INPE). The experiment took place in a reserve of undisturbed rain forest close to Manaus, near the centre of the Amazon basin. Measurements of transpiration and momentum flux were analysed to produce a parameterisation of the forest in terms of its surface and aerodynamic conductance. Measurements of rainfall above the canopy, and throughfall and stemflow below it, have been used to derive the interception loss and the forest structure parameters which control the evaporation of intercepted rainfall. Two models of interception loss, previously used only in temperate forests, were both found to estimate the measured loss to within acceptable limits. The data have been used to calibrate the global climate model at the NASA Goddard Space Flight Center and are also being used to calibrate similar models at the UK Meteorological Office, the US National Center for Atmospheric Research and the meso-scale model at the French Laboratoire de Météorologie Physique.

HAPEX-MOBILHY

In the early summer of 1986, simultaneous measurements of evaporation were made over the major vegetation types within a 100 x 100 km square in southwest France. This international project, HAPEX-MOBILHY, was the first in a series of such experiments designed to give a better understanding of the process of evaporation from large areas and hence an improved parameterisation of surface energy partition at that scale. The Institute's rôle in the experiment was to measure the evaporation from Les Landes pine forest which covers about one-third of the study area.

In the context of climate description, one of the most interesting and significant results of this study is the considerable difference between the forest and other areas of agricultural land within the HAPEX-MOBILHY square. Some initial



The dependence of the relative surface conductance on solar radiation, temperature and specific humidity deficit for Les Landes Forest, compared with the same functions derived previously from the Thetford Forest data set.
Subordination entre la conductivité superficielle relative de la Forêt des Landes et la radiation solaire, la température et le déficit spécifique en eau par comparaison avec celle des mêmes paramètres déduits précédemment à partir des données provenant de la Forêt de Thetford.

comparisons between the two areas confirm that the forest is characteristically different from the other types of agricultural crops in respect of the major controlling influences on the energy balance, namely the albedo and the aerodynamic and surface conductances.

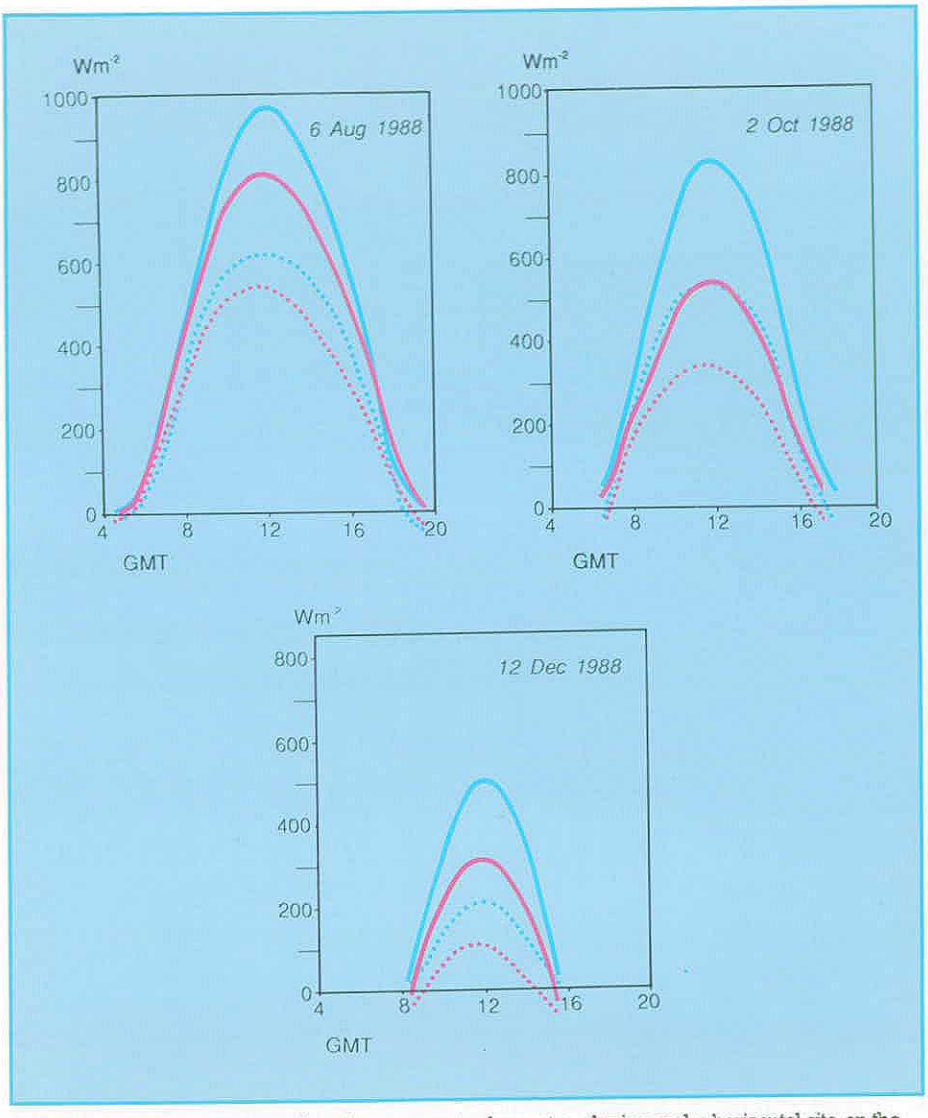
Despite the high aerodynamic conductance, which results from the rough surface, evaporation is reduced by the relatively low surface conductance. The influence which the forest exerts on the atmosphere is very different from that which may be expected from shorter vegetation. The high sensible heat flux results in a deeper atmospheric boundary layer over the forest. This layer has been shown to be capable of producing cumulus clouds over the forest when there were clear skies over the surrounding agricultural land. A 'forest breeze' also results as air is drawn in to replace the air rising above the forest.

The radiation balance of sloping terrain

There is an increasing need to be able to model the energy input to areas of complex topography. The effect of simple slopes on direct beam insolation is understood reasonably well but relatively little information exists for undulating terrain or on the net all-wave radiation balance of slopes.

Measurements of solar and net radiation and other climatic variables have been made on a hill site on the edge of the Chiltern Hills under a wide range of situations. Hourly values for solar and net radiation, plus air and soil temperatures, were recorded for a horizontal slope and for a south-facing slope of 27° for most of the period from August to December 1988.

The ratio of the daily input of solar or net radiation on the slope to that on the horizontal site on the top of the hill varies from about 1.1 in the summer to 2.5 or more in the winter. However, the ratio of solar radiation to net radiation remains constant over the entire period, and this ratio is the same for the slope site and the horizontal site. This factor will simplify the modelling of the radiation balance.



Radiation components measured on three separate days at a sloping and a horizontal site on the edge of the Chiltern Hills, south Oxfordshire.
Éléments de radiation mesurés au cours de trois journées distinctes sur un site en pente et un site horizontal en bordure des Monts Chiltern, dans le sud du comté de l'Oxfordshire.

SEBEX - the Sahelian Energy Balance EXperiment

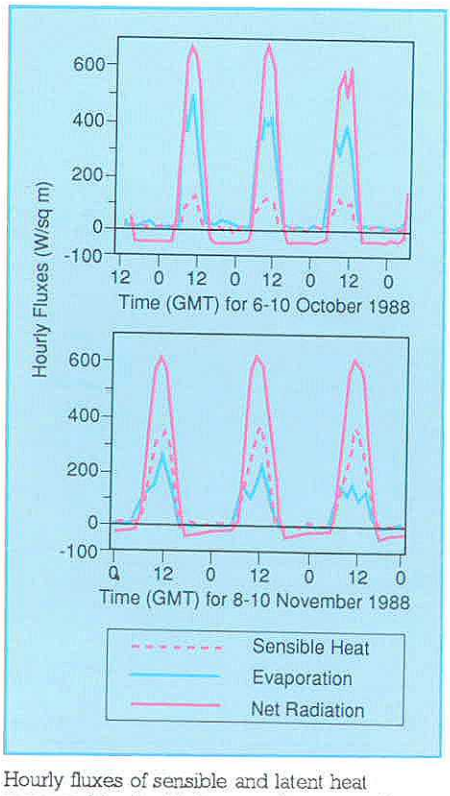
The widespread deterioration of large areas of savannah in the semi-arid regions of Africa is believed to be due to over-exploitation of marginal land by over-grazing, removal of fuel wood or the clearing of natural vegetation for agriculture. The net effect is to degrade the savannah vegetation to the point where areas of bare soil appear between the plants and shrubs. Ultimately no vegetation remains, but just bare, sandy soil. This process of desertification may not be reversible if there is a concurrent climate change. Computer modelling studies have indicated that replacement of vegetation by bare soil may modify the micro-climate in such a way as to reduce the rainfall. However, these climate models are based on simplified representations of the land surface, and accurate fundamental data are needed to calibrate them. The SEBEX project seeks to obtain direct measurements of available energy, evaporation and sensible heat flux from three contrasting

The Hydra being used to measure evaporation from ungrazed savannah at the ICRISAT Sahelian Centre in southern Niger.
L'Hydra mesure l'evaporation du savannah protégé au Centre Sahelien ICRISAT, Niger du sud.

surfaces: fallow savannah supporting a high density of natural vegetation, degraded natural forest with large areas of bare soil and land growing traditional crops such as millet.

The first field season (Campaign alpha) began in September 1988 in collaboration with the ICRISAT Sahelian Centre at their experimental farm in Niger. The objectives were to install and test the equipment and the data processing and analysis procedures, to make measurements of energy fluxes both in an area of fallow savannah and in a bare soil area, and to use these results to calibrate satellite data in an attempt to extrapolate the energy and water balances to a larger scale.

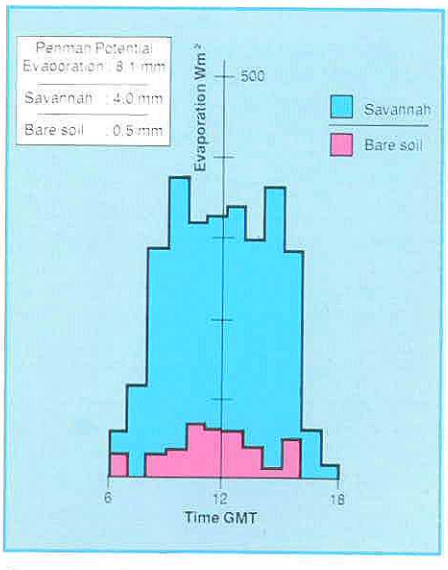
Sensible and latent heat fluxes were measured directly by the Institute's Hydra instrument. The results over the savannah for a sequence of days one week after the last rainfall event of the rainy season (20 mm on 29 September 1988) show that most of the available energy was being used in evaporation. Total evaporation was between 3 and 4 mm per day, about half of the potential evaporation. One month later the energy balance had changed dramatically: sensible heat flux had become less than



Hourly fluxes of sensible and latent heat measured by the Hydra over the savannah.
Flux horaires de la chaleur sensible et de la chaleur latente sur la savanne mesurés au moyen du matériel Hydra.

the latent heat flux and absolute values of evaporation had fallen to only 20% of the potential evaporation.
Evaporation rates from savannah and bare soil indicate the great difference between these two types of surface: over an entire day the savannah evaporated 4 mm of water, nearly 10 times the 0.5 mm evaporated from the bare soil.

Measurements of this type will be invaluable for developing models of the hydrological response to desertification. The database which is being built up within the SEBEX project is unique, and careful thought has been given both to quality control and to computer compatibility so that related research projects can benefit, particularly climate change studies.



Comparison between evaporation over savannah and bare soil.
Comparaison entre l'evaporation du savannah et du sol nu.

Eucalyptus: forest friend or foe?

Forestry practices, either through deforestation or afforestation, are responsible for the largest man-induced land-use change on the planet. It is clear that a knowledge of the potential environmental impacts of these practices is of major importance.

In many tropical and semi-tropical countries the impact associated with the large-scale planting of exotic tree species is a source of concern. The fears

most commonly expressed (usually unquantified) are that the trees use 'excessive' amounts of water, deplete groundwater resources, deplete the soil of nutrients, 'poison' the soil and cause erosion. Interlinked are often socio-economic considerations related to land ownership, the economic returns on forestry in relation to food crops, the availability and price of fuel wood and the creation of jobs in rural areas.

Outside of their native country, Australia, *Eucalyptus* species have often been the subject of such concerns. In Southern India, where considerable eucalypt afforestation had been carried out (often funded by external aid), the 'eucalypt controversy' has become a major issue. These concerns often arise from reports emanating from other countries where environmental conditions are entirely different. Without quantitative, within-country measurements or a knowledge of how different *Eucalyptus* species will perform under different environmental conditions, it is not possible to comment on the veracity of these fears. Although rarely mentioned, there may be positive environmental benefits associated with these plantations in respect of climate or meso-climate modification which may help to halt or reverse desertification trends.

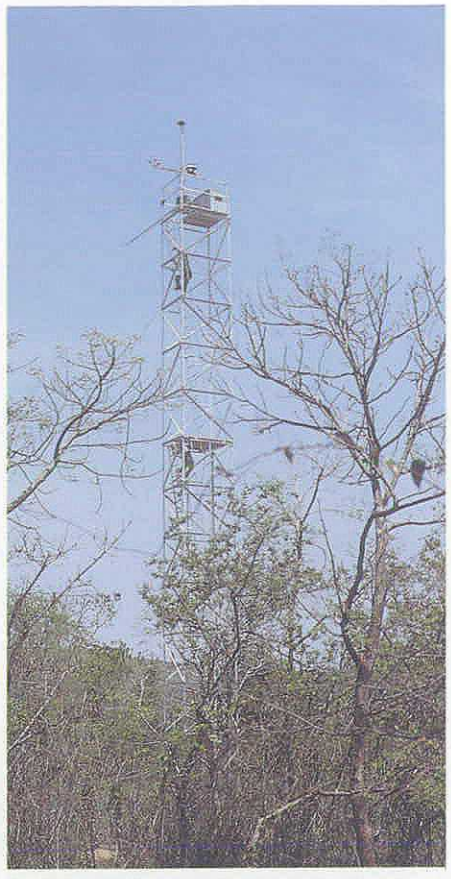
To assess the environmental impact, a collaborative research project was set up, funded by the British Overseas Development Administration. The collaborators were the Institute of Hydrology and Oxford Forestry Institute in the UK, Karnataka Forest Department and Mysore Paper Mills in India.

The present study, which is being carried out at three different instrumented sites in Karnataka, measures the comparative water use of *Eucalyptus* species in relation to other fast growing tree species and agricultural crops, their growth rates, nutrient cycling and their effects on soil erosion.

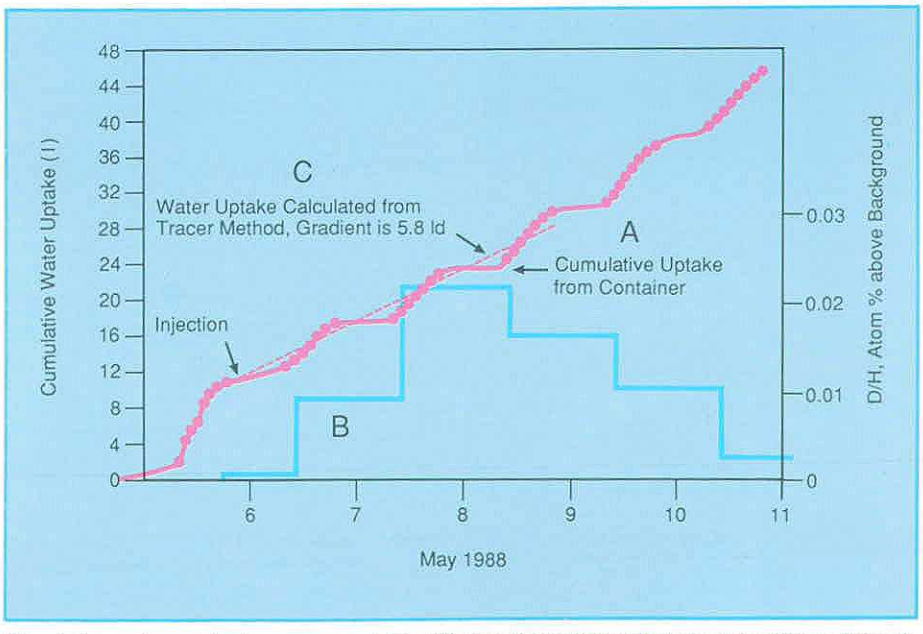
The water use studies involve a range of complementary techniques to measure transpiration and interception. These include deuterium tracing, soil moisture measurements, plant physiological studies and meteorological measurements. Soil moisture measurements provide a continuous record of soil moisture depletion which can be related to water use, provided that root abstraction does not take place either beneath the lowest measurement depth or direct from the water table. Tracing and plant physiological methods give 'snapshot' measurements of water use which are unaffected by the source of the transpired water.

Three major sites (annual rainfall 800 mm to 1000 mm) have now been instrumented at Hosakote, near Bangalore, and at Devabal and Purdal, near Shimoga. At Hosakote the comparative water use of *Eucalyptus camaldulensis, Casuarina equisetifolia, Leuceana leucocephala* and *Elusine coracana* ('ragi' or finger millet) is being measured, together with interception studies on the *Eucalyptus camaldulensis*. At Devabal spacing trials of *E. tereticornis*, with and without ragi intercropping, are being carried out to measure the influence on growth rates and water use. At the Purdal site water use comparisons of *E. camaldulensis* and *E. tereticornis* with the degraded indigenous forest are being made.

Results from the different methods, most of which have been in operation since August 1987, are beginning to show a fairly consistent picture.

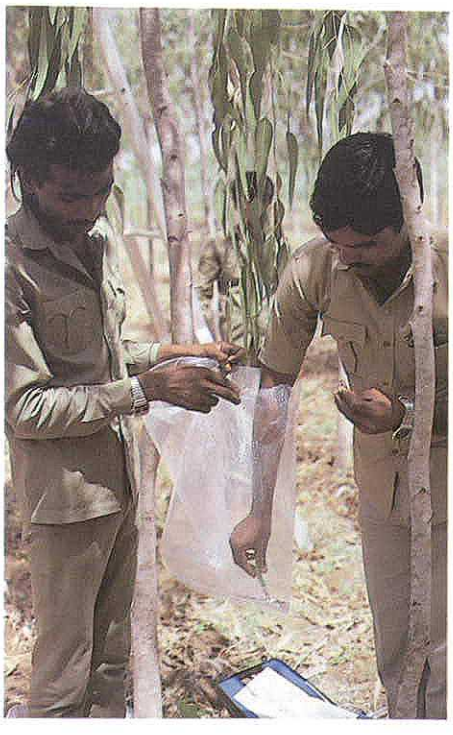


Above-canopy meteorological measurements at the Purdal sites.
Mesures météorologiques au-dessus de la voûte des arbres aux sites de Purdal.



Cumulative water uptake from a severed tree (A), together with the deuterium breakthrough curve (B) and the flow rate calculated from the deuterium tracing method (C).
Prise d'eau cumulative d'un arbre cassé (A), courbe montrant la concentration de deuterium en fonction du temps (B), et le taux de débit calculé par la méthode du traçage au deuterium (C).

Deuterium injection in the excavated tree during the calibration experiment.
Injection de deuterium dans l'arbre creusé au cours de l'essai d'étalonnage.



Deuterium sample calibration. Transpired water is condensed inside plastic bags which are attached around sheets at different levels of the canopy.
Étallonage deuterium type. L'eau de transpiration est condensée à l'intérieur de sacs en plastiques qui sont attachés autour de feuilles de plastiques à differents niveaux de la voûte des arbres.

Deuterium tracing methods were developed and extended within the project. On-site calibrations have verified the technique and routine measurements are now being taken at all sites. Transpiration rates varied from 3.5 mm d^{-1} shortly following the monsoon to 0.8-1.0 mm d^{-1} in the driest part of the year prior to the monsoon.

Interception measurements obtained for the *E. camaldulensis* plot at Hoskote, which show losses of about 10% of the rainfall, are broadly in line with other published results for eucalypts.

Measurements of the mean total water content of the soil profile to a depth of 3 m under *E. tereticornis* at the Devabal site shows that the depletion rates were 0.1 mm d^{-1} prior to the monsoon of 1987, with rates of 4 mm d^{-1} recorded during the dry periods within the monsoon season.

Plant physiological measurements made in *Eucalyptus* canopies indicate that seasonal differences in stomatal behaviour are associated with different soil moisture conditions. The lowest stomatal conductance (g_s) is observed immediately prior to the onset of monsoon conditions and is wholly consistent with the low rate of soil moisture abstraction and transpiration estimated by the deuterium tracing method. In contrast, in and immediately following the monsoon, g_s rises by about a factor of ten, and it is also during this time that the other methods demonstrate the highest transpiration rates. Following the end of the monsoon, g_s values are found to decline but it is at this time that different maximum levels of g_s are found from year to year and are associated with the amount and duration of rainfall and consequent replenishment of the soil moisture store in the preceding monsoon.

The plant physiological measurements of stomatal conductance and leaf photosynthesis can be scaled up to the forest canopy level given a knowledge of the quantity of leaf canopy present. Calculation of transpiration from these physiological studies then provides an independent estimate for comparison with determinations from soil moisture studies and deuterium tracing. Periods when soils are dry correspond to those when air vapour pressure deficits are at their greatest. Studies in which the irrigation of trees has been carried out at these times have shown that there is also some association of high air vapour pressure deficits with low conductances.

Although modelling studies will be necessary to calculate annual values of water use at the different sites, using parameter values derived from the different techniques, it is already clear from individual measurements that fears of excessive water use from *Eucalyptus* species are unfounded. During the dry season the water use is constrained by the availability of soil water and there is no indication either from the deuterium tracing or the plant physiological studies that the trees are transpiring at a rate indicative of groundwater exploitation.

Remote sensing

Satellite measurements are rarely directly related to hydrological variables. Exceptionally, one of the most direct physical relationships is the one between satellite measurements of surface temperature and evaporation rate. Images obtained from satellite sensors in the infra-red band can, after correction for atmospheric emissions, be used to determine surface temperature.

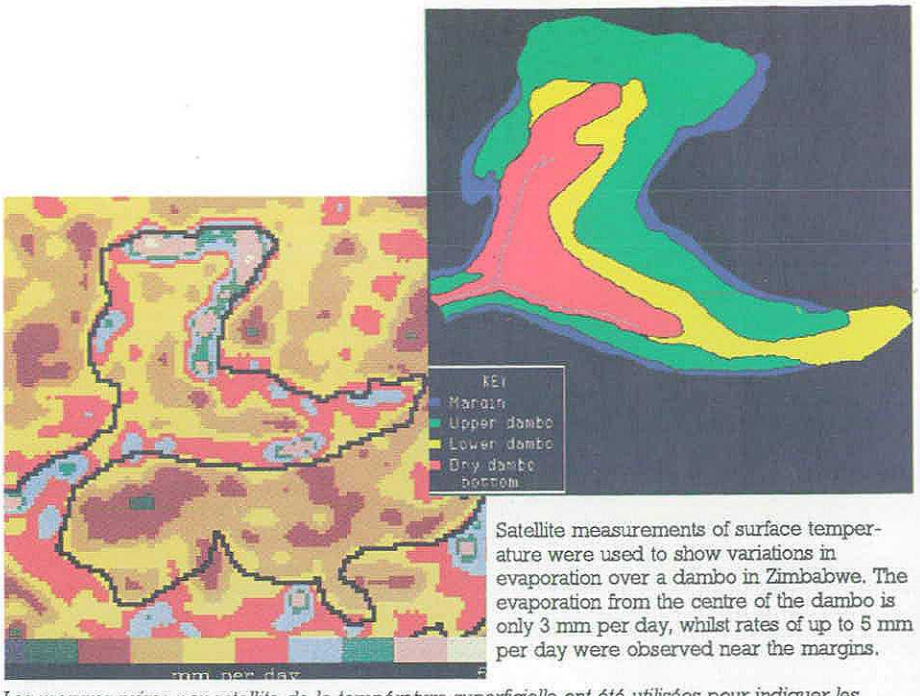
As part of the Institute's contributions to the International Satellite Land Surface Climatology Project (ISLSCP) in its First Field Experiment (FIFE), ground-based measurements of surface temperature and evaporation were made on more than 100 days over sparse prairie in Kansas, USA, in 1987. The measurements of surface temperature were made to simulate those made by a satellite but without the problems of atmospheric emissions or location.

Estimation of evaporation from these surface temperatures showed that they were on average 25% less than direct measurements of surface-measured evaporation. This is probably as a result of the satellite sensors, which look vertically down, seeing too much soil.

In related work, LANDSAT Thematic Mapper data were analysed to determine the spatial variability of evaporation over a dambo (a seasonally waterlogged, grass-covered depression drained by a poorly defined stream

channel) in Zimbabwe. Satellite measurements of surface temperature obtained on 8 August 1986, well into the dry season, were used to give the variation of evaporation over the dambo. The boundary of the dambo showed up well, as did the network of stream beds.

A survey of the dambo and the availability of soil water for evaporation was conducted by Loughborough University. Very good agreement was obtained between the low-evaporation area and their dry dambo bottom, and between the high-evaporation area and their upper part of the dambo where the water table was sufficiently close to the surface to permit the growth of grass.



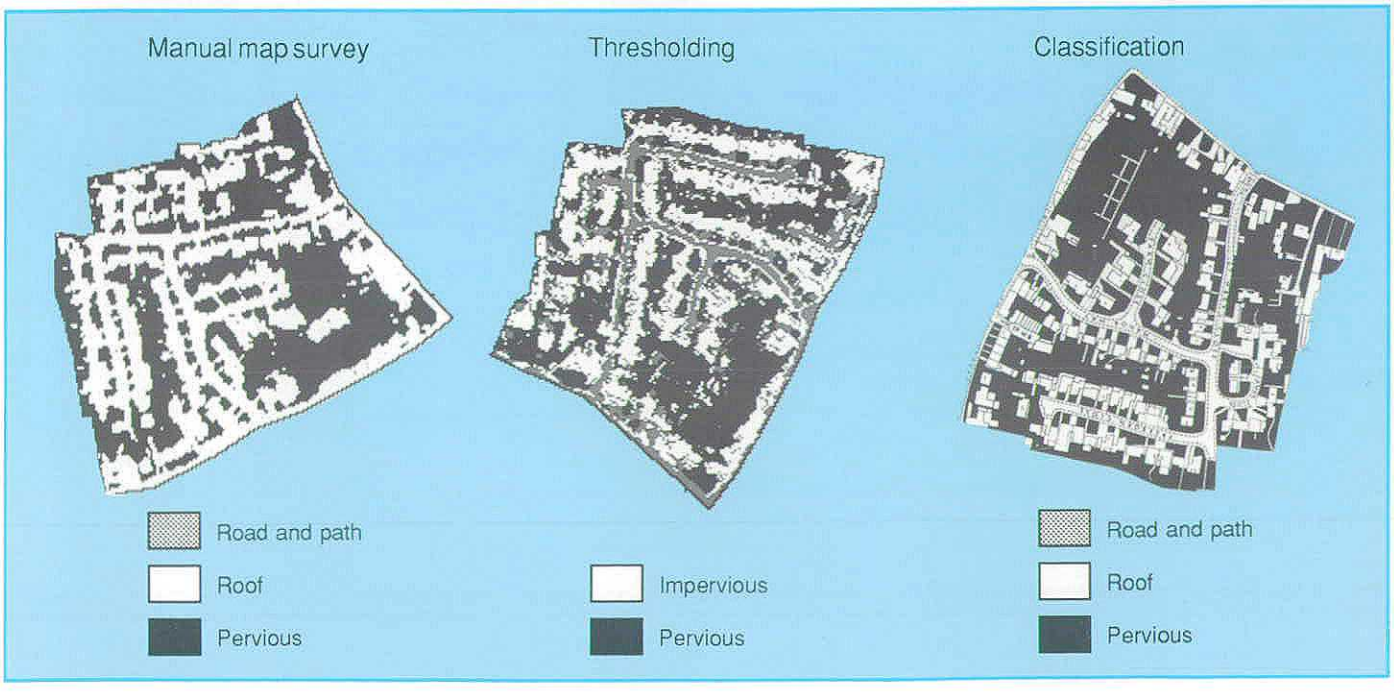
Satellite measurements of surface temperature were used to show variations in evaporation over a dambo in Zimbabwe. The evaporation from the centre of the dambo is only 3 mm per day, whilst rates of up to 5 mm per day were observed near the margins.

Les mesures prises par satellite de la température superficielle ont été utilisées pour indiquer les variations en matière d,évaporation d'une cuvette au Zimbabwe. L'évaporation du centre de la cuvette n'est que de 3 mm par jour, tandis que des taux maximum de 5 mm par jour ont été observés près des bords.

Remotely-sensing impervious surfaces within urban areas.

Increased urbanisation on previously pervious load areas inevitably results in an increase in a catchment's streamflow response to storm rainfall. Obviously this enhanced response of runoff will depend to a great extent on the amount of urbanisation, i.e. the percentage impervious area within the total catchment contributing flow to the sewer system. Thus an identification of the different surface types within an urban environ-ment is vital to provide the necessary information to the water engineer who has to decide on the sewer capacity required.

In the past, this information has been obtained mainly by manual methods such as on-the-ground surveys, map digitisation and, where available, aerial photographs. These methods have proved to be time-consuming (and hence expensive) and often subjective. As an alternative, remote sensing has the potential to provide this information

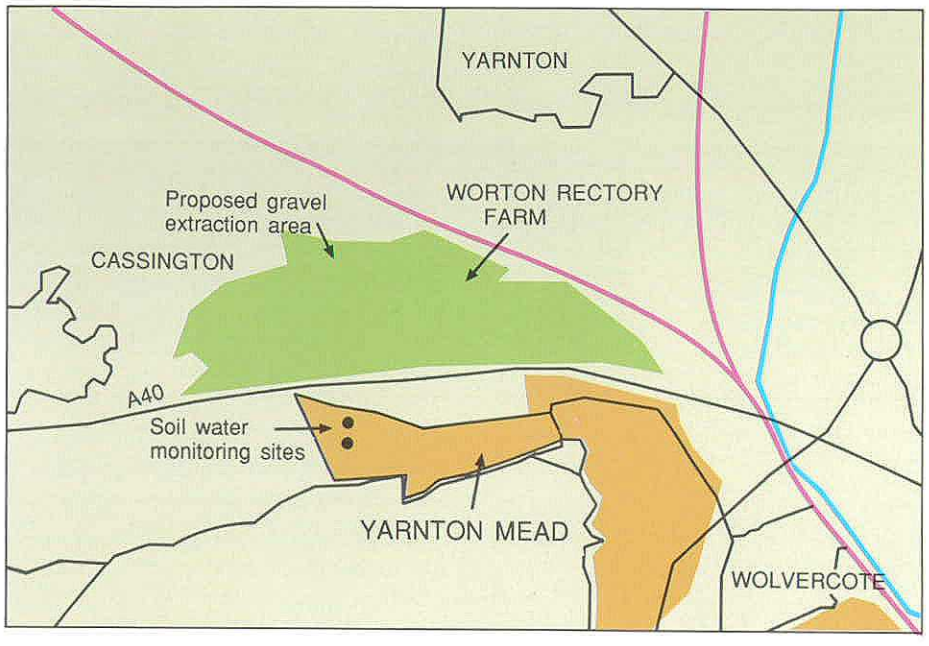


Land cover types in an urban catchment derived from remotely sensed data.
Types de couverture du sol dans un secteur urbain émanant de données prises à distance.

more cheaply and less subjectively than the traditional methods.

Past studies have relied on images obtained from satellite-based platforms such as LANDSAT and SPOT. Although these have proved adequate for identifying the outlines of urban areas, the coarse ground resolutions are such that images of the detailed patterns of different surfaces within urban environments cannot be achieved.

Images obtained from aircraft-borne sensors are a viable alternative because of their finer ground resolution: 2 m or better. The Institute has been studying images of Kidlington, near Oxford, obtained during a NERC airborne campaign using a multispectral scanner. The images obtained have been analysed on an image processing system (I^2S) at Wallingford using various techniques. The results obtained have been compared with those obtained by manual methods and, in general, the agreement has been excellent.



Map showing the location of Yarnton Mead.
Carte de localisation de Yarnton Mead.

Soil water studies on Yarnton Mead

Yarnton Mead is an ancient, undisturbed hay meadow located adjacent to the River Thames to the northwest of Oxford. It supports a unique flora and has therefore been designated a Site of Special Scientific Interest (SSSI). The Institute is monitoring the surface water and groundwater systems of the area. Groundwater models have been written to predict the impact of a scheme to extract gravel nearby, and they have demonstrated that the scheme can be operated so that the impact on the water table levels below the Mead is small.

However, whilst groundwater models can be used at this and at other sites to predict the effect of nearby pumping on water table levels, this information alone is insufficient to predict the response of the flora to these changes. That depends ultimately on the plant species and on the soil type. It is soil water potential which determines whether plants can abstract water from a soil. At sites such as Yarnton Mead with its shallow water table, the plants experience high water potentials throughout the year: the presence of certain species is probably due to this.

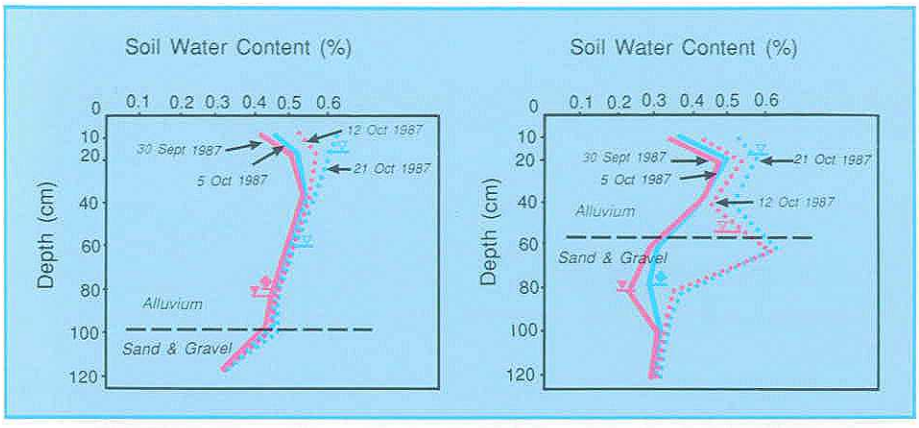
An investigation of the present soil water regime of the Mead soils is being conducted by field observation using neutron probes and tensiometers. This is supplemented by the use of the MUST model (Model for Unsaturated flow over Shallow water Tables, developed by De Laat in 1985) to simulate the effect of water table changes on soil water conditions.

The soils comprise clayey alluvium over sands and gravels: the base of the alluvium varies between 0.5 m and 3.0 m depth. The summer water table fluctuates between 0.70 m and 0.85 m depth and so falls below the alluvium in some places. The consequent effect on soil water content profiles was recorded as the water table rose at the end of summer. During 1987 and 1988, the fall of the water table was not sufficient to restrict the supply of water to the overlying alluvium by capillary rise. In dry years, however, it is probable that the supply of water to plants would be restricted.

MUST estimates of matric potentials at the root zone/subsoil interface, defined at 0.4 m depth, and saturation deficits in the root zone and in the profile as a whole, were compared with field measurements. The results were good for 'normal' rainfall years for which data were available.

The model was then used to predict what might happen if the water table were lowered to greater depths than had been recorded at the Mead. It was found that, in a 'normal' rainfall year such as 1985, assuming 1.0 m depth of alluvium, even if the water table were set at a constant depth of 2.5 m, the effect on matric potentials at the root zone/subsoil boundary would not be serious: matric potentials remain above -400 cm water. This occurs because the alluvium, which has a large water-holding capacity, could supply the plants' water needs without the addition of water from the underlying sands and gravels.

MUST was then run for the same soil with the meteorological data recorded in 1976, assuming constant water table depths of 1.2 m and 1.8 m. The results showed that the vegetation would not be stressed with a 1.2 m water table: actual evapotranspiration rates were hardly reduced below the potential in that situation. However, with the water table set at 1.8 m, capillary rise from it was



Sequences of water content profiles recorded at the end of summer 1987 at sites where the depth of alluvium differs.
Séries de profils de la teneur en eau enregistrée à la fin de l'été 1987 à des sites de profondeurs alluviales variées.

Drilling a pumping test observation well at Wallingford.
Forage d'un puits d'observation pour les essais de pompage à Wallingford.

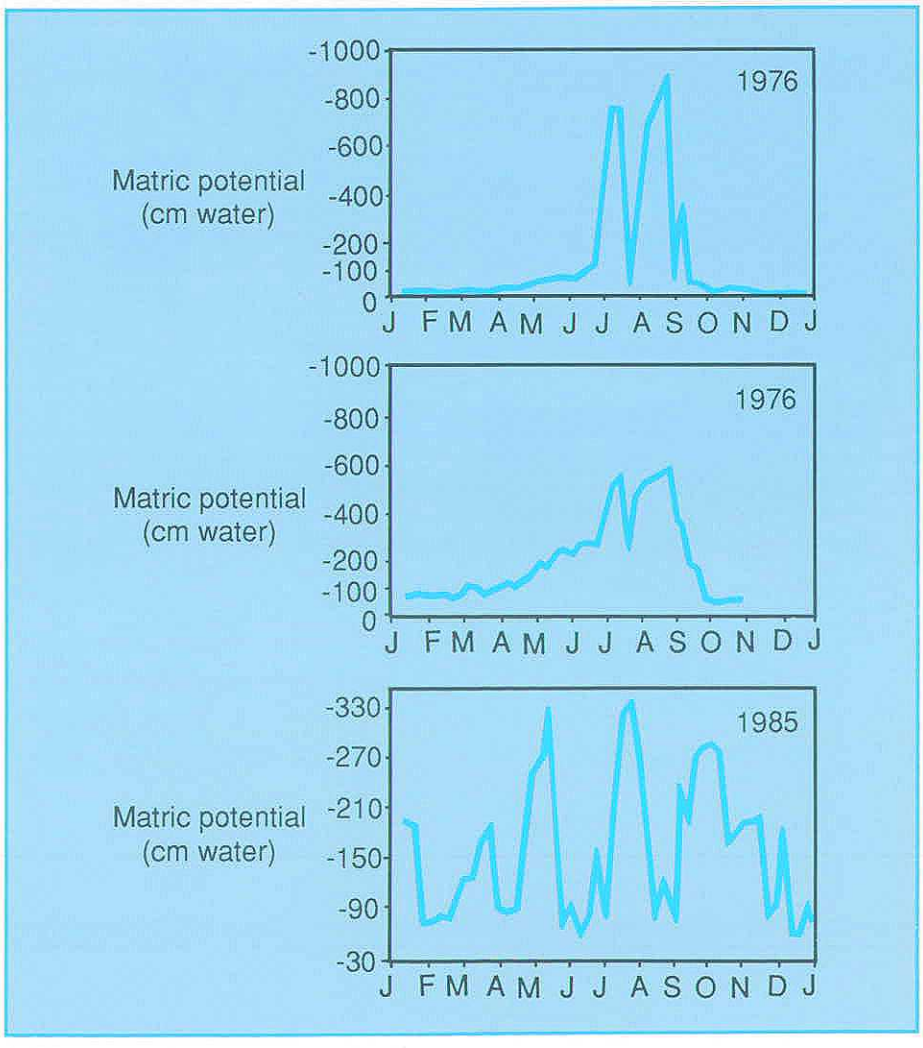
severely limited and consequently very low matric potential (less than -5000 cm water) developed in the root zone. It is very doubtful whether the Mead plants could survive such conditions.

Sand and gravel aquifer characterisation

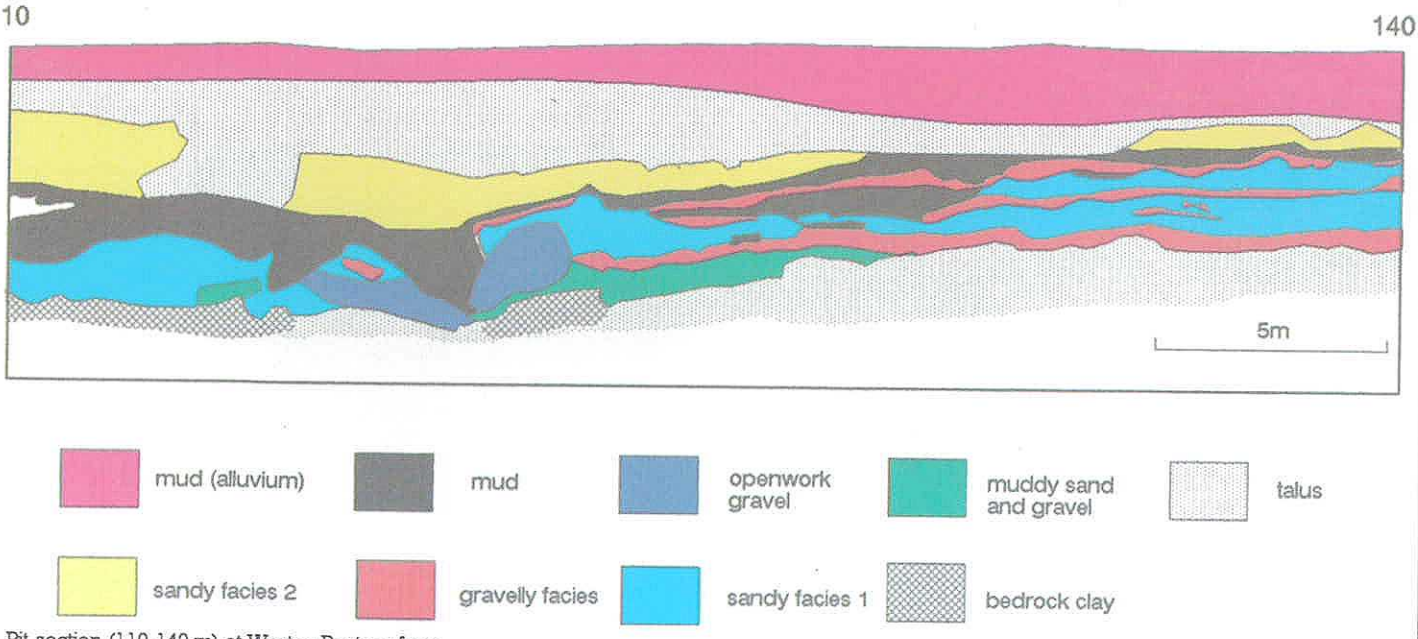
It is estimated that probably 90% of all developed aquifers consist of unconsolidated deposits, mainly comprising sand and gravels. Such aquifers are also shallow, making them vulnerable to man's impact. This not only may affect water supply but may result indirectly in adverse consequences on flora, fauna, agriculture and buildings.

Sand and gravel aquifers are often characterised by a high degree of heterogeneity and yet in most groundwater studies they are invariably treated as homogeneous. A research project is currently investigating the feasibility of synthesising data obtained from borehole cores using the coring technique recently developed at the Institute together with data from gravel pit exposures to derive 3-dimensional representation of aquifer properties.

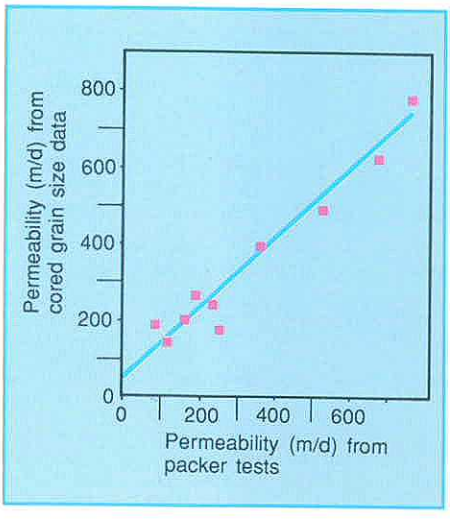
The 3-D arrangement of aquifer elements or facies associations is being investigated at Worton Rectory Farm, near Oxford. The Institute has been working at this site for several years on a hydrogeological study of the effect of sand and gravel extraction on a nearby, ecologically sensitive SSSI. Gravel is



MUST estimates of soil matric potential at 40 cm.
Estimations MUST du potentiel matriciel du sol à 40 cm.



Pit section (110-140 m) at Worton Rectory farm.
Coupe transversale de puits (110-140 m) à la ferme de Worton Rectory.



Relationship between hydraulic conductivities (K) derived from grain size data and packer tests.
Rapport entre les conductivités hydrauliques (K) déduites des données granulométriques et les essais à l'oburateur.

now being dug here and the exposed pit faces provide an opportunity to investigate aquifer element variability. The degree of heterogeneity shown in the pit face is typical of alluvial aquifers.

Values of specific yield and hydraulic conductivity for each facies association are currently being derived from samples collected from this pit (using column drainage and permeameter methods). Particle size analysis is also being carried out on the samples. The results will be compared with data from borehole cores and field pumping and packing test results.

It has been found that conventional methods of borehole sampling give rise to serious sampling errors. However, preliminary work suggests that aquifer properties derived from cored borehole samples may be reliable. At Worton Rectory Farm, close agreement was obtained between values of hydraulic conductivity estimated from cored sample grading and values derived from subsequent packer testing of the borehole at the same sampling intervals. Similarly, at Wallingford, values of specific yield (Sy) obtained from laboratory drainage of borehole cores (Sy=10%) compare well with estimates derived from a pumping test (Sy=10%) and neutron probe measurements (Sy=13%).

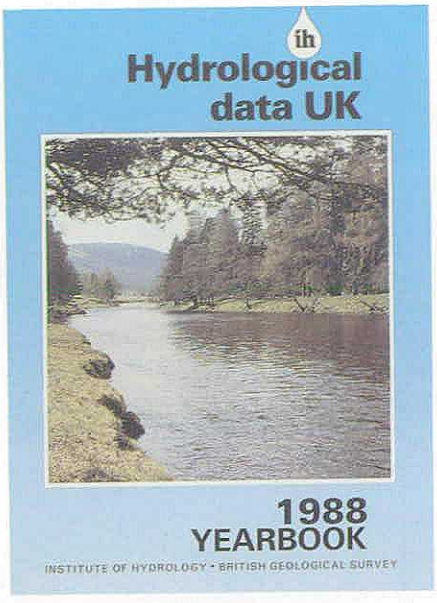
The Surface Water Archive

A prerequisite for hydrological research, and for the management of water resources, is the collection of hydrological data. Since 1982, the national river flow archive has been maintained by the Institute of Hydrology and now comprises over 23 000 station years of data for more than 1200 gauging stations throughout the United Kingdom. The archive is being run in harness with a number of other projects using national flow data sets and is evolving alongside developments in digital mapping and information technology which have great potential to increase the data's utility and increase its exploitation.

Most river flow measurement in the UK is carried out by regional gauging authorities. Following the enactment of the 1989 Water Bill, responsibility for most hydrometric activities passed to the newly-created National Rivers Authority. In Scotland, the seven River Purification Boards are the principal measuring authorities, and the Departments of Agriculture and Environment undertake a joint operation in Northern Ireland. Flow data collated at regional processing centres are sent routinely to Wallingford where they are validated and incorporated into the Surface Water Archive (SWA).

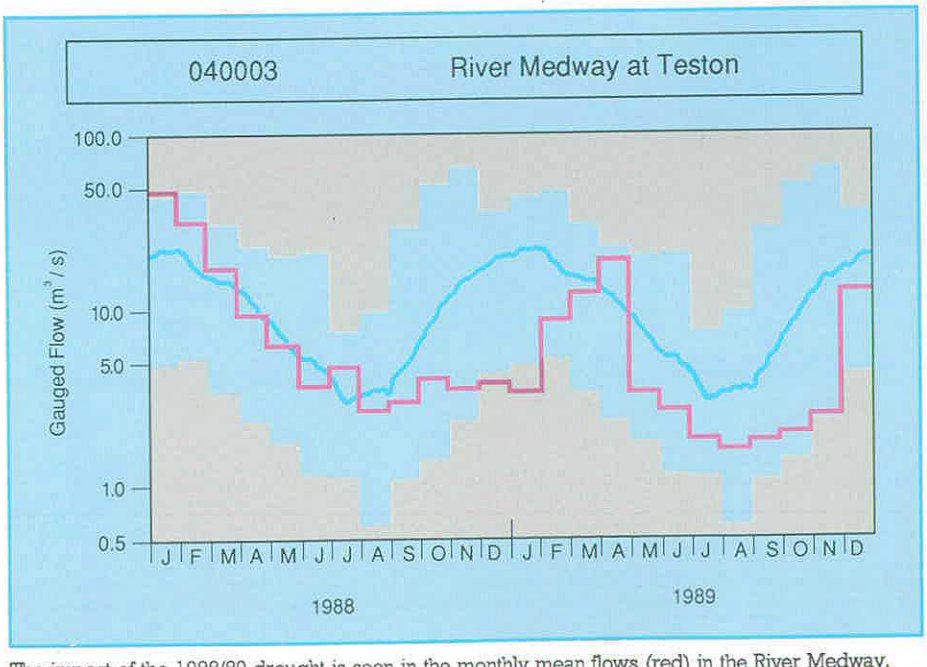
A broadly-based demand exists for hydrological data. To satisfy the requirements of individuals and international agencies alike, the data are made available through a comprehensive data retrieval service. The retrieval software is complemented by a fund of hydrometric knowledge and analytical expertise which serves to assist users to identify and manipulate data - and interpret the results - in a manner best suited to their particular investigation.

Data dissemination is also achieved through the Hydrological Data UK series of publications. This series of Yearbooks and reports was launched in 1985 as a joint venture with the British Geological Survey which maintains the national archive of groundwater levels, also at Wallingford. Ten titles have been published in the series to data and the lag between original flow measurement in the field and its eventual appearance in Yearbook form has been greatly reduced: the 1988 Yearbook (Figure 1) is the first for more than twenty-five years to be published within the following year. Each Yearbook brings together the principal data sets relating to river flow, groundwater levels, areal rainfall and, beginning with the 1986 edition, water quality throughout the UK. A companion report, published on a five-year cycle, provides summary hydrological statistics and details relating to the hydrometric performance of monitoring sites together with, in the case of gauging stations, concise catchment descriptions and qualitative assessment of the net impact of abstractions and discharges on the natural flow regime. The first of these reference volumes,the Hydrometric Register and Statistics 1981-85, was published in 1988.

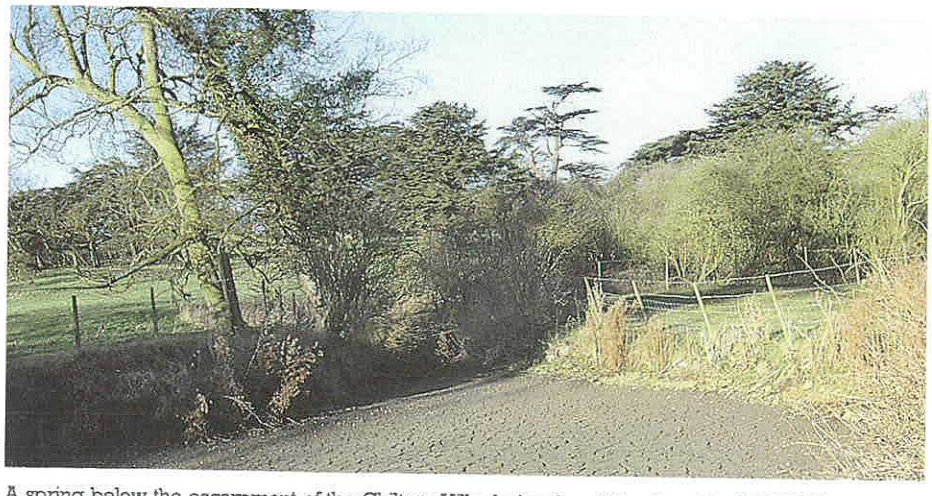


Hydrological Data UK 1988.
Données hydrologiques Royaume-Uni 1988.

A major objective of the SWA project is to provide information upon which assessments can be made of the water resources throughout England and Wales. Early in 1989, at the request of the Department of the Environment, the Institute of Hydrology and the British Geological Survey instigated a monitoring programme to chart the progress of the developing winter drought with particular reference to regional variations in intensity. By the end of January 1989 a notable drought had developed, which in some areas posed a significant threat to the



The impact of the 1988/89 drought is seen in the monthly mean flows (red) in the River Medway. Extreme monthly means and a 30-day running mean for the period 1956/87 are also shown (blue).
L'impact de la sécheresse de 1988/89 est mis en évidence dans la série de débits mensuels moyens (en rouge) du Medway. Les moyennes mensuelles extrêmes, ainsi que les moyennes mobiles de 30 jours, correspondant à la période de 1956/87 sont également tracées (en bleu).



A spring below the escarpment of the Chiltern Hills during the winter drought of 1988/89.
Une source sous l'escarpement des Chiltern Hills au cours de la sécheresse hivernal de 1988/89.

adequacy of water supplies through the ensuing summer. Over England and Wales, the three months commencing in November 1988 were the driest such period since 1879; the accumulated rainfall total fell significantly short of those registered during the prolonged droughts of 1933/34 and 1975/76. The combination of very limited rainfall with exceptionally mild conditions was also without modern parallel. In hydrological terms the drought's development was marked by a virtual absence, in central and southern England, of the expected upturn in riverflows and groundwater levels following the summer of 1988: in an average year a significant increase occurs as evaporation rates diminish rapidly from September. The drought intensified throughout the winter and, by early February, river flows in lowland England were more typical of summer conditions and groundwater levels in some aquifers were comparable with those recorded during the summer of 1976. Entering March many springs and bournes were approaching a year without significant flow. This represented a considerable loss of amenity and a substantial, if temporary, loss of habitat for fish and other aquatic life. A wet interlude in the spring brought temporary relief but the drought entered a second phase as hot and dry weather characterised much of Britain throughout the summer. Widespread water distribution problems were experienced and, by the autumn, the water resources outlook was, generally, fragile. A six-month drought of relatively uniform intensity could be identified throughout much of Britain away from western Scotland. Substantial longer-term rainfall deficits also afflicted parts of southern England and the eastern seaboard of northern Britain. However, a dramatic transformation in hydrological conditions began in mid-December 1989. Sustained and widespread rainfall characterised the early winter, with abundant replenishment of reservoirs and aquifers at the beginning of 1990. Except in a few eastern districts, the December - February rainfall will serve to diminish concern over the prospects for water supply in the coming summer.

The Surface Water Archive provides an essential framework within which to assess the 1988/89 drought's magnitude. It also provides a wide spatial and temporal perspective against which to examine the impact of climatic change on water resources and the aquatic environment in the United Kingdom. However, isolating climatic effect from the normal flow variability, the influences of land use change and the impact of the evolving pattern of water utilisation within individual catchments is a considerable challenge. UK rivers are typically short, shallow and subject to very appreciable artificial disturbance; a continuing commitment to high standards of hydrometric data acquisition and archiving is required if flow regime changes attributable to the 'greenhouse effect' are to be quantified effectively.

The FREND (Flow Regimes from Experimental and Network Data) Project

The International Hydrological Programme (IHP), sponsored by UNESCO, has resulted in numerous individual basin studies but few generalisations of this work. As a contribution to IHP III the objective of the FREND project was to extrapolate these research results by applying statistical analysis and modelling techniques to an extensive hydrological database, with the aim of using representative and experimental basins for monitoring natural and man made changes in hydrological regimes.

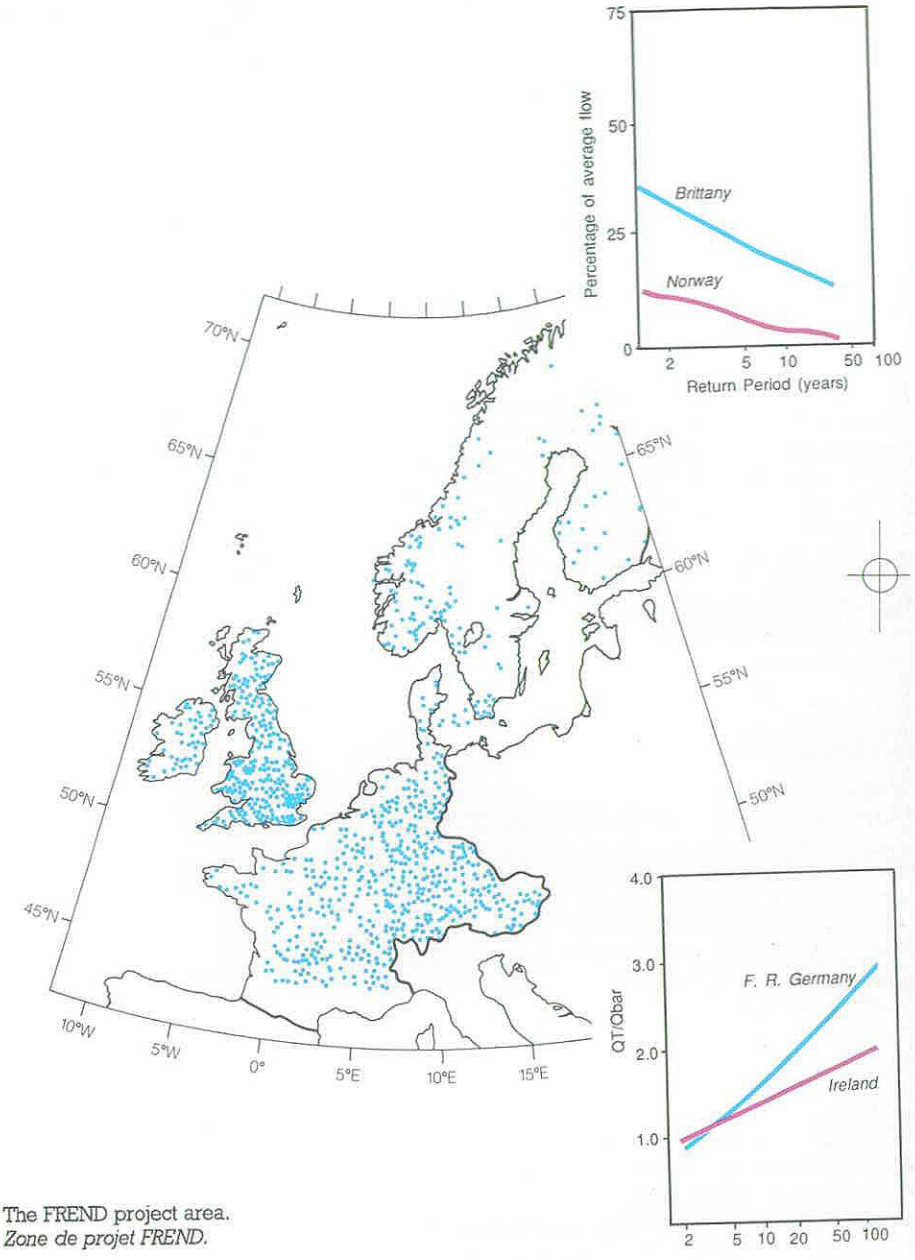
The geographical extent of the FREND project included a sizeable area of northern and western Europe. The project was based at the Institute from 1986 to 1989 and brought together scientists from Belgium, the Federal Republic of Germany, Finland, the Netherlands, Norway, Sweden and the United Kingdom.

One of the most significant achievements of the project was the development of a database of river flow data from over 2000 small research basins and national network stations. In addition an inventory of catchment characteristics has been incorporated into the database, including information on morphometry, soil type, land use and climate of the catchments. These data have now been made generally available for further research.

The description of the spatial and temporal variability of the frequency of both floods and low flows on a regional scale formed a major part of the analysis and used techniques such as flood frequency and low flow frequency curves. The flood frequency plot for Ireland shows the T-year return period flood, QT, plotted as a fraction of the mean annual flood, QBAR. The low-flow frequency curve for Norway is also shown, with annual minima plotted as a percentage of average flow. A classification of the distribution of the annual maximum series of flows identified homogeneous flood groups and the relationship between mean annual floods and catchment characteristics. Similar techniques involving gridded soil, climate and land-use data were used to relate low flows to their catchments.

On a smaller scale the study of base flow and recession used detailed data from the small research basins and the study recommendations of the Federal Republic of Germany's IHP. Similarly, data from research catchments were used to apply a variety of modelling techniques to investigate the impact of human influences on flow regime, with both physical and conceptual modelling of the effect on soil moisture of changes in groundwater level, and the effects on flow regime of land drainage and forestry.

A large international hydrological database from over 2000 basins has been completed and the advantages of using these data with a range of analysis techniques from different research groups has been demonstrated. A wide range of methods for transferring results from research basins and national network stations to areas outside their catchments has been successfully applied and developed. Regional flood and low-flow estimation techniques have clearly benefitted from application to data sets not constrained by national boundaries. This development should lead to improvements in the hydrological aspects of land drainage, water resource and water quality design. The application of models to human impact studies has demonstrated that research developed initially on a small scale can be applied to different but related practical problems in other catchments and countries.



The FREND project area.
Zone de projet FREND.

Spatial dependence in rainfall extremes

The analysis of hydrological extremes has long been fertile ground for the statistically minded. Typical areas of research include testing the sensitivity of analyses to the choice of parent population from which annual maximum river flows are assumed to be drawn, exploring new methods of estimating the parameters of the distribution from a typical sample size of 20 to 50 annual maxima, and seeking ways of combining data from many sites in a region to evolve more reliable estimates of very rare events. However, recent studies have taken research in a new direction by explicitly modelling the dependence that exists between extreme rainfalls observed at nearby sites.

The objective of a 3-year project commissioned by the Department of the Environment was to develop a procedure for estimating the collective risk of an extreme storm occurring at one of a network of critical sites such as impounding reservoirs. The solution is based on the concept of an effective number of independent sites. The model of spatial dependence in annual maximum D-day rainfall is:

$$\ln Ne/\ln N = 0.081 + 0.085 \ln AREA - 0.051 \ln N - \ln D$$

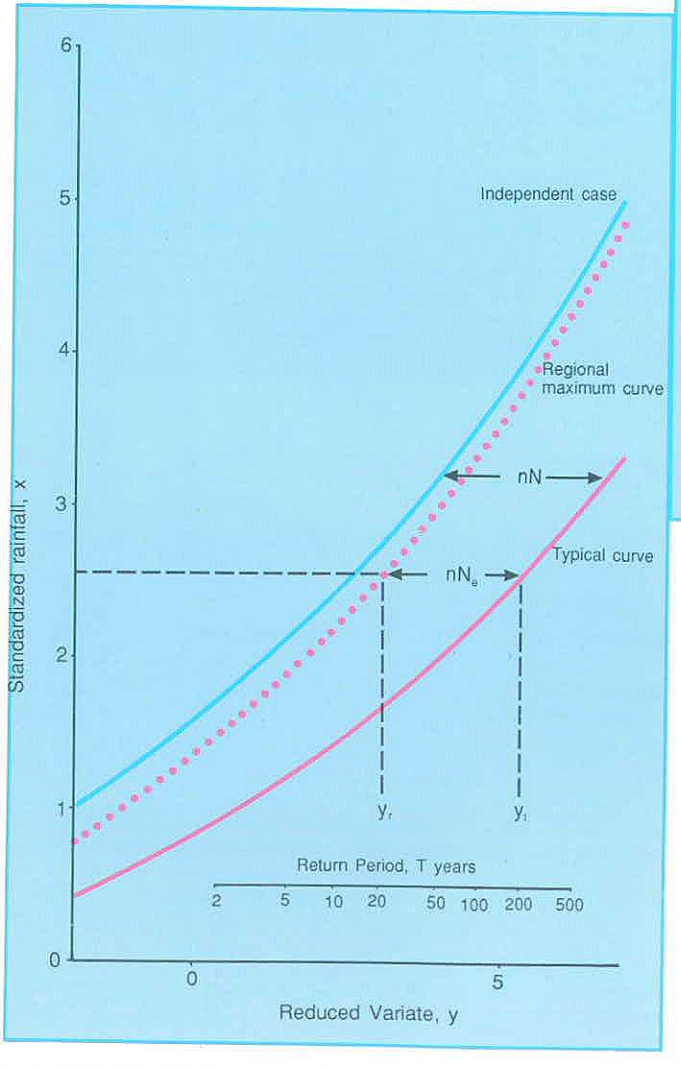
N - number of sites
Ne - equivalent number of independent sites
AREA - area spanned by network (km^2)
D - duration (days)

Although it was designed purely with the collective risk assessment procedure in mind, the spatial dependence model has opened the door to a new approach to estimating very rare rainfall depths at a point. By taking explicit account of spatial dependence it has been possible to resurrect the 'station-year method' of combining records from different sites.

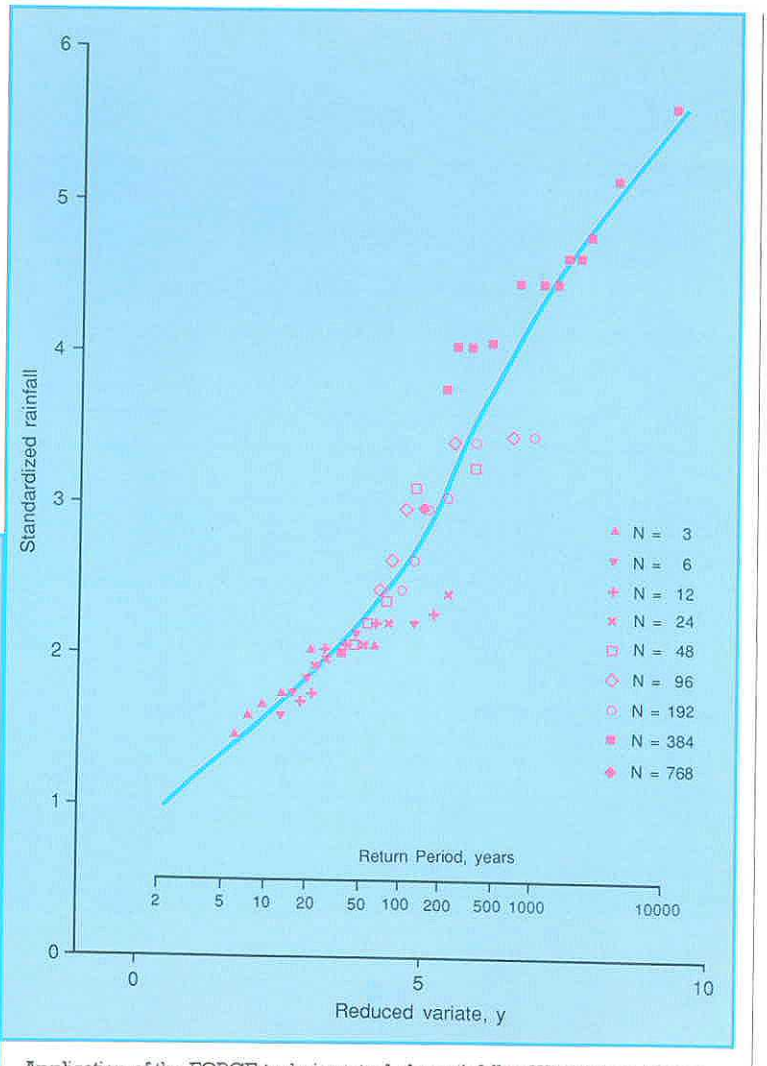
The original station-year method is widely criticized for the assumption that neighbouring records can be treated as if they were independent; the method treats the r largest events observed at a network of N stations operating for m years as the r largest in mN station-years of record, and positions the data points on a frequency plot accordingly. In the modified station-year method the

concept of an effective number of independent sites has been extended to define an effective number of independent station-years; the method therefore treats the r largest independent events correctly as the r largest in m independent station-years of record.

It is now recognized that there are weaknesses in adopting fixed geographical regions when seeking to generalise hydrological extremes: boundaries are subjective, regional homogeneity may be suspect, and abrupt changes in estimates on crossing the regional divide are unrealistic. In a recent study for South West Water, these problems have been avoided by use of a very much more flexible approach to rainfall growth curve derivation: the FOcussed Rainfall Growth Estimation (FORGE) method.



The model of spatial dependence in maximum annual D-day rainfall.
Modèle de la dépendance spatiale sur les précipitations anuelles maximales du jour D.



Application of the FORGE technique to 1-day rainfall at Wimbleball, Devon.
Application de la technique FORGE sur les précipitations d'un seul jour à Wimbleball, Devon.

For any particular focal point, the modified station-year method is applied to plot the six largest independent annual maxima observed at the three nearest stations. The network of gauges analysed is then expanded to six gauges and the six largest independent annual maxima again plotted. The network of gauges is doubled each time that the analysis is repeated until the uppermost points on the frequency plot represent the largest independent annual maxima in the entire data set. The focussed growth curve illustrated for Wimbleball, Devon, is thus based on local data at its lower end but a

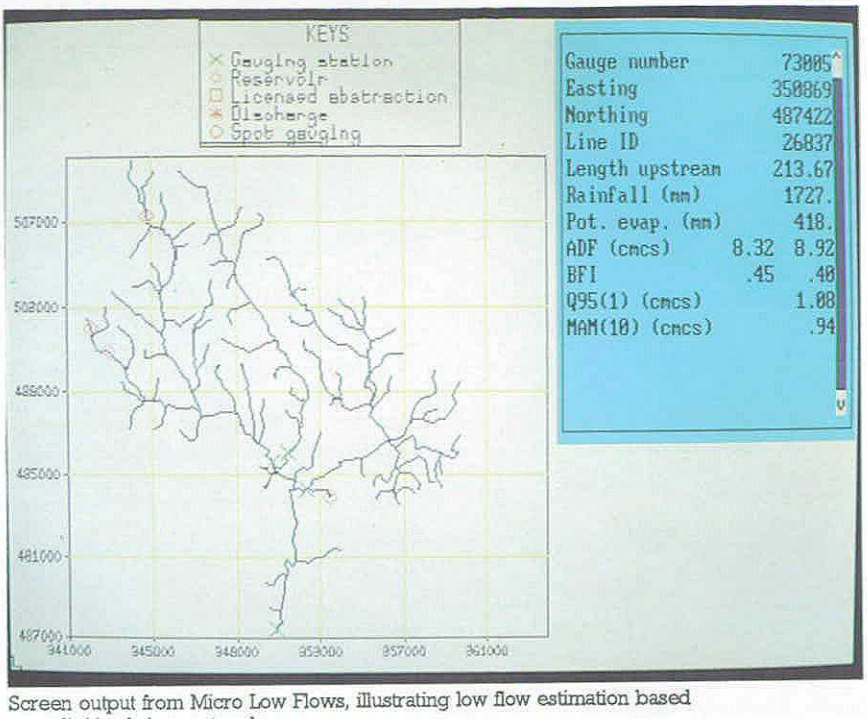
much larger and wider sample of data at its upper end. It is thought that the FORGE technique may have general application wherever statistical estimates of very rare environmental extremes are required. One of the first targets of continuing research is to establish an objective way of fitting the growth curve to the plotted data.

Design flood estimation

The methods of design flood estimation contained in the Flood Studies Report are widely used throughout the United Kingdom. However, research continues into how these techniques may be improved. Flood estimates made at sites with no hydrological data rely on information contained in maps. Key variables describing, for example, the slope, degree of urbanisation or soil type of the catchment, are used to estimate parameters of hydrological models that can then be used to estimate the flood of required return period. Until recently the abstraction of these indices from maps has been a tedious manual task but now many maps are held on computer in digital form and the characteristics can be derived automatically. As well as saving time, this eliminates errors in abstraction and allows more complex measures of catchment properties to be used. Much recent effort has gone into the development of the systems to enable the use of the digital map data and soon the benefits will be available to users of the flood estimation methods.

Soils play a very important part in catchment response yet at present are only crudely indexed for use in the design flood estimation methods. A new soil classification is being developed in a joint project with the Soil Survey and Land Research Centre and the Macaulay Land Use Research Institute. This research is using the Soil Survey's digitised 1:250 000 soil maps and soil property databases, and the archives of hydrological data available at the Institute of Hydrology. The new classification is relevant to both flood and low-flow estimation and it is anticipated that it will benefit other applications requiring a hydrologically-based assessment of soil type.

The performance of the flood estimation procedures, and in particular the rainfall-runoff method, has been the subject of a recent review. This study has produced a quantitative assessment across a set of 74 catchments and a detailed study on a group of six catchments. In different catchments different aspects of the estimation procedures are seen as the weak links; research will be targeted at the problem areas which have been identified.



Screen output from Micro Low Flows, illustrating low flow estimation based on a digitised river network.
Sortie sur écran du logiciel Micro Low Flows, illustrant l'estimation des débits d'étiage sur la base d'un modèle numérique de réseau fluvial

An example of the approach being taken to address specific problem areas is illustrated by a project to improve the estimation of response times on small catchments. Flood Studies Supplementary Report No.16 presented a more robust model to estimate the unit hydrograph time to peak on quickly responding catchments but revealed the need for more data. Although many small catchments are gauged the majority are in upland areas whereas most problems of flood estimation on small catchments are associated with urban or suburban development. Catchments on relatively permeable and often dry soils in south-east England present a particular problem. A set of 15 natural and urbanised catchments ranging in size from 0.8 to 22.0 km^2 has been chosen for instrumentation using intelligent loggers that record only flood hydrographs. Response times will be calculated using information on the timing of the rainfall obtained from the Chenies rainfall radar.

Low-flow design

The last two decades have witnessed a number of severe droughts, most notably in 1975/76, 1984 and 1988/89. Although the concept of a drought is generally well understood, it is essential for hydrological design to develop rigorous and objective procedures for assessing drought severity, for forecasting runoff and for estimating the frequency of low river flows.

Where flow data are available at the site of interest they can be used for hydrological design. However, a number of water resource problems, for example, estimating the dilution of sewage effluent and the licensing of abstractions, are required at sites without hydrological data. The traditional approach to flow estimation at the ungauged site has been to use manually calculated catchment characteristics in regional regression equations. This approach is very time-consuming and error-prone and this prompted the development of automated techniques which have opened up entirely new approaches both for model calibration and application.

These developments have exploited the availability of both vector and gridded data for estimating low flow statistics at ungauged sites. These data included:

- River networks digitised from the 1:50 000 Ordnance Survey map;
- Gridded standard period (1941/70) annual average rainfall;
- Gridded annual average potential evaporation;
- A 26-class classification of the hydrology of soil types (HOST).

Techniques have been developed for overlaying the river network on each of the gridded databases for estimating

mean catchment and climate characteristics weighted by the length of the overlaid river network.

Thus RHOST, for example, is the weighted proportion of soil types, RSAAR the average annual rainfall and LRN the total length of the river network upstream of a given location. These have been calculated for a pilot study area and related to Q95(10), the flow exceeded by 95% of 10-day average discharges, calculated from gauged mean daily flow data, to derive the following equation applicable to the pilot study area:

$$Q95(10) = 3.9*10^{-6}\ RHOST^{0.12}\ RSAAR^{0.802}\ LAN^{1.01}$$

The major advance of this approach has been the automatic calculation of catchment characteristics upstream of any gauging station. However, the same approach can be applied at any ungauged point in the river network for automatic calculation of catchment characteristics which can be substituted into the above equation to estimate low-flow statistics. This enables several thousand flow estimates to be estimated rapidly for all reaches in a given hydrometric region.

Preliminary results indicate that regional low-flow estimates using network methods are only marginally inferior to using the traditional area approach, the proportion of variance explained reducing from 89% to 86% in the case of the pilot study area. This estimation procedure is being incorporated into Micro Low Flows, a PC-based interactive procedure for the rapid estimation of low flows in the UK. The main features of the system are the ability to roam interactively about a river network to display low-flow characteristics, the capability of identifying upstream abstractions and discharges as well as the location of gauging stations, and the spot low-flow current meterings.

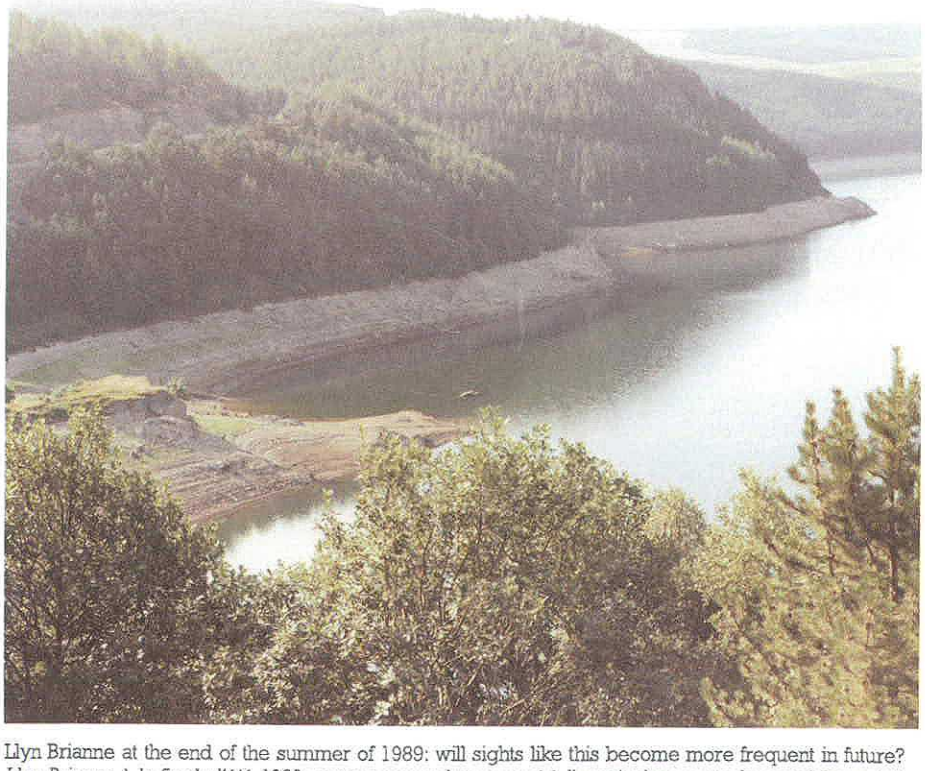
The impacts of climate change on water resources

The 'greenhouse effect' has enjoyed considerable publicity in recent months and many research projects are currently assessing the possible consequences of a change in climate to a wide range of activities. One of the most significant effects of climate change will be on hydrology, and on water resources in particular. Accordingly, several research projects have been initiated at IH to consider the type and degree of impact both within Britain and overseas.

It has become clear that the understanding of many aspects of current hydrological behaviour needs to be refined considerably before serious attempts can be made at estimating future changes. Most of the work on climate change impacts undertaken so far at IH has therefore been concerned, somewhat paradoxically, with understanding past relationships between climate and hydrology. These studies have used regional databases of British and European flow data in conjunction with climatological data supplied by the Climatic Research Unit at the University of East Anglia. It has been shown, for example, that the general pattern of variability in time of several hydrological characteristics (including both high and low flows) is consistent across much of western Europe, and that these patterns bear close resemblance to variations in some key climatic indices. Further studies with the regional databases are attempting to identify the characteristics of a catchment which determine its sensitivity to climatic variability: such studies are also helping with the understanding of the relative importance of different landscape and climate characteristics on variations in hydrological response.

Three ways of estimating future changes in water resources have been identified, and will be explored in the course of several projects. First, hydrological information from warm and cool periods in the past can be compared, although there will be difficulties in finding suitable records. The second involves the transfer of information from a part of the work currently experiencing a climate similar to that suggested for the area of interest (such as Britain). Again, there are methodological problems to surmount, and the relative importance of regional and local controls on climate and hydrology needs to be understood.

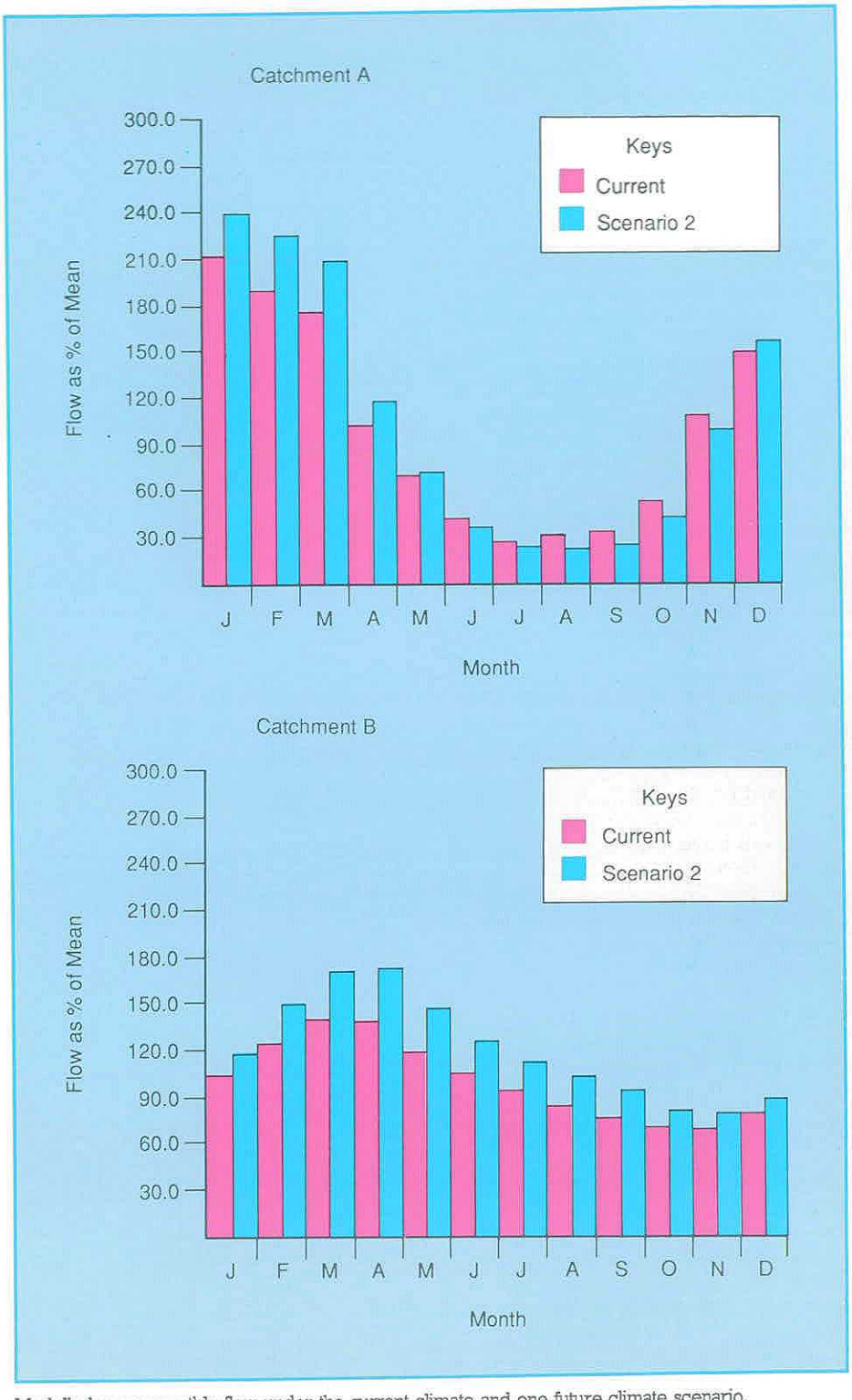
The third route for estimating change -



Llyn Brianne at the end of the summer of 1989: will sights like this become more frequent in future?
Llyn Brianne à la fin de l'été 1989: verrons-nous plus souvent à l'avenir des spectacles aussi navrants?

the one most widely followed and with the greatest potential - uses information on perturbed climate as input to a hydrological model. Appropriate models range from simple regression-based relationships between climate and runoff to complicated physically-based simulations of the rainfall-runoff process. Studies are currently in hand to define models for application to Britain and into methods for defining climate input data at appropriate spatial and temporal scales. Current General Circulation Models have a very coarse spatial resolution (particularly in relation to catchments in Britain) and only poorly reproduce short time-scale variations in climate. For hydrological and water resource purposes, these short-term variations are of greater importance than mean conditions.

Studies of the hydrological consequence of climate change have an important practical benefit, but have also raised questions about areas of current hydrology which are poorly understood. In particular, assessments of possible changes require information on how climate actually controls hydrological response, and the relative importance of climate and landscape characteristics in conditioning sensitivities to change. Attempts to extract information at the appropriate spatial and temporal scale from General Circulation Models have triggered studies into the spatial structure of hydrological variability and characteristics of time series. It is clear that an assessment of possible future hydrological and water resource behaviour, and the development of regional hydrological expertise are fundamental to such an understanding.



Modelled mean monthly flow under the current climate and one future climate scenario.
Débit mensuelle moyenne simulée sous le climat courant et aussi sous un mis-en-scène climatique de l'avenir.

Applications research

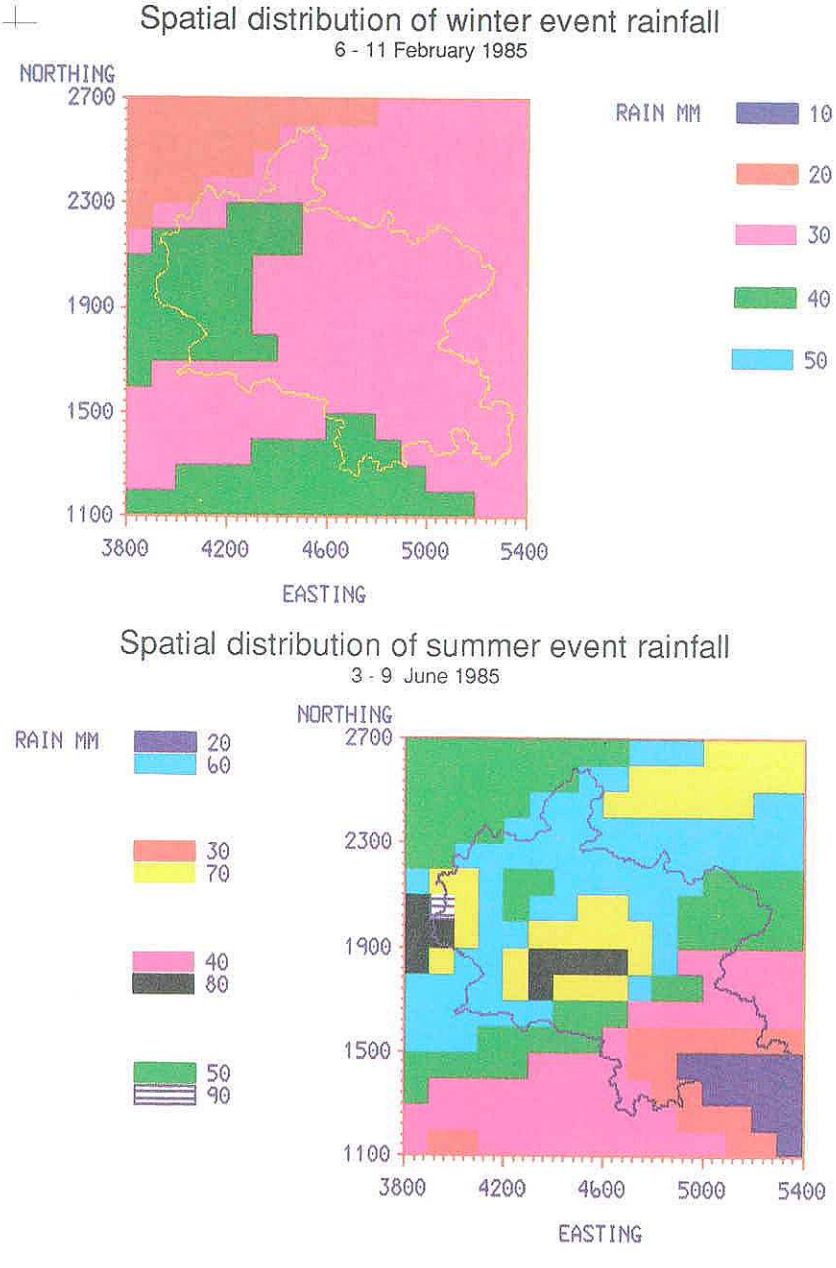
Flooding on the Thames

Pressure for housing developments in the south east has meant that many properties are now at risk from Thames floods. A number of projects relating to this problem have been funded by Thames Water over the years, and include work on the tidal Thames and the Maidenhead area. More recently, we have been funded to supply design hydrographs for the Thames and its tributaries, for input into a hydraulic model of the Thames and its flood plain, developed by Sir William Halcrow and Partners. The results are required to produce constant return period levels along the Thames.

Initially, the reach between Bourne End and Penton Hook has been chosen, although there are plans to extend at least some of the work to the 199 km of the Thames between St. John's and Teddington. The work has involved:

- the development of rating curves for weirs with variable gate openings,
- level frequency analysis using weir tailwater levels which have been recorded by lock-keepers since the latter part of last century,
- an investigation of the cumulation of flows down the Thames, and the dependence between main stream and tributary flows, and
- application of unit-hydrograph rainfall-runoff models to the Thames and its tributaries.

One problem was the development of design hydrographs for the Thames at Cookham, a catchment of some 7000 km^2. Typical 'events' on the Thames at Cookham can last between 6 and 25 days; the duration is a function of the size of the catchment and of the underlying chalk geology. Many of the assumptions behind the unit hydrograph model were examined, including that of spatially uniform rainfall. Surprisingly, over such a large catchment, the total rainfall over several days shows good uniformity in winter events, although summer convective storms are more localised. The direct application of a unit hydrograph model to Cookham gave a 5-year peak flow within 3% of that given by flood frequency analysis and the 5-year flood volume was within the range of uncertainty of the local gauging stations at Bray and Royal Windsor.



Total rainfall during winter and summer events over the Thames catchment.
Précipitations totales au cours des averses d'hiver et d'été sur le bassin versant de la Tamise.

Lower Mekong basin, water balance studies

The Mekong river is 4240 km long and flows from Tibet through six countries to the Gulf of Thailand. In the late 1970s mainstream flows in the Lower Mekong basin were lower than average: in the important rice-growing areas of the delta, saltwater migrated upstream during the dry season, reducing the potential use of the river for irrigation. Over the past 30 years there have been a number of upstream developments which might have had significant effects

on the hydrology of the basin, such as clearing of forest for agriculture and the construction of reservoirs for hydro-electricity and irrigation. Reduction in mainstream flow may also have been the result of low rainfall.

The Institute was commissioned by the Overseas Development Administration to work with the Mekong Secretariat to investigate all of these factors so that their impact on the water balance of the Lower Mekong Basin and the consequences of any future developments could be assessed.

Preliminary water balance study

Data necessary for such a study, including records of rainfall, runoff, evaporation, land use and water quality, had been collected by several national agencies using a range of measurement techniques and over varying periods. Much of these data had been assembled in 1962 by the Mekong Secretariat. However, with the exception of those data from northeast Thailand, there was no correlation between rainfall at different stations in daily, seasonal and annual data, and no long-term runoff records were available.

Despite these constraints, time series and other analyses suggested that the rainfall regime was probably essential stable. Further, there was no evidence to suggest that evaporation had changed with time, although reliable estimates were hindered by the lack of good records of solar radiation. Although there was firm evidence of reduction in runoff from the left bank tributaries between Vientianne and Pakse in the 1970s, without conclusive rainfall records it was not possible to relate this to agricultural or other developments.

Current metering on the Mekong.
Mesure des débits au moulinet sur le Mékong.

Flows in the late 1970s had not been unusually low and were not the result of extreme low flows of short duration. Problems had arisen from lower than average flows during the wet season and the subsequent recession. It seems, therefore, that if changes in hydrology of the lower basin had occurred as a direct result of upstream development, the effects are small.

An urgent and substantial increase in the density of raingauges was recommended, particularly for the more remote mountainous areas of high rainfall. Because of the scale of the problem, a selective approach is necessary.

Network model

A network model covering the whole of the Lower Mekong basin was made up from separate models of the tributary catchments. This model was developed as a tool for medium- and long-term planning and can be applied to a network of alfost any size and complexity since geographical boundaries and water demands can be readily changed. It has been used to investigate the effects of flows in the lower basin of a number of upstream developments but results were not fully conclusive due to the inadequacies in the database.

Dry season flow analysis

This had to be undertaken to provide 'benchmark' flow statistics so that any further changes in the hydrological regime could be monitored and evaluated. Inspection of the available data showed that there has been a decrease in the mean annual flow at all sites, with some losses obviously due to reservoir operation and irrigation. The increase in the mean annual minimum discharge at all sites due to controlled releases from reservoirs could change if abstractions for irrigation are increased in future.

A simple method of detecting upstream changes was developed and tested. This will be important in monitoring the effect of proposed hydro-electric schemes on the Upper Mekong in China.

Water balance of Lake Toba, Indonesia

Lake Toba is a large natural lake situated in a collapsed volcanic caldera in northern Sumatra, Indonesia. It has a surface area of 1200 km^2, which represents about 40% of the total catchment area. There is only one outflow from the lake and two hydropower stations have recently been constructed on this river, each generating some 300 MW.

Almost all of this power is used by an associated aluminium smelter, which has a design output of 225 000 tonnes of aluminium per year. However, lake levels have fallen dramatically since the power plant and smelter were completed in 1984. The Institute has been investigating whether the fall was due to an imbalance of inflows and outflows or a suggested leak from the lake, possibly along a geological fault line or similar feature. Also, because the lake itself represents such an important component of the water balance, an intensive study has been made of rainfall inputs and evaporation losses. The Institute's Hydra equipment was used to measure direct evaporation losses from the lake for a period of two months, then the data run was extended back in time by correlation with evaporation estimates from long-term, land-based climate stations.

This is the first time that the Hydra has been used over a large water body. Preliminary results suggest that Penman open water evaporation estimates are reasonably accurate for Lake Toba. This is partly because there is no sensible heat storage problem in the lake which, because of its proximity to the equator, has a remarkably constant water temperature of about 25°C. In general, large water bodies in higher latitudes act as heat sinks and open water evaporation estimates lag significantly behind those from land-based climate stations.

Preliminary results show that inflows to the lake in recent years have been below the long-term average. Outflows for hydropower have exceeded net inflows and water has been drawn from storage to make up this deficit: hence lake levels have fallen. This has come about because net inflows have been below

General view of Lake Toba, Indonesia.
Vue générale du Lac Toba, Indonésie.

average since 1976. The hydropower design was carried out using data prior to this period and the quantity of water being released for power production has not been reduced to match the lower than expected inflows.

It appears that the safe long-term yield of the lake may have been over-estimated by the designers of the scheme and consequently, unless planned hydropower releases are curtailed, the levels in the lake will continue to decline. The direct measurement of evaporation and detailed analysis of the rainfall on the lake will be used to carry out a more detailed water balance: this will help to show whether a leak has occurred and to what extent reduced rainfall has contributed to the problem.

Hydrology software

For a long time, computing has played an important part in developing and applying research in hydrology. Databases and data processing systems, mathematical models of river basins, simulation of reservoir operation and real time river flow and quality forecasting are just a few of many applications. With the almost universal availability of personal computers, it has been timely to develop a range of hydrological software for use not only within the Institute but more especially for sale outside.

Software products have proved a practical way to transfer IH expertise for application and education. Already our software is helping to solve water resource problems in at least 40 countries around the world. Software and its associated documentation is developed to a high standard and undergoes stringent testing procedures before release. Products currently available are designed to run on IBM PC or compatible machines and plans are afoot to bring out Micro Vax versions. Software products and their associated documentation and manuals are subject to quality control procedures before release. The specialist section which was set up to develop software products is also involved with marketing and responds to sales and technical queries about the products.

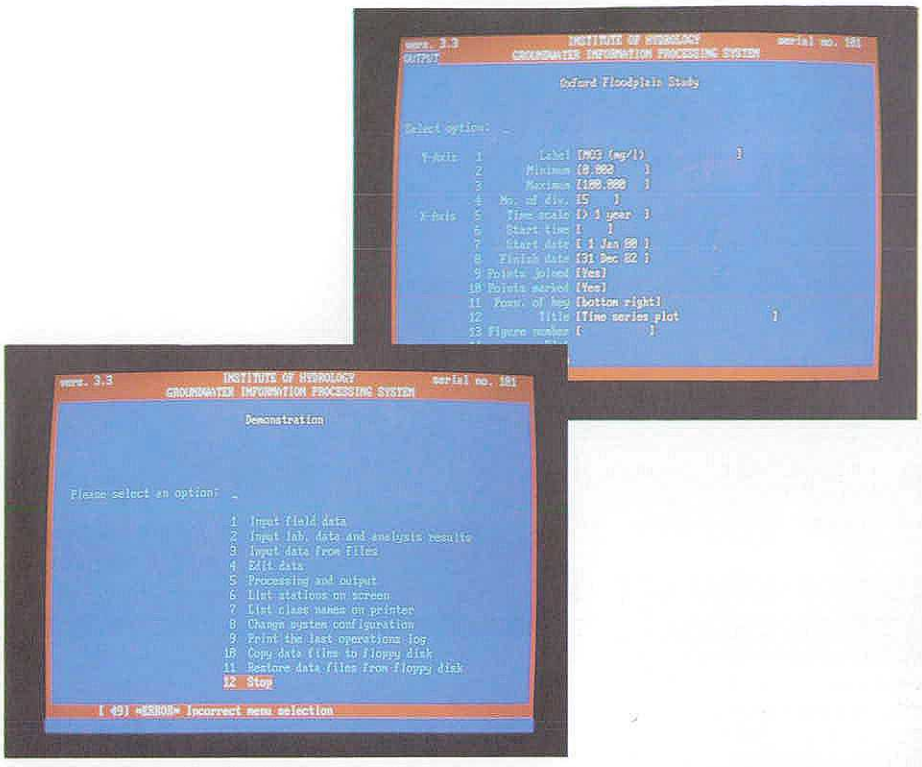
HYDATA is an integrated surface water data processing and analysis system whose design concept is that it may be used by those with no background in datafile structure, the computer operating system, or the running of individual programs. The software is menu driven and includes specialised graphical and printer output. HYDATA is sold as a stand-alone data processing and storage system which includes facilities for derivation of rating equations from river gaugings. Additional modules comprise an expanding range of data transfer and analysis programs. Current modules include logger and telephone telemetry interfaces, double mass plots, flow duration analysis and low flow frequency analysis.

GRIPS is a personal computer software system for the storage and management of data collected during groundwater investigations. The software is based on the extensive experience of the Institute both in the UK and overseas. GRIPS uses a menu-driven user interface similar to HYDATA and has the ability to retrieve data selectively and present it graphically, either in map format or as specialised plots such as lithological logs and Piper diagrams. Maps may be produced of station location, lithological cyclograms, water level, conductivity, ionic concentrations and temperature.

The Micro-FSR package contains routines to aid design flood estimation using the methods contained in the UK Flood Studies Report. It is aimed at the engineer who is familiar with FSR methods but is not necessarily an expert in their application. Menu operation, screen and printer graphics feature in this system also.

HYRROM is a conceptual rainfall-runoff model which predicts river flows from rainfall and evaporation data on a daily basis. Developed at the Institute, it incorporates interception processes as well as soil, groundwater and runoff stores. The model can be calibrated manually or automatically using the in-built Rosenbrock optimisation routine. Output is in the form of colour screen graphics which can be copied to a plotter or graphics printer if required.

New software products currently under development include Micro Low Flows,



Screen output from the GRIPS software system.
Sortie sur écran du logiciel GRIPS.

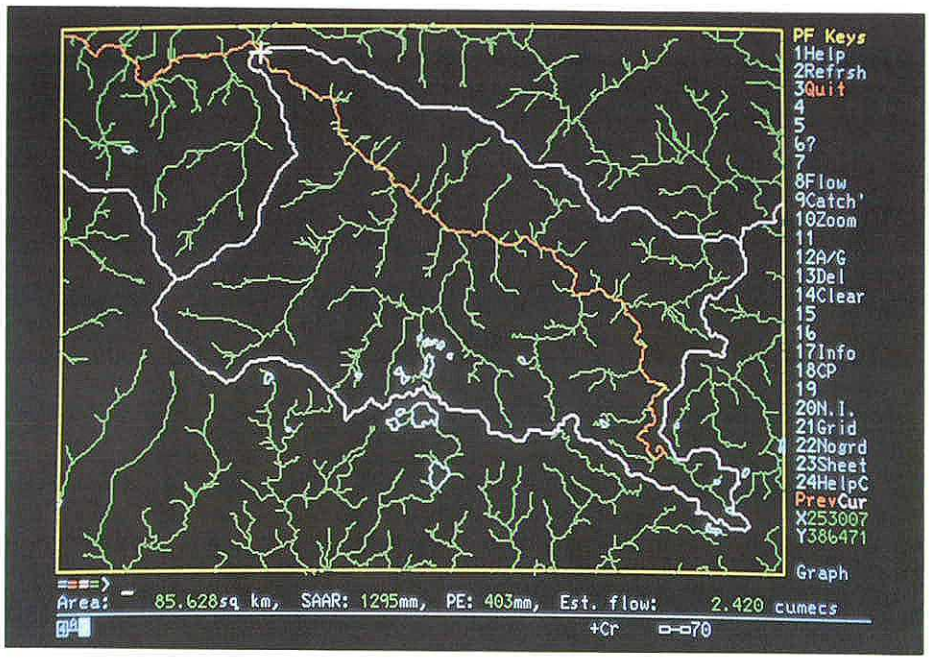
similar in concept to Micro-FSR but based on the techniques published in the UK Low Flow Studies Report. A special feature is the use of the digitised river network as a display background, and the listing of artificial influences on low flows which affect the catchment of interest. A PC water quality database is also under development as well as a PC version of QUASAR, the Institute's water quality simulation model.

Digital map data and the Water Information System

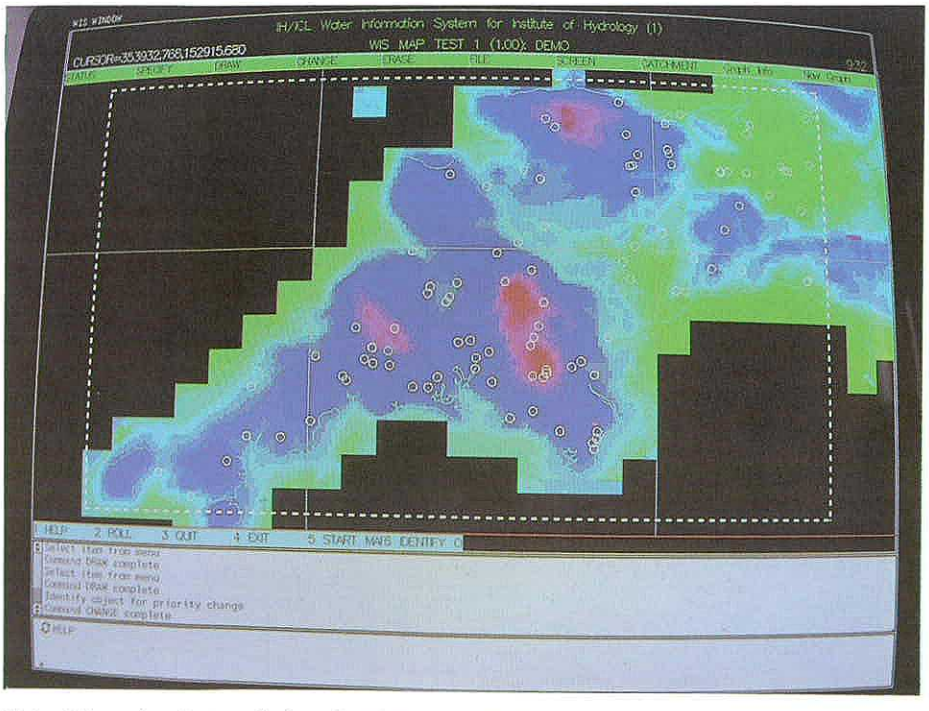
There are two major objectives of storing map information on computers. The first is to enable the user to produce a map showing only the area and detail required, at a scale and in a style appropriate to a particular application. The second objective is to use the speed of the computer to open up new ways of analysing the information and to automate existing labour-intensive procedures.

Central to these objectives is the coming availability of a UK-wide digital terrain model (DTM), which is a 50 x 50 m grid of heights over the entire land surface. Work has started on the development of a hydrologically-appropriate DTM for the UK. The digitised river network is being used to dictate valley form, and tidal range data is being incorporated to aid in the modelling of coastal plains and the inter-tidal zone. The resultant DTM will be better suited to hydrological studies than the currently available Ordnance Survey DTM which was constructed to meet different requirements. An initial application of the DTM is the automatic derivation of a catchment boundary to any point on the ground. This catchment boundary then provides the basis for the extraction of other data already in digital form, such as soil, rainfall and lakes.

Digital data offer far more than the automation of existing procedures. Implicit in the digital terrain data, for example, is information on the slope and hence drainage direction at all points on the ground. Access to this will allow new catchment characteristics to be developed. In particular, detailed slope, aspect and elevation data can be used to improve the estimation of snowmelt rates. The analysis of climate, land use, soil, terrain and river network should allow areas most at risk from acid rain to be identified. The combination of water quality data, flow data and the digitised river network make possible the production of river maps, both existing types such as those of the River Quality Survey and new types. The digitised river network is also the key to systems of access that require data to be sorted in order along a watercourse.



Catchment boundaries and drainage paths produced by a digital terrain model.
Limites d'un bassin versant et trajectoires d'écoulement produites par un modèle numérique du terrain.



Water Information System display, showing long-term annual average rainfall and river gauging stations.
Représentation visuelle d'un Système d'Informations Hydriques, montrant les précipitations annuelles moyennes à long terme et les stations de jaugeage fluviales.

To focus work in this highly exciting field, a new project has been created to develop a unified system. The Water Information System (WIS) allows for the exploitation of both spatial and time-series data, within a single computer package. A variety of map data have been loaded into the system, together with water quality and quantity measurements, and different retrieval methods have been written. Development will continue with the calculation of flow statistics, using characteristics derived automatically, over catchments drawn automatically. Further applications may exploit the river network to model the passage of pollution down river, to help identify the pollution source, and to warn abstractors or other sensitive sites downstream. Although initially serving hydrological applications, WIS could be extended to any environmental problem involving the space and time dimensions.

Instrumentation

Reusable aluminium streamflow structure

Instrumentation for catchment studies can be extremely expensive, and concrete streamflow structures are particularly so. In addition, they are permanent installations which can be undesirable from the environmental aspect. Accordingly, the Institute has developed a demountable aluminium structure which is a significant advance over permanent systems.

The site is initially surveyed and some 20 pads installed in a horizontal plane using a prepared template. The modular design enables the structure to be broken down to sub-units of suitable size for convenient transfer to the site. It is of course the only technique for those sites where access for concrete pouring is impossible. In the event of wear or damage, repair is easily effected by replacement of appropriate sheets. At the conclusion of the study the structure may be dismantled and removed from the site for subsequent redeployment elsewhere with potential cost saving of some £30 000 to £40 000. A unit is currently being installed at Llyn Brianne, in conjunction with the Welsh Water Authority, for water quality studies.

Reusable aluminium flow structure being installed in the Llyn Brianne catchment, central Wales.
Installation d'un ouvrage de régulation réutilisable en aluminium dans le bassin versant de Llyn Brianne, dans le centre du Pays de Galles.

Field calibration of the capacitance probe in Mauritius.
Étallonage in-situ de la sonde de capacité à l'île Maurice.

Soil water measurement in the 10 cm and 5 cm surface zones

The standard technique at IH for measuring soil water content has been the neutron probe within a vertical access tube. This method has been complemented recently by measuring soil dielectric constant using a capacitance probe, also with an access tube. Neither of these techniques is particularly suitable for surface measurements due to interference by the soil-air interface. However, the capacitor plate geometry can readily be modified to allow direct insertion into the soil and new designs under test have two 10 cm (or 5 cm) long , 5 mm diameter stainless steel prods, about 3 cm apart, which are pushed directly into the soil.

For particularly intractable soils an alternative design has detachable prods which can be driven by a demountable tool directly into the soil. This latter technique has the advantage that the prods are left in the soil, and the problem of spatial variation when taking a time series of measurements is avoided. Initial results have been encouraging, with the sensor showing high sensitivity. A recent trial in Mauritius in coral sand gave a reading change of 8000 between dry, blown sand and seawater-saturated sand, which is more than 500 times the reproducibility. Care is needed in the interpretation of such results, as the porosity of the dry site was certainly less than that of the wet site and this has some effect on the sensor reading.

The equipment was first used for ground-based measurements in the AGRISCATT campaign and is currently in use in Niger, West Africa, as part of a programme to measure evaporation from sparse dryland crops which will include further gravimetric measurements of water content to extend the field calibration (see also page 17). The instrument response function has the form:

$$F = A\,[\,B + 1/\,C(M,p)\,]^{0.5}$$

where F is the sensor reading, C is the measured capacitance (a function of the volumetric water content, M and the soil porosity, p) and A and B are instrumental constants.

Automatic collection of field data

The recent introduction of compact solid state intelligent loggers marks a third phase in data collection methods within the Institute's own experimental programmes, following earlier use of first, cassette tape and then solid state RM storage controlled by digital logic. Approximately 100 Campbell Scientific CR10 loggers are deployed, or in preparation, for measuring water quality variables such as pH and conductivity, weight change in lysimeters, stilling well and borehole water level, surface radiation temperature, soil temperature, soil heat flux and meteorological variables from automatic weather stations.

Intelligent loggers provide more scope for interaction between the data collection and the system under study; this can take the form of conditional storage of data, storage of maximum or minimum values and sleeping units that awake to record extreme or specific events. The logger can input command signals to the system when data meets specified values or conditions and can apply conversion factors or calibration expressions to record values in engineering units rather than as raw data.

The scope of these systems is of course considerably enhanced, but commissioning them is significantly different from earlier versions, with an increased emphasis on programming software. On the hardware side, the signal conditioning performance is excellent and their measurement potential can be exploited in any number of applications.

When used with automatic weather stations, the Penman evaporation estimate is programmed into the logger and output data on a daily basis are immediately available via a standard personal computer. Data are stored in a format directly accessible by standard software packages such as Lotus 1-2-3 which allows analysis and plotting without further software development.

Stage-to-flow conversions for our catchment structures can be complex but the characteristics of the individual segments that make up the complete curve have been converted via a statistical package to a polynomial which is programmed into the logger to give direct recording of both stage and flow. Some of the structure installations also now record water quality information such as conductivity and pH. A programme has been developed using logical functions to distinguish and locate events of interest, in this case a rapid increase in flow, to trigger the switch to a faster time base for detailed recording. On conclusion of the hydrograph the logger reverts to the slower time base to conserve storage while the system is in states of no interest. The logger is easily interfaced to a Data Collection Platform transmitter and data from both the Hydra and the automatic weather station (AWS) are received via Meteosat giving rapid up-date of the state of serviceability of systems, particularly useful for remote installation both in the UK and overseas. Following current tests, it will be installed initially in the Sahel region of Niger.

Evaporation measurements with the Hydra

Six HYDRAs have been built in response to a steadily rising demand from both science and commissioned projects. Three are in the Sahel, measuring evaporation from sparse dryland crops, one is in the UK near Oxford, and another has been used first in Indonesia and is currently in Kansas, USA. Experience gained from the field use is continually fed back to improve the facility, with a closely integrated programme to build, calibrate, test and install a further eight instruments.

The Hydra installed on Pulo Tao island, Indonesia.
Installation de l'Hydra sur l'île de Pulo Tao, Indonésie.

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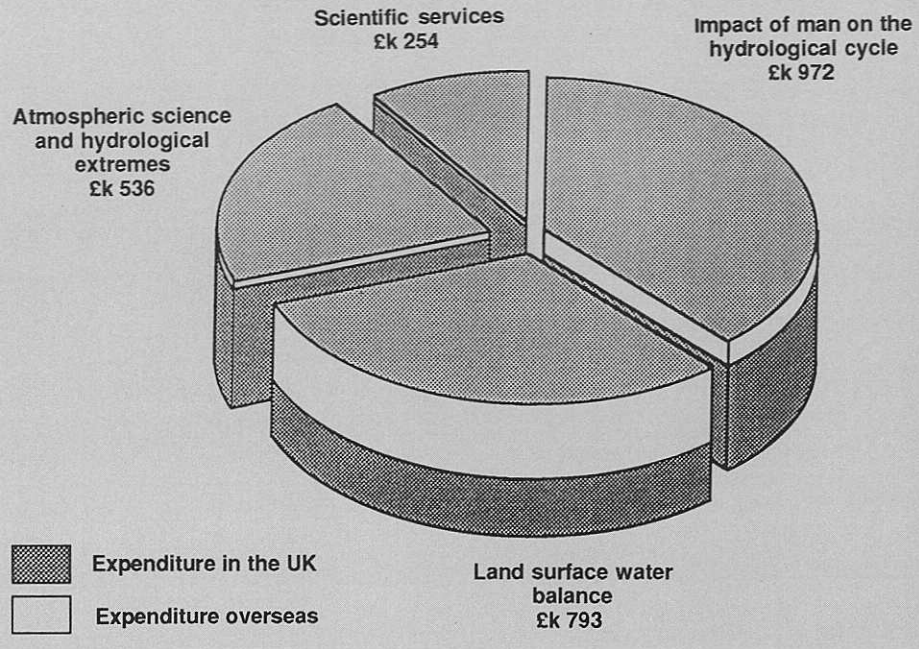
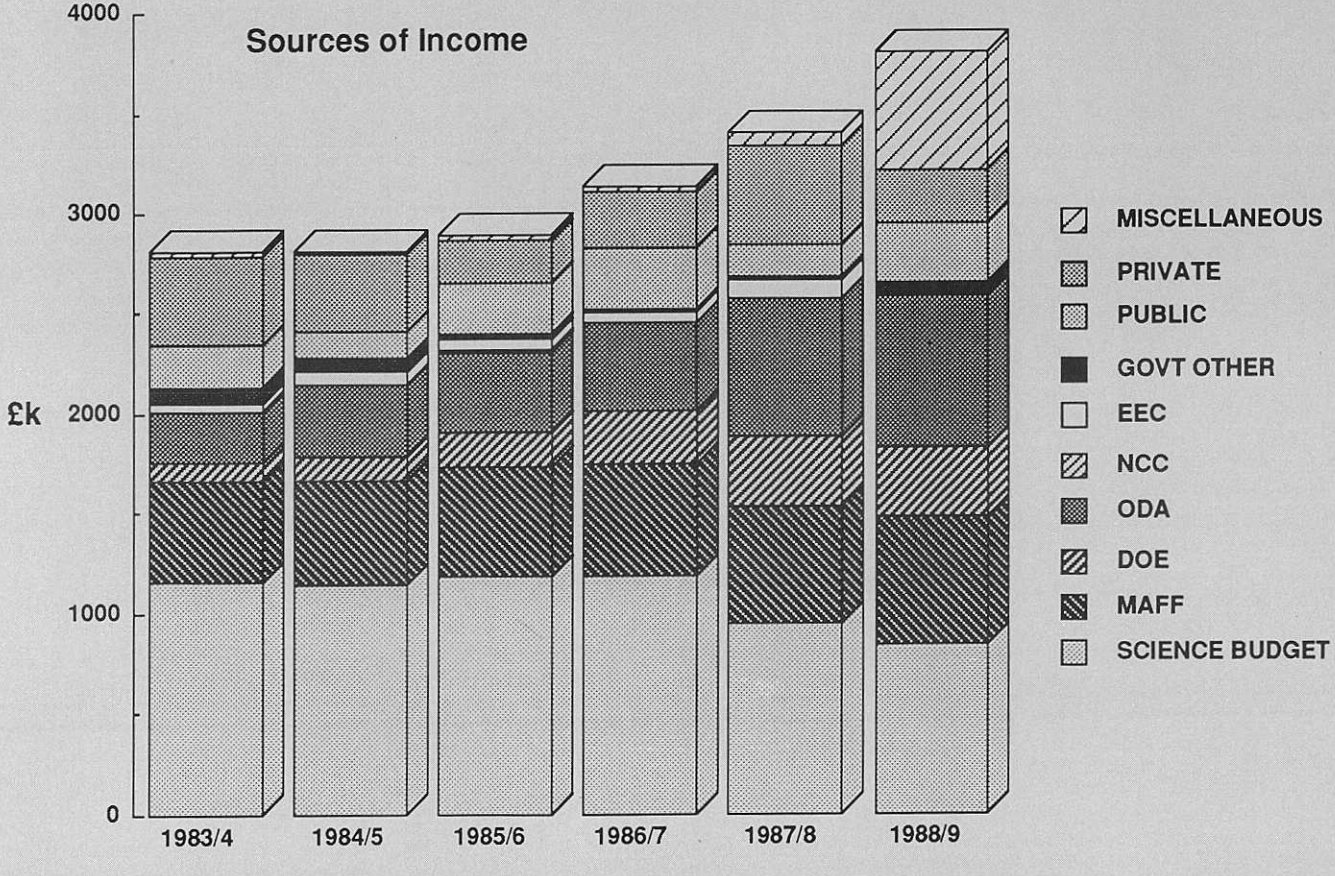
Appendix 1 **Finance and administration**

Finance
Organisation of research within the terrestrial and freshwater interests of NERC is through 12 Programme Areas of science. The Institute participates in four of these programme areas, as shown in the diagram opposite, with expenditure for 1988/89 (as full economic cost) divided between home and overseas activities.

Sources of income
The histogram below shows how the Institute's income has changed during the period 1983/84 to 1988/89 (at cash prices). The Wallingford site is shared with staff from other NERC Directorates for which the Institute receives Science Budget support for provision of site services.





Appendix 2 **IH research projects at 31 December 1989**

Programme 4: Management of aquatic Ecosystems

Development of in-stream flow incremental methodology in British rivers

Programme 5: Impact of Man on the Hydrological Cycle

Experimental catchments
The water use of the Plynlimon experimental catchments
The effect of clear felling on upland runoff
Chemical studies in the Llanbrynmair catchment
Water resource implications of upland afforestation
Fluvial geomorphological research
Conservation management of wetlands
Hydrology and wetland conservation
Hydrological studies, West Sedgemoor
The Hydrological behaviour of flat agricultural catchments
Catchment urbanisation
Urban hydrology process studies
WALLRUS rainfall-runoff model
The effects of agricultural soil erosion on water courses
Water resources study, West Sedgemoor
Soil Water studies, West Sedgemoor

Catchment data
Processing, analysis and modelling of the Plynlimon data
Catchment modelling and data analysis
Kenya hydrological data

Hydrological modelling
Physically-based modelling: development of the IH Distributed Model
The Système Hydrologique Européenne (SHE) model
Real-time forecasting of river flows
Stochastic modelling of hydrological systems
Catchment response in relation to flood frequency curves
Statistical flood frequency estimation techniques
Development of distributed hydrological and hydrochemical models
Weather radar and climatic hazards
Local calibration of weather radar
Development of snowmelt forecasting model
Yorkshire Water flow forecasting system
Development of models for radiological hazard assessment
Flow interpolation model for the River Tamar
Regional and national rainfall forecasting using weather radar

Water quality
Surface water acidification
Modelling the effects of acid deposition
Water quality modelling design and management
Modelling the transport of caesium
Pesticide pollution in catchments
Acid waters monitoring network
Contaminant loads in rivers
Water quality in the Balquhidder catchments
Water colour modelling
Detecting climate change from river basin data

Agrohydrology
Special studies on drip irrigation in Mauritius
Use of collector wells in small-scale irrigation schemes
The application of soil physical techniques to improve irrigation efficiency

Hydrochemistry
Hydrochemical process studies
The impact of forestry on upland water quality
The hydrochemical impact of hardwood plantation
Use of isotopes as environmental tracers

Consultancy studies, UK
Maidenhead flood studies
Tidal Thames defence levels
Analysis of soil water data from Lincoln
Impact of gravel extraction on a Site of Special Scientific Interest (SSSI), Stoke Poges
Chernobyl-derived caesium outputs
Impact of gravel extraction, Woolhampton
Impact of flood plain development on routing and storage of runoff
Groby pool SSSI, Shepshed
Ryall House Farm, Herefordshire
Effect of riparian gravel extraction on water supply
Groundwater study at Colchester
Hydrogeological study of the A27 Westhampnett by-pass
Cotswold Water Park
Nottinghamshire groundwater strategy

Consultancy studies, Overseas
Future water supply strategy, Jordan
Hydrometry for Somalia
Groundwater control, Doha
Hydrology of the proposed Linggiu Dam, Malaysia
Mekong irrigation programme
Lake Toba study, Indonesia
Rainfall study, Solomon Islands
Climatic and physiographic aspects of flood frequency curves
Hydrological modelling studies, Morocco
Water balance of sand quarry, Bangkok

Programme 6: Land Surface Water Balance

Land surface energy balance
Collaboration in the First ISLCP Field Experiment
Hydrological Atmospheric Pilot EXperiment (HAPEX)
Energy balance of the Sahelian savannah (SEBEX)
Modelling regional scale evaporation in the Sahel
Surface energy/water balance studies
Regional scale surface energy balance
Meteorological Office/Institute of Hydrology terrestrial model of land surface (MITRE), for input to GCMs
Boundary layer development in the Sahel
International desertification experiment
Tropical deforestation studies

Vegetation water use
Plant physiological controls of evaporation
Water use efficiency of rainfed crops
Water balance of dryland intercrops
Broadleaf plantation in lowland Britain

Environmental impact of trees
Environmental implications of trees/land use systems
Management of fast growing tree plantations
Western Ghats forest project, India

Sub-surface processes
Soil water measurement techniques
Measurement of soil water in deep unsaturated zones
Process studies of evaporation from shallow aquifers
Water and solute movement in the shallow unsaturated zone
Measurement of soil hydraulic properties
Groundwater investigation at Worton Rectory farm
Use of sulphur hexafluoride as a groundwater tracer
Properties of heterogeneous aquifers
Arid zone recharge
Groundwater modelling research
Groundwater feasibility study, Burnham Beeches
Development of an auger method for well installation
Groundwater storage in chalk aquifers
Water balance of Burntstump landfill site

Physics of surface/near surface hydrological models
The effects of artificial drainage on catchment hydrology
Investigation of storm runoff mechanisms and effects on stream hydrographs
Contribution of chemistry to understanding runoff processes
Development of physical process models of catchment response
Process studies of the effects of upland afforestation on water resources
Turbulent transfer over snow

Remote sensing
Remote sensing of radiation
Remote sensing of semi-arid regions
Remote sensing of soil and vegetation moisture
Remote sensing of groundwater recharge and discharge
European Space Agency ERS-1 mission
Potential application of remote sensing to hydrological problems

Anglo-Brazilian Amazonian Climate Observational Study (ABRACOS)
Micrometeorology and climatology
Plant physiology and soils
Tropical rainforest processes

Programme 12: Atmospheric Science & Hydrological Extremes

Surface water archive
UK surface water data

Catchment characteristics and archives
Development of catchment response models of flood runoff
Updating of Flood Studies Report
Flood event studies
Development of a hydrogeographic data base
Development of the Water Information System
Hydrometric data management (for British Standards Institution)

Flow regimes
Flow regimes in Western Europe
Low flow studies
A water resource study of the River Annan
Development of Micro-Low Flows software
Low flow studies in the North West Water area
Low flow studies in the South West Water area

Storm hazards and hydrological extremes
Hydrological study of flooding in Truro
Use of radar and water level data in studying small catchment response
Review of statistical procedures for flood studies
Development of risk-based criteria for use in economic design of flood protection
Development of direct stage/frequency relationships
Rainfall extremes
Hydrological inputs to the Thames model
Study of acute rainfall variations in upland areas
Reservoir flood estimation courses
Study of rainfall frequency in southwest England
Hydrological input to the Oxford reach component of the Thames model
Flood study of Rufford Park

Climate change
The impact of climate change on water resources
Extreme event hazard reduction

Hydrological software
Software development
HYDATA
HYRROM
GRIPS
QUASAR
The IHDM package
Micro-FSR
Quality assurance of software

Programme 13: Scientific Services

Hydrological instrumentation

Information and coordination

Hydrochemistry laboratory

Appendix 3 **Publications by IH staff in 1988/89**

Joint papers with non-IH staff are also included, with the names of the co-authors in lower case.

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Appendix 4 **IH Publications**

This sample list of publications from the Institute of Hydrology includes some recent additions to the IH Report Series, as well as major research reports and conference proceedings.

The Institute houses the editorial offices for the British Hydrological Society, and also the International Association of Hydrological Sciences (IAHS) Press.

Institute of Hydrology Publications

Flow Regimes from Experimental and Network Data (FREND). 2 volumes. Price: £45.00

Regional Flood and Storm Hazard Assessment. M.Y. Dales and D.W. Reed, 1989. I.H. Report No. 102. Price: £9.00

The Preprograms to the Institute of Hydrology Distibuted Model. L.G. Watts, 1988. I.H. Report No. 103. Price: £5.00

The Instrumentation of Flat Low-lying Catchments for Hydrological Research. D.C.W. Marshall, 1989. I.H. Report No. 105. Price: £6.00

The Catchment Data Research Base at the Institute of Hydrology. A.M. Roberts, 1989. I.H. Report No. 106. Price: £7.00

Experimental Catchments Yearbook 1986. J.B. Blackie *et al.*. New series. Price: £10.00

IH Publications may be ordered from The Librarian, Institute of Hydrology, Wallingford, OX10 8BB. Prices include postage and packing within the UK.

Hydrological Data UK

Each yearbook in the series brings together the principal data sets relating to river flow, groundwater level, areal rainfall and water quality in the UK.

The Hydrological Data UK series may be ordered from The Surface Water Archive Office, Institute of Hydrology, Wallingford, OX10 8BB.

BHS Publications

National Hydrology Symposium. University of Hull. 14-16 September 1987. Price: £18.00

Second National Hydrology Symposium. University of Sheffield. 4-6 September 1989. Price: £20.00

An Introduction to Operational Control Rules Using the 10-Component Method. Allan Lambert. BHS Occasional Paper No.1. Published October 1988. Price: £5.00

Weather Radar and the Water Industry - Opportunities for the 1990s. BHS Occasional Paper No.2. Proceedings of a conference held at IH on 6 April 1989. Price: £12.00

BHS Publications may be ordered from The Editor, BHS, Information Services, Institute of Hydrology, Wallingford, OX10 8BB.

Appendix 5 **Staff list**

Prof W B Wilkinson, PhD — **Director**

M. A. Plummer — **Personal Secretaries**
A. D. Spencer

HYDROLOGICAL PROCESSES

W. J. Shuttleworth, PhD
Divisional Head

B. A. Barton
Secretary

Evaporation Physics
J. H. C. Gash, PhD
- eddy correlation research
A. J. Dolman, PhD
- regional scale energy balance studies
H. R. Oliver, PhD
- applied meteorological research
A. D. Culf, BSc
- boundary layer meteorology
C. R. Lloyd, BA
- eddy correlation research

Vegetation Water Use
J. S. Wallace, PhD
- environmental physiology
J. M. Roberts, PhD
- plant physiology, transpiration
S. J. Allen, PhD
- measurement and prediction of evaporation from vegetation

Agrohydrology
C. H. Batchelor, BSc
- irrigation studies, crop water use
H. M. Gunston, BSc
- tropical agricultural hydrology
C. Lovell, PhD
- land and water management

O.D.A. Coordination
J. P. Bell, B.Sc
- soil physics
I. R. Calder, PhD
- process modelling of soil/atmosphere water movement

Sub-catchment Processes
R. J. Harding, PhD
- process modelling of soil/atmosphere water movement (UK)
R. L. Hall, PhD
- aerodynamic studies
M. Robinson, MSc
- land use and runoff
I. R. Wright, BSc
- analysis interception studies
P. T. W. Rosier
- soil moisture studies
C. J. Pullen, BSc
- interception studies

Sub-surface Hydrology
J. Bromley, PhD
- groundwater resources
J. D. Cooper, BSc
- unsaturated soil water flux studies
D. S. Biggin
- groundwater resources, overseas contracts
A. J. Dixon, BSc
- fluvial sediment - quaternary geology
S. A. Boyle
- soil hydrology
C. M. K. Gardner, PhD
- soil moisture studies
M. G. Hodnett, BSc
- soil water fluxes and crop water use
R. Ragab, PhD
- soil physics

Remote Sensing Applications
J. B. Stewart, PhD
- evaporation and radiation studies
G. Roberts, PhD
- remote sensing/surface hydrology
K. Blyth, M.Phil
- microwave remote sensing
J. W. Finch, PhD
- groundwater and geophysical studies
C. J. Holwill, PhD
- remote sensing

ENVIRONMENTAL HYDROLOGY

P. J. Whitehead, PhD
Divisional Head

J. A. Champkin
Secretary

Water Quality Systems
A. J. Jenkins, PhD
- hydrochemical modelling, acid deposition
A. J. Robson, BSc
- mathematical modelling
D. J. Waters, BSc
- surface water acidification studies
R. J. Williams, BSc
- water quality modelling
J. Clark, BSc
- mathematical modelling
T. B. Staples, BSc
- acid deposition catchment studies
P. C. R. Volkner, BA
- water quality catchment studies

Hydrological Modelling
R. J. Moore, MSc
- hydrological forecasting, weather radar, stochastic hydrology
D. A. Jones, PhD
- stochastic hydrology and hydrological forecasting
A. Calver, PhD
- hydrological analysis and distributed modelling
D. M. Cooper, PhD
- distributed modelling and stochastic hydrology
J. C. Packman, MSc
- urban hydrology
L. G. Watts, PhD
- physics-based modelling
R. W. Thompson, MSc
- hydrological forecasting and control
B. C. Watson, BSc
- weather radar
J. S. Thomas
- general support
J. C. Bathurst, PhD
- river hydraulics, mathematical catchment modelling (seconded to University of Newcastle)

Hydrochemistry
C. Neal, PhD
- chemical hydrology
C. J. Smith, LRIC
- analytical chemistry
M. Neal, PhD
- chemical analysis, x-ray diffraction and mass spectrometry
G. P. Ryland, MSc
- analytical chemistry
T. Conway
- hydrochemistry
A. J. Lardner, BSc
- stable isotope analysis and instrument development

Experimental Catchments

Based at Plynlimon
K. Gilman, MA
- environmental impact, wetlands, mathematical techniques
J. A. Hudson, BSc
- nutrient and snow studies, catchment hydrology, hydrometeorology
G. J. L. Leeks, BSc
- fluvial geomorphology and sediment studies
P. J. Hill
- field measurements; process studies
S. Hill
- laboratory assistant
W. A. Hughes
- network and site maintenance

Based at Balquhidder
R.C. Johnson, BSc
- catchment fieldwork

ENGINEERING HYDROLOGY

F. M. Law, BSc
Divisional head

S.J. Beresford
Secretary

Flow Regimes and Environmental Management
A. Gustard, PhD
- regional resource studies
A. Bullock, PhD
- low flows and environmental management
A. J. Wesselink, Ir. (Wageningen)
- European flow regimes
R. P. C. Brown, BSc
- low flows and environmental management
J. M. Dixon
- hydrologist

Flood and Storm Hazard
D. W. Reed, PhD
- applied hydrology
D. C. W. Marshall, MSc
- engineering hydrology
P. S. Naden, PhD
- applied hydrology
E. J. Stewart, MSc
- rainfall studies
A. C. Bayliss
- hydrometry
J. C. Elliot, BSc
- applied hydrology

Impacts of Climate Variability and Change
N. W. Arnell, PhD
- water resources impacts, flood frequency analysis
N. S. Reynard, MSc
- hydrometeorologist

Catchment Characteristics and Archives
M. J. Lowing, PhD
- catchment response, group manager

Surface Water Archives
M. L. Lees, BSc
- hydrometric networks, archive manager
T. J. Marsh, BSc
- editor, Hydrological Data UK series
I. G. Littlewood, PhD
- environmental hydrologist
S. J. Bryant, BSc
- hydrometric data processing and archiving
S. C. Loader, BSc
- hydrometric data processing, system development
J. Carr
- catchment data acquisition
S. Black
- Surface Water Archives office

Catchment characteristics
R. V. Moore, MSc
- digital mapping and information systems
D. G. Morris, BSc
- hydrological and geographical databases; digital terrain models
N. J. Bonvoisin, BA
- hydrological and geographical databases; computer applications

Flood Event Modelling
D. B. Boorman, PhD
- flood event modelling
M. Polarski, BSc
- engineering hydrology
H. Houghton-Carr, MSc
- engineering hydrology
M. C. Clayton
- hydrologist

Catchment Data Management and Modelling
J. R. Blackie, MSc
- catchment studies, land-use change
C. W. O. Eeles, BSc
- conceptual modelling of land-use change
A. M. Roberts
- catchment database manager
C. Hughes, MSc
- hydrometeorological data
A. Matthews
- hydrological data processing; visits officer
T. K. M. Simpson
- hydrological data processing and analysis

APPLICATIONS RESEARCH

M. A. Beran, BSc
Divisional Head

S. Austin
Secretary

Consulting Services
F. A. K. Farquharson, MSc
- overseas contracts, flood estimation
R. B. Bradford, MSc
- groundwater resources management
J. R. Meigh, PhD
- water resources and flood estimation
Y. P. Parks, MSc
- reservoir operation and water resources
M. C. Acreman, PhD
- flood estimation (seconded to NERC HQ)
K. J. Sene, PhD
- hydrological modelling and evaporation estimation
M. P. McCartney, MSc
- water resources and flood estimation
V. J. Bronsdon
- hydrological assistant; cartographer

Hydrology Software

Development
C. S. Green, PhD
- engineering hydrology and software development
K. B. Black
- computer programming

Quality Assurance
R. F. Templeman, PhD
- data processing/software testing and sales
J. R. Parker
- P.C. operations/software

Instrumentation
T. J. Dean, PhD
- instrument development
M. Turner
- instrument development
D. D. McNeil, BSc
- instrument development
M. R. Stroud
- instrument technician
M. E. Walker
- instrument technician
R. G. Wyatt
- instrument technician

Workshop
A. C. Warwick
- instrument craftsman (workshop manager)
G. H. Walley
- instrument craftsman
J. P. White
- instrument craftsman

POLICY STUDIES AND INFORMATION

A.G.P. Debney, BSc
Divisional Head

S. Austin
Personal Secretary

Policy Studies
B. S. Piper, MSc
- reservoir operation, irrigation studies

Information Services
C. Kirby, BSc
- head of information and publication
J.S. Gregory, BA
- assistant information officer
P.J.E. Silverside, BSc
- production editor
J.H. Griffin, MPhil
- production editor
J.M. Hyslop, BSc
- desktop publishing

Library
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