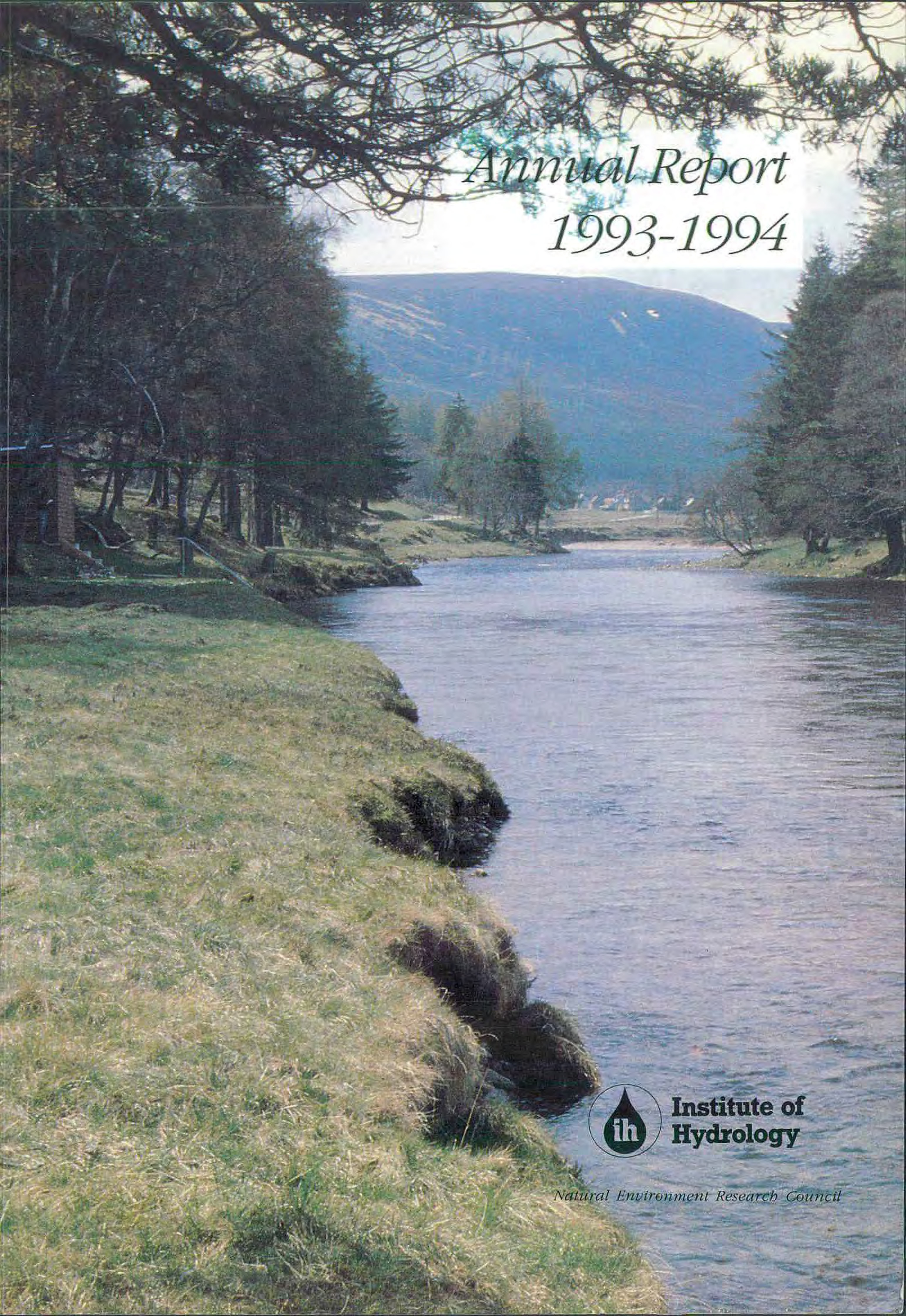

Annual Report 1993-1994

Institute of Hydrology

Natural Environment Research Council

Foreword

The past year has been one of considerable change in NERC, both in the focus of its science and in its structures. The catalyst for these changes was the publication of the White Paper *Realizing our Potential*. NERC was given a new mission for its science to embrace the concepts of meeting the needs of its user communities and contributing to wealth creation and the quality of life. We have, of course, always paid close attention to these objectives, but there is now a clear need for a sharper focus and better articulation of what we do in these areas. Basic science and long-term monitoring are also included in our mission, and due weight must also be given to these when developing our science strategies.

The science directorates will cease to exist towards the end of 1994, and new structures will be put in place. TFSD Institutes are being regrouped as the Centre for Ecology and Hydrology. However, decisions arising from the Multi-Departmental Scrutiny of Public Sector Research Establishments may result in further organisational changes within NERC.

An important activity during the year has been the preparation of a new science and technology strategy for the terrestrial and freshwater sciences. Publication was in July, and a number of research areas were identified for priority support.

This is my second and final foreword. During my relatively short time with NERC, I have come to appreciate and value the breadth and strength of our work in the terrestrial, freshwater and hydrological sciences. This Report illustrates IH's extensive programme which encompasses most fields of hydrology. Highlights for me include the progress on a number of international programmes (such as ABRACOS, IGBP and GEWEX) which form an important element of NERC's global environmental research programme. IH is also in a lead position in NERC's new LOIS (Land-Ocean Interaction Study) Community Research Programme. Other exciting developments have been in areas of real-time hydrological forecasting and information systems.

Finally, I should like to state how much I have appreciated the friendships that I have established with so many members of our community. It is these that will be my most valued and lasting memories of NERC.

C Arme
Director of Terrestrial and Freshwater Sciences

Front cover illustration:
Mar Lodge gauging station on the River Dee, Scotland
Photograph: Mike Lowing

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Report of the Institute of Hydrology 1993/1994

Natural Environment Research Council

Contents

Director's Introduction

Professor Brian Wilkinson

I am pleased to report that 1993-94 has been another year of growth in income and staff numbers. Our vibrant science continues to be supported through core Science Budget, Community Research Programmes (such as Terrestrial Initiative in Global Environmental Research (TIGER) and Land Ocean Interaction Study (LOIS)), Special Topic and users' commissioned research funding.

Two major events of the year have been:

- the publication of the Government's White Paper *Realising our Potential - a Strategy for Science, Engineering and Technology*; and
- the Office of Public Service and Sciences: *Efficiency Scrutiny of Public Sector Research Establishments.*

The evidence presented to the Efficiency Scrutiny involved a major input from all senior Institute staff and took a great deal of time and effort: we await the Government's response.

With respect to the White Paper, it was encouraging that NERC was confirmed as the lead organisation for research, survey and training in environmental sciences. I support the policy that scientific and technological research must contribute more effectively than in the past to national prosperity and the quality of life. Our science is applicable to a range of community issues and results of our research are widely applied by UK industry and commerce.

During the course of 1993/94 the Institute of Hydrology worked with some 50 UK companies, either undertaking research projects or in joint ventures. For example, over the last few years, the Institute, in collaboration with ICL, has developed a computer based environmental management information system for use in IH research projects or by other water organisations. This major computer package has now been purchased by National Power plc to assess possible impacts of their abstractions or discharges from or to freshwaters. Another example of joint research is the River Flow Forecasting System (RFSS) developed by IH in association with Logica Industry Limited for the National Rivers Authority. This is a generic technology for producing forecasts of level and flow in real-time, from telemetered data, at many points across large complex river networks. The system is now being used by organisations in the UK and overseas. It employs mathematical models of hydrological and hydrodynamic processes operating within catchments and updating techniques to improve forecasts so that timely flood warnings or other flow predictions can be given. Flooding is a world wide problem and disrupts more people's lives than any other natural disaster, except drought. The potential market for the provision of flood warning schemes is therefore very large and the Institute, using the above technology and working with UK consultants, has a major role to play in this area.

The Institute of Hydrology's reports, scientific papers and software are widely used by industry and commerce. It is difficult to quantify the benefits resulting from such use but it is worth noting that the Flood Studies Report produced by the Institute in 1975 has been used for 20 years by consultants, highway authorities, local authorities and indeed any organisation with a need to design a road culvert, river bridge, reservoir dam or any other hydraulic structure against flood risk. Although the information, published originally in five fat volumes, is now available for sale from the Institute as a computer software package (Micro-FSR), the 1975 Report and its subsequent Supplementary Reports are still in constant demand worldwide and have been reprinted. However, additional data and improved analytical methods are now available and the Institute has been commissioned by the Ministry of Agriculture, Fisheries and Food and the National Rivers Authority to produce a completely new generation of flood and rainfall frequency information and to present this in a new Flood Estimation Handbook. This research project commenced on 1 April 1994 and will take four years to complete. I anticipate that in due course the value of the Flood Estimation Handbook to the water industry will be as effective and long-lasting as its 1975 predecessor.

There are many other examples of the Institute's outside links with business in the body of the Report. However, the Institute must keep abreast of the needs of industry and commerce. One means will be through the Government's Technology Foresight Programme. IH has contributed to this and will respond to the output once this is available.

The Institute's involvement in international science has been sustained during the year. Global climate change predictions are made using General Circulation Models (GCMs). Results from these mathematical models are needed to develop future climate scenarios, i.e. for a selected area is it going to be wetter or drier, warmer or colder, etc. in 20, 40, 60 years? Due to the inadequacies within the models and data, such scenarios are at present somewhat imprecise and improvements are therefore needed in GCM modelling procedure and model parameterisation. Working within the overall objectives of the International Geosphere and Biosphere Programme (IGBP) and the World Climate Programme (WCP), the Institute is contributing to improvements on both fronts. Representation in the GCMs of the energy and water fluxes in the semi-arid regions of the world will be greatly aided by the WCP - Hydrosphere Atmosphere Potential Evaporation EXperiment (HAPEX)-Sahel study which took place in Niger during 1992. The Institute contributed fully to the management and science of this major international programme which has led to the most comprehensive set of meteorological and hydrological data ever collected for the Sahel. This research is described more fully in the body of the report. Research with similar objectives but in a totally different climatic setting has proceeded in the Amazonian rainforest in Brazil as part of the Anglo-Brazilian Amazonian Climate Observation Study (ABRACOS). This project is now in its final year and a major conference to review all of the findings from this four-year ABRACOS programme took place in September 1994.

Both of the above projects contribute in a major way to improved parameterisation of the GCMs. However, it has also been recognised for some time that there is the need to improve the *vertical* and *horizontal* representation of hydrological fluxes at the land surface within the GCMs. Thus the GEWEX Continental scale International Project (GCIP) has as one of its principal aims the coupling of physically-based hydrological flow models into the atmospheric models. The test site chosen is the basin of the Mississippi. IH, through the NERC TIGER programme, is developing macroscale hydrological models as a contribution to this international programme. This is a newly emerging area of science and there are many scientific and technical problems to be overcome before full integration of these models is possible. I was therefore honoured to be asked by the International Association of Hydrological Sciences to coordinate and edit the Proceedings of the International Symposium on Macroscale Modelling of the Hydrosphere held in Yokohama in July 1993.

On the European front, the Institute has been successful in obtaining funding for a number of important research projects within the European Union 3rd Framework Programme. Partnerships with other European research organisations working within the hydrology and water resources field are essential if European research issues are to be properly addressed. The Institute has a long and successful history of working in this way. Our FRIEND (Flow Regimes International Experimental and Network Data) network in Northern Europe has been in place since 1984. I was therefore particularly pleased to be involved with a FRIEND collaborator (the French research organisation - CEMAGREF) in establishing a European Network of Freshwater Research Organisations (EurAqua). Although only established in 1993 EurAqua now represents ten member states of the European Union and is becoming an influential body in relation to freshwater research throughout Europe.

The Institute's structure of four Science Divisions and an Administration Group has been in place since 1988. This worked well in general, but the growth in staff numbers in recent years and the shifts in science priorities had begun to cause problems. Following discussions with senior staff, the Institute has now been structured into five Science Divisions; the Administration Group remains essentially unchanged. The opportunity was also taken to review the scientific priorities of Sections within the Divisions and to change these where necessary. The new structure is shown in Appendix 2. IH science for 1993/94 is presented within this report in five chapters, each describing highlights of the research that now lies within the new Science Divisions.

In April 1994 Professor John Krebs, Chief Executive of NERC, grouped the Institute of Freshwater Ecology, the Institute of Hydrology, the Institute of Terrestrial Ecology and the Institute of Virology and Environmental Microbiology into a new Centre for Ecology and Hydrology. The Centre will promote interdisciplinary science between the Institutes and reinforce the links with the university community, Government departments, industry and commerce. I have been appointed as the Acting Director of the Centre for Ecology and Hydrology. For the present my Deputy Director, Mr Tony Debney, will be the Director (Acting) of the Institute. The Institute will be in safe hands.

Brian Wilkinson
Director

Présentation du Directeur

Je suis heureux de vous annoncer que l'année 1993-94 a été une nouvelle année de croissance à la fois pour notre chiffre d'affaires et pour nos effectifs. Notre domaine scientifique si passionnant est toujours financé grâce au Budget Scientifique de base, à des Programmes de Recherches Communautaires (tels que la Recherche sur l'Environnement Global d'Initiative Terrestre [Terestrial Initiative Global Environment Research (TIGER)] ou l'Etude de l'Interaction entre la Terre et les Océans [Land Ocean Interaction Study (LOIS)]), à des fonds prévus pour les Sujets Spéciaux, et aussi grâce à des commandes de recherche appliquée.

Les deux principaux événements de l'année ont été :

- La publication du Livre Blanc du gouvernement intitulé *«Se Rendre Compte de notre Potentiel - une Stratégie pour la Science, l'Ingénierie et la Technologie»*, et
- L'Office du Service Public et des Sciences: Analyse de l'Efficacité des Etablissements de Recherche du Secteur Public.

Les preuves fournies à l'Analyse d'Efficacité ont inclus des données fournies par tout le personnel d'encadrement des Instituts, ce qui a pris beaucoup de temps - nous attendons encore la réponse du Gouvernement.

Pour ce qui concerne le Livre Blanc, il a été encourageant d'apprendre la confirmation du rôle du NERC en tant qu'organisation directrice de la recherche, de l'étude et de la formation dans le domaine des sciences de l'environnement. Je soutiens la politique qui veut que la recherche scientifique et technologique contribue, d'une manière plus efficace que par le passé, à la prospérité nationale et à la qualité de la vie. Notre science s'applique à tout un éventail de questions communautaires, et les résultats de nos recherches sont appliqués très largement par l'industrie et le commerce au Royaume Uni.

Durant l'année 1993/94, l'Institut d'Hydrologie a travaillé avec quelques 50 sociétés britanniques, soit en réalisant des projets de recherche, soit sous forme d'entreprises en participation. Au cours des dernières années, par exemple, l'Institut a développé un système de données de gestion de l'environnement, en collaboration avec ICL, utilisé dans les projets de recherche de l'IH ou par d'autres organismes concernés par l'eau. Ce progiciel majeur vient d'être acheté par la société National Power plc pour évaluer les impacts possibles de leurs prélèvements et refoulements d'eau douce. Autre exemple de recherche conjointe : le Système de Précision des Débits des Cours d'Eau [River Flow Forecasting System (RFFS), développé par l'IH en association avec Logica Industry Limited pour le compte de la National Rivers Authority. Il s'agit d'une technologie générique destinée à établir des prévisions de niveau et de débit en temps réel, à partir de données de télémétrie obtenues à de nombreux points de référence éparpillés sur des réseaux fluviaux complexes et très étendus. Ce système est actuellement utilisé par plusieurs entreprises au Royaume Uni et d'outre-mer. Il utilise des modèles mathématiques de processus hydrologiques et hydrodynamiques actifs dans des bassins hydrographiques, et des techniques de mise à jour permettant d'améliorer les prévisions de manière à ce que des préavis d'inondations ou d'autres prévisions de débit puissent être émis suffisamment en avance. Les inondations constituent un problème affectant le monde entier et responsable de plus de désagréments dans la vie des personnes que tout autre désastre naturel, sauf la sécheresse. Le marché potentiel pour la mise en place de dispositifs de préavis d'inondation est donc très important, et l'Institut a un rôle primordial à jouer dans ce domaine, en collaboration avec des experts du Royaume Uni et en exploitant les technologies décrites ci-dessus.

Les comptes-rendus, bulletins scientifiques et logiciels de l'Institut sont très utilisés par l'industrie et le commerce. Il est très difficile de chiffrer les effets bénéfiques de cette utilisation, mais il est à noter que le Compte-Rendu des Etudes sur les Inondations [Flood Studies Report] rédigé par l'Institut en 1975 constitue un outil de référence depuis 20 ans, auprès des experts-conseils, des ponts et chaussées, des autorités locales, et de tout organisme qui a besoin de dessiner un ponceau pour une route, un pont sur une rivière, un barrage ou toute autre structure hydraulique devant résister aux risques d'inondation. Malgré leur disponibilité actuelle sous forme de progiciel informatique (Micro-FSR), les données d'origine du Compte Rendu de 1975, publiées à l'époque en cinq gros volumes, et de ses éditions supplémentaires, sont toujours très demandées dans le monde entier, et ont fait l'objet d'une réimpression. Cependant, de nouvelles données et des méthodes analytiques améliorées sont maintenant disponibles, et l'Institut a été chargé par le Ministère de l'Agriculture, de la Pêche et de l'Alimentation et par la National Rivers Authority, de fournir une nouvelle génération, entièrement renouvelée, de données concernant les crues et les précipitations, et de présenter ces données sous forme d'un nouveau Manuel de Prévision des Crues. Ce projet de recherche a démarré le 1er Avril 1994, et il faudra environ quatre ans pour en terminer la réalisation. Je prévois que le nouveau Manuel de Prévision des Crues sera, à terme, aussi efficace et durable que son prédécesseur de 1975.

Il y a de nombreux autres exemples des liaisons industrielles et commerciales de l'Institut dans la partie principale du compte-rendu. Cependant, l'Institut doit toujours être en mesure de répondre aux besoins de l'industrie et du commerce. Un des moyens à notre disposition sera le Programme de Prévoyance Technologique du Gouvernement. L'IH a contribué à ce programme, et réagira aux résultats lorsqu'ils seront disponibles.

La participation scientifique de l'Institut au niveau international a été maintenue durant cette année. Les prévisions de changements dans le climat mondial sont réalisées grâce aux Modèles de Circulation Générale [General Circulation Models (GCM)]. Les résultats tirés de ces modèles mathématiques sont nécessaires pour le développement des scénarios climatiques futurs, c'est à dire pour répondre à la question de si, dans une zone donnée, le climat sera plus sec ou plus humide, plus chaud ou plus froid, etc ..., et ce dans 20, 40 ou 60 ans. Du fait de l'inadaptation de certains aspects des modèles et des données, les scénarios sont actuellement quelque peu imprécis, ce qui veut dire que l'on va devoir améliorer le processus de modélisation GCM et de paramétrage des modèles. En travaillant dans le cadre des objectifs généraux du Programme International Géosphère et Biosphère [International Geosphere and Biosphere Programme (IGBP)] et du Programme du Climat Mondial [World Climate Programme (WCP)], l'Institut contribue aux améliorations sur les deux fronts. Dans les GCM, la représentation des flux d'énergie et d'eau dans les régions semi-arides du monde sera largement améliorée par l'étude appelée Expérience Hydrologique et Atmosphèrique Pilote [Hydrological and Atmospheric Pilot EXperiment (HAPEX)-Sahel], réalisée au Niger en 1992. L'Institut a pleinement participé à la gestion et au contenu scientifique de ce programme international majeur, qui a contribué à la réalisation de l'ensemble de données météorologiques et hydrologiques le plus complet jamais recueilli pour le Sahel. Une description plus détaillée de cette recherche est donnée dans le corps du compte-rendu. Des recherches visant des objectifs semblables, mais dans un cadre climatique totalement différent, ont été conduites dans la forêt tropicale humide amazonienne, au Brésil, dans le cadre de l'Etude d'Observation Anglo-Brésilienne du Climat Amazonien [Anglo-Brazilian Climate Observation Study (ABRACOS)]. Ce projet vit actuellement sa dernière année de réalisation, et une grande conférence de revue de l'ensemble des découvertes de ce programme ABRACOS sur quatre années a eu lieu en septembre 1994.

Les deux projets évoqués ci-dessus apportent une contribution majeure à un meilleur paramétrage des GCM. On sait cependant, depuis un certain temps, qu'il est nécessaire d'améliorer la représentation *verticale* et *horizontale* des flux hydrologiques à la surface de la terre, dans les GCM. C'est ainsi que le projet international GEWEX à l'échelle continentale [GEWEX Continental scale International Project (GCIP)] a, comme l'un de ses principaux objectifs, l'intention de coupler les modèles physiques de flux hydrologiques aux modèles atmosphériques. Le site de test choisi est le bassin du Missisipi. A travers le programme TIGER du NERC, l'IH développe actuellement des modèles hydrologiques à macro-échelle en tant que contribution à ce programme international. Il s'agit d'un domaine entièrement nouveau de la science, et il y a de nombreux problèmes scientifiques et techniques à résoudre avant de pouvoir assurer l'intégration complète de ces modèles. J'ai donc eu le grand honneur d'être choisi par l'Association Internationale des Sciences Hydrologiques pour assurer la coordination et la rédaction des Minutes du Symposium International sur la Modélisation à l'Echelle Macro, qui s'est tenu à Yokohama en Juillet 1993.

Sur le front européen, l'Institut a réussi à obtenir un financement pour plusieurs grands projets de recherche au sein du Programme 3ème Cadre de l'Union Européenne. Des partenariats avec d'autres organismes européens de recherche dans le domaine de l'hydrologie et des ressources en eau sont essentiels si nous voulons aborder correctement les questions de recherche. L'Institut a une longue expérience, couronnée de succès, de ce type d'approche. Notre réseau FRIEND (Données d'Expériences Internationales sur les Régimes d'Ecoulement et les Réseaux [Flow Regimes International and Network Data) en Europe du Nord est opérationnel depuis 1984. Par conséquent, il m'a été très agréable de travailler avec un collaborateur FRIEND (l'organisation française de recherche - CEMAGREF) pour la mise en place d'un Réseau Européen d'Organismes de Recherche sur l'Eau Douce (EurAqua). Bien qu'il ne fut inauguré qu'en 1993, EurAqua représente actuellement dix états membres de l'Union Européenne, et commence à avoir de l'influence dans le domaine de la recherche au sujet de l'eau douce à travers l'Europe.

La structure de l'Institut, qui est constituée de quatre Divisions Scientifiques et d'un Groupe d'Administration, existe depuis 1988. Cette structure a bien fonctionné, dans l'ensemble, mais l'augmentation des effectifs au cours des dernières années, ainsi que le déplacement des priorités de la science, avait commencé à poser des problèmes. Suite à des discussions avec le personnel d'encadrement, l'institut a maintenant été structuré sur la base de cinq Divisions Scientifiques; le Groupe Administratif est resté inchangé, pour l'essentiel. On a aussi profité de cette occasion pour revoir les priorités scientifiques des Sections à l'intérieur des Divisions, en les modifiant le cas échéant. La nouvelle structure est représentée dans l'Annexe 2. La science au sein de l'IH en 1993/94 est présentée en cinq chapitres, chaque chapitre constituant une description des grandes lignes de la recherche qui se fait désormais dans chacune des nouvelles Divisions Scientifiques.

En Avril 1994, le Professeur John Krebs, président directeur général du NERC, a regroupé quatre instituts, «Institute of Freshwater Ecology» (écologie de l'eau douce), «Institute of Hydrology» (hydrologie) «Institute of Terrestrial Ecology» (écologie terrestre) et «Institute of Virology and Environmental Microbiology» (virologie et microbiologie liée à l'environnement), dans le nouveau «Centre for Ecology and Hydrology» (centre dédié à l'écologie et à l'hydrologie). Le Centre aura pour tâche de promouvoir la science interdisciplinaire entre les Instituts et de renforcer les liens avec la communauté universitaire, les ministères du Gouvernement, l'industrie et le commerce. J'ai été nommé Directeur Provisoire du Centre for Ecology and Hydrology. Pour le moment, mon Directeur Adjoint Monsieur Tony Debney agira en tant que Directeur (Provisoire) de l'Institut. L'Institut sera donc en de bonnes mains.

Brian Wilkinson
Directeur

Hydrological Processes

"For the wonderful and secret operations of Nature are so involved and intricate, so far out of the reach of our senses, as they present themselves to us in their natural order, that it is impossible for the most sagacious and penetrating genius to pry into them, unless he will be at the pains of analysing nature, by a numerous and regular series of experiments; which are the only solid foundation whence we may reasonably expect to make any advance, in the real knowledge of the nature of things." *S. Hales (1727).*

At the beginning of the eighteenth century Stephen Hales conducted some of the first experiments to unravel the mysteries behind the biological processes controlling water use by plants. His basic approach, of building knowledge by careful experimental observation, has been and continues to be the primary *modus operandi* of many environmental scientists.

Unfortunately we now live in a world where environmental changes are happening on scales and at rates unimaginable in Hales's time. Widespread land-use changes, degradation of forests and drylands are all potential threats to our future wellbeing. We now realise how carefully we must conserve and manage our water resources in the face of increasing present-day demands and for future world populations. The need for the 'regular series of experiments' required for sustainable solutions to these problems has never been more acute and the research programme of this Division gives priority to those environmental issues which have a widespread effect on the quality of human life, both from a national and an international perspective. Where possible, the associated economic implications of environmental changes are also evaluated, to provide well-founded guidance to environmental managers and policy makers. The Division responds to the needs of customers by taking on a substantial amount of high quality research work, which is commissioned by UK and overseas clients. The entire research programme maintains strong links with key universities and research institutes throughout the world, and by the effective dissemination of the results through scientific publication. Our specific mission is to:

- develop the field experimental techniques necessary to follow and measure the physical and biological processes which take place in the natural environment;

- improve our quantitative understanding of these physical and biological processes in the terrestrial hydrological cycle, from local to global scales, including the impacts of human activities which may alter it.

Global processes

Climate change predictions are made with Global Circulation Models (GCMs): numerical, computer models which cover the world's atmosphere in a three-dimensional grid. Current models have grid cells several hundred kilometres across and it is unlikely that in the near future this will be reduced to less than 100 kilometres. Within each cell, the whole hydrological cycle is represented by a single set of equations. There are few areas of the world where uniform vegetation exists at that scale and it is necessary to derive methods of describing the combined effect of the component vegetation and soil types, to produce the energy and water budgets of regions, i.e. to aggregate sub-scale variability to produce grid-scale values, also referred to as 'upscaling'.

Considerable international effort is being directed at measuring and modelling the GCM grid-scale hydrological balance, largely concentrated in a series of mesoscale (typically 10 km grid square) field experiments. The Global Processes Section has been actively involved in this series of experiments, both in the collection of field data and in upscale modelling of the component surface fluxes. For example, HAPEX-Sahel, which took place in Niger during 1992, produced a comprehensive dataset of the hydrology and meteorology of a 100 km square in the Sahel during a two-month intensive observation programme.

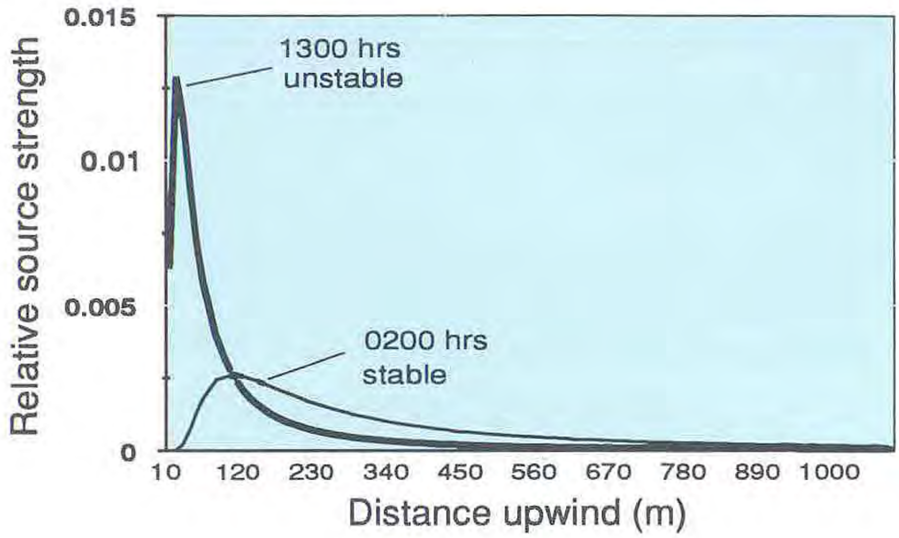


Figure 2 *Relative contribution from upwind sources of evaporation for measurements made at the IH tiger bush site in Niger, West Africa, with a wind direction of 180°, and two different atmospheric stabilities. The thick line represents contribution from bushes and the thin line from bare soil.*

Contribution relative des sources d'évaporation en amont du vent, pour les mesures réalisées sur le site de végétation tigrée («tiger bush») de l'IH au Niger, Afrique Occidentale, avec une orientation du vent de 180° et deux stabilités atmosphériques différentes. La ligne épaisse représente la contribution des bandes de végétation, et la ligne fine celle de la terre nue.

The analysis of these data has been the catalyst to producing new ideas in aggregating evaporation fluxes at a number of spatial scales.

At the plot scale (typically 100 m grid) there was a need to interpret evaporation measurements from natural Sahelian vegetation, which is inherently variable. A particular problem was the tiger bush (Figure 1), which consists of strips of dense bush vegetation interspersed with areas of bare soil at the scales of tens of metres. Micrometeorological measurements, made in the turbulent boundary layer just above the surface, sample a "footprint", the area of which varies according to atmospheric stability. With a thermally unstable atmosphere, convection leads to better mixing and a shorter footprint, concentrated closer to the measurement site; conversely under stable conditions the footprint stretches further from the instrument. A model, based on diffusion theory, has been derived which allows these effects to be quantified (Figure 2). When it was applied to the tiger bush site it was possible to demonstrate how the measured flux should vary with wind direction as it responds to the relative sizes of the bush and bare soil components in the footprint.

The data from the tiger bush also provided the incentive for the development of a new two component modelling strategy. There is a great difference in behaviour between the two elements of tiger bush. The bare soil has a high surface temperature and low evaporation, while the bushes have a low surface temperature and high evaporation. In fact the evaporation from the bushes was found to be greater than the net radiation which they were receiving — extra energy was being provided by lateral

Figure 1 *The Institute of Hydrology micrometeorological tower over tiger bush in Niger, West Africa, during the HAPEX-Sahel experiment.*

Tour micro-météorologique de l'Institute of Hydrology sur la végétation tigrée du Niger, Afrique Occidentale, pendant l'expérience HAPEX-Sahel.

advection from the bare soil patches. This situation could not be modelled with either a single one-dimensional model, or with the patch (or tile) model shown in Figure 3(a), in which two energy balances are drawn up in parallel. Better results were obtained with the coupled model shown in Figure 3(b), which allows the two surface types to interact. In theory, the amount of interaction — and hence evaporation — decreases as the scale of the heterogeneity increases. The coupled model can be expanded to give a general formulation which can deal with heterogeneity at all scales. This is achieved by using the blending height for the junction of the three resistances, *A* (see Figure 3c). The blending height depends on the length scale of the heterogeneity and is where the atmosphere is still in equilibrium with the surface but above which the surface appears as uniform.

The tile model approach can also be applied to the problem of representing the sub-GCM grid-scale variability in rainfall produced by local convective storms. Recent GCM land surface schemes have introduced canopy water balance equations which include this variability, but do not distinguish between wet and dry areas when solving the energy balance equations. It has now been shown that this leads to overestimation of the evaporation of intercepted rainfall by tropical forest of typically 30 per cent. Using a more realistic tile model in the one-dimensional version of the UK Met Office GCM, it was found that treating wet and dry areas as separate areas leads to better predictions. In terms of the model shown in Figure 3(c) this situation is treated by setting r^3_a and the surface resistance for the wet surface — say r^1_s — both equal to zero.

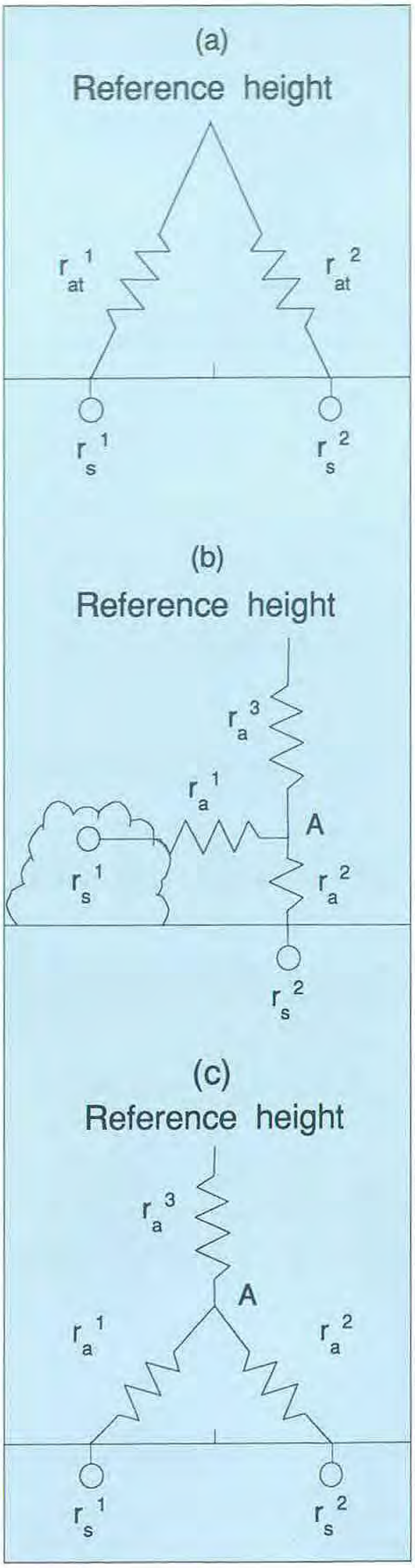


Figure 3 *Schematic diagram of resistances in different models: (a) patch or tile, (b) coupled and (c) the new general model*

Schéma des résistances au niveau de modèles différents : (a) pièce ou tuile, (b) couplé et (c) le modèle général nouveau

Improved predictions of climate change

The joint UK-Brazil investigation of the links between tropical deforestation and climate (ABRACOS) is nearing completion and 1993-94 saw one of the longest and most successful field campaigns ever carried out. Unexpected seasonal and spatial variability in the forest behaviour was observed, already incorporated into the UK Hadley CCM which now predicts significant reductions in evaporation and rainfall as a result of complete deforestation of the Amazon.

Forest transpiration model works worldwide

The water use of forests throughout the world is of major importance in water resource assessment, timber production, rehabilitation of degraded lands and climate change studies. A general model of transpiration from forests of varying degrees of complexity, from tropical to temperate has been developed, based on the fundamental physiological characteristics of the trees and has been shown to work well in a wide range of forest types, including Amazonian rainforest in Brazil, eucalyptus plantations in India and 'set aside' broadleaf plantations in the UK.

Bio-fuel plantation trials in the UK

As pressure mounts to find more environmentally acceptable sources of energy production than fossil fuels the Energy Technology Support Unit (ETSU) of the UK Department of the Environment has initiated trials to look at the feasibility of using fast growing tree species for energy production. Fast growth can only be sustained by an adequate water supply so IH has been contracted to measure the water requirements of promising 'bio-fuel' tree species such as poplar. State-of-the-art instrument technology is being applied to obtain the data needed to design sustainable bio-fuel production systems.

Vegetation and soil processes

In common with much of the world's vegetation, the majority of stands of forest or shrubs contain mixed species and are heterogeneous in both vertical and horizontal dimensions. The growth and water use of these plant communities are controlled by soil processes, which also dominate the net flux of water as evaporation, or into rivers and aquifers as runoff and drainage. It is therefore necessary to quantify the effect of vegetation and soil processes on the hydrological cycle, especially where it is dominated by trees and shrubs. Previous studies of forests have tended to concentrate on uniform monocultures, but our current emphasis is on situations where species exist naturally or are planted as mixtures. Predicting the growth and water use of such complex systems requires detailed information about the light interception and transpiration of the principal components of the heterogeneous stands.

A number of plant physiological techniques can now be used to measure transpiration from canopy layers within a stand or from individual trees or shrubs. These measurements, taken over relatively limited periods, are used to develop transpiration models, which can then be combined with long-term weather data for estimating vegetation water use over substantial periods. Estimates from physiological methods give a unique insight into within-stand competition processes and transpiration losses. In circumstances where conventional soil moisture or micrometeorological methods are inappropriate (for example because of shallow water tables or limited fetch conditions) they also offer an alternative way to measure total stand transpiration.

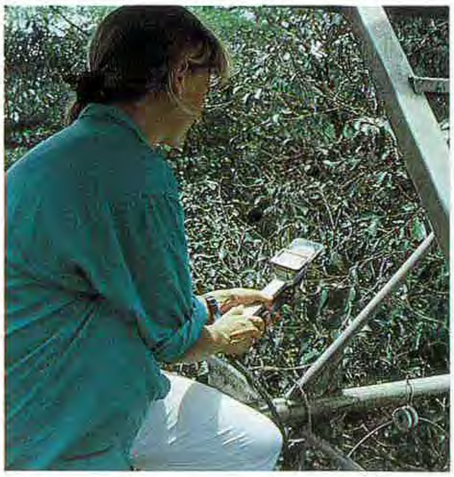


Figure 4 *Leaf gas exchange is monitored through the forest canopy with an infra-red gas analyser*

L'échange des gaz au niveau des feuilles est surveillé à travers la couverture végétale que constitue la forêt, à l'aide d'un analyseur de gaz aux infrarouges.

Two main approaches have been used in a number of studies in different geographical regions. Measurements of leaf gas exchange (water vapour and CO_2) have been made with both infrared gas analysers and diffusion porometers and the stomatal conductance values obtained are used in two ways. Firstly, they give insight into the functional relationships between stomatal conductance and controlling variables such as solar radiation, atmospheric humidity deficit and soil water content. Secondly, stomatal conductance data are used to develop sub-models to calculate whole canopy transpiration models. One such model developed at IH is called 'CLATTER' and has been successfully tested against independent measures of transpiration in Eucalyptus plantations in South India, broad leaf woodlands in the UK and tropical rainforest in Brazil. This approach is continuing, using stomatal conductance data from additional sites within Amazonia operated by the ABRACOS project, and also in a recently-established study of the hydrological effects of short-rotation energy coppice in the UK, a project run under a contract from the UK Energy Technology Support Unit (ETSU). Leaf area index and its vertical distribution is an important input to transpiration models and efforts are being made, both in the rain forest and energy coppice studies to improve direct and indirect ways of measuring leaf area.

Another method for measuring transpiration directly from individual trees or shrubs is the stem heat balance method. This approach has already been used successfully to separate transpiration of the dominant shrub, *Guiera senegalensis*, from the total evaporation from the semi-arid savannah in the West African Sahel. The stem heat balance method has been used on two poplar clones in the ETSU study where measurements were taken continuously during three intensive observation periods throughout the summer of 1993. Preliminary results indicate that transpiration can be very high from the poplar coppice, up to

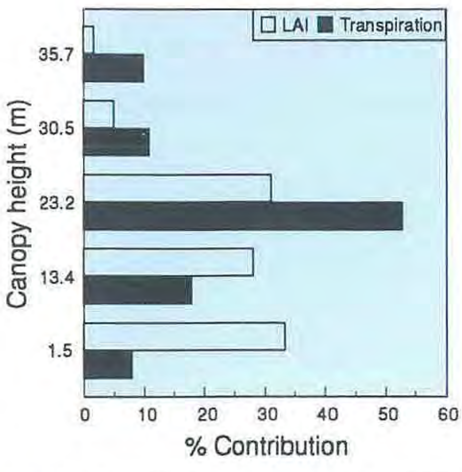


Figure 5 *Vertical distribution of leaf area index (LAI) in tropical rain forest, Manaus, Amazonia, Brazil, and contribution to forest transpiration*

Distribution verticale de l'indice de surface des feuilles [leaf area index (LAI)] dans une forêt tropicale humide, à Manaus, Amazonie, Brésil, et sa contribution à la transpiration de la forêt.

8 mm day^{-1}, which is greater than the 'upper limit' predicted by the potential evaporation rate. These results are supported by independent stomatal conductance measurements.

An important land use in a number of regions is agroforestry, a system in which trees or shrubs are grown in association with crops or pasture in a spatial or rotational arrangement. There are both ecological and economic interactions between the trees and other components of the system. Success or failure of the many permutations of tree

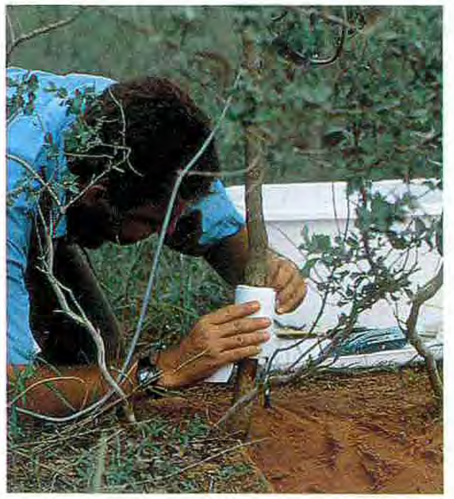


Figure 6 *Transpiration of individual shrubs in the Sahel is measured with a sap flow gauge*

La transpiration des arbustes individuels dans le Sahel se mesure à l'aide d'un mesureur d'écoulement de la sève.

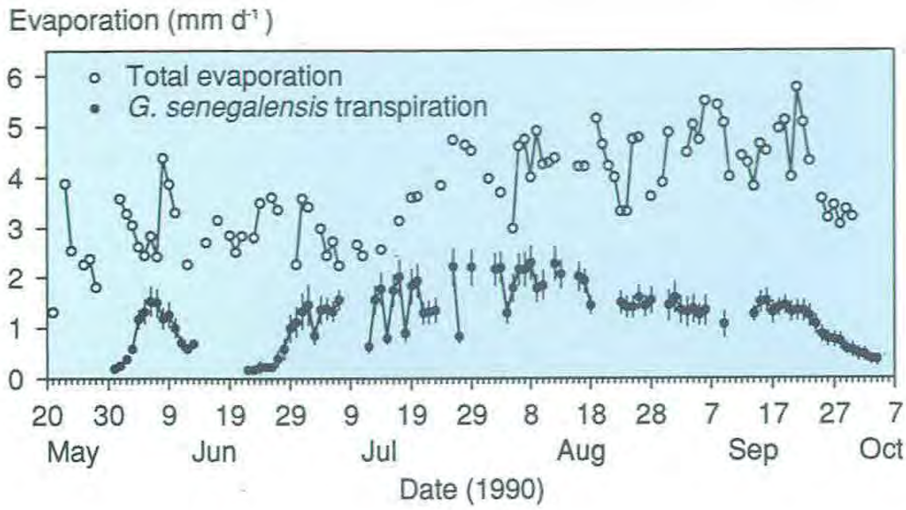


Figure 7 *Total evaporation (measured by the stem heat balance technique) systematically exceeds transpiration from the Guiera bushes*

L'évaporation totale (mesurée par écoulement de la sève) est systématiquement plus élevée que celle des buissons Guiera.

and crop depends mainly on the extent to which the components are complementary in their use of water, light and nutrients. A collaborative project with the International Center for Research in Agroforestry (ICRAF) in Kenya and the University of Nottingham has been established to make detailed studies of the water balance of an agroforestry system and how the rainfall is partitioned by the components of the system. The experimental site is on sloping land at ICRAF's semi-arid field station at Machakos, Kenya. The agroforestry trial is comprised of trees of *Grevillea robusta* with a crop of maize or cowpea.

The practical aspects of the project concentrate on the development and testing of suitable ways of measuring all the key components of the water balance. Total water use by the agroforestry system is measured with a neutron probe; time domain reflectometry and the soil capacitance insertion probe. Soil evaporation is measured using microlysimeters placed beneath the crop, trees or beneath both crop and trees. The fraction of the total transpiration which comes from the trees is estimated by monitoring representative individual trees with stem heat balance devices. Preliminary results indicate that the trees can abstract substantial amounts of water from depth, well below the annual crop root zone.

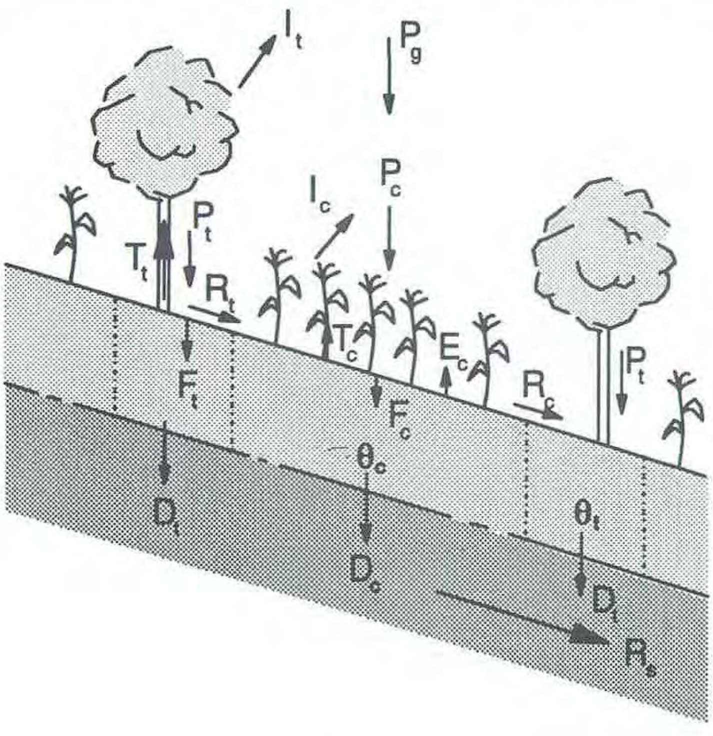


Figure 8 *A schematic representation of an agroforestry system on a hillslope*

Représentation d'un système ... sur une pente d'une colline

Much progress has been made in describing heterogeneity in mixed vegetation and in understanding the above-ground structure and processes such as light interception and stomatal behaviour which determine transpiration of component species. In contrast, the quantity, distribution and functioning of plant root systems, particularly in mixed communities, has been very little studied and understood. In future more focus will be put on below-ground processes, especially in cases where there are mixtures of species. This focus is particularly appropriate in agroforestry where the component species of any system should be compatible both above and below ground.

Below-ground processes have also been largely ignored in both tropical rain forests and replacement vegetation. The traditional view of rainforest root systems is that they are shallow and can adequately supply the vegetation with water from soil frequently wetted by rain. This cannot be the case for rainforest growing in regions where dry periods of up to four months occur, yet throughout which transpiration is maintained. Rainforest regions where these conditions prevail, such as the eastern Amazon, have been heavily deforested for agriculture which has often been found to be largely unsustainable. Research associated with future cropping options for these abandoned agricultural initiatives will include studies of the rooting behaviour of species, particularly in mixtures.

Sustainable agrohydrology

Agriculture is the most widespread and important land use and one in which changes are very common. Food has to be produced to feed increasing populations world wide and at the same time the environment needs to be protected and conserved. In temperate zones intensive, high-input farming can and often does lead to pollution of aquatic ecosystems, whereas in semi-arid areas the problem is generally one of optimising production from limited water and land resources and avoiding dryland degradation.

The objective in focusing on these issues is to develop schemes for the efficient use of water in agriculture and the regional assessment of sparse water resources. Emphasis is on hydrologically marginal areas and the study of dryland degradation processes. It is expected that this work will contribute to the evolution of strategies for the development of sustainable and environmentally acceptable agricultural practices.

Degradation of agricultural land is occurring at an alarming rate in arid and semi-arid areas of the world. Current estimates are that drylands comprise more than one-third of the world's land surface, and that as much as 75% of this area may be affected by degradation. In collaboration with the Lowveld Research Stations (LVRS), a catchment in Zimbabwe has been instrumented to study the feasibility of using an integrated catchment management approach as a means of halting and, possibly in the long-term reversing, land degradation in a typical semi-arid catchment. Hydrological processes are being studied at a range of scales (i.e. plot, field, sub-catchment and catchment) in the Romwe Catchment. In parallel with the hydrological observations, socio-economic surveys are also being carried out in the catchment to assess the underlying causes of degradation and the future cost of its continuation.

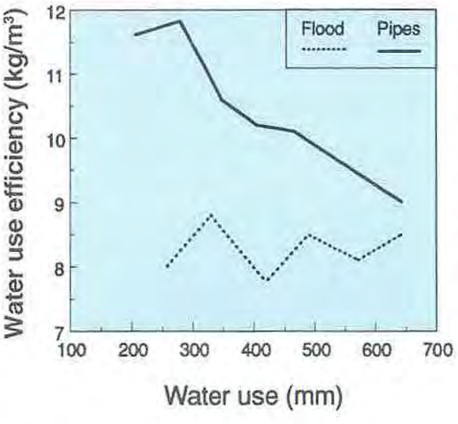


Figure 9 Water use efficiency can be improved by up to 40% by using subsurface pipe irrigation instead of flooding the ground surface.

Le rendement en eau peut être augmenté de 40% si l'on utilise un système d'arrosage par des tuyauteries sous la surface, plutôt que d'inonder la surface du sol.

A collector-well garden was set up in the catchment in 1991: this is used by 46 households as a source of vegetables and income from the sales of their produce. Further improvements in resource management in the catchments are being encouraged by using participatory extension schemes. Since 1991 a further eight collector well gardens have been set up in south-east Zimbabwe. The technical performance of the collector wells is currently being assessed as are the socio-economic and institutional constraints on community gardening.

Irrigation using simple irrigation techniques has shown that water-use effectiveness can be improved by up to 40% with some crops by using subsurface pipe irrigation instead of traditional flood irrigation. It has been demonstrated that subsurface irrigation can be incorporated easily into traditional gardening systems as part of a package of resources to improve water use efficiency and reduce risk of crop failure.

Figure 10 The Lowveld experimental station

Station expérimentale de Lowveld

Figure 11 Socio-economic surveys have shown the positive impact of community gardens on household incomes

Des études socio-économiques ont démontré l'impact positif des jardins communautaires sur les revenus familiaux.

Impacts of global environmental change

We live in a world where environmental changes are happening on scales and at rates previously unknown. There is a need to monitor what is happening now and to estimate impacts of possible future global environmental changes. This global perspective means that monitoring, interpreting and modelling efforts must look beyond the catchment: hence emphasis is given to the use of remote sensing techniques, digital global data sets and Geographic Information Systems (GIS) to measure and model hydrological behaviour over large regions.

There are three main areas of work in this field. The first is monitoring environmental change. Remotely-sensed images are currently being used to assess vegetation changes and dryland degradation in southern Niger. Nine Landsat MSS images acquired during the period 1972 to 1990 are being analysed to identify areas undergoing dryland degradation. Initial results show that large annual variations in vegetated areas can occur. Future work includes identifying the types of vegetation (natural/cultivated) most affected, and the role of rainfall in determining the extent of vegetated areas.

The second area of work is on describing and interpreting past and current hydrological variability, focusing on patterns in variability over a large geographical region. As part of the FRIEND project (see page 23), hydrological anomalies over Europe have been mapped and the pattern is currently being interpreted in terms of variations in atmospheric circulation patterns. For example, Figure 12 shows runoff for two seasons — the winters 1971/2 and 1979/80 — across Europe. Runoff was well below average across most of western Europe in 1971/72 but in 1979/80 most of western Europe had high runoff; the Nordic countries, on the contrary, showed the reverse.

The third area is estimating the future hydrological impacts of global environmental change using large scale models of hydrological processes. This approach has been used to investigate the potential

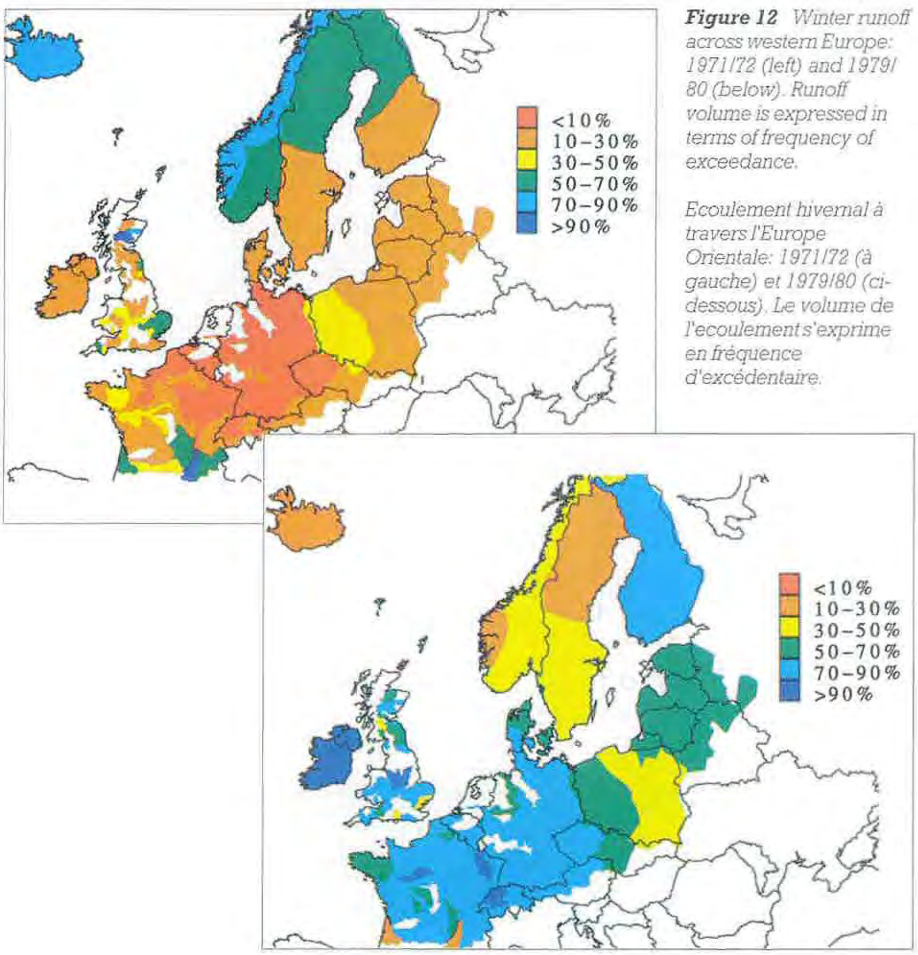


Figure 12 *Winter runoff across western Europe: 1971/72 (left) and 1979/80 (below). Runoff volume is expressed in terms of frequency of exceedance.*

Ecoulement hivernal à travers l'Europe Orientale: 1971/72 (à gauche) et 1979/80 (ci-dessous). Le volume de l'ecoulement s'exprime en fréquence d'excédentaire.

Dryland degradation

- Collaborative research with the Lowveld Research Station in Zimbabwe and the British Geological Survey has demonstrated the potential for using small communal or allotment-type irrigated gardens as a means of alleviating poverty and reducing land degradation in semi-arid areas overlying basement aquifers. Collector-well garden schemes have been set up at village sites in south-east Zimbabwe, now followed by schemes funded by an NGO, Plan International.
- In south-west Niger the SAGRE (Semi-Arid Groundwater Recharge) project is investigating recharge rates under a range of land-use types. Of particular interest is the significant difference in recharge rates between areas of millet cultivation and natural open forest: this has implications in the light of changing land-use patterns.
- Water balance studies of the deep unsaturated zone to obtain recharge rates are being carried out in the La Mancha area of central Spain. This work is part of the second phase of the EFEDA study (ECHIVAL Field Experiment in Desertification-threatened Areas), based within a 1000 km² catchment which has been heavily overpumped to provide groundwater for irrigation.

Global change impacts

- Remotely-sensed data have also been used to produce hydrologically-relevant classifications of land use within many catchments. The resulting spatial data sets have provided parameters for catchment hydrological models with spatially distributed land use.
- A review of the implications of global warming has recently been completed for the National Rivers Authority. The review covered all aspects of the NRA's activities, and outlined a number of ways in which the NRA could prepare for global warming, given the current uncertainties and the time horizon over which impacts might be felt.

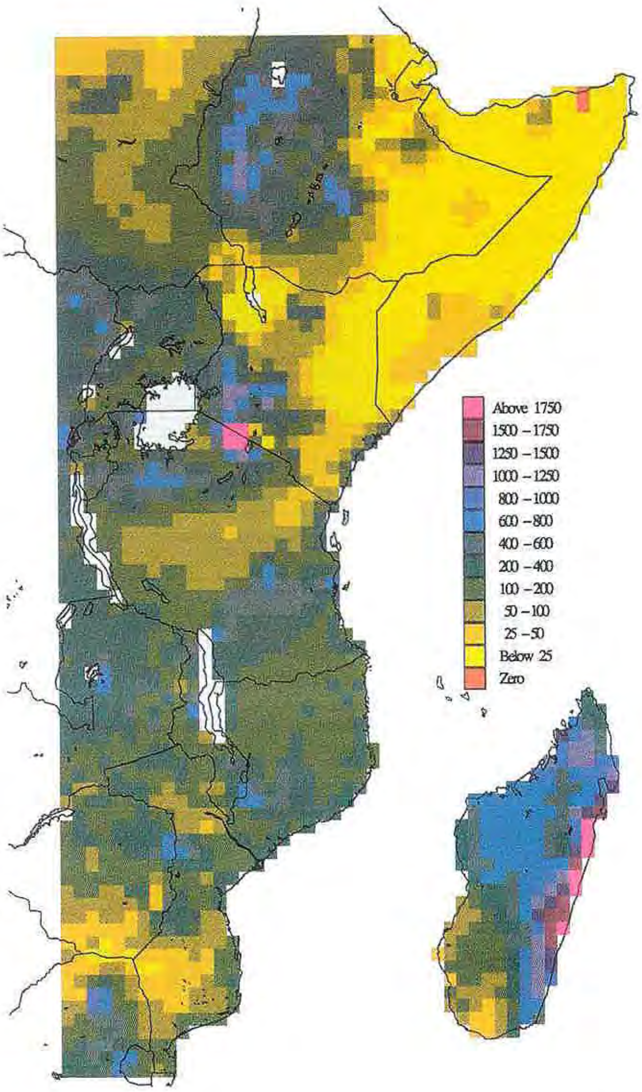


Figure 13 *Average annual runoff across East Africa, simulated using a simple water balance model*

Ecoulement annuel moyene à travers l'Afrique Occidentale, simulé à l'aide d'un modèle simple d'éqilibre d'eau

effects of global warming on hydrological regimes in the UK, the European Community and East Africa. Particular effort has been directed towards creating climate change scenarios at a spatial scale suitable for catchment-scale hydrological studies, and developing water balance models which can be applied across a large geographic domain, such as a continent.

Figure 13 shows average annual runoff estimated across East Africa using a simple water balance model with parameters estimated from gridded soil and vegetation data. This model is being used with climate change scenarios supplied by the Intergovernmental Panel on Climate Change (IPCC) to estimate the sensitivity of water resources in East Africa to global warming. Hydrological models have also been applied to examine the effects of land use change. Such changes are being modelled using Soil-Vegetation-Atmosphere-Transfer schemes (SVATs) so that the results can be extrapolated to predict the effects of future land-use changes.

Environmental impact studies at thsi scale require global-scale data sets and procedures capable of estimating relevant hydrological properties over very large regions. Algorithms are being developed to process data collected over a large region using remote sensing, and other data sets relevant to global change research are also being collated. Remotely-sensed and other spatial data sets are integrated with each other and with hydrological models through the use of GIS.

For example, methods have been developed to estimate sensible heat fluxes from Landsat satellite data: when these are combined with information on incoming solar radiation, it is possible to estimate latent heat fluxes over a large area, and hence regional evaporation. The methods are being applied in the HAPEX-SAHEL project in Niger.

Figure 14 shows variations in sensible heat flux over a 15x15 km region south of Niamey, two weeks after the end of the rainy season. The lowest values of sensible heat flux — and hence the highest evaporation — are over the wet soils in the Niger valley in the north-east of the image, over small pools and, in the centre of the image, over comparatively dense vegetation.

Active and passive microwave sensors are being used to determine soil moisture contents and their spatial and temporal variability, and the extent of surface water, particularly from flooding. Progress has been made using ERS-1 and Landsat TM satellite data, together with images of the grassland parts of the Plynlimon catchment, UK, which have been acquired from the 1994 NERC airborne campaign.

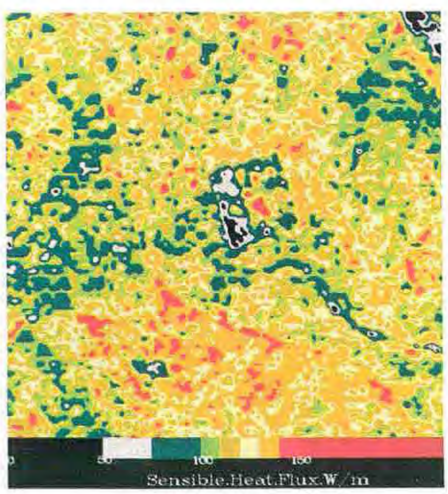


Figure 14 *Sensible heat fluxes (W m^{-2}) from the HAPEX-SAHEL site in Niger*

Flux de chaleur détectables (en W m^{-2}) sur le site HAPEX-Sahel au Niger

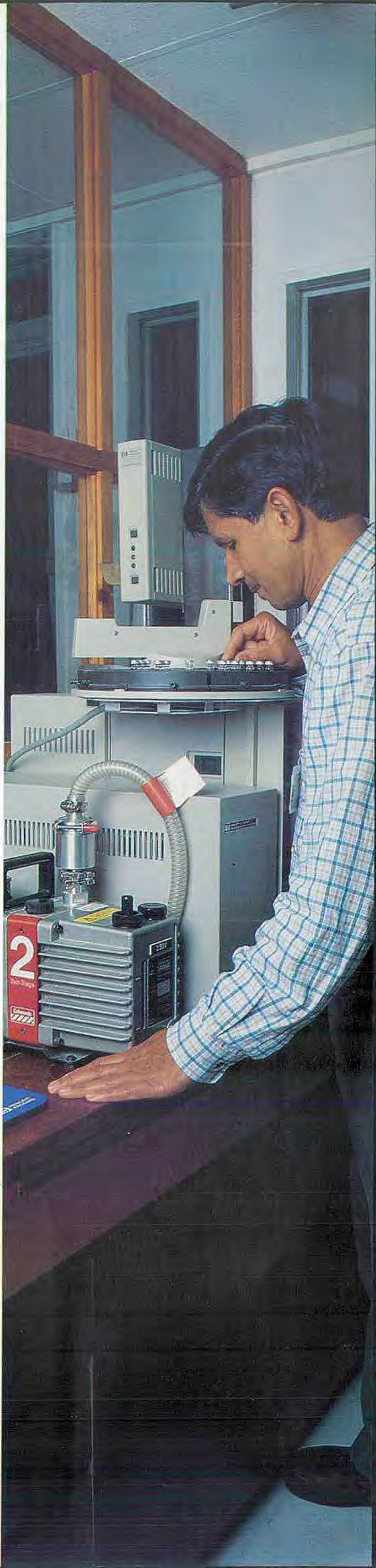
Environmental Hydrology

The problems of pollution impinge on all aspects of modern life. Acid rain creates problems of heavy metals in public water supplies, damages fisheries in upland streams and corrodes buildings. Industrial and domestic effluents discharged to rivers creates pollution problems for downstream water suppliers, can lead to fish kills and reduces the amenity and conservation value of river systems. Land-use change such as deforestation generates sediment release and can produce dramatic changes in nutrient loads entering streams. Finally, agrochemical flushes from land surfaces find their way into water courses and cause problems for stream life and public water supplies. Over the past ten years IH has responded to the major shift in public interest towards environmental and pollution issues by creating the Environmental Hydrology Division. The remit has been to understand the dynamics and key processes controlling environmental pollution and to develop models that can be used for scientific and management purposes. A wide range of user groups have supported our research including MAFF, NRA, DOE, ODA and the Water Companies. At the same time successful bids to TIGER, the NERC/AFRC and the EU have ensured the highest quality science.

The Division has particular strength in modelling and chemistry and one of the best analytical facilities in the UK, producing the highest quality data for chemical hydrology studies. Our modelling skills cover statistical approaches such as time series analysis through lumped conceptual modelling to semi and fully distributed models of flow and water quality.

First priority is given to research in the United Kingdom but — like the rest of the Institute — the Division's remit is worldwide, with the following mission:

- investigating and understanding processes controlling hydrology, chemistry and, where necessary, biological behaviour;
- developing linked physical, chemical and biological models that describe the key mechanisms operating;
- applying the models to answer scientific, operational and strategic management questions.



Water quality systems

The Institute has been working for over three years on both experimental and mathematical techniques with which to assess the impact of climate change on biogeochemical and ecological systems.

In the experimental approach a major new facility has been created in southern Norway in collaboration with scientists and institutes across Europe. This EC-funded project is investigating the effects of a CO_2-enriched environment and temperature increases on entire forested headwater catchments in Norway. A greenhouse covering an area the size of a football pitch provides a controlled environment for studying impacts on hydrology, soils, chemistry and biology (see Figure 15). Projected increases in CO_2 and temperature are expected to affect temperate and boreal forests at many levels. Soil biogeochemical changes will occur and enhanced mineralisation may result in the release of methane and nitrous oxide, both greenhouse gases, and thereby introducing a positive feedback mechanism into the greenhouse effect. Nutrients such as phosphorus and nitrogen may be released as soils warm and nitrates will further acidify already acid soils in northern Britain and Scandinavia.

The CLIMEX experiment will seek to reproduce a future climate and the subsequent impacts on a wide range of physical chemical and biological systems will be monitored to detect trends. The experiment will provide a unique, integrated database for modelling applications, the second major area of study.

In a separate project, funded by the Department of the Environment, Institute scientists are developing mathematical models for predicting impacts of climate change. The three main objectives of the project are:

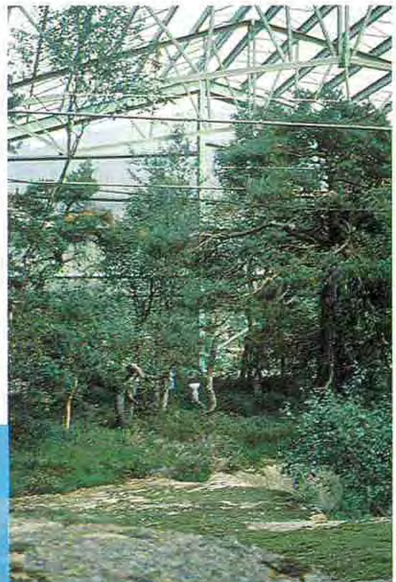
(a) to provide core models for predicting impacts of climate change on biogeochemical and ecological systems;
(b) to provide models that will simulate impacts under both transitional and equilibrium climates;
(c) to provide models which link with geographical information systems to examine impacts across the UK.

The concept of linking a model with a GIS system and databases has been exploited during the project to predict, for example, the risk of nitrogen pollution in the Bedford Ouse catchment following fertiliser application and a particular rainfall event. The high risk of nitrogen pollution then becomes clear and an agricultural non-point source pollution model linked to databases such as HOST (Hydrology of Soil Types), land use, topography and evaporation can provide a powerful tool for assessing climatic change on land use change.

Other demonstration models have been developed such as a linked grassland-nitrogen hydrological model that simulates upland pasture systems. This model is being used to investigate different climate effects and preliminary results suggest much increased grass production during spring with reduced productivity in drier summer months. Nitrogen release is significant following dry summer spells.

Mathematical techniques for assessing climate change impacts are exemplified by a new model for describing instream faecal coliform dynamics. Funded by the DOE with contributions from the National Rivers Authority, the model development is based on a two-box structure describing the concentration of organisms in the flow and the number of organisms in static residence or bed dead zones within the river channel. A novel approach is used to describe the process of transfer of organisms between the flow and static residence. This new concept in entrainment/deposition modelling was derived from observations made during a series of controlled experiments whereby artificial releases were used to perturb the stream channel in the absence of external inputs of organisms. The model has been calibrated to the field data and gives a good fit to the observed time series.

The model has been extended by including terms for temperature and solar radiation effects on coliform mortality which have been derived from the literature and incorporated into the IH-QUASAR water quality modelling package. Application of the model to the River Exe has been successful but it should be recognised that the model is still very much developmental. Future applications of the model which might be considered include sediment transport and the transport of particulate-associated contaminants such as heavy metals or trace organics.



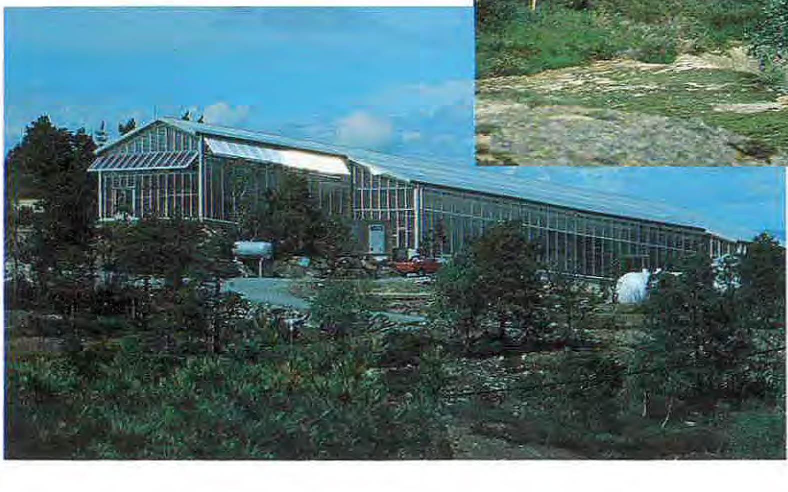


Figure 15 *The experimental enclosure at Risdalsheia, southern Norway (below); the greenhouses (right) contain whole catchment ecosystems*

L'enceinte expérimentale de Risdalsheia, au sud de la Norvège (ci-dessous); les serres (sur la droite) renferment des écosystèmes de bassins hydrologiques complets.

Pollution hydrology

Winter cereal production is now a common practice throughout much of western Europe. To ensure successful yields of these cereals, farmers suppress the growth of indigenous grass species with high application rates of pre- or post-emergent herbicides. However, despite following standard or approved practice, these herbicides can escape from the agricultural environment and pollute surface and groundwater resources.

IH scientists are studying this scenario at a field site at Wytham in Oxfordshire. The site was selected because its heavy clay soil requires an extensive artificial drainage system, comprising slotted plastic field drains and mole drains drawn by a beam plough. Soils of this type, with their accompanying drainage system, represent over 10% of the land area of England and Wales. Their particular interest lies in a high propensity for rapid water movement via preferential flow paths along macropores, although the hydraulic conductivity of the soil matrix itself is low. These macropores can include worm burrows, fractures and artificially induced moling fissures. When macropore flow processes are induced by rainfall, herbicide can be transported rapidly through the soil profile into the drainage system and ultimately into the river.

The rapid changes in soil hydrological conditions and water chemistry are monitored in the field by a large number of instruments (including pressure transducer tensiometers, capacitance probes and a neutron probe) connected to data loggers. Flow monitoring and automatic sampling equipment has been installed to measure field drain flow, mole drain flow, overland flow (surface runoff) and subsurface lateral flow. The installation of some of these instruments can be seen in Figures 16 and 17. Data are routinely downloaded from the loggers, while water samples are collected and analysed for the herbicide isoproturon and various anions in the Institute's chemistry laboratories.

An example of the highly detailed information provided by the field instruments can be seen in Figures 18 and 19. The rapid response of the field drain and the transient movement of water by lateral subsurface flow is a characteristic of preferential flow. This type of water movement contrasts with the slower downward piston flow characteristic of soils with apparently higher hydraulic conductivity where water movement is through the soil matrix.

The high isoproturon concentrations observed (up to 290 $\mu g\, l^{-1}$) are also a feature of preferential flow, because the rapid water movement reduces the opportunities for re-adsorption of the transported pesticides. Comparison of

Figure 16 *Installation of Pressure Transducer Tensiometers (PTTs) around a mole drain at Wytham Farm, Oxford*

Installation de Tensiomètres Capteurs de Pression (TCP) autour d'un drain de môle à Wytham Farm, Oxford

Figure 17 *Water sampling equipment at Wytham Farm, which is triggered automatically once significant water flow begins*

Matériel d'échantillonnage de l'eau à Wytham Farm, déclenché automatiquement dès qu'il y a un écoulement d'eau significatif

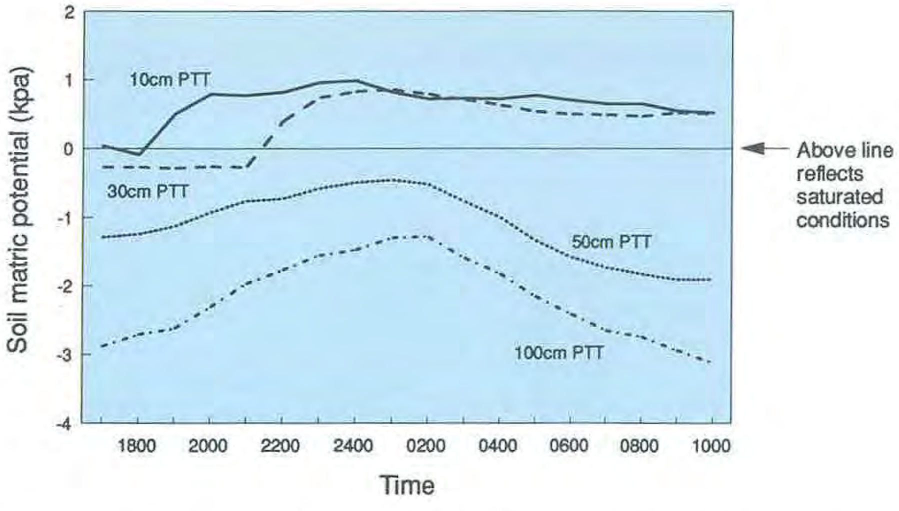


Figure 18 *Pressure Transducer Tensiometer data for the storm event described in Figure 19*

Données TCP pour le phénomène de tempête décrit à la Figure 19.

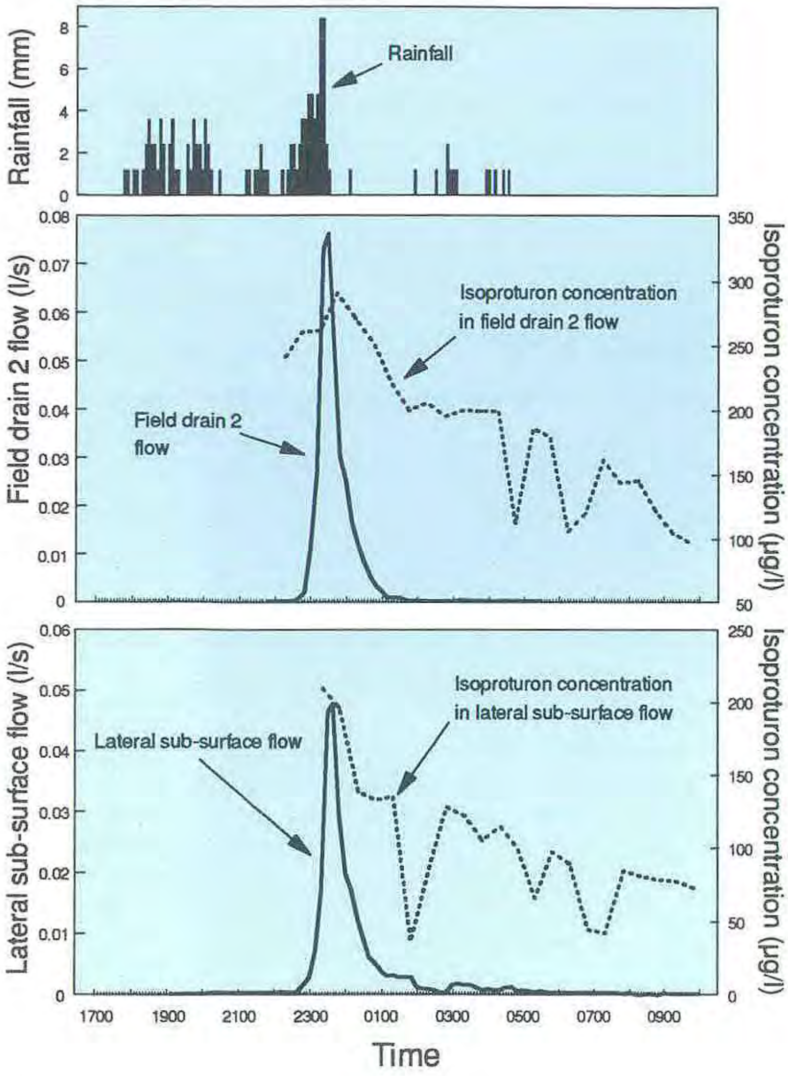


Figure 19 *Storm event at Wytham Farm over the period 31 March to 1 April 1994. Field drain and lateral subsurface outflows are shown with the incoming rainfall. Concentrations of isoproturon (herbicide) found in samples taken from these waters are also shown.*

Phénomène de tempête à Wytham Farm, sur la période du 31 mars au 1er avril 1994. Le drainage des champs et les écoulements latéraux sous la surface sont représentés, tout comme l'apport des précipitations. Les concentrations d'isoproturon (herbicide) trouvées dans des échantillons prélevés dans ces eaux sont aussi représentées.

the rainfall and flow data with soil water potentials at different depths measured by the tensiometers gives a clear picture of how the new water is moving through the soil. Saturation, followed by a head of water, is first detected at 10 cm and then at 30 cm within the upper soil horizon. This representss the formation of a transient perched water table, causing water to move down-slope (lateral subsurface flow) and then through fissures to the mole drains in the lower horizon (50 cm), which remains unsaturated during the storm.

In addition to studying the fate of pesticides in the soil, the Institute is collaborating with the British Geological Survey in establishing the fate of pesticides deep below the soil in the unsaturated and saturated zones of a Chalk aquifer in Hampshire. This is an issue of great environmental importance as pesticides which reach the groundwater may persist for many years.

An important technique in studying the potential of a pesticide like isoproturon to degrade or adsorb to the Chalk is to use a radio-labelled analogue in laboratory microcosms. The amount of adsorption or degradation of the compound can be accurately measured in a liquid scintillation counter. The scintillation counter (Figure 20) can process hundreds of determinations automatically to a high degree of accuracy, much more rapidly and cheaply then conventional analysis. Using a series of microcosms with material obtained at different depths from the field site, the complete breakdown of isoproturon was monitored over time. The results indicate that the potential for isoproturon degradation in the unsaturated Chalk is negligible. This evidence goes some way to confirming the threat to groundwater posed by pesticide that escapes from and moves below the topsoil.

Attempts are now being made to model the movement of pesticides to groundwater resulting from sequential applications to crops above an unconfined aquifer, using the model LEACHP. The key input data for the model were the

Figure 20 *A liquid scintillation counter is used to help determine the degradation potential of pesticides.*

On utilise un compeur de scintillement liquide pour aider à déterminer le potentiel de dégradation des pesticides.

application history of each field, together with meteorological conditions that prevailed over the period. Other information on the adsorption and half-lives of the chemicals was derived from the laboratory studies described above. A model simulation was carried out for the herbicide atrazine, which had been applied to maize in several of the years of the simulation period of 1987 to 1992.

The concentrations of atrazine that were likely to reach water table depth were calculated from the model results. The scenario at the end of the simulation period is compared to measured values taken from a borehole on the site. Given the inherent difficulties in measuring herbicide concentrations at these low levels, the observed and predicted values are acceptably close. However, the model always under-predicts the measured values, and it is therefore possible that some other aspect of pesticide transport remains unaccounted for by the model. It is known that chalk contains fractures, which under some conditions transport water rapidly through the profile. The possibility that pesticide is transported to the water table in this way will form part of future investigations in this project.

Hydrochemistry

Emphasis has been placed on characterising man's impact on stream and river water quality for upland and lowland systems by studying and modelling chemical transport through catchments to river courses.

For the past decade, IH has undertaken detailed studies on the chemical variations in water quality for streams draining an acidic and acid sensitive spruce forested area of mid-Wales. The results of these studies show that deforestation has led to an increase in nitrate, dissolved organic carbon, bromide and aluminium, together with reductions in calcium and alkalinity (Figure 21). For nitrate, potassium and alkalinity, the perturbations have only lasted for about three years as regrowth of vegetation has started to mitigate the changes.

However, for the other components the changes continue to be marked. For sodium and chloride, concentrations increase with time due to a corresponding increase in the rainfall input but deforestation leads to relatively lower concentrations than with the maintained forest. The results are related to (1) reduced atmospheric scavenging of sea salt and sulphur due to the removal of the trees, (2) increased losses of nutrients from the soils because of lower uptake by the vegetation, (3) increased aluminium releases from the soil's cation exchange store following increased nitrate generation and (4) either a reduced contribution of groundwater to the stream or an acidification of the groundwater.

In terms of environmental and water management issues, nitrate production will probably not be important because the baseline levels in the stream are so low. The increase in aluminium concentrations may extend the length of the stream which is unsuited to fish. Potential water treatment problems for sensitive catchments during deforestation are more likely to arise from the increases in manganese, dissolved organic carbon (colour), bromide and iodine.

At Plynlimon, detailed process studies have been undertaken to characterise the contribution of ground and soil waters to the stream. This is an area where rocks have been considered impermeable and groundwater has been assumed not to exist. However, it has not yet been possible to explain the chemistry of the stream at baseflow. Whereas stormflow stream chemistry is highly acidic and can be explained by increased contributions from acidic soil waters, baseflow water is of moderate alkalinity and relatively high pH, unlike any water type previously sampled within the catchment. A number of boreholes have now been drilled within the catchment: without exception, groundwater has been found. The borehole waters are more alkaline than those in the soils, which may help to explain the source of baseflow stream waters. Groundwater alkalinity has increased during the flow recession of

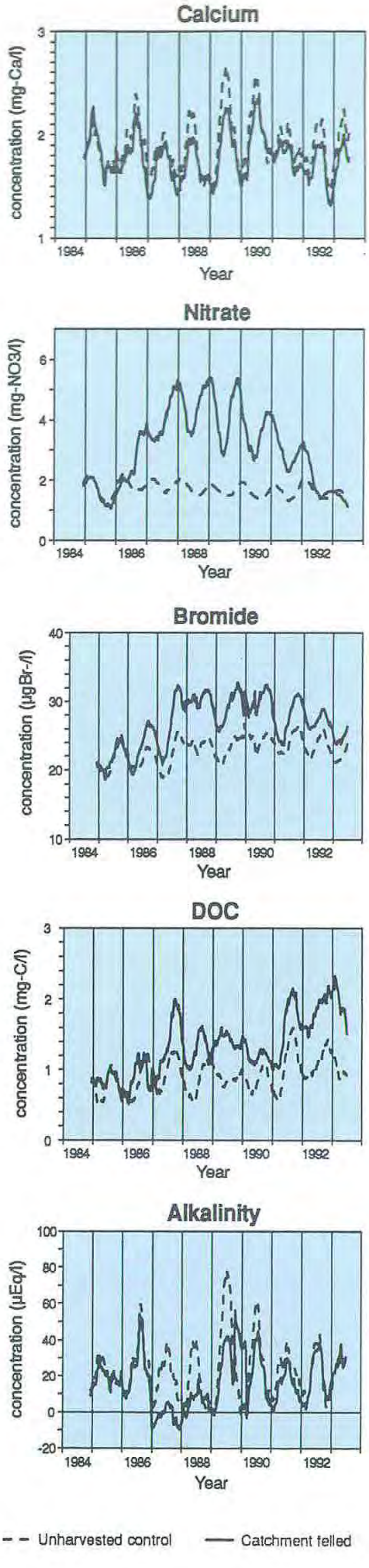


Figure 21 *The effects of felling on calcium, nitrate, bromide, dissolved organic carbon and alkalinity for Hafren forest streams, Plynlimon. Deforestation of one of the catchments took place late in 1985.*

Les effets de l'abattage des arbres sur le calcium, les nitrates, les bromures, le carbone organique en solution et sur l'alcalinité, pour les ruisseaux forestiers, Plynlimon. La déboisement de l'un des ruisseaux a eu lieu à la fin de 1985.

the past few months. High inorganic carbon levels have been found — excess pCO_2 values between 20 and 100 times atmospheric, i.e. significantly higher than in the stream and sufficiently high to degas visibly when a sample is taken.

The longer-term aspects of stream water quality changes have also been examined for Hafren stream waters and have been related to rainfall inputs. The results provide little evidence of further increases in acidity or of depletion of base cations in the streams over the last 11 years: i.e. water quality is not deteriorating. However, rises of DOC, bromide and iodine in the stream waters have been found, suggesting that there may have been an increase in organic breakdown over the last decade.

Catchment distributed modelling

One of the key scientific questions being addressed is that of applying hydrological models at progressively larger spatial scales, while still retaining their essential physical basis. The demand for the development of suitable 'scaling-up' techniques arises between all scales. For example, work on nitrate modelling described below illustrates the move from the plot scale to a catchment of 43 km^2.

Other current initiatives are even more demanding of scaling-up techniques. The requirement in the LOIS (Land Ocean Interaction Study) programme is for water quality and sediment fluxes into the North Sea from the UK between Great Yarmouth and Berwick, a contributing catchment area of some 59 200 km^2. Improved hydrological representations within Global Climate Models (GCMs) — part of the NERC's TIGER programme, and the wider GEWEX Continental-scale International Project (GCIP) — require procedures to cope with grid squares of the order of 10 000 to 50 000 km^2 and river basins such as that of the Arkansas Red River (750 000 km^2).

While specific water quality problems are often localised and derive from a single point source, such as a leaking landfill site or an effluent discharge pipe, wider scale problems may occur when chemicals, for pest control or crop fertilisation, are applied over a large area. In this instance, both the hydrologist and the public at large may wish to know the likely progress of contamination to water bodies which may have amenity value or be used for water supply. Staff at IH have recently completed a MAFF-funded study of the transport and transformation of nitrate to surface waters.

A proportion of nitrate is derived from sewage treatment works, and atmospheric deposition contributes some, but much of it is of agricultural origin. It is leached from the soil when there is an imbalance between plant uptake and nitrate availability. This occurs, for example, if nitrogen fertiliser is applied at a time when it cannot be taken up by plants before being washed through the soil, or if there are no plants to take up the nitrate produced naturally in the soil.

The work at IH has included modelling at both plot and catchment scales, with application of models to data at the appropriate scale from ADAS, AFRC (now BBSRC) and NRA sources. The models are designed to simulate the transport of nitrate through the soil and the transformations between nitrogen species which influence nitrate concentrations. They require information on the hydraulic properties of the soil, topography, crop type, continuous meteorological data, information on crop management, animal husbandry and on rates of transformation processes in the soil. For particular crops, the rate of root uptake of nitrate is needed. Catchment-scale modelling requires further information on the river network and its hydraulic properties, non-agricultural point sources of nitrogen, and nitrogen transformation processes in rivers.

Plot scale experiments can provide sufficient information for models based on the principles of soil water physics. In these models the mass continuity equation is combined with an equation for potential flow to produce a non-linear form of the convection-dispersion equation. This can be solved to give a flow field which may be used within a transport and transformation equation for nitrogen. Solution of these equations provides, in principle, continuous estimates of soil water and nitrate content through time throughout a soil profile. IH staff have applied a one-dimensional model of this type, SOILN, to data from Rosemaund and Brimstone experimental farms (ADAS and BBSRC), and have developed a two-dimensional model based on the IH Distributed Model (IHDM) which has also been applied to data from Brimstone Farm.

However, at the catchment scale, it is impractical to use models with such a fine scale of process representation. Although computational requirements may be of some concern, the main consideration is that the key processes can be captured using models which either ignore or have the effect of averaging less important processes. Frequently, mass is conserved within a large scale compartmental framework and movement between, or within, model compartments can be described more empirically.

A model of this sort has been developed for use with a square horizontal grid, of the order of hundreds of metres, and several soil layers. Agricultural inputs and soil type are estimated by grid square and a fixed flow network linking grid squares is based on surface topography (Figure 22). The model includes simulation of unsaturated vertical movement between soil layers and lateral flow between grid squares and along the schematic stream network. The model has been applied at the Bourne Brook catchment (43 km^2) near Coventry, a former Nitrate Advisory Area. Simulations of nitrate concentrations in the stream may be compared with measured values.

At a still coarser scale, as required within the LOIS modelling project (59 200 km^2), many of the contaminants come from point sources. The main water quality modelling effort is to describe adequately the movement and transformation of contaminants in rivers. However, agricultural inputs are also important, as are the effects of changes in land use, set-aside regulations and environmental policy, with an increasing use of chemical buffer zones around water courses.

To model these impacts at the large scale, it is clearly inappropriate to use grid squares of a few hundred metres, but it is important to use the correct physical basis for the model in order to assess the impact of future environmental change. Hence, a further set of scaling-up techniques will need to be developed. Agricultural sources of contamination may be inferred from crop census information, used with approximate knowledge of chemical application by crop type. With knowledge of soil properties and meteorological data, the

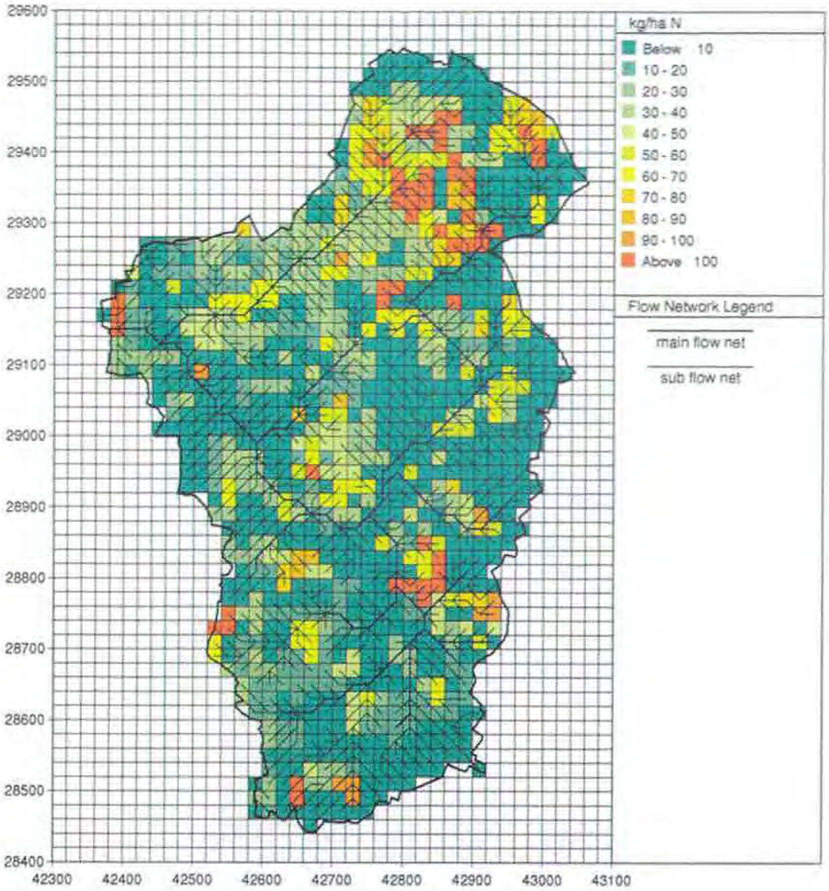


Figure 22 *The Bourne Brook catchment showing grid model structure and spatial pattern of soil mineral nitrogen at 1 September 1991.*

Bassin hydrologique de Bourne Brook, montrant la structure du modèle de quadillage et la configuration spatiale de l'azote minéral dans le sol, le 1 er septembre 1991.

movement below the root layer may then be inferred and travel times to groundwater bodies or surface water courses estimated to predict the evolution of concentrations of water quality variables.

While the question of water quality modelling on a large scale is a particularly difficult one requiring both the velocity and the location of water to be accurately modelled, other scaling-up problems have different demands. Work in progress for MAFF on flood defence aims to investigate the impact of climate and land-use changes on flooding in large catchments. Here the volume of runoff and its timing are the key variables, while the precise route of the water is not important and simplified unit hydrograph models for runoff production are an appropriate solution.

Furthermore, as in the case of suitable hydrological representations for use in GCMs, explicit routing of water through successive reaches of the river is not required and, therefore, advantage can be taken of the natural averaging processes operating within large (10 000 km^2) catchments.

The approach taken for the routing uses a distributed network width function as its fundamental descriptor of spatial variation. An example is shown in Figure 23 for the Severn basin to Haw Bridge (9895 km^2) distributed across HOST (Hydrology of Soil Types) classes. This is constructed by overlaying the digitised river network at a scale of 1:50 000 onto the 1 km gridded soil data. There are 29 soil classes across the UK and the proportion of each soil type is given for each of the kilometre squares. The network width function is produced by counting the number of channels at successive 1 km distances from the basin outlet, as measured along the river network. These are then allocated according to soil type. The resulting plot

- **Land Ocean Interaction Study (LOIS)**
  Key contributions to this community programme are in areas of chemical: analysis, data management and modelling. Chemistry laboratories in Wallingford and York are centres for analysing river water samples collected routinely from the Yorkshire Ouse and Tweed catchments. The NRA database for these catchments has been assessed, quality-controlled and integrated with existing IH databases to provide data for models and their verification. The IH QUASAR model is being developed to compute fluxes of material and flow from the study catchments to provide a means of investigating potential land use and climate change impacts.

- **The Acid Waters Monitoring Network** (for DOE)
  The Wallingford laboratory performs major ion analysis of samples from 22 surface water sites in the UK. Data are stored centrally at IH and reported nationally via annual summaries and internationally as the UK contribution to the UNECE International Cooperative Programmes on Surface Waters (centred in Oslo) and on integrated catchment monitoring (centred in Helsinki).

- **Critical loads for surface waters** (for DOE)
  The MAGIC model forms a key tool for the assessment of critical loads for S and N deposition to ecosystems in the UK. The model has been used to assess the impact of acidic emissions reduction scenarios on surface water acidity to aid the UK input in negotiation over a new UNECE sulphur emissions protocol.

- **Water, erosion and land management in Nepal** (for ODA)
  This joint research project between IH and the Royal Geographical Society in association with the National Agricultural Research Centre, Nepal, undertakes detailed monitoring of water flow, chemistry and erosion in five catchments in Nepal. Models developed from the process data will help aid soil and water management and land use planning at the catchment scale.

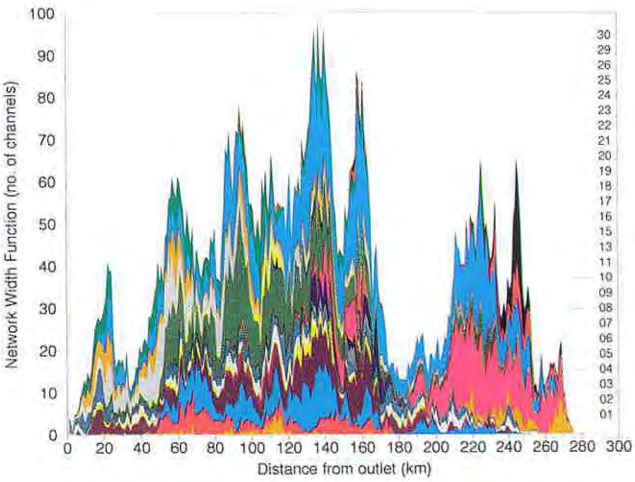


Figure 23 Network width function for the Severn basin to Haw Bridge showing the number of river channels distributed across HOST soil classes against distance from basin outlet

Fonction de largeur du réseau dans le bassin de la River Severn, jusqu'à Haw Bridge, indiquant le nombre de chenaux de rivière répartis sur les classes de sol HOST, par rapport à la distance de la sortie du bassin

model scale; within each unit small catchments are identified for calibration; these small catchments are subdivided into independent hillslopes of different characteristics for the detailed modelling of their hydrological response. A key question now being addressed is how many hillslopes are required to model adequately the runoff from an area.

Once the calibration phase is complete, moving up to the model scale is accomplished by classifying the hillslopes within the larger area of given soil type and then scaling the hillslope responses by the appropriate area of the particular type hillslope in order to generate the overall response. The river network routing then takes the results up to the GCM grid scale and beyond.

may be used in conjunction with runoff responses for each soil type and a two-parameter convection-diffusion equation for the channel flow routing. Essentially, the procedure means that runoff models are combined in different ways in different parts of the catchment according to distance from the basin outlet, enabling considerable simplification in the flow modelling for the large catchment as a whole.

This routing strategy has also been adopted in work carried out under the TIGER project towards the development of physically-based hydrological models for implementation in GCMs. The key components here are the moisture flux back into the atmosphere and the outflow from major rivers into the oceans. The models are also required to be very simple and computationally efficient while retaining their physical basis. This requirement has led to the strategy shown in Figure 24 to cope with sub-grid variability. The GCM unit grid square is broken down into its component soil and land cover classes, referred to as the

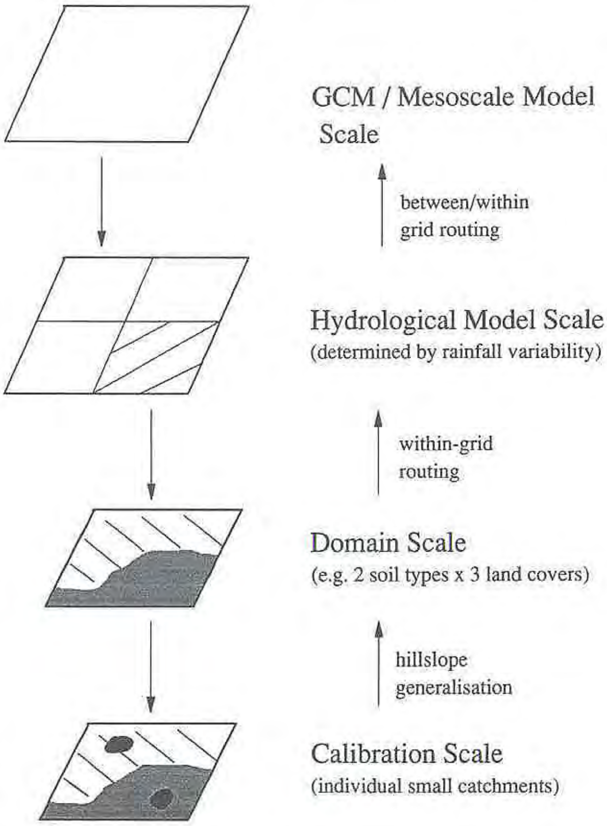


Figure 24 Strategy for linking different scales within hydrological macromodel developments for GCM application

Stratégie permettant de lier les différentes échelles au sein des développements de macro-modèles hydrologiques pour des applications GCM

Engineering Hydrology

The Engineering Hydrology Division aims to advance the science of estimating and forecasting the extremes of hydrological variables. It develops and applies hydrological models so as to improve the cost-effectiveness of engineering provision for water resource and flood defence applications in the water industry.

To this end, our mission is to:

- develop techniques for estimating the extremes of low flow discharges for given frequency and durations at both gauged and ungauged sites;
- derive new generalised methods of rainfall and flood frequency estimation;
- model the impact of artificial influences including land use change and resource development;
- develop techniques for assessing the impact of river flow regimes and channel morphology on freshwater ecology;
- develop procedures for estimating and forecasting precipitation rates using radar and raingauge information;
- combine hydrological models with data acquisition systems to develop real-time flood forecasting and drought management systems;
- improve the effectiveness of hydrological design by transferring the results of hydrological research to European and overseas applications and practitioners.

Flow regimes and environmental management

The estimation of low flow statistics is a major component in the authorisation of licenses to abstract from surface or groundwater, of consents to discharge effluent or treated water to receiving water bodies, in the determination of minimum acceptable flow regimes, and in hydropower design. The UK water industry requires low flow statistics at around 4000 locations per year for design purposes, the large majority of which are distant from gauging stations. Consequently, there has been a wide reliance upon low flow estimation procedures, including the 1980 *Low Flow Studies Report*, its 1992 successor *Low Flow Estimation in the United Kingdom* (IH Report No. 108) and the widespread adoption by the National Rivers Authority of Micro LOW FLOWS software. This PC implementation of the 1992 report has markedly reduced the staff resources required by the water industry for low flow estimation.

However, such procedures have been partially restricted in their relevance and application in the past because they provide estimates of *natural* low flow statistics, whereas it is considered that the flow regimes of perhaps only 10% of British rivers can be described as natural. The large majority of catchments and rivers possess low and normal flow regimes which are artificially influenced by man, principally by abstractions, discharges and impounding reservoirs, and which may bear little resemblance to natural conditions. This year has seen the completion of a three-year research and development contract with the NRA to address this issue by developing methods of estimating low flows in artificially-influenced catchments, and by upgrading Micro LOW FLOWS software with a capability that is set to find wide application within the UK water industry.

Because of the prior expectations of the high operational demands upon the outputs of this project, the activities have combined components of original hydrological research with database management, existing GIS and computing technologies into the development of a new upgraded software product, Micro LOW FLOWS Version 2.1.

The underlying hydrological techniques involved at a particular design site are first the estimation of natural flow statistics on a monthly basis, second the accumulation of monthly artificial influence information for all upstream occurrences of abstractions, consents and reservoirs, and third the aggregation of these two to estimate artificially influenced low flow statistics.

Developments in natural river flow estimation have been made with respect to monthly mean flows, monthly flow duration curves and monthly low flow frequency. Complex database designs have been established to archive the detailed and interlinking abstraction and consent holdings, with data loading procedures which handle the non-standardised holdings of the UK water industry. The artificial influence features and associated data are all linked to a national computer database of river stretches, which is archived in a structured manner which allows the identification or quantification of all features upstream of any stretch.

Estimating the impact of artificial influences upon low flows is relatively straightforward in catchments which are dominated by surface water impacts. The first principal difficulty that was overcome was the complexity of abstractions, where a single licence can authorise multiple abstraction sites, multiple purposes and seasonal periods; the second main difficulty was the general paucity of real data quantifying actual abstractions and discharges. The latter has been solved by using actual data where these exist and by simulating actual values using default parameters that simulate monthly abstractions based on the historic behaviour of abstractors in different regions of the country in different water use sectors.

Estimating the impact of groundwater abstractions upon low flows has traditionally posed a vexed question, introducing complexities of depletion volumes and time-lagged impacts. In the past, this

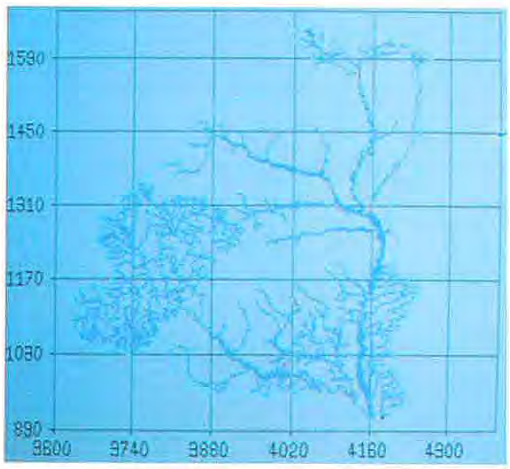


Figure 25 *Example of Micro LOW FLOWS river network for the Stour and Avon catchments*

Exemple du réseau fluvial Micro DEBITS FAIBLES, pour les bassins hydrologiques des River Stour et River Avon

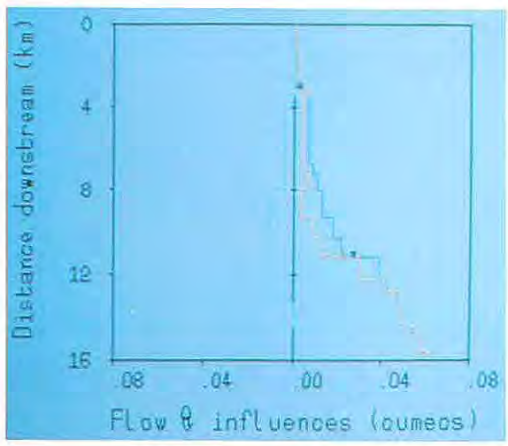


Figure 26 *Residual flow diagram illustrating change in discharge downstream*

Schéma de l'écoulement résiduel, montrant la modification de rejet en aval issue had been addressed by general rules-of-thumb or by the development of complex catchment-specific groundwater models. This project, with a requirement to provide techniques on a national scale, evaluated three analytical solutions against observed river flow and pumping data before selecting the Theis solution which requires input of aquifer property parameters and the distance of the borehole from the stream.

The low flow design procedures, with the underpinning national computer databases of rivers and climate and soil indices, the groundwater impact solution, the database structures for archiving and editing artificial influence data have all been combined to produce Version 2.1 of Micro LOW FLOWS. Undergoing Beta tests in 1994 prior to general release during 1995, and with forecast widespread adoption by the NRA, Micro LOW FLOWS will provide the capability to estimate natural and artificially influenced low flow statistics at approximately 250 000 river stretches (Figure 25).

A further substantial development is the new capability to generate river profiles (residual flow diagrams) illustrating the relative magnitude of natural and artificial flow components from headwaters to estuaries (Figure 26). Other software features offer the capability to investigate impacts upon downstream flows of scenarios such as increasing water demand (by purpose and/or by region) or the construction of new reservoirs, abstractions or discharges.

Although partially constrained by the absence of real data in many circumstances, and with scope for upgrading certain of the hydrological and technological components, the capability of the new Micro LOW FLOWS introduces a new era of science and technology into the investigation and planning of artificial influences upon low flows.

- **Habitat modelling and instream flow requirements: River Piddle** (for NRA South Western Region)
  Following the success of the River Allen study the IFIM methodology is being applied to three sites in the River Piddle catchment to assess the impact of the present groundwater abstraction regime on available habitat for salmonid fish species.

- **Assessment/design of habitat improvement/restoration procedures for river flood defence schemes** (for MAFF)
  A project to assess the effectiveness of habitat restoration procedures carried out as part of flood defence schemes, and aid design, through the application of the IFIM to a case study on the River Wey.

- **Ecologically Acceptable Flows** (for NRA)
  Assessment of the use of the Instream Flow Incremental Methodology (IFIM) using the Physical Habitat Simulation system for use in the UK through the application of the IFIM to 11 study sites in England and Wales.

- **Habitat modelling and instream flow requirements: River Allen** (for NRA Wessex region)
  The first application of the IFIM using PHABSIM to a current water resource management problem in the UK. The project assessed the impact of public water supply groundwater abstraction on habitat availability for selected fish species on two sites on the River Allen.

- **Ecologically Acceptable Flows: River Bray and River Barle** (for NRA South Western Region)
  This project assessed the impact of direct water abstraction (for public water supply and fish farming) from two rivers in southwest England.

- **European Atlas of Small-scale Hydropower Resources** (for EC ALTENER programme on behalf of the European small-scale hydropower association)
  Completion of a study to assess the feasibility of developing an Atlas of small hydroelectric resources to identify hydropower potential within EC countries. Phase 1 of the study initiated in Spain, Italy and UK.

- **FRIEND** (International Research Programme for UNESCO IHP-IV)
  Completion of the second phase of the *Flow Regimes from International Experimental and Network Data* research programme, in northern and western Europe, which analysed time series and spatial thematic data using consistent flood and low flow analysis methods at a European scale.

- **Naturalised river flow records of the Essex Region** (for Anglian NRA)
  A baseline review of NRA Anglian Region's hydrometric data and naturalisation techniques is now complete: the first phase in naturalising the river flow records in Essex.

- **Land-use change in Southern Africa** (for ODA)
  Investigation of the hydrological impact of afforestation in the Eastern Highland region of Zimbabwe using time series flow and rainfall data from paired experimental catchments.

- **Water availability assessment in the Philippines** (for World Bank)
  Completion of a national study (with HR Wallingford, for the National Irrigation Administration in Manila) of the flow regimes of the Philippines, directed towards the assessment of water availability for rice irrigation at ungauged sites

- **Survey of hydrometric data provision in Europe** (for NRA)
  Survey of the organisation of hydrometric services in Europe as part of the continuing efficiency review of hydrometry within England and Wales

- **Real-time forecasting of river flows** (for MAFF)
  Strategic research on flow forecasting and weather radar for flood warning and water management

- **Yorkshire River Flow Forecasting System** (for NRA Northumbria and Yorkshire Region / Logica)
  Maintenance and support of generic, configurable flow forecasting system in operational use throughout the Yorkshire region for flood mitigation and warning and water management

Flood and storm hazard

The estimation of environmental extremes continues to be a rich seam of research for applied hydrologists and statisticians. The pooling of gauged data across several sites is important to deriving regional growth curves for the estimation of very rare events. In studies of rainfall frequency, it is evident that geographical proximity is a useful guide to the choice of records to pool; thus the focused rainfall growth estimation (FORGE) method gives emphasis to rainfall records close to the site for which the design estimates are required. However, flood occurrence is spatially less uniform, being influenced by the response characteristics of the subject catchment. The drainage network can have a marked influence on the speed of response, while soils and geology affect the volume of response; the most dramatic of land uses, urbanisation, affects both. So on what basis are regions to be constructed for pooling flood records?

One approach is to group catchments according to their flood regime, so that only data from hydrologically similar catchments are pooled together for flood growth curve derivation. A natural starting point is to index flood regime by statistics representing the size, variability and skewness of the annual maximum floods, perhaps expressing the mean annual maximum flood as a runoff rate in mm h^{-1}. However, given the high sample variability of these measures for the record lengths typically available, it is important to corroborate that the proposed regional groupings respect flood regime differences in a wider sense. Otherwise, devising a scheme of allocating ungauged sites to an appropriate region may be both difficult and unrewarding. The underlying danger is that, if used to:

- **construct regions,**
- **define growth curves,**
- **develop estimation methods for ungauged sites,**
- **judge success,**

the annual maximum data will be over-plundered.

A different approach is being taken in research for the *Flood Estimation Handbook*[1]. Here, regions are being constructed principally from flood date information. The dates are taken from the Institute's dataset of peaks-over-threshold events, comprising some 77 000 floods on 857 UK catchments. This reserves the flood magnitude data for the other tasks.

Although other indices are being considered, three are already proving useful in discriminating flood regime: the mean and standard deviation of flood date — which together summarise the seasonal distribution of flood events — and the coefficient of variation of recurrence intervals (CVRI) — which indexes the irregularity of flood occurrence in time.

Geographical trends in these indices are summarised in Figure 27, in which the dots are placed at catchment outlets. High values of CVRI (red) denote catchments where floods occur irregularly, i.e. where there is a tendency for several floods to occur in rapid succession, followed by a long flood-free interval. A strong geographical grouping is seen in eastern England, where the combination of climate (low rainfall and high potential evaporation) and generally permeable soils leads to long periods of soil moisture deficit (SMD) during which flood formation is moderated. Using only generalised estimates of month-end SMD, the control on flood regime is well illustrated (Figure 28).

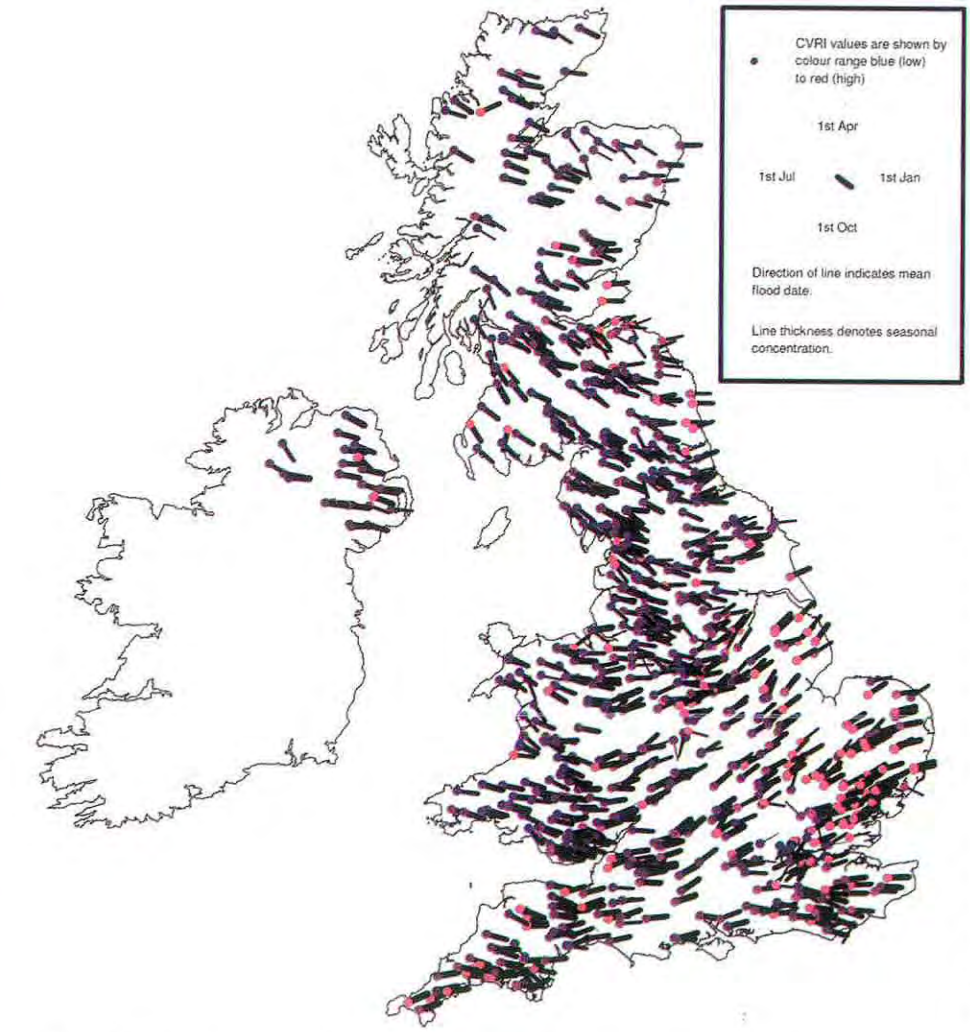


Figure 27 *A representation of the flood regime of 857 UK catchments derived from flood dates*

Représentation du régime des crues pour 857 bassins hydrologiques au Royaume Uni, déduite des dates des crues

[1] Research is under way to develop a compendium of flood estimation methods to supplant the *Flood Studies Report* and its much used supplements. With complementary studies of rainfall frequency funded by the NRA, the *Flood Estimation Handbook* lies at the heart of MAFF's flood research programme.

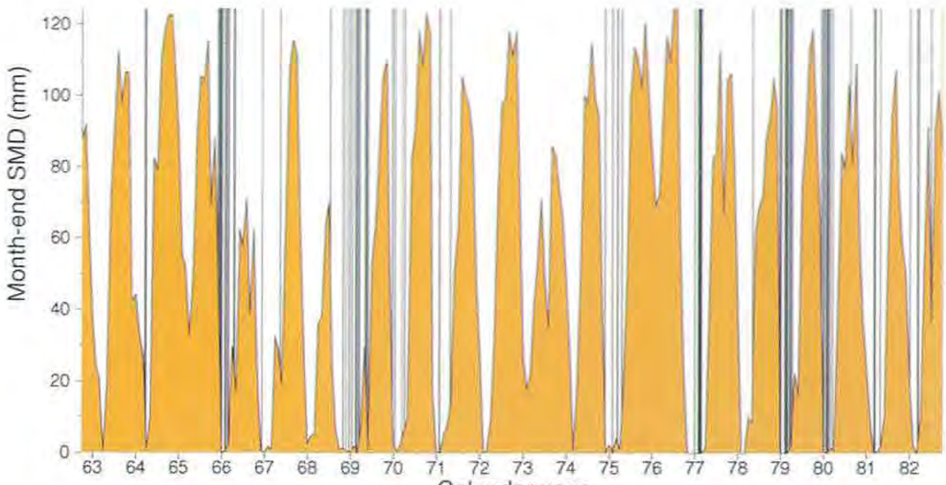


Figure 28 *Irregular flood occurrence on the Glen at Kates Bridge, Lincolnshire (342 km²) — flooding is restricted to periods when soil moisture deficit is at or near zero. Lines show POT flood occurrences.*

Occurrence irrégulière d'une inondation sur la River Glen au niveau de Kates Bridge, Lincoln-shire (342 km²) — la crue est limitée aux périodes où la valeur du déficit hygrométrique du sol est égale à ou proche de zéro.

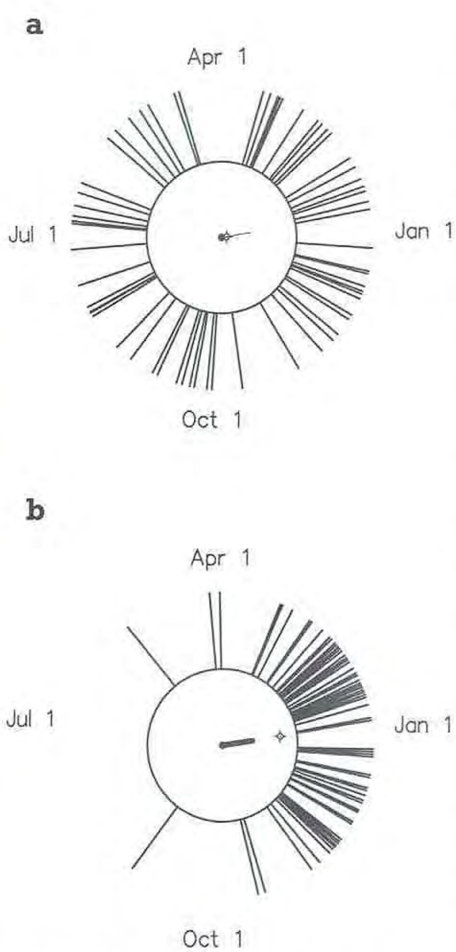


Figure 29 *Seasonal distribution of floods: (a) Beam at Bretons Farm, Greater London, (b) Tiddy at Tideford, Cornwall*

Répartition saisonnière des crues: (a) River Beam à Bretons Farm, dans l'agglomération londonienne, (b) River Tiddy à Tideford, en Cornouailles

The seasonality of flooding is summarised by the stems leading from the dots in Figure 27, the direction indicating the mean date. Strong traits are evident locally and nationally, with many catchments in the west characterised by a mean flood date in the autumn or early winter, whereas a later date is typical in the east. This reflects the role of SMD in inhibiting flood formation in summer months.

The stem widths in Figure 27 denote the strength of the seasonal concentration. Catchments where the seasonality of floods is relatively weak are shown by thin lines, and include some moderately large, substantially urbanised, catchments which show little seasonal preference in flood occurrence (e.g. Figure 29a). At the other extreme are catchments which exhibit a strongly seasonal flood regime (e.g. Figure 29b). Geographical trends in the degree of seasonality are not very marked.

In developing the index of flood irregularity, it was found that calculated values of CVRI are rather sensitive to the period of record, with records including one or more droughts generating higher values than drought-free periods. A special procedure was devised to adjust derived values to a standard 20-year period (1963-1982), applicable even to stations with no gauged records in this period. Where possible, the threshold defining the flood series was adjusted to yield the equivalent of 80 peaks during the standard period.

- **Small catchment flood estimation** (for MAFF)
  New equations for the estimation of the instantaneous unit hydrograph time-to-peak Tp(0) and the mean annual flood (QBAR).

- **Indices of flood regime from date information** (for MAFF)
  Flood date information held on the IH peaks-over-threshold flood database has been used to produce indices describing the seasonality and irregularity of flooding.

- **Rainfall frequency analysis** (for NRA)
  Review of methods of rainfall frequency estimation currently in use in England & Wales and development of new procedures.

- **Joint probabilities studies for reservoir flood safety** (for DOE)
  An appraisal of the ICE guide on reservoir safety standards, taking into account the multivariate dependence between the various flood producing inputs such as rainfall extremes, snowmelt and wind speed.

- **Allowance for discretisation effects in hydrological and environmental risk estimation** (for NERC)
  An examination of the effect of discretisation, in time-series data, upon the estimation of extremes. Correction factors for converting maxima measured from time-averaged data to maxima from continuous data were derived for a number of environmental variables.

- **Kenwith at Bideford, flood review** (for NRA)
  A flood storage reservoir spilled, unexpectedly flooding property it was designed to protect.

- **Weather radar and storm and flood hazard** (for CEC)
  Completion of two-year EPOCH project on the use of weather radar in hydrology for improved rainfall measurement and forecasting over space, for flood forecasting and for design storm and flood estimation

Systems modelling: the IH Grid Model

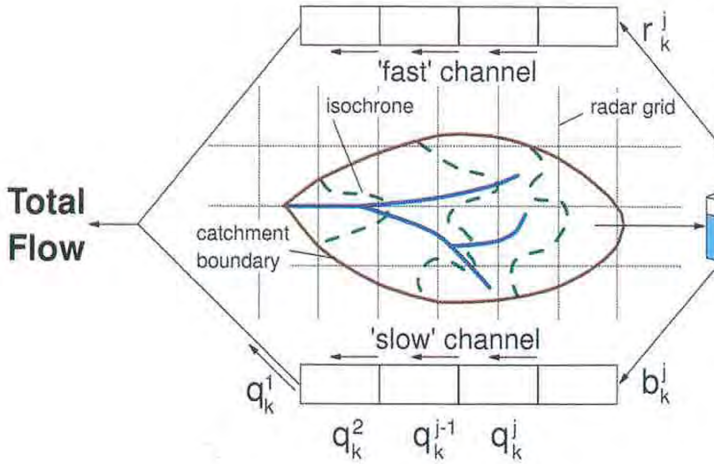


Figure 30 *The IH Grid Model*

Le Modèle de Quadrillage de l'IH

The IH Grid Model provides a practical methodology for distributed rainfall-runoff modelling using grid-square weather radar data that is especially tailored for use in real-time flood forecasting. The model is configured so as to share the same grid as used by the weather radar, thereby exploiting to the full these distributed rainfall estimates.

An intrinsic problem associated with models configured on a square grid is the potentially large number of model parameters which can be involved. If a different set of parameters is used for each grid square, the total number of parameters can become large, even for basins of modest size, and there may be strong dependencies between sets. This problem of "over-parameterisation" is avoided by using measurements from a contour map or digital terrain model (DTM) of the basin together with simple linkage functions. These functions allow many model variables to be prescribed through a small number of regional parameters which can be optimised to obtain a good model fit.

The Grid Model has two main components. First, a runoff production function based on a saturation excess principle is used to represent the absorption of rainfall, by the soil/vegetation assemblage over the grid square area, and the generation of lateral water transfers to fast and slow response pathways. The second component is responsible for the translation of water along these pathways. The key linkage function used to define runoff production is a relationship between slope, as measured from the DTM, and absorption capacity.

In the simple form of model, termed the SGM, the average slope within a grid square is related to the total absorption capacity of the square. Two basin-wide parameters, defining the upper limits of slope and absorption capacity, establish the relationship across the basin. A probability-distributed variant of this model, the PGM, accounts for the frequency of occurrence of different slopes within the square, and hence for varying absorption capacity and runoff production.

Further variants considered include a formulation based on a topographic index control on saturation and the use of Integrated Air Capacity soil survey data as a surrogate for absorption capacity. Impervious areas may also be introduced through the identification of urban areas, using a land cover classification derived from Landsat satellite imagery.

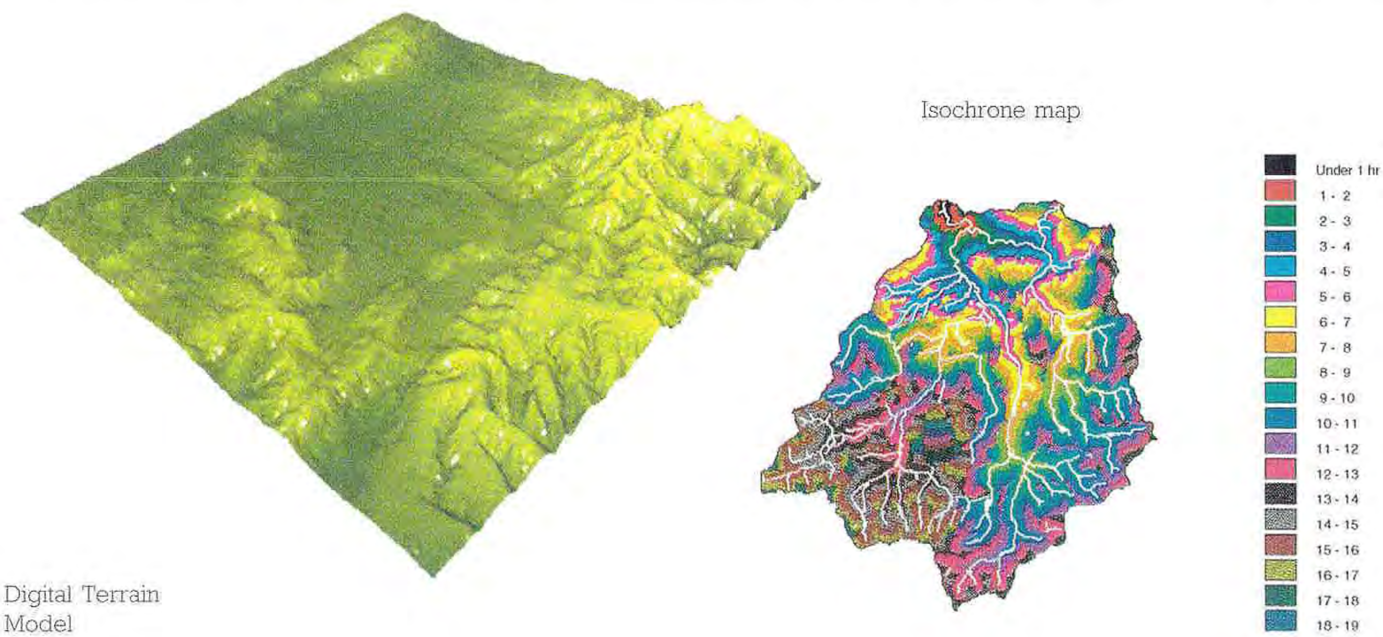


Figure 31 *Isochrone map derived from a digital terrain model: the Mole at Kinnersley Manor*

Carte isochrone dérivée d'un modèle numérique de terrain: River Mole à Kinnersley Manor

The "linkage function" used to define the translation component of the model is based on a relationship between distance to the basin outlet, as inferred from the DTM flow paths, and time-of-travel to the basin outlet. A velocity model is introduced to establish the link between these two quantities. The basic velocity model assumes two path-dependent velocities, one characteristic of hillslope pathways and the other of river pathways. This allows isochrones — lines joining points of equal time-of-travel to the basin outlet — to be derived automatically using the DTM (Figure 31).

Translation of water through a zone between two adjacent isochrone lines is represented as a discrete kinematic wave model, receiving lateral inflows from the areas of runoff production associated with the zone. A feature of this routing formulation is that, whilst the simple isochrone method is wholly advection-based, it also incorporates diffusion effects through its discrete space-time formulation.

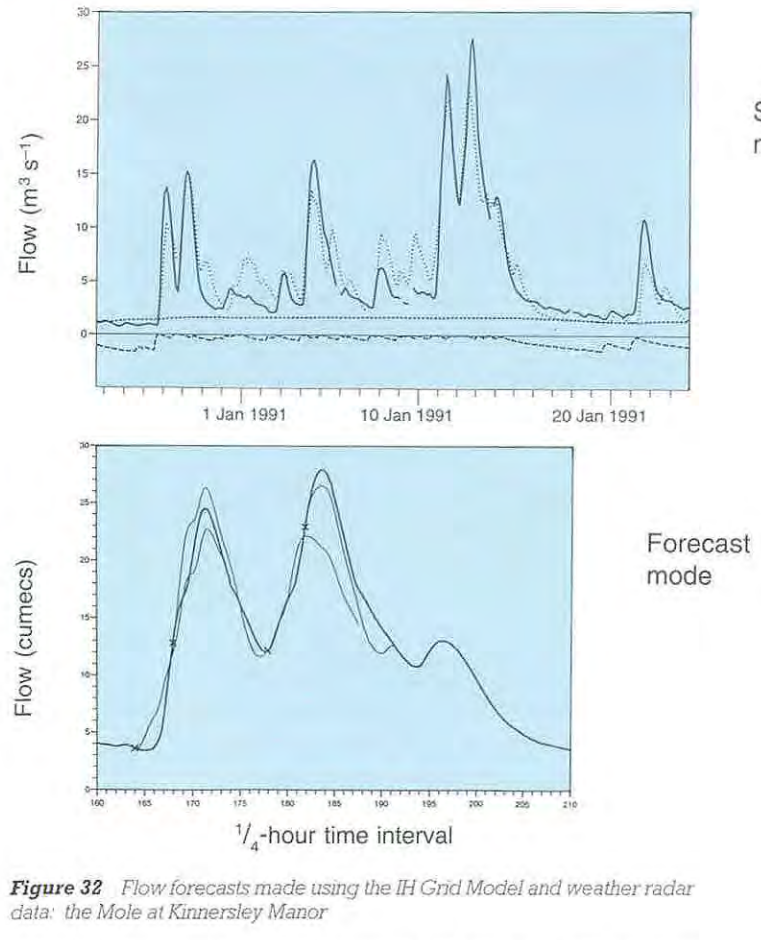


Figure 32 *Flow forecasts made using the IH Grid Model and weather radar data: the Mole at Kinnersley Manor*

Prévisions d'écoulements réalisées à partir du Modèle de Quadrillage de l'IH et des données des prévisions météorologiques: R. Mole à Kinnersley Manor

- **Anglian Flow Modelling System** (for Servelec/NRA Anglian Region) Completion of systems analysis study, which identified 600 locations throughout the Anglian Region requiring forecasts and proposed a solution based on the IH RFFS software for implementation

- **Development of improved methods of snowmelt forecasting** (for NRA) Review of historical snow data, enhancement of instrumentation for study basins in four field areas and exploration of lumped and distributed snowmelt model formulations for use in operational flood forecasting

- **RQFS: River Quality Forecasting System** (for NRA Northumbria and Yorkshire Region) Feasibility study to investigate extending IH's generic River Flow Forecasting System to forecast water quality variables, using the River Aire through Leeds as a test case.

- **Storms, floods and radar hydrology** (for CEC Environment Programme) Project to investigate the use of weather radar for measuring and forecasting storms and floods

- **Short-term consultancy in hydrological models** (for WMO) Consultancies to plan a European workshop on the application of weather radar in hydrology and water resources (Toulouse, France) and a mission (with the Met. Office) to the Salto Grande Dam in Uruguay/Argentina to advise on rainfall and flood forecasting and dam operation

- **HYRAD: HYdrological RADar System** (for NRA Northumbria and Yorkshire Region) Development and delivery of a Windows 3.1 weather radar processing and display system for real-time and off-line use. The system incorporates a hydrological radar kernel which corrects for anomalies in the radar image, calibrates the radar using raingauges, constructs rainfall forecasts and derives basin average rainfall; an interface to IH's RFFS software facilitates forecasting of flows in real-time.

- **Design of radar/raingauge networks for hydrological use** (NERC Special Topic) Using a network of over 50 recording raingauges in the Brue catchment, Somerset, along with three scanning radars, to investigate the accuracy of different sensors to measure rainfall, the natural variability of rainfall and the sensitivity of catchment runoff and models to rainfall uncertainty and variability

- **Short-period rainfall and flow forecasting incorporating weather radar data** (NERC Special Topic) A project (in collaboration with University of Reading) to develop a physical-conceptual rainfall forecasting model, incorporating assimilation of weather radar, weather station and Meteosat data, in conjunction with a rainfall-runoff model for real-time flood forecasting. The Brue catchment experimental facilities are being used to support model formulation and evaluation.

The approach also has significant computational speed advantages over schemes that use a convolution operation.

In practice, when calculating isochrones, a "Catchment Definition" algorithm developed for use with the DTM is first used to define flow path distances to the catchment outlet. Transfer of DTM path information to the distributed model then allows hillslope and channel velocities to be estimated as part of the overall model calibration process, yielding optimised isochrones and improved forecast performance. Consideration of alternative velocity models, including a form which employs slope as part of a Chezy-Manning relation, failed to provide improved performance. The final form of translation component adopted employs two kinematic routing cascades operating in parallel, one acting as a pathway for saturation excess runoff and the other for soil water drainage to groundwater (Figure 30).

Four catchments, ranging in size from 100 to 275 km^2, were used for model development, calibration and assessment: one in the Thames basin, one in northwest England, and the other two in South Wales. The results obtained show that when prevailing conditions make weather radar a good estimator of rainfall at ground level, significant model improvement is obtained by replacing data from a single raingauge by 2 km grid square radar data (Figure 32). However, the possibility of low-level enhancement of rainfall below the beam and blockage effects adversely affects the flow forecasts obtained for the hillier catchments.

Whilst no one model variant consistently outperforms the rest, the Probability-distributed Grid Model (PGM) based on a power distribution of slope gives the best overall performance. Assessments using the Grid Model with areal average rainfall data as input and using a lumped rainfall-runoff model, the PDM, allowed the value of distributed data and a distributed model structure to be tested.

The case for using either distributed data or a distributed model structure for flood forecasting is not overwhelming, at least when based on the storm periods considered for model assessment which are dominated by more widespread low pressure storm tracks. However, there is evidence that even for these storms the use of distributed forms of data and model can improve the accuracy of flood forecasts for larger catchments.

A broad conjecture, in part supported by the results of the assessment, is that a lumped rainfall-runoff model should suffice for widespread low pressure storms, particularly if the catchment is not hydrologically varied or too large. However, for storm structures whose magnitude is less than that of the basin for which flood forecasts are required, there is value in adopting a distributed approach. This is likely to be the case for convective storms which were absent from the storms used for assessment. A further potential advantage of distributed models is in their transferability to forecast flows for an ungauged catchment. Both good and bad results have been obtained; further work is needed to achieve a more resilient transfer.

For forecast updating in real time, a new state-updating form of the Grid Model has been developed and assessed against an error prediction technique. The method of state updating applies a smoothly varying adjustment to the water contents of the cascade of kinematic routing stores, the adjustment decreasing upstream, so as to achieve better agreement between modelled and observed flow at the basin outlet. This method of updating proves better than the persistence-based error predictor approach for the faster responding Welsh catchments although there is little difference overall.

A particularly important practical result of the assessment is the excellent performance of both the lumped PDM and distributed Grid Model when applied to the Rhondda and Cynon catchments in South Wales. Whilst the forecasts are obtained assuming perfect foreknowledge of future rainfall, they do seem to indicate the significant potential value of using rainfall-runoff models as a basis for flood warning. Indeed, forecasts as good as these are rarely obtained from other UK catchments served by a single raingauge. One recommendation, therefore, is to give serious consideration to implementing an operational flood forecasting system for South Wales, possibly based on the River Flow Forecasting System (RFFS) kernel developed by the Institute of Hydrology for the National Rivers Authority.

Water resource systems

This field study of flood runoff at several sites within the 50 km^2 mixed urban/rural catchment of the Cut near Bracknell was started in April 1993. Concerned mainly with combining the runoff response patterns from different land-uses, the study also includes the effects of drainage throttles, flood storage ponds, areal rainfall patterns, and seasonal variation in response. The aim is to develop models for flood estimation and catchment planning in mixed catchments, and to generalise design conditions by studying the relative frequency of individual flood events at the different sites.

Urban impacts on surface runoff and flooding depend on the underlying natural runoff response, the distribution and type of urban surfaces, and the behaviour of the urban drainage system. The impacts vary: under heavy rain, the drainage system may surcharge causing pressure surges, localised choking or flooding, and the operation of flow controls (flap valves, pumping stations, overflows, on/off-line tanks). Summer thunderstorms cause the greatest risk of urban flooding (despite dry soil conditions), while rural runoff is predominantly a winter phenomenon. Coincidence of maximum urban and rural runoff may never occur, and flood storage so determined may be unnecessary, or even counterproductive.

UK data on the response of mixed catchments are scarce. Urban catchment data come from studies of summer runoff in about 17 small (<2 km^2), fully sewered catchments, none of which included storage ponds. Data on how processes combine in the larger (<100 km^2) mixed catchments typical of catchment planning studies are rarer: only five catchments in the UK Representative Basin Network are both less than 100 km^2 and greater than 25% urban, and none has separately monitored urban and rural subcatchments. An example of the problems caused by this gap in the data is percentage runoff estimation: the Flood Studies Report equation (based on larger catchments) often predicts higher rural runoff than the urban runoff predicted by the sewer model WALLRUS (based on the small catchments). This anomaly arises from deriving the Flood Studies Report equation mainly from winter data and the WALLRUS equation from summer data; a better interpretation is that rural percentage runoff in *winter* can exceed urban percentage runoff in *summer*.

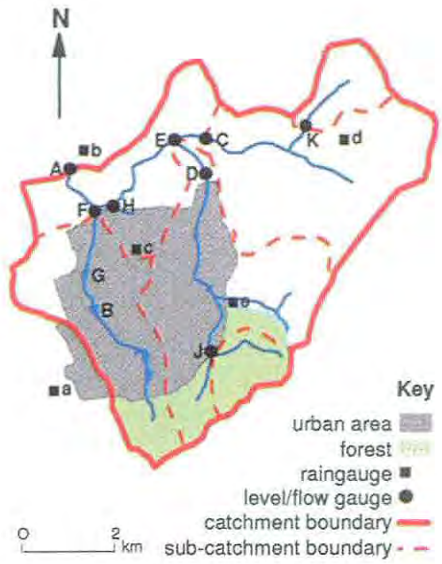


Figure 33 *The Cut to Binfield catchment*

Le bassin hydrologique de la Cut à Binfield

Figure 33 shows the catchment of the Cut to Binfield (A) including approximately 20 km² of the town of Bracknell. Typical of many urban areas in southern Britain, Bracknell is a new town in a mixed agricultural/woodland setting, with separate surface runoff and sanitary sewers, several flood storage ponds, and continued pressure for development. Flow records have been collected at Binfield for 35 years, largely covering the period of major expansion. Three small urban subcatchments draining to the Mill Pond (B) were monitored during 1975-80 and used to develop the WASSP sewer model. In 1986, as part of a catchment study, Thames NRA installed five temporary river level gauges. Three of these are still operational: Warne Bridge (C) on the rural upstream part of the Cut catchments, and Warfield (D) and the weir site (E) on the urbanising Bull Brook catchment. This latter catchment includes three major storage ponds and the outfall from Ascot sewage works.

For this study, depth/velocity monitors have been installed on the main Bracknell surface water outfall, a triple 1800 mm diameter sewer at Jocks Lane (F). Monitors have also been installed on two (B, G) of the six main storage ponds upstream and on a smaller surface outfall (H) having no upstream ponds. One of the monitored storage ponds is the (on-line/wet) Mill Pond (B), where the WASSP flow gauges have been recommissioned, and a further gauge installed to monitor pond outflow. The second pond is the (off-line/dry) Oldbury (G), originally doubling as a horse paddock, but now redeveloped as a wasteland under a 'car-park on stilts'. Additional wooded (J) and agricultural (K) subcatchments are also due to be monitored. Recording raingauges have been installed (a,b,c,d) and further rainfall data are available from Chenies weather radar.

This study is being supported by MAFF with the co-operation of the NRA Thames Region, Thames Water, Bracknell Forest Borough Council, and ADS Environmental Services.

Water resource investigations

The Institute supports British consulting engineers and international agencies such as the World Bank, WMO and the UN in analysing a number of complex water resource problems. Two examples of this applied research are presented to illustrate the type of problems that are addressed. The studies undertaken cover most aspects of engineering hydrology, including flood and low flow estimation, real-time flood forecasting, groundwater exploration and development, urban hydrology, reservoir operation and water resources studies. Projects may last from a few weeks to one or two years, but a typical study involves work by several staff over a period of a few months.

Lesotho Highlands water project, Southern Africa

Lesotho is often referred to as the mountain kingdom: the elevation of the land surface ranges from 1400 m to over 3000 m. It is a country with few natural resources apart from water, which its neighbour, the Republic of South Africa, lacks. A major scheme is currently being implemented by the two governments which will ultimately transfer some 2200 million m³ of water annually (equivalent to the average freshwater flow of the River Thames at London) into the headwaters of the Vaal river system, which feeds the Johannesburg-Pretoria industrial area. This entails construction of up to seven major dams, a series of transfer tunnels, some with pumping, and a hydropower scheme on the final outfall tunnel to South Africa.

- **Real-time Flood Forecasting System — Hong Kong** (for Drainage Services Department, Hong Kong)
  Development of a real-time flood forecasting system for the 70 km² Indus catchment in the New Territories. The system had to cope with the very rapid flood response caused by extreme typhoon rainfalls on small, steep catchments.

- **Chichester flood study** (for NRA Southern Region)
  Evaluation of the return period of the January 1994 flood event using historic water level records. Investigation of the particular hydrogeological conditions which gave rise to the flood.

- **River Frome flood study** (for NRA Severn Trent Region)
  Estimation of design inflows for a hydraulic model of the lower Frome catchment to provide maps of flood extent for a range of return periods.

- **Arab Potash project — Jordan** (for Arab Potash Company)
  A study to examine the feasibility of integrating surplus wadi baseflows and abstractions from two wellfields. Groundwater flow models were designed for each wellfield to examine alternative abstraction scenarios and the impact of competing demands for water supplies.

An annual royalty payment will be made to Lesotho by the South African government. However, the transfer treaty calls for this to be calculated on the basis of "an agreed hydrology for the years 1930 to 1983", and the two parties have been discussing for some time the appropriate inflow series to be used. The Institute was initially called in to review previous studies, and then to produce suitable flow series on which to base this important calculation.

Flow records begin in the late 1960s, but there are rainfall records prior to this. The method adopted was that of stochastic extension of the annual flow series, but using the pre-1960s rainfall record to steer the stochastic generation, such that the generated flows make the best possible use of all available information contained in the longer rainfall records. Essentially, the model is based on a multiple regression approach, using the information from the long-term rainfall records to estimate flows in years with no flow data. However, in addition the model can make use of years where the flows are not known precisely, but can be defined by realistic upper and lower bounds.

These bounds are determined by assuming, for example, that the annual flow is equal to that at the next flow gauge downstream (an upper bound). A lower bound can be set by assuming that the flow in any year is equal to the sum of the observed monthly flows plus flows transferred from upstream stations for missing months. Similar bounded rainfall series may also be utilised by the model, such that information contained within incomplete rainfall records may nevertheless be utilised by the model. The uncertainty in each generated annual flow value which results both from unexplained variance and from uncertainty in parameter estimation is included as a random, or stochastic, element.

The key new technique applied in this modelling approach is that of Gibbs Sampling, which provides an objective method of generating multivariate data from a multi-dimensional probability distribution. Here, this would be the joint distributions of all the unknown values: model parameters and unobserved data. This is believed to be the first use of such a technique for water resources modelling.

Lake Victoria water balance study, East Africa

Lake Victoria is the largest lake in Africa, and has a surface area of some 67 000 km^2, roughly equivalent to the area of Belgium and The Netherlands combined (Figure 34). The lake has a single outlet at Jinja in Uganda: since 1954, this has been regulated at the Owen Falls dam, which now generates most of Uganda's electricity requirements, with a surplus for export to neighbouring countries. The outflow from the lake is the main source of water for the White Nile, making a small but important contribution to the flow in the main Nile down to Cairo.

Figure 34 *Map of Lake Victoria and catchment*

Carte du Lac Victoria et de son bassin hydrologique

Despite the construction of Owen Falls dam, there still remains a massive potential for additional hydropower development both there and further downstream in the White Nile. The key question for planners is what will be the future behaviour of lake levels and the lake outflow. The Institute has made three major studies of the hydrology of Lake Victoria, supported by the Overseas Development Administration. Methods used have included monthly and annual water balances, and multivariate stochastic simulations of future lake levels. Figure 35 illustrates the observed and predicted lake levels from 1955-1990.

Most recently, a preliminary assessment has been made of the possible impacts of climate and land use change on lake levels. These studies have helped provide a better understanding of the response of the lake to past climatic events and have provided several possible scenarios for the behaviour of lake levels and outflows in the future. The existing hydropower plant at Jinja is currently being rehabilitated and an additional 80 MW generating capacity has been installed based on our projections on future lake outflows.

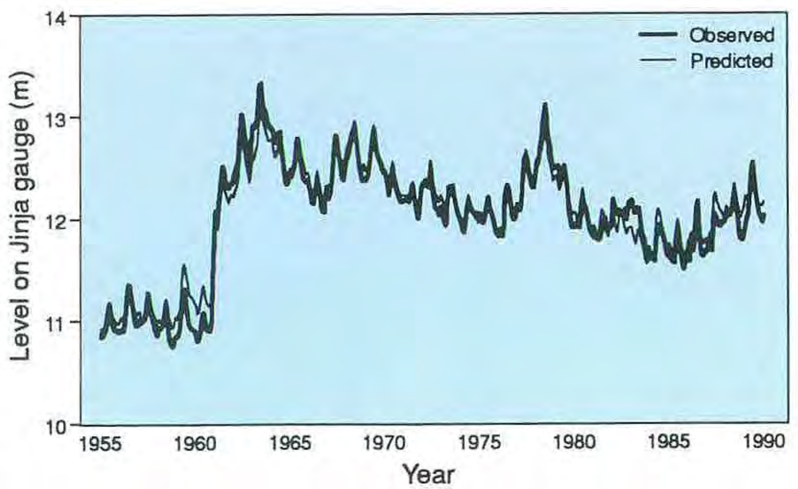


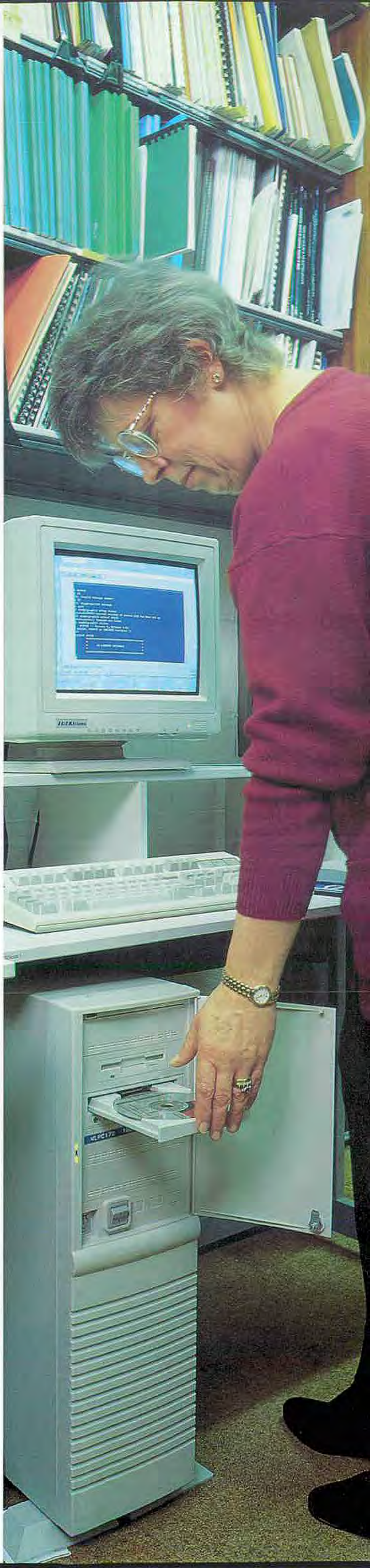
Figure 35 *Comparison of observed and predicted lake levels*

Comparaison entre les niveaux constatés et les niveaux prévus du lac

Information Hydrology

This new Division seeks to provide key data essential for regional water management or site design and to communicate that information via all the modern media required by users. While first priority is given to the United Kingdom, the Division's remit is pan-European and will become increasingly international with time. The Division seconds staff to the International Association of Hydrological Sciences Press, which is based at Wallingford, and also provides editorial and publishing support to the British Hydrological Society. To achieve our objectives, our mission is to:

- collate, quality control and publish time series and spatial datasets that describe any part of the hydrological cycle over a region;
- reveal the coherent structures within environmental datasets relevant to the water industry;
- program to commercial standards the science findings of the Institute as well as publishing them through every relevant outlet in printed and electronic form;
- use metadata cataloguing and wide area networks to collect and distribute the facts on which the subject flourishes;
- bring advances in information technology into the hands of water scientists in NERC, the UK water industry and academia.



The Institute of Hydrology Digital Terrain Model

The increasing availability and utility of spatial data in digital form, whether in conventional databases or more particularly within Geographical Information Systems (GIS), has had a profound effect upon how hydrological research is carried out. The ability to characterise and associate areal properties within regions and catchments, freed of the constraints imposed by conventional maps at various scales, has led to methods of rapid, automatic parameter derivation for use in models or for display purposes.

A powerful tool in blending morphology, drainage and areal properties has been under development at the Institute for over five years. This is a hydrologically appropriate digital terrain model (the IHDTM). Derived from digital 1:50 000 scale contours leased from the Ordnance Survey (OS) and rivers digitised from OS 1:50 000 maps, the IHDTM has square grid nodes at a spacing of 50 m and an elevation stored to a vertical resolution of 0.1 m. DTMs based purely upon elevation sampling — which is how contours are derived — have drawbacks when used for hydrological analysis; in areas of low relief insufficient elevation detail is available to predict the location of drainage channels accurately.

The novelty of the IH approach is in harmonising the terrain model with a river network. This ensures that, throughout the DTM, the drainage profile to the digitised rivers is consistent at every node closest to or on the river.

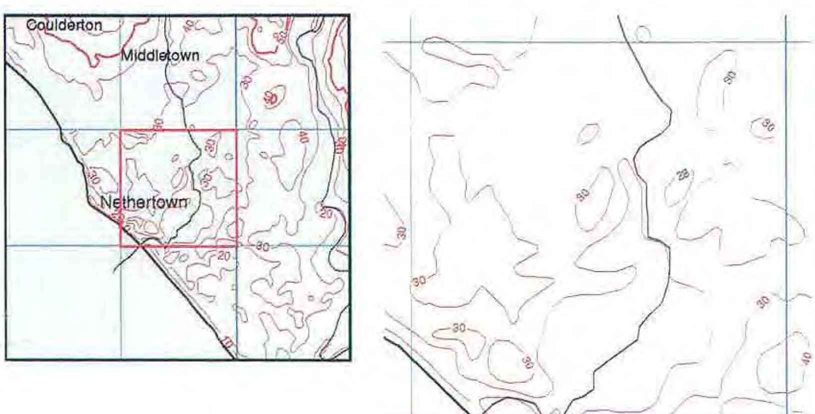
Each grid node has five classes of information held: ground elevation; surface type (land, sea, river, lake); inflow pattern — i.e. which of the surrounding eight nodes drain to the central node; outflow direction — which one of the surrounding eight nodes is downstream of the central node; and cumulative catchment area — the number of grid nodes draining through the node in question. In areas of very low relief, such as fenland areas, where drainage may be conditioned by tides or pumping, drainage directions are inserted by following the advice of regional agencies. In other areas, local depressions or "sinks" apparently have no outlet; the DTM generation software ensures that these sinks are "unblocked" and that water would be eventually routed down the drainage channels.

The IHDTM dataset is stored on an Oracle RDBMS and occupies approximately 900 Mb of storage. Figure 36 shows the progression from an OS source map to digital vector data (rivers, coastline, lake and contours) to an elevation grid. Note the preparation of a continuous river from the original, interrupted dataset (e.g. at road crossings, place names, urban areas).

A feature of the DTM and its holding inflow patterns and outflow directions is that the whole logical drainage grid may be illustrated (Figure37(a)). These patterns allow an automatic derivation of catchment areas: a highlighted point and its associated catchment are overprinted on the same figure. Using catchment area as a filter, plots may be generated which show a drainage network of a density similar to conventional maps. Figure 37(b) has the filter set at 0.2 km^2 along with the 1:50 000 digitised river dataset. In addition, the widths of the drainage channels have been displayed as a function of the catchment area upstream of any given point. Whilst the linkage of a catchment area with river flow is not a direct relationship, such a variable width could be used as a crude surrogate for river flow. A perspective view of the portion of the DTM used in these figures is shown in Figure 37(c).

The IHDTM allows users to quantify morphological features both to a high resolution and as area-based averages. One of the most significant applications is the derivation of slope measures and their integration into hydrological models. Before DTMs were available, parameterisation of slope was largely confined to simple river channel measures, usually moderating the effects of headwater and catchment outfall extremes or sampling valley profiles. Measures of overland slope are easily available from the IHDTM, but some mechanism of representing both the range of slopes and their frequency of occurrence is desirable. One approach has been to generate a series of classes for slopes and curvature, to identify areas which favour concentration of runoff. Catchments may be characterised by the summation of slope class members.

As the IHDTM has an intrinsic structure related to the drainage network, the ease of derivation of some measures is transformed. The hypsometric curve is a plot of cumulative area against elevation: Figure 38 depicts hypsometric curves



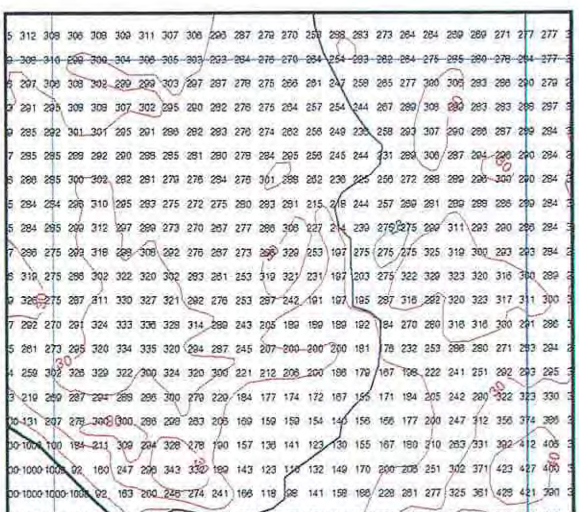
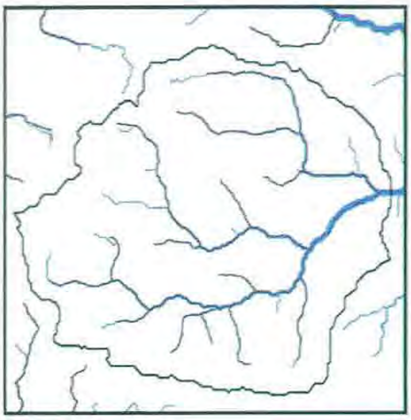


Figure 36 *The progression from an OS source map, through digital vector data (rivers, coastline, lakes and contours) to an elevation grid*

Méthode de progression partant d'une carte IGN et passant par des données vectorielles (rivières, littoral, lacs et contours), pour arriver à un quadrillage d'élévation

a



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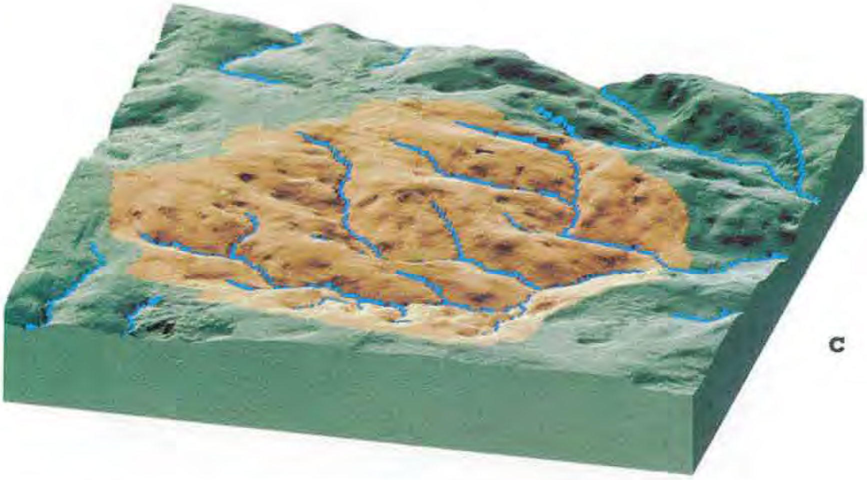


c

Figure 37 *Three views of a catchment; (a) Flow directions based on a 50m grid; (b) Drainage network with threshold of 0.2 km and width proportional to catchment area; (c)Perspective diagram using 50m height grid*

Trois vues d'un bassin hydrologique : (a) Sens d'écoulement basés sur un quadrillage de 50 m; (b) Réseau de drainage avec un seuil de 0,3 km et une largeur proportionnelle au bassin hydrologique; (c) Schéma en perspective utilisant un quadrillage de hauteur de 50 m

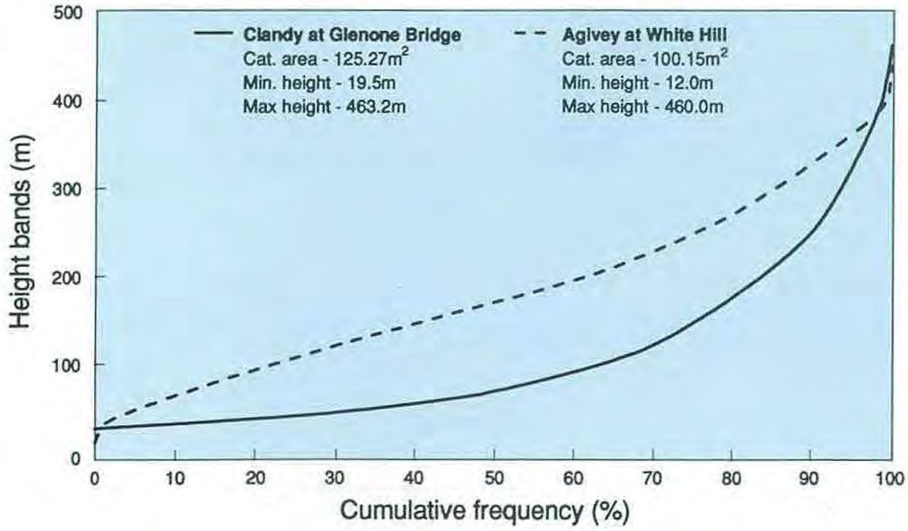


Figure 38 *Hypsometric curves for two catchments within the River Lagan basin, Northern Ireland*

Courbes hypsométriques concernant les trois bassins hydrologiques dans le bassin de la River Lagan, en Irlande du Nord

- **Mass data transfer**
  6.7 Gb data transferred to an Oracle RDBMS, including the National River Flow Archive and digitised UK river networks.

- **The 1988-92 drought** (for DOE/NRA)
  A major documentation of a remarkable climatic event which stimulated reviews of water management policies throughout much of Europe.

- **Northern Ireland network review** (for DOE NI)
  Baseline review of user-perceived flow monitoring needs with an innovative methodology to assess data utility for gauging station records. Recommendations aimed at establishing a resilient network able to meet the hydrometric needs of Northern Ireland in the 21st century.

- **Management of spatial data**
  Providing efficient management and access to spatial data across IH. To ensure access within the Arc-Info GIS system, datasets were duplicated or links with the Oracle RDBMS effected.

- **Areal rainfall estimation** (for the water industry)
  Implementation of the Voronoi interpolation method — this ensures a smooth surface which passes through all the individual raingauge locations. Novel weighting of data values by an optimised power of their long-term average.

- **European rivers report** (for European Environment Agency)
  Review of digital river mapping in the EC, co-authored by Danish National Environmental Research Institute.

- **Advanced hydrological mapping package**
  The Dgener8 package will allow users to construct hydrological maps from spatial and time-series datasets, using the whole range of IH output devices.

- **Database utility and access support**
  Provision of utilities to render the UNIX system more friendly and provide efficient retrieval routes to IH data systems.

plotted for two catchments within the River Lagan basin in Northern Ireland, used as a characteristic to depict the distribution and proportion of gauged areas within elevation bands during a review of the flow gauging network.

The British Geological Survey group at Wallingford has used the catchment boundary derivation to illustrate the results from the geochemical surveying of areas around disused mines in Wales and Northern Ireland. The IHDTM structure has been configured to enable the user to climb up the river network, identifying drainage paths and measuring their length. Distributed flood forecasting models have been under development (see page 26) which associate estimates of velocities of travel along the land and river components of these paths.

From any point within a catchment, a travel time of runoff to the outlet may be calculated and a pattern of isochrones — lines joining points of equal travel time to the basin outlet — established for the catchment. The rainfall input to these models is from weather radar data, based upon a 2 km grid at five-minute intervals; additional input from the DTM is an average slope calculated from the 1600 points associated with individual cells in the rainfall grid. After evaporation loss has been subtracted from the rainfall, this slope is used as a control in apportioning the remaining rainfall between runoff and infiltration into the soil.

An area of potential application relates to the ability of the IHDTM to describe aspect — that is, the angle and direction of the normal to the land surface. This feature may permit better estimation of parameters which have a directional component in addition to a sensitivity to altitude, such as rainfall in upland areas where the representativeness of catches has been a matter of concern for some time.

Further details are available in a DTM newsletter available freely from *David G Morris* at the National Water Archive at the Institute.

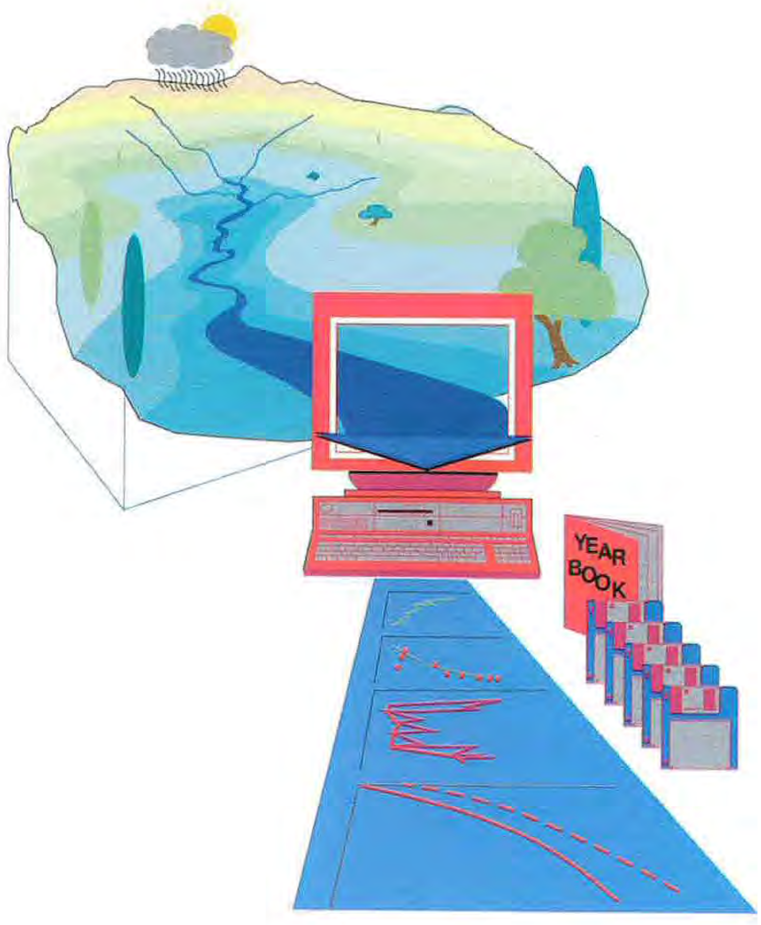
Hydrology software

The Institute of Hydrology seeks to encourage use of its research for the benefit of mankind. To achieve this end we aim to transfer appropriate scientific expertise and knowledge, for rapid and innovative application, to a wide range of academic, industrial and Governmental users. One of our chosen routes is via the production and sale of original software, derived from the results obtained by the scientists and engineers of the Institute.

Products chosen to be put in the market place, through the Professional Software Series, are developed within a quality management system to ensure a software tool which is best suited to hydrological practitioners. In this way, the hydrological knowledge developed in the Institute is transferred to many outside organisations through each software product, encouraging its use in engineering, planning and education.

A Hydrological Software group was formed in 1989 specifically to explore the development of user friendly, attractive software packages for microcomputers, encapsulating scientific methodologies and techniques researched at the Institute. Eight major software packages make up the portfolio of 1993/94 Institute of Hydrology Professional Software products. These are:

- HYDATA v3.1a — Hydrological database and analysis suite of programs
- HYFAP v1.0 — Annual maximum frequency analysis program
- HYQUAL v1.0 — Water quality database
- HYRROM v2.0 — Conceptual rainfall runoff model
- Micro-FSR v2.0 — Design flood estimation program for Flood Studies Report implementation, reservoir routing and CIRIA balancing pond simulation
- QUASAR — River water quality model with dynamic and probabilistic options
- GRIPS — Groundwater information processing system
- Micro-LOW-FLOWS — Low flow and flow duration curve estimation procedures



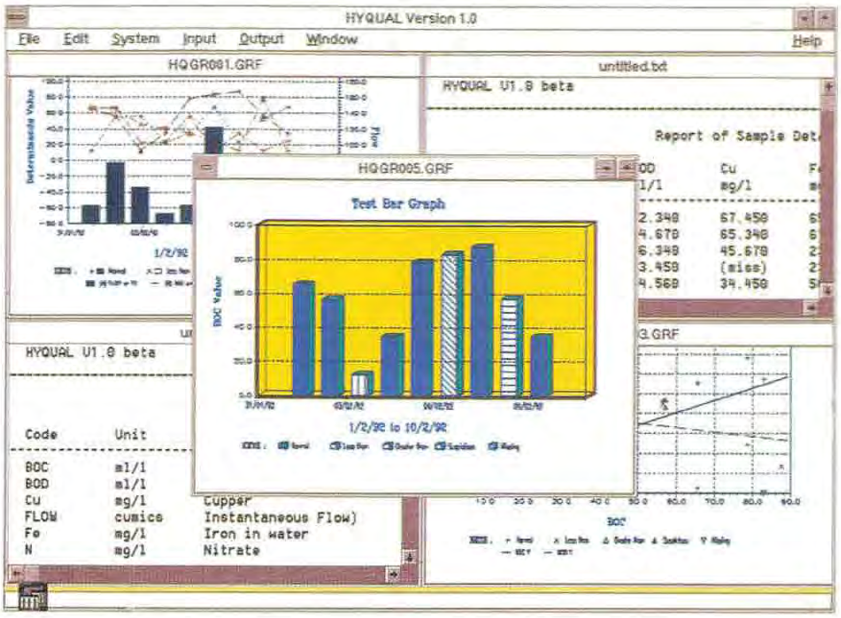


Figure 39 *HYQUAL user interface screen*

Ecran d'interface utilisateur HYQUAL

The existing software packages are supported through a help desk, and are maintained with a programme of development to expand the scientific functionality, and to improve user interfaces to keep pace with the industry standards.

HYDATA: successful scientific dissemination through software

IH originally produced a PC-based hydrological database for internal use more than 20 years ago, based on the knowledge gained running the UK Surface Water Archive, and hydrological analysis experience worldwide through commissioned research projects. HYDATA proved so popular to customers of commissioned research projects that IH chose to supply the software for outside users, to encourage the efficient storage of hydrological information, enable verification of data, rapid visualisation, and common use of IH hydrological analysis techniques by world-wide hydrological practitioners.

HYDATA not only allows the regular collection and efficient management of hydrological information, it also encourages the standardisation of operational and water resources analysis methods, thus facilitating the comparison of results from different areas. The package is undergoing continual upgrades, to include new appropriate IH developments and in response to ideas from users. Users are supported through the IH software help desk. Valuable input from customers has ensured that HYDATA is a tailor-made software product for hydrological practitioners with a Windows development plan for the future that will allow alternative relational database technology links.

WMO and ODA have long recognised the importance of suitable tools and training for hydrological practitioners and have jointly sponsored IH to undertake training in Nairobi, Kenya, through annual workshops within the regional postgraduate diploma course in operational hydrology. This has culminated, in 1994, in the designation of the Institute for Meteorological Training and Research in Nairobi as the first regional training centre for HYDATA, and in the production of a complete HYDATA training package by IH including lecture notes, overhead transparencies and exercises. The training course describes the hydrological techniques and their suitability for common problems as well as the operation of HYDATA.

The success of HYDATA sales and training has led to its use in more than 50 countries worldwide, including over 20 in Africa. As a result of this success it has the potential to underpin regional research. An example of a current

- **Metadata Cataloguing** (for global change community)
  Entries for the gamut of the IH data holdings have been passed through to the NERC's corporate Digital Data Catalogue and so to GENIE.
  E-mail address :
  MLL@UK.AC.NWL.IA

- **HYQUAL released: the water quality database and analysis system**
  The package and training were provided to British Airports Authority for management of water quality information at six airports.

- **Development of SWIPS to beta-test release version**
  The Soil Water Information Processing System will be available on general release in 1994/95.

- **Software quality assurance manual**
  Development of a QA manual for software development within IH to ensure high-quality software solutions for users.

- The Water Information System, WIS, has been installed in the IH Stirling office to act as an integrated archive and information system, in support of the experimental catchment and regional water data.

- Implementation of WIS at the technical headquarters of National Power in Swindon continues: the system is to be used as the company's primary environmental monitoring and planning application.

- Further research is being conducted into the translation of data formats, the transfer of large volumes of hydrological data, and the standardisation of data-dictionaries, as part of several related projects requiring the establishment of large environmental databases.

research project benefiting from this is the recently-launched Africa FRIEND project, a collaborative venture between the nine countries of southern Africa, organised through IH. One of its main objectives is to develop region-wide methods of low flow estimation in ungauged catchments. HYDATA has been adopted as the standard database and analysis system for this project, together with the HYDATA utilities for transferring hydrological data between participating countries. SADC wish to retain HYDATA as their archive for the results of the research and continued future development. Thus HYDATA places well-researched hydrological techniques in the hands of practitioners, encourages dialogue between users and IH, underpins regional hydrological research, and acts as an ambassador for the professional IH approach.

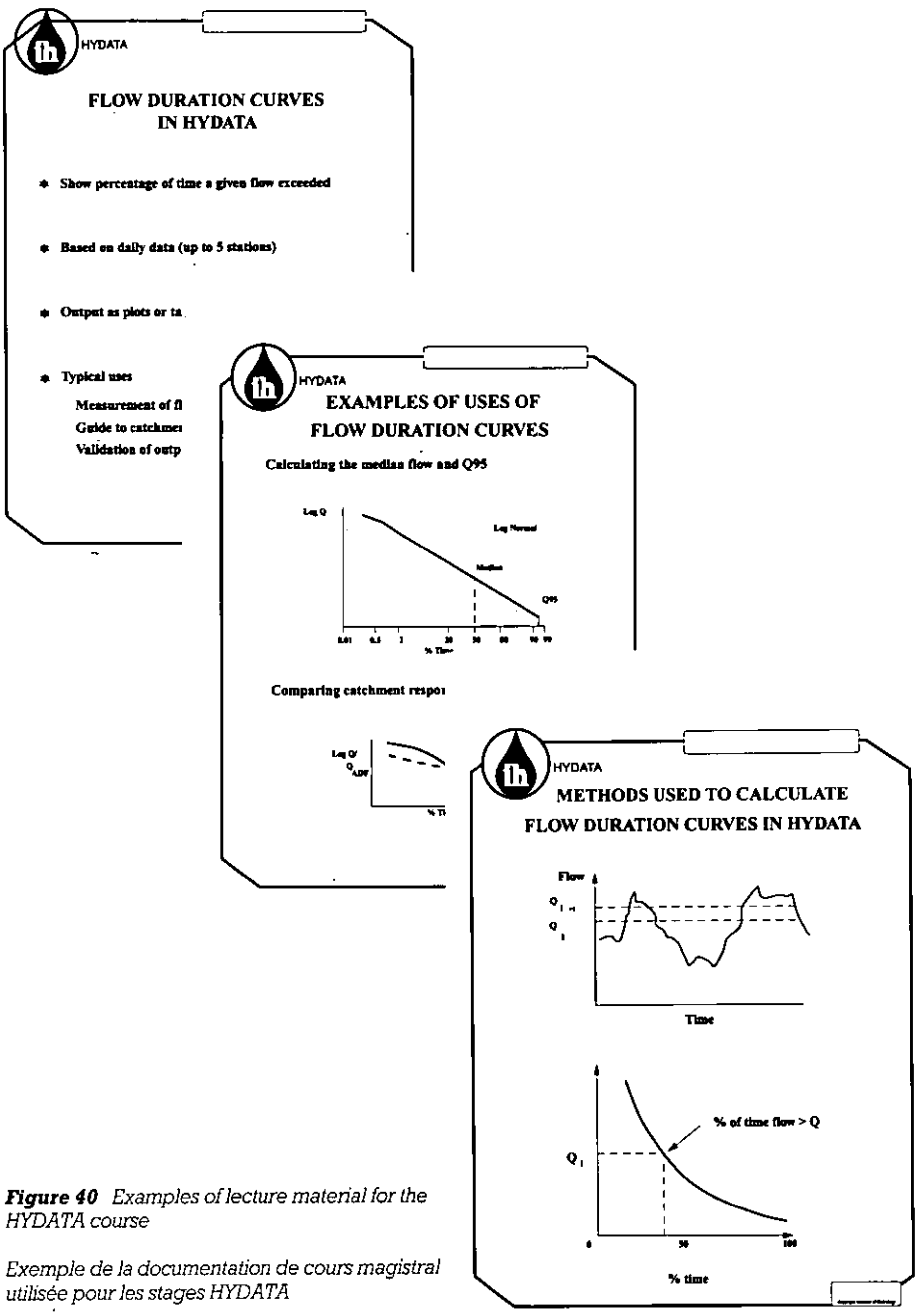


Figure 40 *Examples of lecture material for the HYDATA course*

Exemple de la documentation de cours magistral utilisée pour les stages HYDATA

Hydrologic geographical information systems

Substantial experience has been acquired in the implementation of environmental databases and information systems over the past five years, during the design and development of the Water Information System, WIS. This expertise is now being applied to the challenges of the Land-Ocean Interaction Study, LOIS, in providing data management support to the river-basin component of the River-Atmosphere-Coast Study, RACS(R).

The Rivers Datacentre's principal objectives are to collate, organise and maintain hydrological and related data for the LOIS research programme, in support of the research staff involved in the study itself:

- Collation, standardisation, maintenance and dissemination of large volumes of diverse data relating to the study area of the Humber Basin and adjacent catchments emptying into the North Sea;
- Establishment of hardware and software platforms appropriate to an archive of this scale;
- Preparation of data dictionaries, formatting standards and transfer protocols to manage the inward and outward flow of data and information.

With such broad multi-disciplinary scientific activity, this preparation has already involved substantial amounts of detailed liaison with the other research and data-management centres contributing to the LOIS project. In this way, common requirements for the various components of the programme are being met in a uniform manner, across the variety of establishments involved in the management of hydrological, ecological, geological and marine databases. The aim is to provide as consistent an approach as possible, with a minimum of bureaucratic hindrance to the provision of a comprehensive and accessible data infrastructure for LOIS research personnel. With planned volumes starting at 10 Gb, increasing to 20 Gb as new LOIS data accumulate, this is of great importance to the success of the project as a whole.

The Water Information System has been selected as the strategic core of the suite of software required for the datacentre,

Figure 41 *The Yorkshire Ouse is the most intensively studied river in the LOIS programme*

La River Ouse, dans le Yorkshire, est la rivière la plus intensément étudiée dans le programme LOIS

based on the Oracle RDBMS. The WIS database is unique in its ability to store large volumes of spatial, time-series and determinand data within a unified logical and physical model, and is thus a highly appropriate means of meeting the requirements of the LOIS project. The system provides a range of data-manipulation and presentation functionality, through which the vast amounts of data generated may be accessed efficiently and effectively. This achieves the primary aim of any environmental information system, in the transformation of raw data into intelligible and usable information.

WIS has been installed on new hardware at IH to support the preparation and loading of base data from a range of sources, IH itself supplying digitised river maps, flood studies data, and a hydrologically-appropriate digital terrain model for the project. A range of associated data is being collated from three regions of the National Rivers Authority, the Ministry of Agriculture, Fisheries and Food, HM Inspectorate of Pollution, two universities, and other research institutes. The combined archive is planned to cover water quantity, quality, abstraction and discharge data; land use and land cover data; spatial data; and population, census, and administrative boundary details.

Over the past year, additional storage space has been procured and installed at IH to accommodate the data, the database software has been installed, and arrangements have been made for the migration of historical data from the NRA into the new archive. A first set of dictionaries of features, chemistry, consents, abstractions, hydrology and biology have been compiled to define the data, and translation tables have been prepared to convert determinands from the contributing systems into the standards set for the LOIS project.

A particularly daunting challenge has been identified in the problem of translating and standardising data from such a range of sources. The initial batch of data from two regions of the NRA has involved nearly twenty different data transfer formats, and common standards for coding systems, definitions or units for the variety of data types which are to be stored by the system have not yet been defined on a national scale. It is hoped that the results of these efforts may be useful in defining new standards for hydrological and environmental data storage and transfer.

In this way the section is encountering the same obstacle as that facing so many environmental researchers today: as our understanding of the integrated nature of the environment improves, so the breadth of study and volumes of data increase at dramatic rates. The technical challenge is to organise and archive these data as effectively and efficiently as possible, in order to present a coherent, reliable, and usable summary of information to researchers, so that the conclusions drawn are based on incontrovertible fact.

The Library service

The Library houses a comprehensive collection of books, reports and periodicals in the hydrosciences. Over the year demands upon the service from both Wallingford site staff and external users continued to increase. Library statistics show a holding in excess of 26 000 items, occupying a potential shelf length of more than 400 m. Besides 6200 books, it has the United Kingdom's most comprehensive series of hydrology and water environment journals from around the world.

A growing number of visitors come to the Library each year to make use of our facilities — there were 165 in 1993/4. We also handled 864 external telephone enquiries during the year, many of them associated with Institute publications. A wide variety of services and resources were provided for readers, and we continued to expand our stock, acquiring relevant new journals and books published in our subject area. Holdings of books and reports were recorded on our online database IHLIB.

Information services included selective dissemination of information from Current Contents on Diskette, and retrospective bibliographic retrieval from online and CD-ROM sources. Our CD-ROM collection is rapidly expanding: notably Geobase (which includes Geographical Abstracts) was added in 1993/4. Our emphasis on tuition for those scientists who wish to use CD-ROMs for their own literature searches has proved increasingly popular. Readers have also been encouraged to register for the BIDS ISI service, available over JANET (Joint Academic Network): this gives access to a range of online Citation Indexes.

Income from sales of the Institute's publications, for which the Library is responsible, showed a considerable increase during this period. For part of the year we were able to employ a part-time professional information scientist, which enabled us to improve and develop various aspects of the service.

Our activities continue to be hampered by lack of space — this year more shelving has had to be moved in to accommodate our reports collection, further reducing the number of seats available for readers. A large proportion of the stock remains in closed storage.

International Association of Hydrological Sciences Press

It is now 70 years since the first in the famous red book series covering IAHS conferences was published. In the past year ten more have been produced, including No 222 on *Future Groundwater Resources At Risk*. The entire series is available in the IH Library for consultation. The role of the Institute staff who are seconded to the Press is to manage professionally the complete publishing and sales process under the guidance of the IAHS Secretary General, Mr Henny J Colenbrander, who is based in the Netherlands.

The range of subjects covered by this series is very wide indeed as might be expected in such a multi-disciplinary science as hydrology; topicality has also inevitably influenced the coverage too. IAHS is proud of its achievement in gaining such a wide international authorship and these red books form the best English language source of hydrological analysis for many countries of the world. To ensure that developing countries are not denied access to this knowledge base, IAHS Press delivers a free copy of each publication to 49 contact libraries around the world.

The publishing success of the year was the *Hydro GIS* volume for the Vienna conference (Publication 211) which sold out so rapidly that it has been reprinted. The *Hydrological Sciences Journal* continues to provide an outlet for scientific results from a wide international background: 33 papers appeared in the six issues covering 1993. The entire Journal contents, which commenced in 1956, have been indexed by author, but they need to be computerised (as do the red book papers) to permit searches by topic and locality.

Land-use and Experimental Hydrology

The way the land surface of the planet is used and managed strongly influences both the movement of water and waterborne substances within the hydrological cycle.

It is extremely important, therefore, to study the ways in which land use — and particularly land-use change — impacts on hydrology. Recognising that the largest land-use changes occurring on the planet today involve deforestation and afforestation, it is appropriate that much of the work of the Division is related to forest hydrology. These studies range in scale from understanding how individual leaves are wetted by raindrops of different sizes to determining how deforestation may influence the water balance of the whole of the Zambezi basin. The geographical scope of the work is global. Catchment studies at Plynlimon, Balquhidder and Coalburn, together with recent studies under the LOIS programme (see page 36), provide long-term data sets of the impacts of land use and land-use change in the UK. These are balanced by experimental studies of the impacts of plantations of fast-growing trees in India and Sri Lanka. More recently, using knowledge gained elsewhere, the Division is helping African countries to determine how land-use change affects the water balance of African lakes.

These experimental studies, and those of the other Divisions, require "state of the art" instruments, and instrumentation services for the whole Institute are developed and provided by the Instrument Section within this Division. Our mission is:

- the development of a holistic understanding of the impact of land use and other anthropogenic changes on hydrology, both within the UK and overseas, as a means towards improving quality of life and economic wellbeing;

- improving predictions of the impacts of land use change upon catchment water yield, floods, low flows, subsurface water and waterborne fluxes;

- developing and supporting "state of the art" hydrological instrumentation systems to further IH science and for commercial exploitation.

Land use and water efficiency

There is now abundant evidence that coniferous afforestation in the UK increases annual water loss to the atmosphere (and so increases water supply costs to the nation), but it is far from clear at exactly which stage in a forest plantation rotation these losses become significant. A review of the first 25 years of the Institute's long-running catchment study at Coalburn in Cumbria has shown that use of water by the slowly growing plantation forest is only now — some 20 years after planting — approaching that of the preceding moorland grass cover. There is also still much to be learned about the within-year impacts of forestry, both on flood flows downstream and upon the dry weather flows of rivers.

Rather more is known about the behaviour of plantation forestry in more tropical regions. In particular, the Institute has been heavily involved with work to elucidate the effect of *Eucalyptus* species on water supplies in southern India — long a *bête noire* amongst conservationists, who often blame these species for depleting groundwater reserves and causing village wells to run dry. The results are complex: at some experimental sites eucalypt plantations use no more water than indigenous forests but at one deep-soil site the water use is considerably higher and exceeds the annual rainfall. At all sites, the water use of trees exceeds that of agricultural crops. This is because forests are believed to consume more water than other vegetation types for three main reasons: (1) trees are able to abstract soil water from greater depths, (2) their aerodynamically rougher canopies lead to higher evaporation rates in wet conditions and hence higher interception losses, and (3) they are there all the year round. Further work is being carried out on the water use efficiency of different tree species, to identify those most suitable for planting in areas of restricted water supply.

Experimental catchments

The wise use of upland water resources requires the acceptance of environmental responsibility as well as enjoyment of the commercial benefits. This is recognised by a number of public and private organisations involved with water issues in Britain. For instance, the remits of the National Rivers Authority, the Department of the Environment, the Water Companies, the Forestry Commission, MAFF, the Scottish Office and the Welsh Office all include an obligation to sponsor research into the links between the atmospheric, terrestrial and aquatic environments. The aim is to ensure that sensible and sustainable exploitation of water resources is compatible with water and nature conservation, minimisation of pollution, amelioration of flooding threats and the maintenance of low flows.

Over a period of some 25 years, the Institute has developed a thriving research programme, studying — in representative areas of Britain — all hydrological aspects of the various phases of the forestry cycle: afforestation, maturity, clear felling and the second rotation.

The development framework in the uplands seems set to change, bringing with it increasing needs for environmental research. Higher EC standards for potable water will stimulate a shift towards the high quality water in the uplands at the expense of more polluted river and groundwater from the lowlands of Britain.

The quest for less dependence on non-fossil-fuel or power generation will introduce a conflict in the storage/discharge rules of major upland reservoirs as more of these are fitted with electricity generating turbines. As the demand for agricultural products from the uplands decreases, there is likely to be a move towards a second wave of forestry development. This will not be for strictly commercial or strategic reasons but as an alternative to set-aside, as an environmental protection measure, and (because of more attractive and imaginative planting schemes) as an incentive for tourism and leisure activities.

Increased forestry activity of a new type will bring with it fresh questions about the impacts of ground preparation during afforestation in the uplands, and the longer-term changes associated with canopy closure: increased evaporation, reduced streamflow (particularly low flows), nutrient losses, increased acidic inputs and changes to freshwater ecosystems. This could include losses of certain macrophyte and invertebrate communities and reductions in the populations of salmonid fish resulting from changes to the food chain and changes to the physical habitat such as the structure of sediment deposits for spawning, shading and temperature and direct chemical toxicity from acidity and associated metal pollution. Expansion of the area drained and planted for forestry will also have impacts, some of them hydrological, on the remaining areas of semi-natural grassland and blanket mire that are highly valued for nature conservation.

The next phase of afforestation will have the benefit of the land-use change studies already in place: Coalburn, Balquhidder and Llanbrynmair (afforestation), Plynlimon and Balquhidder (clear-felling). The Llanbrynmair data have been subject

Figure 42 *Excavation of the modelled flood alleviation channel on the River Spey*

Creusement du chenal d'atténuation des crues sur la River Spey to preliminary analysis during the past year: compared with an unforested control catchment (the Delyn), streamflow in the forested Cwm catchment has reduced in the long term, following an initial increase caused by drainage and consequent dewatering of the catchment. It also appears that low flows (generally in summer) have decreased in the forested catchment at Llanbrynmair relative to the control, although there is little evidence of an absolute decrease in low flows. This finding will be of great concern to both the forestry and water industries, as it confirms the predictions from a modelling study done at Balquhidder. To some extent, however, it contradicts results from the Coalburn afforestation study, which has indicated a sustained increase in low flows in the special circumstances of that study which may be explained by the drainage of deep peat during a period characterised by generally increasing streamflow.

As well as land-use changes there are other less predictable changes occurring in the uplands that can be identified by ongoing hydrological monitoring programmes. The characterisation of climatic variability is a valuable by-product of the use of control catchments to isolate the effects of land use change. Thus the Wye catchment and its sub-catchments at Plynlimon, the Delyn catchment at Llanbrynmair and the Upper Monachyle catchment at Balquhidder — all moorland/grassland catchments — have shown long-term variations in rainfall, streamflow and possibly evaporation that, once quantified, will give a better indication of the important climatic controls on upland hydrology. This will lead to improved calibration of hydrological models that can then be used with more confidence to predict the potential effects of various land use change and climatic change scenarios. In particular, the THISTLE (upland evaporation) model, designed to estimate the daily evaporative losses from different upland vegetation types including forestry, is being further developed. The within-year water balances at Plynlimon and Balquhidder have indicated that groundwater recharge, storage and discharge is far more significant than was originally thought at the beginning of any of these experiments. This has led to the recent installation of a network of boreholes at Plynlimon for monitoring water level and chemistry. This will enable the eventual introduction of better calibration of the groundwater component of both hydrological and hydrochemical models of upland catchments.

Other aspects of climate change are also being studied at Plynlimon. Climatic and hydrological changes, as well as anthropogenic sources of pollution, are responsible for variations in acidic inputs to ecosystems and, by causing natural changes in wetness and chemical content of soils, are also responsible for modifying the rate of gaseous fluxes to and from the atmosphere. Some of these, particularly carbon dioxide and methane, are important greenhouse gases, and there is the potential for gross changes in concentrations of these gases in the atmosphere as the extent of perennially wet areas is reduced by direct human actions, i.e. drainage or vegetation cover

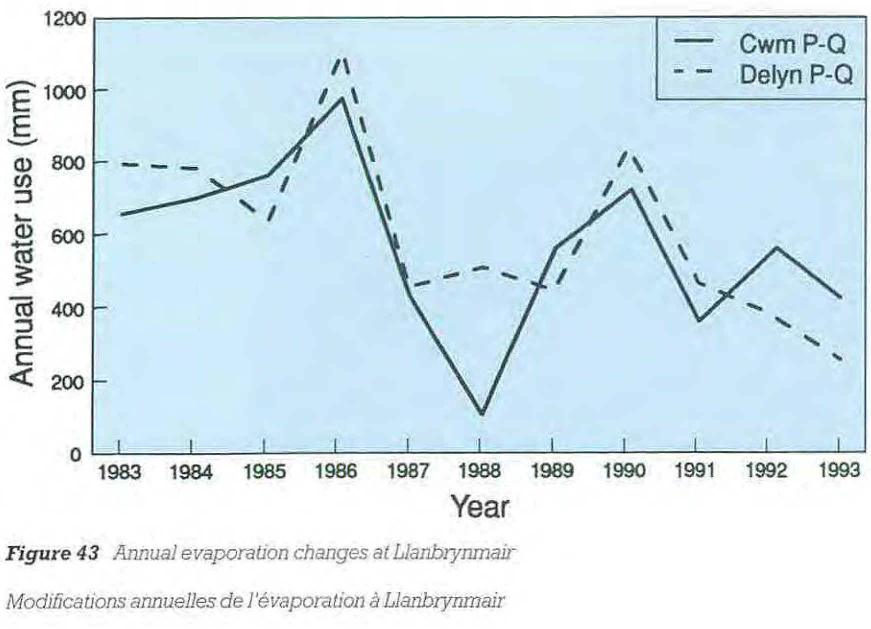


Figure 43 *Annual evaporation changes at Llanbrynmair*

Modifications annuelles de l'évaporation à Llanbrynmair

- **Wetland studies**
  Long-term studies of the hydrology of wetlands have investigated the impacts of development pressures on wetlands. A current joint project between IH and the hydrogeological division of BGS is developing methodologies to predict the impacts of groundwater abstraction and to assist with the licensing of new pumping wells in East Anglia.

- **Hydrological impact model for Sri Lanka** (funded by ODA)
  Experimental studies have been initiated with the University of Peradeniya, Kandy, Sri Lanka, as part of a Link Programme with Oxford Forestry Institute. Collection of data at two sites is on-going to calibrate a process-based hydrological impact model to aid decision-making concerning land-use planning and reforestation in the region.

- **Jersey catchment study**
  A catchment study (in collaboration with the British Geological Survey) is providing better quantification of the renewable groundwater resources of Jersey to aid decision-making on the sustainability of the present levels of exploitation .

- **Impacts of timber-felling on particulate loads in rivers** (for the NRA)
  A three-year study of the effects of felling on stream sediment loads and consequent environmental impacts is being carried out for the NRA by the IH Scottish Office. The work is closely-linked to water chemistry studies.

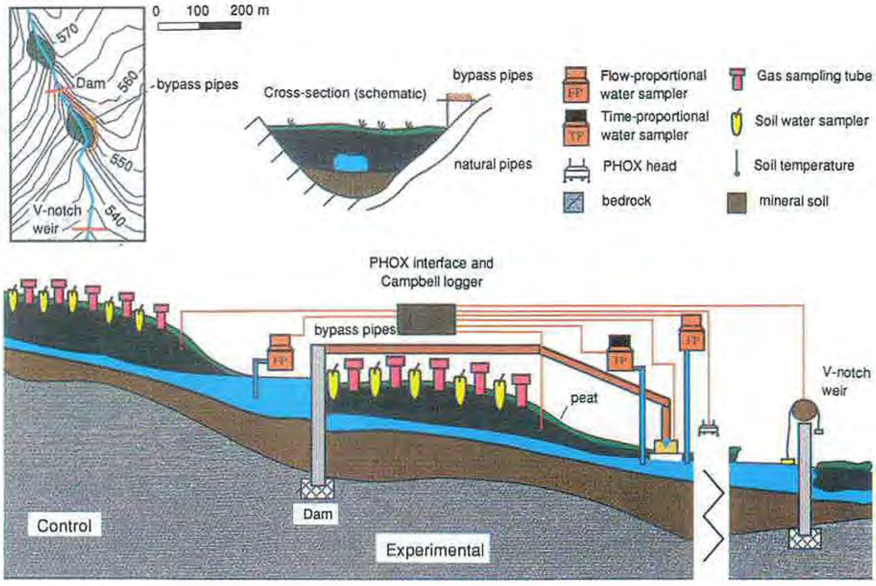


Figure 44 *Layout of the climate change manipulation site on the Cerrig yr Wyn wetland at Plynlimon*

Disposition du site de manipulation des modifications du climat, sur les terres marécageuses de Cerrig yr Wyn, à Plynlimon (Pays de Galles)

changes, or by the indirect effects of increased atmospheric pollution. To quantify this a joint IH/ITE wetland manipulation study, funded by the Welsh Office, has been in progress for three years at Cerrig yr Wyn in the Wye catchment. Climatic change effects on drainage have been simulated by bypassing a small area of valley flush during the summer months, rewetting in the autumn and assessing the impacts on gaseous losses from the wetland and on the chemistry of the drainage water from this and a control wetland. A second phase of the experiment has now been started where an alternative scenario, increased summer rainfall and runoff, will be simulated. The ultimate aim is to develop coupled atmospheric, soil and streamflow models that can predict the effects of various climatic change scenarios on greenhouse gas losses, water quality and the physical wellbeing of the wetlands themselves.

Sediment and waterborne fluxes

The mobility of many substances through river systems is determined by their association with the movements of water. Intensive hydrological measurements and analyses are therefore essential ingredients in quantifying the flux of materials through river basins. Materials subject to transport will often be natural (e.g. eroded river bank sediments), but the human effect on their release is increasing. Understanding the processes by which materials enter and are conveyed through river systems is therefore of particular concern. Land-use practice and land-use change may have major impacts on the fluxes. It is most important to assess these impacts, and to apply the research to develop scientifically-sound ways of avoiding pollution hazards.

Collaboration with universities is proving useful in improving our understanding of the processes controlling flux. Transport of material from catchment surfaces through the River Severn basin is being studied with Exeter University. Work with Birmingham University has used innovative monitoring to focus on patterns and processes controlling bank erosion and output into the river system: rates of erosion have proved higher than expected (>1 m of bank per annum — exceptional for British rivers). It has also been possible to identify the time at which river banks fail, and to relate that to patterns of floods and climate.

Coarse, bed-load sediments and fine, suspended loads have been monitored at a range of catchment scales from small headwaters in the Plynlimon experimental catchments (linked closely to other IH studies there) to large river systems such as the Yorkshire Ouse,an important part of the multidisciplinary LOIS programme. In LOIS, the loads carried in solution are measured as well as particulate matter, and this programme will give us better measures of the fluxes from rivers to the sea than ever before.

- **River Tweed**
  A water quality model of a mixed agriculture river basin with no heavy industry, has been developed using QUASAR.

- **Land-use model**
  The Balquhidder data sets, together with those from Plynlimon, are currently being used to develop and refine catchment scale evaporation models, that were initially developed by IH from small scale process studies. The models enable the experimental catchment results to be applied more widely throughout the UK uplands and should represent a valuable predictive tool for water resource and environmental managers alike.

- **River Spey reach morphology**
  A study was recently completed on the River Spey where a hydraulic model was developed jointly by IH and Hydraulics Research (HR Wallingford) to demonstrate the impacts of sediment deposits and man-made changes such as flood bank construction, flood plain management, bridge construction and flood channel construction.

- **Environmental Change Network**
  As part of the TIGER programme, the IH Stirling Office has been involved in the NERC Environmental Change Network (ECN) programme through the technical working group advising on hydrology, meteorology and water quality. The case for a Cairngorms site to be included in the network has been developed with Scottish Natural Heritage (SNH) and the Institute of Terrestrial Ecology.

Instrumentation

Hydrology is, very largely, an observational science. In recent years, modelling has assumed greater importance, as scientists attempt to apply the principles inferred from observation to predict the behaviour of hydrological systems. The quality of the principles and of the predictions can only be as good as that of the measurements made to derive the former and to check the latter. There is, therefore, a requirement for instruments to measure a wide range of hydrological variables reliably and accurately, and also for methods to characterise the parameters controlling water flow and waterborne transport. Theoretical methods and models are developed continually, and the range of problems tackled by hydrologists is widening, leading to a continuing demand for sensors to measure new variables and for improvements to existing sensors.

The Automatic Soil Water Station

The Automatic Soil Water Station (ASWS) is the latest instrument system to be developed by the Institute. It relies on an integrated use of four sensors to provide a continuous measure of the state of water in the soil at specific points within a site, and so to allow the flow of water to be inferred. The four sensors used in the ASWS are capacitance probes and pressure transducer tensiometers, which have been developed previously by IH, gypsum resistance blocks and soil thermometers.

The capacitance probe was developed at the Institute as an alternative to the well-established neutron probe. By comparison, it is smaller, lighter, cheaper, less time-consuming in use, non-radioactive and has better resolution of both water content and depth. It has been available commercially for some years. A version has been developed more recently to measure water content near the soil surface by replacing the electrodes of the original probe by two metal prongs, which can be inserted directly into the soil. A variation of this probe is used in the ASWS. Modifications have been made, both to the values of electronic components and to the body of the probe, so as to allow it to operate whilst buried in the soil for long periods. The optical output from the probe is fed directly to a decoder in the logging unit.

Potential applications of the various forms of the capacitance probe include investigations of groundwater recharge and pollutant transport in the unsaturated zone, irrigation scheduling, ground truth for remote sensing observations of soil water, and slope stability studies. Its application to flood forecasting is being evaluated under contract to the National Rivers Authority.

Tensiometers have been developed and used at IH for many years. These encompass both traditional, manually read mercury manometer devices and pressure transducer tensiometers (PTTs) suitable for automatic data logging. Different types of PTT have been produced: some allow the tensiometer to be serviced in the field without removal from the soil, while some are designed for installation at depths of 20 m or more down a borehole. The former type is used in the ASWS. The latest version uses a solenoid-operated valve to seal the tensiometer: this also provides an inlet for flushing water, which exits via an automatically operating water diode valve.

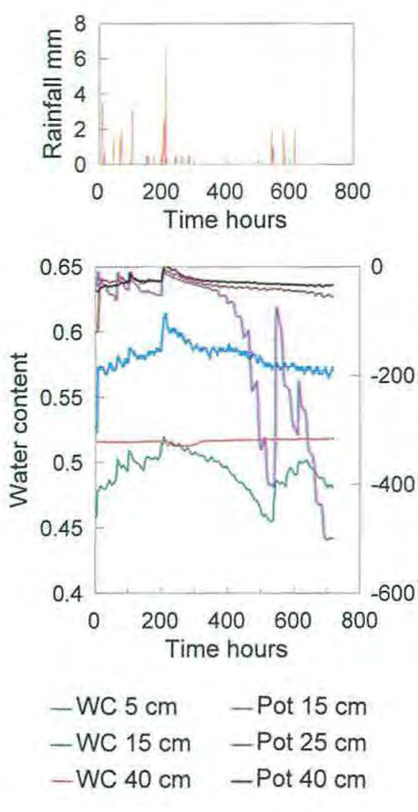


Figure 45 *Variations in water content and potential at three depths in the soil profile at three depths in a clay soil during April 1993*

Variations du taux d'humidité et du potentiel à trois profondeurs différentes du profil du sol dans un sol de l'argile en Avril 1993

- **Groundwater instrumentation**
  Recent groundwater hydrological investigations include the installation of multiple piezometers, microcosms and coring of glacial sands and gravels at Villa Farm landfill site, Warwickshire, at Shoreham, Sussex (geochemical investigation of saline interface), at a contaminated land site in Birmingham (investigation of chlorinated solvents and metal concentrations in the unsaturated zone), at Sonning, Berkshire and near Leuven, Belgium for herbicide degradation laboratory experiments.

- **Instrument evaluation**
  Two advanced on-line water quality monitors have been bought by the Instrument Section for evaluation, so that the Section will be able to provide advice and/or hire equipment to users for water quality monitoring.

- **Direct evaporation observation**
  Evaporation has been measured by the IH-developed Hydra instrument on a grassed ridge in Plynlimon, which showed evaporation being consistently about 85% of the Penman potential evaporation estimate.

- **Strata wetting measurements**
  Deep neutron probe access tubes in laterites and sandstones have been installed using commercial drilling equipment in Niger, West Africa and in central Spain.

- **Cold climate evaporation studies**
  Hydras have been operated successfully down to -10° C and with some success down to -30° C in Northern Canada, as part of the BOREAS international collaborative experiment.

Gypsum resistance blocks have been found over the years to be an economical and reliable solution to the problem of measurement of soil water potential when it is too dry for water tensiometers. These blocks are, therefore, deployed in the ASWS to cope with dry conditions.

Soil temperature completes the suite of subsurface variables recorded by the ASWS to indicate, for instance, when the soil may be frozen. Conventional thermistors are used for this, having been found to be robust and reliable over many years of use. Lastly, a tipping bucket raingauge is connected to the logging unit, so that rainfall can be recorded along with the subsurface variables.

The standard ASWS configuration is for gypsum blocks and pressure transducer tensiometers to be installed at depths of 0.15, 0.25 and 0.5 m depth, for capacitance probes at 0.05, 0.15 and 0.5 m, and soil thermometers at depths of 0.05, 0.15 and 0.25 m, although there is provision for up to five of each type of sensor (except for temperature) if desired. The heart of the logging unit is a Campbell CR10 data logger in a waterproof container, which records all the variables, normally hourly.

Figure 45 shows water content and potential at three depths simultaneously, along with rainfall, for a period of one month recorded hourly on a clay soil near the Institute's Wallingford site. This shows rapid response to rainfall at all depths and illustrates that the use of instrumentation systems such as the ASWS have the potential to reveal hydrological behaviour in great detail and thus help build an improved understanding of hydrological processes based firmly on field observation.

WISER — An integrated water flow and quality station

Population growth and economic developments are placing increasing pressure on natural water resources, both in the demand for water and in the pollution inputs to water bodies. The effective assessment, development and management of these water resources rely on the efficient and accurate collection of the relevant water quality and river flow data. The "Wallingford Integrated System for Environmental monitoring in Rivers" (WISER), developed by the Instrument Section, and deployed within the LOIS programme (see page 36), is an integrated system for the automatic measurement, recording and transmission of these data in river basins.

WISER incorporates on-line sensors to measure the key physical and chemical water quality parameters of a river. Sensors provide measurements of water temperature, turbidity, electrical conductivity, dissolved oxygen and pH. A measurement of river level using a pressure transducer is used to estimate river flow. All these data are recorded on a data logger, at an interval determined by the user. A degree of data processing can be easily incorporated, if required. The system also has a flexibility that allows further sensors and an automatic water sampler to be interfaced to the logging equipment. This permits analysis of other chemical parameters to be made. Data from the sensor systems can also be used to initiate a wide range of intelligent automatic bulk sampling strategies. Software to control the data logger and samplers has been written within the Section. A further feature of the system is the capability to transmit the recorded data via land-based telemetry or satellite (e.g. METEOSAT). Thus data can be collected remotely in a format that is readily compatible with computerised data processing techniques and provides an early warning of problems at a measuring site.

WISER is an integrated water quality monitoring system based on commercially available equipment which is currently being installed in the U.K.. As well as providing the hardware and software necessary for the automatic measurement, logging and transmission of water quality data, IH also has the expertise necessary to install the water quality stations, and to train local technicians in the operation and maintenance of the equipment, thereby providing a complete system package.

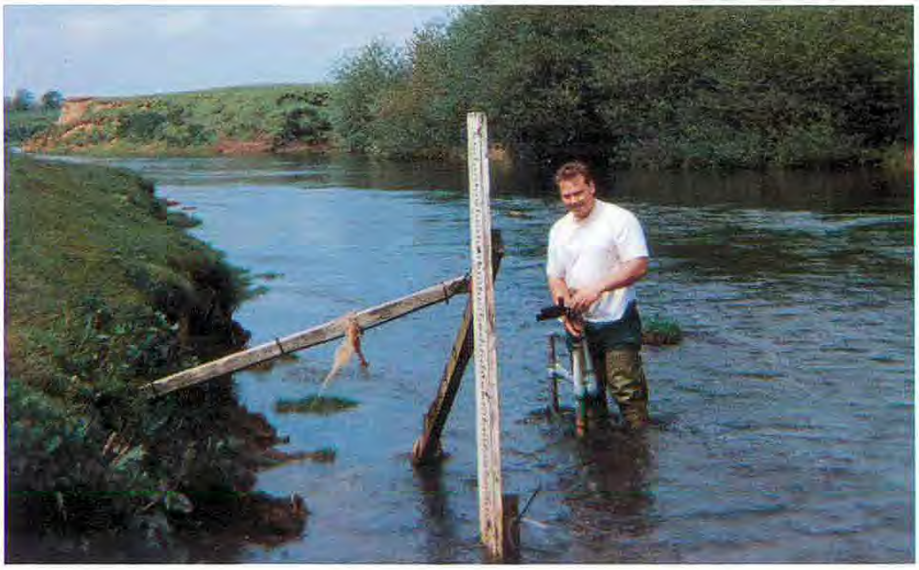


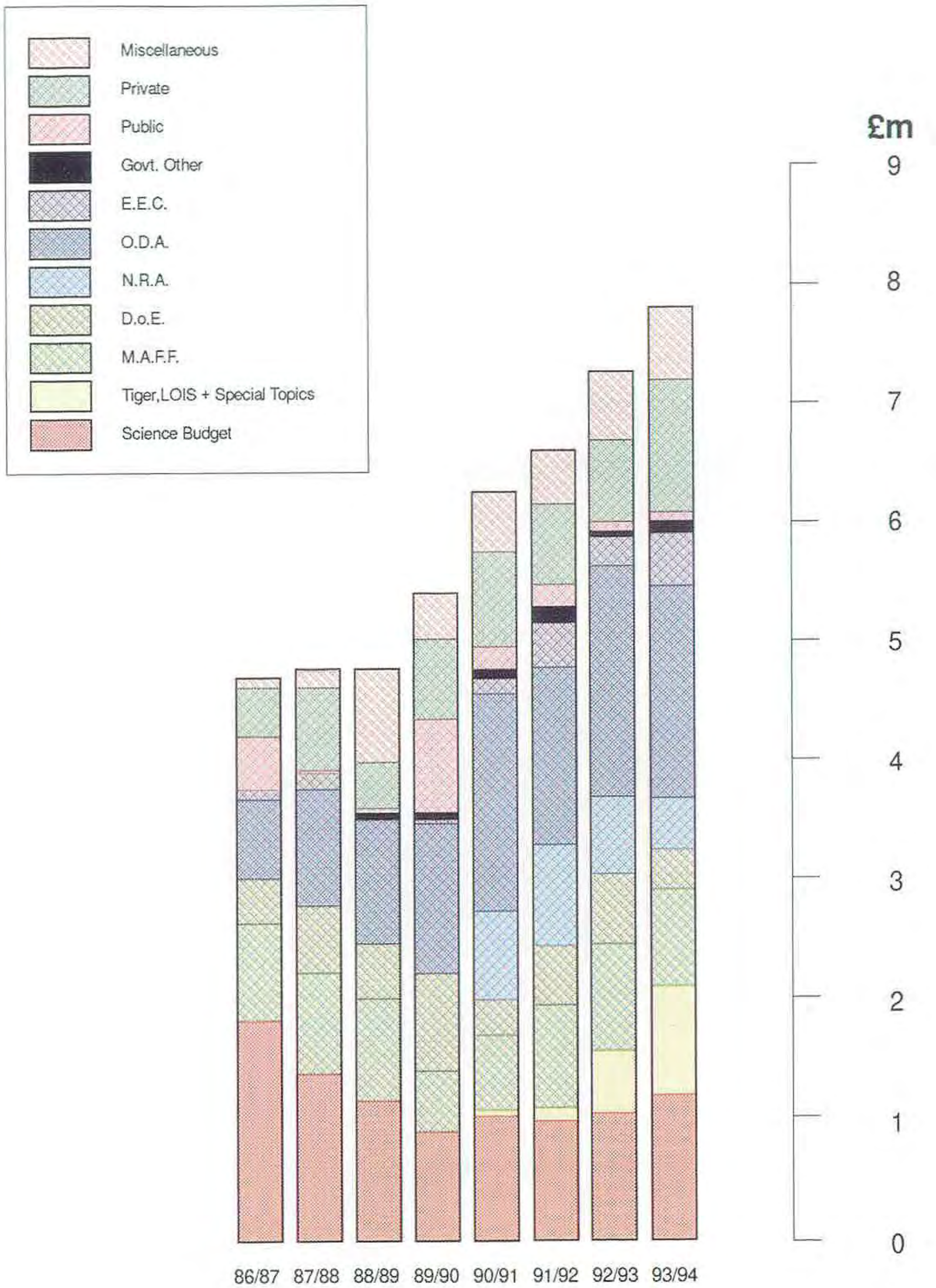
Figure 46 *Installation of turbidity sensors at a LOIS monitoring station*

Installation des capteurs turbidimétriques dans une station LOIS

Appendix 1 Finance

Sources of income

The histogram shows the sources of the Institute's income over the past eight years, adjusted to 1993/94 prices.



Appendix 2 Staff list as at 1 July 1994

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Acting Director
Institute of Hydrology

E. J. Memish
Personal Secretary

N. R. Runnalls, MSc
– marketing coordinator

Prof. W. B. Wilkinson, PhD
Acting Director,
Centre for Ecology
& Hydrology

V. Lynch
Personal Secretary

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Divisional Head

B. A. Hawker
Personal Secretary

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R. J. Harding, PhD
– meteorologist
A. D. Culf, PhD
– boundary layer meteorology
C. R. Lloyd, BA
– evaporation physics
I. R. Wright, BSc
– micrometeorology
E. M. Blyth, MA
– climate modelling research
C. Huntingford, PhD
– climate modelling research
C. M. Taylor, MSc
– mesoscale modelling research

Vegetation and Soil Processes

J. M. Roberts, PhD
– plant physiology, transpiration
S. J. Allen, PhD
– evaporation from semi-arid vegetation
R. L. Hall, PhD
– evaporation modelling
M. G. Hodnett, BSc
– soil water fluxes
C. J. Holwill, PhD
– evaporation from semi-arid vegetation
N. A. Jackson, MSc
– water use in agroforestry systems

* The first name in each section is that of the Section Head

Sustainable Agrohydrology

C. H. Batchelor, PhD
– irrigation studies, crop water use
J. Bromley, PhD
– groundwater resources
C. J. Lovell, PhD
– soil and water conservation
R. Ragab, PhD
– soil physics modelling
H. G. Bastable, PhD
– water balance modelling
A. J. Semple, MA
– environmental economist

Impacts of Global Environmental Change

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G. Roberts, PhD
– surface hydrology, remote sensing
J. B. Stewart, PhD
– evaporation and radiation studies
D. S. Biggin, BA
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K. Blyth, MPhil
– microwave remote sensing
J. W. Finch, PhD
– groundwater and GIS
I. G. Littlewood, PhD
– environmental impact hydrologist
N. S. Reynard, MSc
– hydrometeorologist

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Divisional Head

J. A. Champkin
Personal Secretary

Water Quality Systems

A. Jenkins, PhD
– modelling
D. B. Boorman, PhD
– water quality modelling
R. P. Collins, BSc
– climate change impacts on water quality
A. Eatherall, PhD
– water quality modelling & GIS
D. R. Lewis, PhD
– river quality modelling
C.E.M. Sefton, BEng
– environmental modelling
M. Renshaw, MSc
– acid deposition
R. J. Wilkinson, BSc
– water quality modelling
S. Tolchard
– database and graphical support

Pollution Hydrology

R. J. Williams, BSc
– water quality modeller
A. C. Johnson, PhD
– environmental microbiologist
A. Haria, BSc
– soil physics
P. C. R. Volkner, BA
– water quality catchment studies
V. Cruxton, BSc
– soil moisture studies
A. Williamson, BSc
– water quality modeller

Appendix 1 Finance

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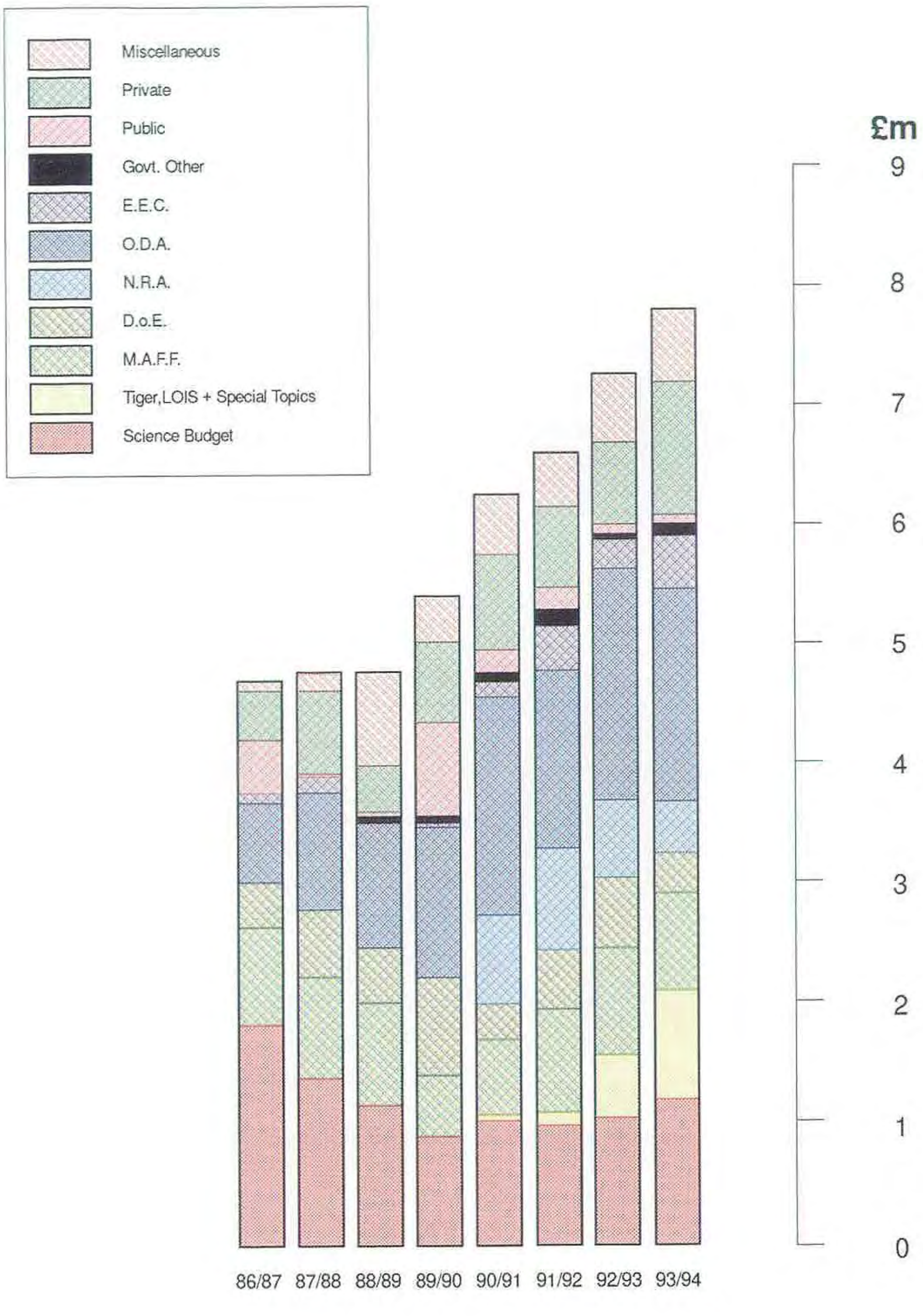

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– water quality modeller

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A. J. Andrews, BSc
– low flows & GIS

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– low flows; water resources
H. G. Rees, MSc
– European database manager; FRIEND
A. E. Sekulin, MSc
– hydrological programmer
J. M. Dixon
– hydrologist; Welfare Officer
K. M. Irving, BSc
– low flows; artificial influences
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– environmental hydrologist

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C. R. N. Elliott, BA
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I. M. Gowing, BSc
– environmental modelling

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C. J. Smith, LRIC
– analytical chemistry
C. L. Bhardwaj, PhD
– analytical chemistry
A. J. Robson, BA
– mathematical modelling
M. Neal, PhD
– chemical analysis, X–ray diffraction & mass spectrometry
H. A. Jeffery
– analytical chemistry
M. L. Harrow
– analytical chemistry
S. K. C. McCrorie
– analytical chemistry

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A. Calver, PhD
– hydrological modeller
D. M. Cooper, PhD
– distributed modelling, stochastic hydrology
S. M. Crooks
– applied hydrologist
T. Spijkers, MSc
– hydrologist
P. Broadhurst, MSc
– mathematical modeller
B. Gannon
– hydrologist

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D. C. W. Marshall, MSc
– engineering hydrology
A. C. Bayliss, HND
– flood analysis
I. J. Dwyer, MSc
– mathematician
T. K. Jones, BSc
– hydrology
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– rainfall studies; HYREX
D. S. Faulkner, BSc
– rainfall studies

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R. J. Moore, MSc
– hydrological forecasting, weather radar, stochastic hydrology
D. A. Jones, PhD
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– hydrological forecasting and control
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– distributed forecasting
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– weather radar studies

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K. J. Sene, PhD
– hydrological modelling, evaporation estimation
H. A. Houghton-Carr, MSc
– flood estimation; real-time forecasting
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F. Cecil
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Sediment & Waterborne Fluxes
G. J. L. Leeks, BSc
– LOIS CEH programme manager; sediment transport
S. D. Marks, BSc
– geomorphologist / sediment studies
G. P. Ryland, MSc
– analytical chemist (LOIS)
P. Wass, MSc
– hydrology & sediment transport (LOIS)

Instrumentation
J. D. Cooper, BSc
– soil water instrumentation
A. J. Dixon, BSc
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D. D. McNeil, BSc
– instrument development
P. Hodgson, PhD
– instrument development
M. R. Stroud
– instrument technician
M. E. Walker
– instrument technician
R. G. Wyatt
– instrument technician
J. G. Evans, BSc
– instrument development

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G. H. Walley
– instrument technician
J. P. White
– instrument technician

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– management information systems
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T. A. Gibson
A. Napper
E. A. Ostler
L. Ross, BA

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P. M. Sanders
V. Lambeth

Switchboard & Reception
E. Younghusband

Typing Pool
J. Hornsby
S. Smith
S. J. Fairhurst
H. J. Turner

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R. G. Drewett
– handyman/driver
J. Spencer
– caretaker/groundsman
H. V. R. Jones
– driver

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J. H. Jones
– storekeeper

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J. Fisher, BSc - University of Lancaster
A. Collins, BSc - University of Exeter
S. Foster, BSc - University of Birmingham
S. Henworth, MSc - University of Southampton
K. J. Neylon, BSc - Reading University
D. A. Post, BSc - University of Lancaster
A. Wild, BSc - Salford University
H. L. Grew, BSc - University of St Andrews

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R. Brand – University of Luton
I. Brightman – University of Luton
E. Brown– Coventry University
A. Cole – Sheffield Hallam University
C. Coulson – University of Luton
M. D. Cranston – Sunderland University
O. Highway – Coventry University
D. R. Hill – Plymouth University
M. Hodgson – Coventry University
L. Kneeshaw – Sunderland University
N. Koria – Sheffield Hallam University
Y. O. Man – Sheffield Hallam University
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S. J. Rollason – University of Luton
P. Ultsch – Oxford Brookes University

COMMUNITY SCIENCE & MANAGEMENT

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M. A. Beran, BSc
– TIGER programme manager; TFS climate change coordinator

H. R. Oliver, PhD
– TIGER III coordinator
M. Howarth
– finance & administration
S. G. Austin
– secretary

Appendix 3 Scientific output

(i) Scientific papers

Albuquerque, M.A., Wood, M. & **Johnson, A.C.** 1993. Degradation of atrazine in soil and sediments. In: Internat. Symp. on Subsurface Microbiology, Bath, UK, H-45.

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ADMINISTRATION

A. D. R. Gray
Head of Administration

Financial Management & Accounts
H. M. Wood
– Finance Officer
A. M. Davies
– management information systems
L. A. Aspinall, BSc
H. G. Thomas
T. A. Gibson
A. Napper
E. A. Ostler
L. Ross, BA

Establishments & Personnel
S. A. Fenton
P. M. Sanders
V. Lambeth

Switchboard & Reception
E. Younghusband

Typing Pool
J. Hornsby
S. Smith
S. J. Fairhurst
H. J. Turner

Site Services
J. R. Fraser
– site services
I. R. Standbridge
– carpenter
R. G. Drewett
– handyman/driver
J. Spencer
– caretaker/groundsman
H. V. R. Jones
– driver

Stores
J. H. Jones
– storekeeper

Sediment & Waterborne Fluxes
G. J. L. Leeks, BSc
– LOIS CEH programme manager; sediment transport
S. D. Marks, BSc
– geomorphologist / sediment studies
G. P. Ryland, MSc
– analytical chemist (LOIS)
P. Wass, MSc
– hydrology & sediment transport (LOIS)

Instrumentation
J. D. Cooper, BSc
– soil water instrumentation
A. J. Dixon, BSc
– drilling and groundwater monitoring
D. D. McNeil, BSc
– instrument development
P. Hodgson, PhD
– instrument development
M. R. Stroud
– instrument technician
M. E. Walker
– instrument technician
R. G. Wyatt
– instrument technician
J. G. Evans, BSc
– instrument development

Workshop
A. C. Warwick
– workshop manager
G. H. Walley
– instrument technician
J. P. White
– instrument technician

CASE STUDENTS

L. Bull, BSc – University of Birmingham
A. Collins, BSc - University of Exeter
J. Fisher, BSc - University of Lancaster
A. Collins, BSc - University of Exeter
S. Foster, BSc - University of Birmingham
S. Henworth, MSc - University of Southampton
K. J. Neylon, BSc - Reading University
D. A. Post, BSc - University of Lancaster
A. Wild, BSc - Salford University
H. L. Grew, BSc - University of St Andrews

SANDWICH COURSE STUDENTS

H. Bigley – University of Luton
R. Brand – University of Luton
I. Brightman – University of Luton
E. Brown– Coventry University
A. Cole – Sheffield Hallam University
C. Coulson – University of Luton
M. D. Cranston – Sunderland University
O. Highway – Coventry University
D. R. Hill – Plymouth University
M. Hodgson – Coventry University
L. Kneeshaw – Sunderland University
N. Koria – Sheffield Hallam University
Y. O. Man – Sheffield Hallam University
S. P. McGrath – Reading University
M. Paskiewiczl – Plymouth University
S. J. Rollason – University of Luton
P. Ultsch – Oxford Brookes University

COMMUNITY SCIENCE & MANAGEMENT

TIGER (Terrestrial Initiative in Global Environmental Research)

M. A. Beran, BSc
– TIGER programme manager; TFS climate change coordinator

H. R. Oliver, PhD
– TIGER III coordinator
M. Howarth
– finance & administration
S. G. Austin
– secretary

Appendix 3 Scientific output

(i) Scientific papers

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(iii) Software development

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(iv) Instrument provision/installation 1993/94

The Instrument Section provides a wide range of data capture systems for the experimental activities of this institute and also, through an NERC Automatic Weather Station Pool, supports Higher Education Institutions undertaking hydrological research.

April 1993

Rebuilding of micromet tower in Brazil for ABRACOS project
Manufacture of 24 puncture tensiometers

May

Building, calibration and testing of stage recording systems for mill stream (IFE Wareham) utilising three sets of five pressure tranducers and logging systems

June

Development of mole sampler pump control system for Wytham 2 field experiment
Finalising design and testing installation equipment for buried capacitance probes — part of ASWS system
NERC Pool AWS preparation and installation, Isle of Skye
Maintenance / re-calibration of four AWS systems and three river-level systems at Balquhidder

July

Finalising design and testing SCIP — organizing in-house manufacture, calibration and testing of ten units
Installation of mill stream stage recording systems (IFE Wareham 3*5 pressure transducer tensiometer logging systems)
Calibration, testing and installation of AWS system at Eisteddfa Gurig, Plynlimon, to replace system damaged by sheep
Preparation, calibration and user training for NERC Pool AWS (to be installed by user at Brighton)
Manufacture of cables for Norway TDR system
Calibration and testing of six PTTs for Kenya

August

Maintenance, testing and installation of the following systems for the Wytham 2 experiment:
2*6 PTT logging systems
3*5 PTT logging systems
overland flow logging system
V-notch level system
Installation equipment for ASWSs manufactured
Provision of logger for use with ORG 105 precipitation sensor

September

Building, testing and installation of three mole sampler pump control and rainfall monitoring systems for Wytham
Installation of ASWS at Wytham
Building, calibration, testing and installation of stage backup logging systems for Plynlimon to replace obsolete Leupold & Stevens stage recorders for Cefn Brwyn, Hafren, Hore, Tanllwyth, Severn Trapezoidal and Cerrig-yr-Wyn flumes
AWS for Swanbourne
NERC pool AWS installation
Two ASWSs installed at Plynlimon for Beta testing

October 1993

Preparation, calibration and testing of two Hydras for the BOREAS project in Canada, staring Feb/Mar 1994
Two ASWSs installed at IH Met site for beta testing
Two SCIPs and readers for Kenya
Two SCIPs and readers for Niger

November

One AWS, one river level and two level and soil tension systems for Zimbabwe
Design and building ratescaler test unit

December

Providing SCIP plus reader and calibration equipment for Cameroon
Testing and temperature compensation of ten in-house manufactured SCIPs of improved design
Building voltage controllers, junction box and cables for sap flow gauges

January 1994

Calibration of 15 Druck pressure transducers for Space Technology Systems Ltd
Designing, building and testing of 20 logging systems for river level and turbidity monitoring and bulk sampler control for the LOIS project

February

AWS system for Coalburn
Servicing the Plynlimon AWS/logging systems
Installation of two Hydras, met and temperature measuring equipment in Canada as part of the BOREAS project

March 1993

Manufacture of ten IH-designed psychrometers
Preparation and calibration of one Hydra for international comparison in Netherlands and two Hydras for use in Brazil
Manufacture of three large tipping bucket flowmeters using laser welding

Abbreviations

ASWS	=	Automatic soil water station
AWS	=	Automatic weather station
DCP	=	Data collection platform
IRT	=	Infra-red thermometer
PAR	=	Photosynthetically active radiation
PTT	=	Pressure transducer tensiometer
SCIP	=	Surface capacitance insertion probe
TDR	=	Time domain reflectometry

Appendix 4 Research projects

The Institute of Hydrology is a component body of the UK Natural Environment Research Council. Its science contributes to the integrated research programmes of the Terrestrial and Freshwater Sciences Directorate, involving four other institutes and several university units.

Programme 3 — Global Environmental Change

Surface and boundary layer measurements, Sahel
Joint fluxes in tropical forests
Understanding SVATS for global modelling
Macromodelling (TIGER III)
Automatic weather station, Wytham site
Hydrological impacts modelling (TIGER IV)
Biome change as a climatic feedback

Tropical Rainforest Processes

ABRACOS: micrometeorology and climatology
ABRACOS: plant physiology and soils
ABRACOS: Tropical rainforest processes
Application of ABRACOS to planning LBE

Climate change

Climate change and water resources in East Africa
CLIMEX – climate change experiment
Hydroclimatology: atmosphere and hydrology in Europe
EC climate change and water resources

Programme 4 — Water Management and Hydrological Extremes

Experimental catchments

Plynlimon water use
Effect of clear felling on upland runoff
Impacts of riparian wetlands on stream chemistry
Water resources and afforestation in Scotland
Fluvial geomorphology
Conservation management of wetlands
Erosion of forest roads
The protection of East Anglian wetlands
Impact of particulate outputs from timber harvesting

Catchment data

Plynlimon data water information system

Hydrological modelling

Real-time forecasting of river flows
Distributed hydrological and hydrochemical models
Yorkshire river flow forecasting system
Development of improved methods of snowmelt forecasting
Storms, floods and radar hydrology
Short-term consultancies in hydrological modelling
HYRAD – Hydrological Radar System
River Soar flood warning system

Consultancy, UK

Minor repayment studies
Sub-surface exploration contracts
Jersey catchment study
River Lavant flooding investigation, Chichester
Resource strategy planning
Pakistan flood course

Consultancy, Overseas

Future water supply strategy, APC Jordan
Support services for overseas repayment studies
Real-time flood forecasting – Hong Kong
World Flood Study – Phase III
Review of Lesotho highlands Water Resources Division
Water resource development, The Philippines
Global water scarcity
Hydrological review of the Kafue River, Zambia
Tanga and Morogoro water supply, Tanzania

Surface Water Archive

UK surface water data
Water resources research progress

Flood event modelling

Continuous simulation model for flood estimation
Representative basin database
Hydrological summaries for Great Britain

Flow regimes

Flow regimes in Western Europe
Micro-low-flows
Physical habitat simulations in rivers (PHABSIM)
Low flow estimation in artificially influenced catchments
Modelling faunal and floral-response
European small hydropower atlas
Southern Africa low flows
Naturalised flows in Essex
UK low flow training course
Ecologically acceptable flows

Storm hazards and hydrological extremes

Review of flood studies, statistical procedures
Flood estimation methods: training courses
Rainfall forecasts, Cameroon hydroelectric schemes
Rainfall frequency study: England and Wales
Flood response of large catchments
ADEPT – analysis of dependent time-series
Strategy for successor publications to the *Flood Studies Report*
Restatement of FSR rainfall-runoff method
Catchment characterisation for flood estimation
Confluence flood: joint probability

Hydrological software

Software development
HYDATA
HYRROM (hydrological rainfall runoff model)
GRIPS (groundwater information processing system)
QUASAR – VAX-version model
QUASAR – PC conversion
Micro-FSR
FFAP (flood frequency analysis package)
HYQUAL (water quality database)
Software training
Provision of QUASAR and DMM
HYDATA dissemination
HYDATA for Uganda
SWIPS sales and development
IHACRES sales and development

Micro-low-flows sales
HYDATA – Windows development

Hydrologic Geographic Information Systems
Development of a hydrogeographic database
Water Information System
Redigitising the rivers of the NRA North West Region
WIS for rivers affected by cooling water

Agrohydrology
Small-scale irrigation schemes: collector wells
Management of limited water resources
Low-cost, high-efficiency irrigation
Agricultural chemical transport in soils and rocks
Irrigation using collector wells

Urban hydrology
Urban impacts on flood runoff in medium-scale mixed catchments
Urban drainage in the developing world

Hydrological Radar Experiment (HYREX)
Short-period forecasting incorporating radar data
Radar-raingauge networks for hydrological use

Programme 5 — Land/Ocean Interaction Study (LOIS)

Land/Ocean Interaction Study (LOIS)
Operational management and preparation for field science
Analytical chemistry
Database/GIS for LOIS data centre
LOIS core modelling
LOIS – remote sensing of river corridors
Instream water quality modelling

Programme 6 — Hydrological Processes

Regional scale modelling
FIFE/BOREAS
UK Meteorological Office joint development (MITRE)
A model of seasonal vegetation growth for GCMs
Development of SVAT models in EFEDA
Tundra soil-vegetation-atmosphere climate interaction

Dryland degradation processes
Plant physiological controls of evaporation
Hillslope flow process study: Zimbabwe
Water resources in the Messara valley

Environmental impact of trees
Environmental implications of trees and land-use systems
Western Ghats forest project, India
Impact of eucalyptus plantations in Portugal
Water balance of African lakes
Land-use change, Upper Mahaweli catchment, Sri Lanka
Hydrological effects of short-rotation energy coppice
Water resource modelling for large catchments
Water resources in Southern Africa

Semi-arid zone water balance
Water use efficiency of rainfed crops
Water use by vegetation in the Sahel
Arid zone recharge (SAGRE)
HAPEX II - Sahel: soils
Remote sensing of semi-arid regions
Water balance of agroforestry system on hillslopes
Land-use change and over-exploitation of water resources, Spain

Surface and subsurface processes
Burnham Beeches groundwater feasibility study
Stream hydrograph and storm runoff mechanisms
Continuous monitoring of soil moisture for the NRA
Worton Rectory Farm groundwater investigation
Analysis of Coalburn catchment data
Herbicide degradation in the sub-surface
Development of a consistent procedure for groundwater estimation
Effect of forestry on summer baseflows

Remote Sensing
European Space Agency ERS-1 mission
Application of remote sensing to hydrology
Evaporation input for GCMs from satellite data
PC-based system to use satellite data
EC - ASEAN regional remote sensing, ERS-1

Programme 11 — Freshwater Biology and Water Quality

Water quality
European network of catchments
Pesticide pollution in catchments
Acid waters monitoring network
Organics in the aquatic environment
Critical loads of sulphur and nitrogen
Nepal research project
Modelling *E. coli* concentrations in streams
Acid mine modelling
Environmental change in ecosystems
Nitrogen module for MAGIC
Fate of pesticides in unsaturated/saturated zones
Biodiversity in the Himalaya – Darwin Initiative

Hydrochemistry
Forestry impact on upland water quality
Identifying hydrological flow pathways, Spain
Assessing hydrochemical flow pathways
Hydrochemical process studies – TFS/BGS

Programme 13 — Scientific Services

Hydrological instrumentation
Capacitance probe
Automatic weather station
Field instruments
Maintenance and development of Hydra equipment
Soil laboratory physics equipment pool and services

ODA coordination
ODA programme coordination
IAHS/ODA UNESCO funding
HOMS activities
Information and dissemination activities
ODA hydrological adviser
ODA Resource Centres Scheme

Hydrochemistry laboratory
Chemistry laboratories
Acid waters central chemistry
Environmental isotopes

Appendix 5 Committee representation

International committees

Name of committee	Staff member
CEC Workshop on Integrating Radar Estimates of Rainfall in Real-time Flood Forecasting	R J Moore
European Geophysical Society Hydrological Sciences Committee	R J Harding
European Network of Experimental & Representative Basins	M Robinson (UK representative)
FRIEND Steering Committee	A Gustard (Chairman)
GEWEX Continental International Programme (GCIP) Science Panel	W B Wilkinson
GEWEX Continental International Programme (GCIP) Science Panel	N W Arnell
IDNDR Working Group on Drought Mitigation	J S Wallace (Chairman) J R Meigh (Secretary)
IDNDR UK Coordinating Committee	W B Wilkinson
International Association of Hydrogeologists - UK Committee	W B Wilkinson
International Association of Water Pollution Research & Control (IAWPRC), UK Committee	W B Wilkinson
International Committee on Atmosphere-Soil-Vegetation Relations	J S Wallace (UK representative)
International Journal of Climatology: Editorial Board	R J Harding
Journal of Agriculture & Forest Meteorology: Editorial Board	J S Wallace
NATO Panel on Science of Global Environmental Change	M A Beran (Chairman)
UNEP/WMO/FAO Global Terrestrial Observing System Committee	M A Beran
UNESCO International Hydrological Programme IV Project H-5-5 — FRIEND	A Gustard (Chairman)
UNESCO International Hydrological Programme – UK Committee	W B Wilkinson (Chairman)
WMO Commission for Hydrology	W B Wilkinson (UK Principal Delegate)
WMO Commission for Hydrology: Advisory working Group	M A Beran
WMO Commission for Hydrology: Working Group on Operational Hydrology, Climate and the Environment	M A Beran (Chairman)
WMO-RA VI Working Group on Hydrology	M A Beran
WMO-RA VI Applications of weather radar data to hydrology and water resources	R J Moore (Rapporteur)

National committees

Name of committee	Staff member
1994 GEWEX Conference Committee	J B Stewart (Chairman)
British GENIE Data Users Committee	F M Law
British Geomorphological Research Group	P Naden (Hon. Treasurer, 1993)
British Hydrological Society Main Committee	C Kirby (IH representative/Editor)
British Hydrological Society Main Committee	F M Law
British Hydrological Society Research Sub-Committee	F M Law (Co-chairman)
British Hydrological Society Southern Section Committee	N W Arnell
BSI Measurement of Fluid Flows:Estimation of Uncertainties PCL/2/8	I G Littlewood
BSI Precipitation Measurements PCL/3/-/2	D G Morris, J R Blackie
BSI subcommittee on Dilution Gauging	K Gilman (Chairman)
CIRIA Steering Committee - Rising Groundwater Levels - London	W B Wilkinson
CIRIA Steering Committee - Rising Groundwater Levels - Birmingham	W B Wilkinson
DOE Critical Loads and Acid Deposition Group	A Jenkins
DOE Water Quality Advisory Committee	P G Whitehead
Environmental Physics Group of the Institute of Physics	J B Stewart (Chairman)
GENIE Joint Date Centres Data Users Committee	M A Beran
Geological Remote Sensing Group of the Geological Society	J W Finch (Secretary)
Hazards Forum:Natural Hazards Sub-Committee	F M Law
Institute of Physics - Environmental Physics Group	J B Stewart (Chairman)
Institution of Agricultural Engineers - Soil & Water Specialist Group	H M Gunston
ICE Conference on Groundwater Problems in Urban Areas - Organising Committee	W B Wilkinson (Chairman)
ICE Reservoir Floods Working Party	F M Law (Technical Secretary)
Institution of Environmental Sciences Council	H R Oliver
Interdepartmental Committee for Hydrology	W B Wilkinson (Chairman)

Interagency Research Committee on the Hydrological Use of Weather Radar	R J Moore, R M Austin (Secretary
IWEM River and Coastal Panel	F M Law
IWEM Water Resources Panel	T J Marsh
Meetings Committee, Royal Meteorological Society	J B Stewart
NRA Research Fellowships Committee	P G Whitehead
ODA Engineering Research Group	A G P Debney
ODA Remote Sensing Working Group	J W Finch (Chairman)
Southampton University Institute of Irrigation Studies, Advisory Board	H M Gunston
Surface & Groundwater Archives Steering Group	M L Lees, T J Marsh
UK GEWEX Forum	M A Beran
University of Reading Postgraduate Research Institute for Sedimentology, Advisory Board	W B Wilkinson

Research Council committees

NERC Airborne Remote Sensing Steering Committee	J W Finch
NERC Arctic Terrestrial Ecology Special Topic Steering Committee	R J Harding
NERC Atmospheric Sciences Committee	W B Wilkinson
NERC Equipment Pool for Field Spectroscopy Steering Committee	J W Finch
NERC/ESRC Land Use Programme Advisory Committee	W B Wilkinson
NERC HYREX Committee	R J Moore, E J Stewart (Secretary)
NERC Information Services Advisory Committee	F M Law
NERC Land Ocean Interaction Study (LOIS) - Steering Committee	W B Wilkinson
NERC Land Ocean Interaction Study (LOIS) Data Centre Managers Committee	R V Moore (Chairman) C I Tindall (Secretary)
NERC Scientific Computing Advisory Committee	P G Whitehead
NERC Terrestrial & Freshwater Sciences Committee	W B Wilkinson
NERC TIGER 3 Working Group	J H C Gash
TFSD Computing Strategy Committee	P G Whitehead
TFSD Programme Area 13 Core Group	A G P Debney (Chairman)
TFSD Programme Area 3 Core Group	M A Beran (Chairman)
TFSD Programme Area 3 Core Group	N W Arnell (Secretary)
TFSD Remote Sensing Strategy Group	J S Wallace
TIGER Steering Committee	M A Beran (Secretary)

Appendix 6 The UK HOMS office

The Hydrological Operational Multipurpose System (HOMS) is a scheme sponsored by the World Meteorological Organisation in Geneva with the main aim of providing hydrological advice and information to developing countries. Well over a hundred countries around the world run HOMS National Centres which act as a clearing house for hydrological requests. Over 400 packages of information ("components") are available, covering a wide range of hydrological topics in the fields of instrumentation, techniques or software, supplied by the country which has produced them. Detailed abstracts of all the components are listed in the HOMS Reference Manuals kept at the National Centres and other relevant Institutions. The HOMS National Centre for the UK is at the Institute of Hydrology, and is funded by the Overseas Development Administration. The UK has produced over 5% of the total number of components in the scheme and regularly deals with requests for them from many parts of the world. Surveys of the users of the information have confirmed that HOMS is providing a valuable service, both directly to developing countries and also to those who are going to work in those areas for which packages can be obtained. A further five UK components have been accepted for inclusion in the scheme when the manual is next updated.

Dr Howard Oliver (Institute of Hydrology) is the UK HOMS representative.

Appendix 7 Links with other organisations

Collaboration with other research organisations

UK research organisations

In addition to numerous collaborative research projects with sister Institutes in the Natural Environment Research Council, the Institute of Hydrology is also involved in collaborative projects with many other UK research organisations, including

- Geography Dept, Oxford University
- Queen's University, Belfast
- University of Sheffield
- University of Lancaster
- University of Wales, College of Cardiff
- Macaulay Land Use Research Institute
- Soil and Water Research Station (ADAS)
- Water Resource Systems Research Unit, Newcastle University
- Royal Geographical Society
- Rutherford Appleton Laboratory

International research organisations

IH is currently involved in more than 58 international projects in collaboration with more than 90 research organisations worldwide:

Europe
Czech Hydrometeorological Institute
European Centre for Medium Range Weather Forecasts
GRDC, Koblenz, Germany
ORSTOM, Montpellier, France
CEMAGREF, Lyon, France
Agricultural University, Wageningen, The Netherlands
Norwegian Institute for Water Research (NIVA)
NERI, Denmark
Institute of Meteorology and Water Management, Poland
Universade Tecnica de Lisbõa, Portugal
TGM Water Research Institute, Czech Republic
Informatics, University of Oslo
BITÖK, University of Bayreuth, Germany
CREAF, University of Barcelona, Spain
Dept of Earth Sciences, University of Alicante, Spain
Dept of Soil Sciences, University of Freiburg, Germany
University of Ghent, Belgium
University of Warsaw, Poland
European Science Foundation

Africa
ICRISAT Sahelian Centre, Niger
University of Dar es Salaam, Tanzania
Department of Research & Specialist Services, Zimbabwe
Depts of Water Affairs in Botswana, Lesotho, Malawi, Mozambique, Namibia, Swaziland, Tanzania, Zambia, Zimbabwe and the Republic of South Africa

Americas
Center for Ocean-Land-Atmosphere Studies, USA
University of Arizona, USA
US Geological Survey, Atlanta, Georgia
CDESON, Sonora, Mexico
ITSON, Sonora, Mexico
Instituto Nacional de Pesquisas Espaciais, Brazil
Instituto Nacional de Pesquisas da Amazonia, Brazil
Centro de Pesquisa Agroforestal da Amazonia Ocidental, Brazil
Centro de Energia Nuclear na Agricultura, Brazil
Cooperation Nacional Forestal, Chile
University of La Serena, Chile
University of Virginia, USA

Asia & Australasia
Australian National University, Canberra
National Agricultural Research Centre, Nepal
Karnataka State Forest Department, India
Ministry of Agriculture & Water Development, Sri Lanka
University of Peradeniya, Sri Lanka
University of Agricultural Sciences, Bangalore, India

Client organisations

UK government
Department of the Environment
Ministry of Agriculture, Fisheries & Food
Overseas Development Administration
Defence Research Agency
Department of Trade & Industry
Welsh, Scottish and Northern Ireland Offices
National Rivers Authority
Scottish Natural Heritage

UK private sector
UK Clients have included GEC Marconi, HR Wallingford Ltd, Logica, Wilson Energy Associates Ltd and ICL.

International
The Institute of Hydrology has been commissioned to undertake hydrological studies in more than 33 countries, for governments, international agencies and private sector clients. Projects were undertaken during 1993/94 for

- Commission of the European Communities – DGs I, XI & XII;
- States of Jersey Public Services;
- World Meteorological Organization;
- UNESCO;
- Government of Lesotho;
- Government of Hong Kong;
- Mysore Paper Mills Ltd;
- Intessa, Spain;
- Verdeacqua, Italy.

The Institute is a member of, or actively supports, a number of industrial associations which represent the interests of a far larger community of users of our research results, including CIRIA (Construction Industry Research and Information Association), ADA (Association of Drainage Authorities), ESHA (European Small-scale Hydropower Association), UKIA (United Kingdom Irrigation Association), TRA (Tropical Agriculture Association), TFRG (Tropical Forest Resource Group) and SWIG (Sensors in Water Interest Group).

The Institute has broadened its contacts with technology transfer organisations, including The Licensing Executives Society; The Technology Broker; The European Association for the Transfer of Technologies, Innovation and Industrial Information; CEC Value II Programme, and DTI Technology Innovation Programmes. Membership of international networks includes Euraqua (European Freshwater Research Organisation), Techware (Technology for Water Resources) and NETT (Environmental Business)

Appendix 8 The Institute's contribution to the TIGER programme

The Institute of Hydrology provides the main administrative office for the NERC Community Programme TIGER (Terrestrial Initiative in Global Environmental Research), a five-year programme aimed at understanding processes at the land surface which are involved in Global Environmental Change. The Institute is extremely active in the scientific programme through its contributions to field studies at TIGER's tropical forest and savanna flagship sites, and its models of boundary layer and catchment processes (described in the Hydrological Processes and Environmental Processes section).

As a Community Programme, much of TIGER research is conducted within multilaboratory consortia. This imposes additional burdens on the leading laboratory, a role undertaken by the Institute in the consortia dealing with macromodelling and with field studies.

The purpose of the TIGER Office, housed at the Institute, is to manage the entire programme: this spends £4 million annually at 50 different universities and research groups. The Office's primary official purpose is to service the Steering Committee and several *ad hoc* committees. TIGER's four programme areas — Carbon Cycling, Trace Gases, Energy and Water, and Ecosystem Impacts — have science coordinators, whose policies are set by the Office. Much of the work of the TIGER Office and the coordination team is to assist the consortia and the individual scientists with the conduct of their research.

All TIGER's 100 awards have been subject to international peer review, also handled by the Office at IH. Grants to universities are made by the NERC's Higher Education Section following authorisation from the Office so records have to be maintained of financial and scientific details of each award. The TIGER programme is entering a new phase with the initial award period coming to an end and a requirement for the selection of research groups who will receive continuation awards.

A key objective of the TIGER Office is to engender a community spirit. Internally this is done through annual review meetings and seminars, and the newsletter *TIGER EYE* (published from ITE, Edinburgh). External relations are another important way of community building. The office has organised joint activities between Research Councils and ensures that TIGER findings are fed into the worldwide network of national and international programmes such as the IPCC and IGBP.

Max Beran is the TFS Climate Change coordinator; **Howard Oliver** is the TIGER III Coordinator.

Appendix 9 Training and education

In addition to applied research for private sector clients, the Institute of Hydrology also has an active programme of Technology Transfer and Training. Research results are disseminated through a wide range of publications, software packages, lectures and training courses.

Courses

In the year to March 31st 1994, courses were given by IH staff in collaboration with the facilities provided by Water Training International at Tadley and Kilwinning:

ER2 (1 week) –
Design flood estimation in the UK
ER6 ($^1/_2$ week) –
Basic design flood estimation in the UK
SP348 (1 week) –
Low River Flows

Staff contributed to other short courses:
Flood control for specialists from Pakistan (organised with HR Wallingford)
Small dam design, Gabarone, Botswana
Water availability assessment, Manila, The Philippines
Baseline monitoring in semi-arid zones, UNESCO/IAH International Workshop, Hyderabad, India
Potential applications of ERS-1, seminar in Manila, the Philippines
ERS-1 SAR applications for natural hazards monitoring, ASEAN Regional Training workshop, University of the Philippines

Software training

12-26 February 1994
HYDATA workshop, Institute for Meteorological Training and Research, Nairobi (funded by WMO and ODA).
20/21 September 1993
MicroLow Flows training course for NRA Welsh region
23 November1994
MicroLow Flows training course for NRA Thames region
8/9 March 1994
QUASAR training course for Thames Water plc
23 August - 3 September 1993
HYDATA training course, Dar Es Salaam, Tanzania

Training given to university students

Institute staff co-supervised postgraduate students working for doctorates at the universities of Salford and Reading:

J. Butterworth (working in Zimbabwe)
S. Gaze (working on the SAGRE programme in Niger)
A. Wild (hydrometeorological inputs to the Irish Sea)

In addition, several postgraduate CASE students are registered with the Institute:

M. Albequerque, BSc – Soil Science Dept., Reading University
L. Bull, BSc - Birmingham University
A. L. Collins, BSc - Exeter University
S. Evans, BSc – University of Nottingham
J. Fisher, BSc – Lancaster University
N. Harris, BSc – Birmingham University
K. Heppel - Oxford University
S. Henworth, MSc – Southampton University
K. J. Neylon, BSc – Reading University

D. A. Post, BSc – Lancaster University
H. L. Grew, BSc – St Andrews University
M. J. Varley, BSc – Lancaster University
J. S. J. Worrall, BSc – Institute of Sedimentology, Reading University

MSc students were hosted from the universities of Birmingham, Freiburg, Imperial College, Reading, and University College, London.

Three months industrial experience and research training is being given to MSc students from Birmingham University studing water quality modelling and from Sunderland University studying neural networks for water resources studies. A meeting was arranged for six students from Birmingham studying the suitability of the IH package HYQUAL for water quality information in the UK.

Several staff act as PhD external examiners at the universities of London, Reading and East Anglia.

Professional qualifications

IH staff Ann Calver, Ian Littlewood and Frank Law have been officially designated as Corporate membership interviewers for the Institution of Water and Environmental Management.

Liaison with schools

The Institute participates in the national School Work Experience Scheme and ten students from local schools worked at IH for one or two periods during the year. IH staff also attended school-employer link meetings and other career-oriented occasions at local schools. This year also saw the introduction of an Engineering Education scheme whereby the Institute joined forces with King Alfred's School in Wantage and a team of four pupils worked on an IH instrument development project.

Our contribution to the Office of Science & Technology's SET7 initiative was to organise an environmental essay competition within local schools. Book prizes were presented to the winner, Hannah Barclay, and her school, King Alfred's, Wantage, at a small ceremony at their end-of-year prize-giving on 12th July 1994. Hannah is pictured here with Head Teacher Mr Michael Jones and IH Schools Liaison Officer Andrew Eatherall. Her winning entry is reproduced opposite.

A slightly different angle on the SET7 theme was our "Take your daughters to work" day. The idea for this national scheme came from the USA who hosted a similar day a year ago. Seven daughters of members of staff came into the Institute for a day. They spent two hours with their own father, then they had presentations describing a typical work day from six female members of staff, and finally spent two hours with someone else's father. The objective was to sow the seed of ambition to combat the otherwise serious drop of confidence that usually occurs with teenage girls by showing them other role models in addition to motherhood and teaching. We were particularly keen to show that we, as a society, care about their careers and wish to make sure that no untapped talent is neglected: who knows, we may have inspired a future Institute Director.

Humans' use for water

by

Hannah Barclay, King Alfred's School, Wantage

We use water for lots of different things. We use it for everyday things like washing-up, keeping clean and for staying alive; drinking. But have you ever stopped to think how the water is got to us clean and fresh? Or how much we use in our everyday lives?

In my project I've written about human beings use for water; what we use water for and how much we use. I've also included how water gets to us and how water is cleaned.

What do we use water for in the home?

In the home alone we use about 3,500 litres of water every week. We use water in toilet flushing, to brush our teeth, a shower or a bath, to cook food, to wash-up, etc. In fact we use a lot more water than we need. We take fresh clean water for granted but people in many parts of Asia, Africa, and South-America have not got any running water. To get water from wells or carry it in jars from rivers far from their home.

How much water do we use in our everyday lives?

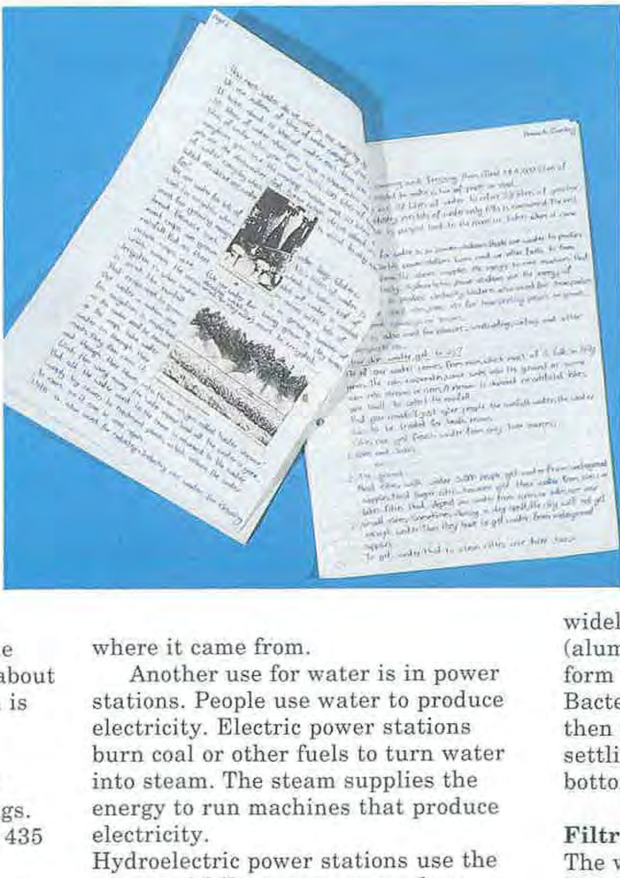
We use millions of litres of water every day just for use in the home. It takes about 10 litres of water each time you flush the toilet, 30 litres of water when you have a shower. You use up to 80 litres of water when you have a bath. 100 litres of water us needed every time you use the washing machine and 50 litres goes when you use the dishwasher. Human beings drink about 2.4 litres of water every day which is vital to stay alive.

What else do we use water for?

We use water for lots of other things. Water is used for irrigation where 435 litres of water is used for growing enough wheat to bake a loaf of bread. Because such a lot of water is needed most crops are grown in areas with lots of rainfall. But as there is a growing number of people, crops are being grown in dry areas which means the area must be irrigated. Irrigation is when water is used like rainfall that crops need to grow. The water a nation uses for irrigation is important as the water cannot be reused as the crops take water in through their roots. They then pass it out through their leaves into the air as gas called 'water vapour'. Winds then carry away the 'water vapour' and all the water is gone. But all the water used in the home is returned to the water supply by sewers to treatment plants, which return the water to rivers so it can be used again.

Water is also used for industry. Industry use water for cleaning foods and canning and freezing them. About 144,000 litres of water is needed to make a tonne of paper or steel.

Manufacturers use 27 litres of water to refine 38 litres of gasoline. Although industry uses lots of water only 6% is consumed. The rest of the water is pumped to the rivers or lakes where it came from.



Another use for water is in power stations. People use water to produce electricity. Electric power stations burn coal or other fuels to turn water into steam. The steam supplies the energy to run machines that produce electricity.

Hydroelectric power stations use the energy of falling water to produce electricity. Water is also used for transportation. People have used seas, rivers etc. for transporting people or goods to different countries or towns.

Water is also used for pleasure: windsurfing, surfing and other water sports.

How does water get to us?

All of our water comes from rain, most of it falls in hilly areas. The rain evaporates, some sinks into the ground or some rain into streams or rivers. A stream is dammed or artificial lakes are built to collect the rainfall.

But you couldn't just give people the rainfall water: the water has to be treated for health reasons.

Cities can get fresh water from only two sources:

- Rivers and lakes
- The ground

Most cities with under 5,000 people get water from underground supplies. Most larger cities, however, get their water from rivers or lakes. Cities that depend on water from rivers or lakes are near small rivers. Sometimes during a dry spell, the city will not get enough water. Then they have to get water from underground supplies.

To get water that is clean, cities use three basic processes:

- Coagulation and settling
- Filtration
- Disinfection

Most small US towns get water by drilling wells and pumping up underground water. The water is chemically treated and then pumped to consumers. Most towns also pump water into tall towers. When water is released from these towers, the force of gravity distributes it through the piping system.

Coagulation and settling

The untreated water (raw) flows into the treatment plant and is mixed with chemicals called coagulants. The most widely used is aluminium sulphate (alum for short). In the water the alum form tiny sticky globs called flocs. Bacteria sticks to the flocs. The water then goes to the settling basins. In the settling basin the flocs settle to the bottom. This removes most impurities.

Filtration

The water then goes through the filter. The filter consists of a bed of sand, or sand and coal 76 cm deep on top of 30 cm of gravel. As the water trickles through the filter, any remaining particles are screened out.

Disinfection

This kills disease-carrying bacteria by adding a substance called chlorine. Most cities chlorinate their water even if they do not treat it in any other way. The diagram traces the eight-hour course of water.

Appendix 10 Visitors

Since water is central to so many human activities, there are many players benefiting from hydrological R &D. These are spread throughout Government, public and private services, agriculture, industry, environment and academia. Over and above regular meetings which take place with other researchers and our customers, the work of the Institute continually attracts many visitors with wide interests in water across business, academic and planning issues from throughout the UK, the European Community and from many other overseas countries.

The Institute regularly hosts visits explaining the role of NERC and research in hydrology to organised parties. During the year we were delighted to welcome students from:

Water Resources Technology and Management MSc Course, University of Birmingham;

Hydrology for Environmental Management MSc course, Imperial College, London;

Centre for Analytical Research in the Environment, MSc course, Imperial College, London;

Hydrology students, Meteorological Institute, Albert-Ludwigs University, Freiburg, Germany;

Hydrogeology MSc course, University of Reading;

Postgraduate course in water resources, Centre for Arid Zone Studies, University College of North Wales, Bangor.

Prof Ryuicho Sudo, Dept of Civil Engineering, Tohoku University, Japan, (centre)and Dr J F Solbé from Unilever (right) with Tony Debney, during a visit to IH in July.

At the end of November 1993 we entertained a small party from the Institute of Meteorology and Water Management, Poland. Other distinguished visitors included:

Dr J Brouwer, University of Wageningen / ICRISAT;

Dr S Blazkova, TGM Water Research Institute, Czech Republic;

Professor Sir Bernard Crossland, Queen's University, Belfast, Chairman of the Hazards Forum;

Dr P V Seethapathi, National Institute of Hydrology, Roorkee, India;

Dr Andras Szöllösi-Nagy, Director of Water Sciences, UNESCO;

Professor John Thornes, Kings College, London;

Mr T S W Wong, Nanyang Technical University, Singapore;

Professor H P M Gunasena, Dean of the Faculty of Agriculture, University of Peradeniya, Sri Lanka;

Professor Z K Kundzewicz, World Meteorological Organization;

Mr Robert Malpas, Chairman of NERC and of the Cookson Group.

In June 1994 Mr John Vereker, Permanent Secretary at the Overseas Development Administration, visited IH scientists in the field when he opened one of the ODA-funded market garden irrigation schemes in Zimbabwe.

Appendix 11 Hydrological review of 1993/94

Hydrological monitoring

Hydrological data, of known quality, are essential both to understand hydrological processes and to develop effective water management policies and procedures. Hydrometric data acquisition, appraisal and analysis achieved a high profile in the recent past which has seen an extension of the range of recorded variation in runoff and recharge rates in a number of regions of the United Kingdom. The attendant scientific and public interest in the clear demonstration of the UK's continuing vulnerability to unusual climatic conditions has focused attention on the search for viable sustainable development strategies and catchment management plans: both will need to pay particular regard to the importance of a healthy aquatic environment. The increasing prominence of such issues, together with their complexity, underlines the need for comprehensive and well-managed hydrological data sets — supported by a range of readily-accessible spatial information (see page 32) — to help develop ever more environmentally sensitive approaches to water management.

Since late 1988, when drought conditions were developing throughout much of eastern and southern Britain, the Institute of Hydrology, in partnership with the British Geological Survey, has maintained a national hydrological review at the behest of the Department of the Environment. A major component in this programme is a monthly series of reports on rainfall, river flows, groundwater levels and reservoir contents throughout Great Britain. These Hydrological Summaries exploit the data held on the National River Flow and National Groundwater Level Archives to provide the necessary historical perspective within which to assess the severity of contemporary flood or drought episodes. The assembled statistics, together with the authoritative commentary which accompanies them, provide the basis for a range of briefing notes, articles and technical papers designed to help formulate policy and increase both scientific and public awareness of water issues. Data for the Hydrological Summaries are provided largely by the National Rivers Authority in England and Wales and the River Purification Boards in Scotland; most of the rainfall figures are furnished by The Met. Office. Additional hydrological and climatological information is provided by a number of sources. These include the Institute's long-term catchment experiments in Scotland and Wales and the meteorological station at Wallingford (see page 40 and below).

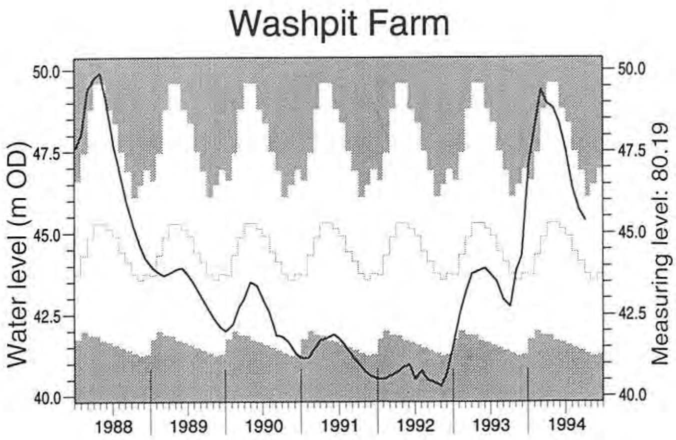
The year 1993/94

Regional rainfall totals for 1993 were mostly a little above the long-term average and, significantly, spatial contrasts were much less marked than in the preceding five years. Overall, a distinct moderation in the normal north-west/south-east rainfall gradient across Great Britain could be recognised. This was associated with a continuing recovery in water resources in the English Lowlands. The recovery in runoff and recharge gained momentum through the autumn and, by the late winter of 1993/94, testified to a transformation — since the height of the drought — which is without any close parallel this century.

The start and end of 1993 were characterised by very wet conditions and several notable flood events. In mid-January sustained frontal rainfall and a rapid temperature rise, which triggered snowmelt across a wide range of elevations, produced unprecedented flows in several rivers draining from the Scottish Highlands. Most notably, the River Tay established a new maximum daily mean flow for the entire National River Flow Archive — 1965 $m^3 s^{-1}$ on 17th January. With near-synchronous peaks occurring in all tributaries, floodplain inundation was very extensive: flood damage in Perth on the North Muirton estate alone was estimated to exceed £10 million. In the city centre many houses had been constructed with ground floors elevated slightly above the level of the surrounding ground such that generally only the basements were inundated during floods. The benefits of this adaptation to flood risk has been considerably reduced in modern times by the conversion of the basements into flats.

Overall, the impact of the January 1993 flood would undoubtedly have been greater without the introduction of a flood warning scheme two years earlier, which was principally a response to the flooding of February 1990 — at the time the highest on record. The relatively close juxtaposition of two extreme events, comfortably exceeding the previous highest flows in a 40-year record — and the corresponding large decrease in the return periods associated with major flood discharges — generated considerable concern in Scotland. However, less formal early records of water levels in Perth stretching back around 200 years, indicate that the 1990 and 1993 events are less outstanding when considered in a fuller historical context — emphasising the value of collating and examining historical information from all sources when assessing the rarity of contemporary flow conditions.

In southern Britain, the late winter and early spring of 1993 rekindled fears of a further drought episode. England and Wales



Well No: TF81/2 Aquifer: Chalk and Upper Greensand
+ extremes & mean monthly levels (1950-1987)

Washpit Farm groundwater hydrograph 1988-94

Hydrographe des eaux de surface pour la ferme de Washpit, 1988-94 rainfall for February and March combined was the second lowest for 200 years and notable sequences of dry days were reported throughout central England.

Thereafter, however, the persistence of rain-bearing frontal systems across southern Britain was remarkable and concern for the water resources outlook was soon allayed. In some eastern districts, April began an extended sequence — interrupted only by August — of wet months which stretched well into 1994; for many catchments this represents the most persistently unsettled sequence on record. The April-October period was, for England and Wales as a whole, the wettest since 1968 and with temperatures substantially below those recorded in, for example, 1989 and 1990, evaporation rates were subdued and soils dried out only sluggishly. An exceptionally wet September resulted in the early elimination of soil moisture deficits and a very early commencement to the aquifer recharge season. Seasonal rises in groundwater levels were brisk and sustained, in the Chalk especially. By year-end, water-tables were close to seasonal maxima over wide areas, only 18 months after overall groundwater resources had been exceptionally depressed. On the evidence of a limited network of long-term monitoring sites, groundwater resources in the summer of 1992 had been the lowest since at least the turn of the century.

The wet autumn in the English Lowlands was not matched in Scotland where a remarkably wet phase which, in the west, could be traced back to 1988, ended in the late summer of 1993. Some western catchments registered their driest August to November period in twenty years and isolated examples of drought stress could be identified — for instance the very limited late-autumn storage in a number of upland reservoirs restricted hydro-power generation and a number of new period-of-record monthly minimum flows were established for Highland rivers.

December 1993 was wet in all regions; for England and Wales it ranks amongst the four wettest months in the last 15 years, some southern districts recorded well over twice the 1961-90 average rainfall. Precipitation was relatively evenly distributed through the month, an important factor in limiting the severity of flooding which, nonetheless, was reported in many catchments around the turn of the year. Flooding was especially serious in parts of southern England. Flood warnings

The Chilgrove well overflowed in January 1994

Débordement du puits de Chilgrove, Janvier 1994

were common in the South-West and on 30th December the River Pol (Cornwall) burst it banks, flooding over 100 properties: rapid runoff from a large car-park above the village may have been an exacerbating factor locally. Along the coast in Sussex, where most headwater streams are sustained by outflow from the Chalk, runoff rates increased less dramatically, but from mid-December onwards water-tables, already at above average levels, rose exceedingly quickly as some localities received the equivalent of 40% of their annual average rainfall in the 10-week period beginning in early December. In the Lavant catchment (above Chichester) groundwater levels rose about 25 metres in three weeks. One consequence was that the Chilgrove borehole — which is thought to have the longest continuous series of recorded levels in the world — began to overflow and continued in artesian condition for over a fortnight. Such conditions have occurred on only a handful of occasions since observations began in 1836 and the record levels at the nearby Compton observation borehole (in a series from 1894) confirm the exceptional nature of this event. The normally dry valleys draining from the South Downs carried substantial runoff and the Lavant recorded a peak flow substantially greater than its previous recorded maximum, causing the protracted inundation of parts of Chichester and massive disruption to transport.

Recent temporal contrasts in aquifer replenishment have been extreme with less than 50% of average throughout much of the eastern Chalk over the four winters up to and including 1991/92 followed by more than 200% over the subsequent winters. Correspondingly the winter and spring of 1993/94 witnessed a substantial headwater extension of the river network. This was especially noticeable in eastern and southern England where, two years previously, many springs and winterbournes were dry, with a considerable loss of aquatic habitat. Some spring-fed rivers established new record 12-month runoff totals over the period ending in the late spring of 1994 and for a significant proportion of lowland rivers mean flows over the 18 months to May were around three times the average for the preceding 18 months. It clearly remains important to establish how resilient ecological systems are to the abrupt habitat changes of the scale recently experienced.

Entering the summer of 1994, accumulated rainfall totals, in the 6-15 month timeframes especially, were exceptionally high in southern, and parts of eastern, England — commonly unprecedented in catchments with areal rainfall records of 30 years or less. A useful index of the unsettled nature of weather conditions in the recent past is the dearth of dry days recorded for the Institute's Meteorological Station. Only around 70 were registered over the period from August 1993 to May 1994: in an average year 120-130 days would be expected. In contrast to several recent years, the water resources outlook was healthy in all regions as the summer decline in river flows, groundwater levels and reservoir stocks gathered momentum.

Wallingford meteorological station: 1993 summary

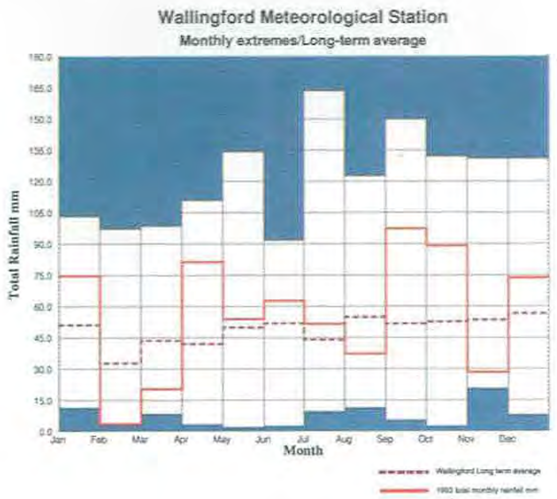
The meteorological station maintained by the Institute of Hydrology has been in operation since 1962. Located at National Grid Reference SU 618 898 at an altitude of 48 m OD, it is recognised as a voluntary climatological station reporting to the UK Meteorological Office. Data from this site — where the temperature readings include regionally notable grass minima — contribute to the national climatological archives and are used to both to support the national hydrological monitoring programme and a range of research activities.

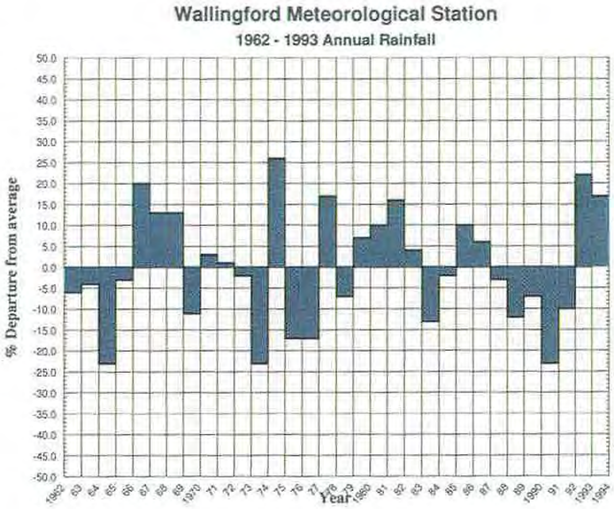
1993 meteorological review

1993 was a mild, dull year with very modest rainfall early in the year more than counterbalanced by a protracted wet phase which began in the early spring. The annual rainfall total fell short of that for 1992 but was substantially above average and more than a third greater than the mean for the drought years of 1989-91. Although 1993 was appreciably cooler than four of the preceding five years, average temperatures just exceeded the long-term average, continuing a sequence of warm years beginning with 1988. Over this period temperatures have exceeded the preceding average by about one degree Celsius. However, there was little evidence of this tendency when, following an exceptionally unsettled January, persistent anticyclonic conditions in the late winter and early spring resulted in a lengthy cold spell and a very notable dry interlude. February was the driest on record at the Wallingford site and, in March, a sequence of 18 dry days was registered (3rd–20th). The 53 days from the 28th January produced an accumulated rainfall total of less than five millimetres — the longest period required to reach this very modest threshold in the entire record. Significant rainfall at the end of March heralded four consecutive wet months and, although August was largely dry, weather patterns in the early autumn were dominated by the passage of an unremitting series of Atlantic frontal systems. Hours of sunshine in September established a new minimum for the month and the combined September-October rainfall total was the highest in the 33-year record. After a respite in November, appreciable rainfall was recorded on all but seven days in December, the latter half of which witnessed moderate local flooding on several occasions.

Plots of monthly rainfall in 1993 (plus mean, max and min for POR)

Tracés compacts des précipitations et de l'ensoleillement mensuels pour l'année 1993 (avec moyenne, maxi et mini pour les précipitations globales)





Annual rainfall totals for the IH Met. Station expressed as percentage departures from the long-term average

Précipitation annuelle de la station météorologique IH s'exprim comme la différence pourcentage de la moyenne historique

Month	Mean air temperature °C				Total rainfall mm			Days with rain	Total sunshine hours		
	1993	lta*	max	min	1993	lta*	%*		1993	lta*	%*
Jan	5.9	3.5	9.8	2.9	74.7	50.4	148	25	32.6	47.8	68
Feb	4.1	3.4	6.9	2.1	3.8	32.7	12	5	53.4	73.5	73
Mar	7.3	5.9	11.1	2.3	20.4	44.5	46	4	121.7	103.8	117
Apr	9.6	8.2	13.3	5.7	81.5	40.8	200	15	100.0	150.1	67
May	12.4	12.0	16.9	7.1	53.9	49.7	108	12	170.6	183.4	93
Jun	17.2	15.0	20.9	9.6	62.8	51.6	122	11	196.9	192.6	102
Jul	17.1	17.4	20.6	10.8	51.7	43.9	117	13	157.4	185.6	85
Aug	16.4	16.9	20.7	9.7	37.3	55.5	67	6	193.9	175.3	111
Sep	13.0	14.0	16.7	8.3	97.4	50.3	194	17	83.6	142.9	59
Oct	8.5	10.2	12.4	5.5	99.7	51.5	193	14	102.2	97.7	105
Nov	4.7	6.4	8.5	1.8	28.5	54.3	53	7	72.6	64.7	112
Dec	5.6	4.7	8.9	2.9	73.7	56.0	131	23	49.6	38.2	130
YEAR	10.2	9.8	13.9	5.8	685.4	582.2	118	152	1334.5	1455.6	92

* lta is the long-term average (based on 1962-1991 data); % is the 1992 figure as a percentage of lta.

Appendix 12 Abbreviations and acronyms

ABRACOS	Anglo-Brazilian Amazonian Climate Observational Study
ADAS	Agricultural Development and Advisory Service (MAFF)
AFRC	Agricultural and Food Research Council
BBSRC	Biotechnology and Biological Sciences Research Council
CEC	Commission of the European Communities
CEMAGREF	Centre National de Machinisme Agricole du Génie Rural des Eaux et des Forêts
CLIMEX	Climate change Experiment
DOE	Department of the Environment
EPOCH	European Programme on Climatology and Natural Hazards
ETSU	Energy Technology Support Unit
EU	European Union
EurAqua	European Network of Freshwater Research Organisations
FRIEND	Flow Regimes from International Experimental and Network Data
GCIP	GEWEX Continental-Scale International Project
GCM	General Circulation Model
GEWEX	Global Energy and Water Experiment
GIS	Geographical Information System
HAPEX	Hydrosphere Atmosphere Potential Evaporation Experiment
HYREX	Hydrological Radar Experiment
ICRAF	International Center for Research in Agroforestry
IDNDR	International Decade for Natural Disaster Reduction
IFIM	Instream Flow Incremental Methodology
IGBP	International Geosphere Biosphere Programme
LOIS	Land Ocean Interaction Study
LRTAP	Long Range Transboundary Air Pollution
MAFF	Ministry of Agriculture, Fisheries & Food
NRA	National Rivers Authority
ODA	Overseas Development Administration
SADCC	Southern African Development Coordination Conference
SVAT(S)	Soil Vegetation Atmosphere Transfer (Scheme)
TIGER	Terrestrial Initiative in Global Environmental Research
WCP	World Climate Programme
WMO	World Meteorological Organization

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