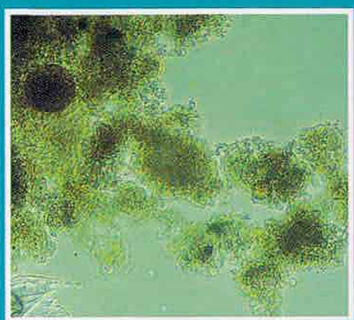
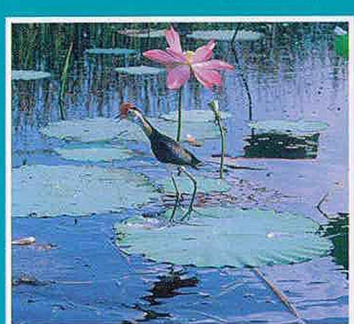
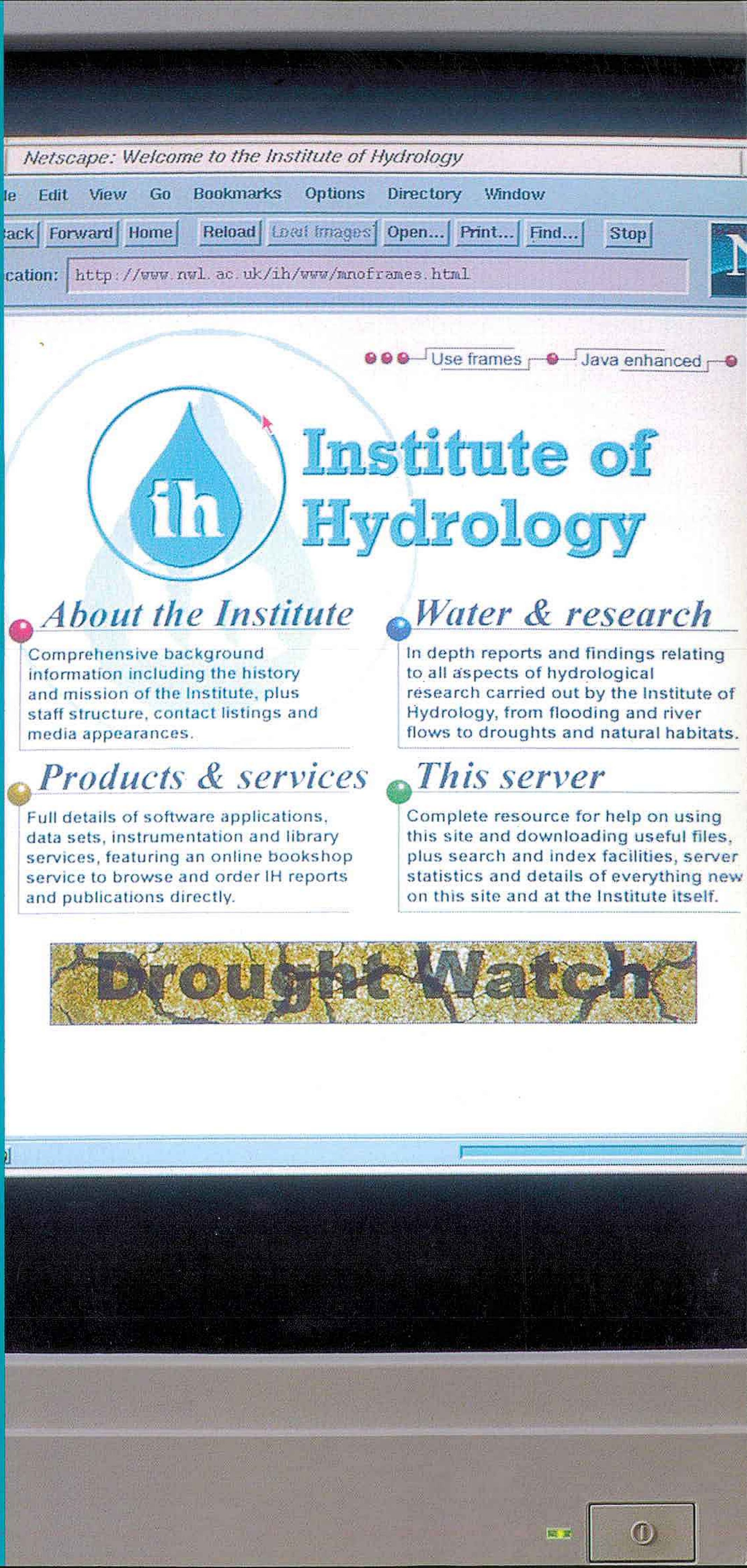






Institute of Hydrology

Scientific Report 1996-97

Centre for Ecology & Hydrology

Natural Environment Research Council

The IH vision

We seek to advance and apply hydrological science to improve the management and sustainable use of fresh water for a better environment and an improved quality of life.

Priority is given to:

- research leading to increased understanding of the hydrological cycle and of its component physical, chemical and biological processes;

- experimentation, monitoring and modelling to investigate variability and change in freshwater systems to reveal and predict the impact of human activities;

- securing relevant data to further such research and provide a sound basis for advice in the broad area of water affairs and public services.

Scientific Report of the Institute of Hydrology 1996/97

Centre for Ecology and Hydrology

Natural Environment Research Council

Contents

Director's introduction	
Soil and soil/vegetation interactions	
Uptake of water by roots in agroforestry	
Interactions in sparse-vegetation-canopy	
Land use science	**6**
Hydrological effects of short rotation energy coppice	6
Himalayan river sediments	8
Impact of particulate outputs associated with timber harvesting	9
Combining hydro-ecological, agricultural and socio-economic modelling (CHASM)	
Freshwater resources	**12**
Global water scarcity: African case study	12
Groundwater recharge in central Spain	14
Estimation of annual river mass loads	16
Biodiversity and population processes	**18**
Dambo processes integration experiment	18
Pevensey levels, Sussex, UK	18
IUCN freshwater policy for wetland conservation	19
Economic valuation of wetlands	19
Pollution assessment and control	**20**
The effects of tree harvesting on streamwater quality	20
Pesticides in the Chalk aquifer	22
Behaviour of oestrogenic substances in rivers	24
Environmental risks and extreme events	**26**
Rainfall mapping in upland areas	26
Global change	28
Persistence of rainfall in the Sahel	28
The CLIMEX project	29
Water and carbon in tropical biomes	32
Integrating generic science	**33**
Using satellite radar to monitor surface soil moisture	33
Combined H_2O and CO_2 flux system	35
Appendices	
1 NERC structure	36
2 IH Staff	37
3 CEH Core Strategic Research Programmes	42
Publications	44

human practices in agriculture and industry pollute significant quantities of our freshwater resource ?

IH research helps answer these questions by concentrating on three areas: (1) the physical processes that control the mass transfer of water within the hydrological cycle; (2) the physical and chemical processes that affect water quality; (3) studies of water resources, where the focus is on the quantities of available fresh water; and the occurrence of hydrological extremes.

Physical processes are studied across a range of scales. At the smallest (millimetres to metre) we now recognise the importance of below-ground processes which control the net exchange of energy and water with the atmosphere, rivers and aquifers. Specific new areas for research include the study of how soil heterogeneity (variability, cracks, macropores etc.) and soil-root interactions affect the water balance. At a field scale most of the world's vegetation occurs in mixtures, so we have focused more attention on the partitioning of water in the complex plant communities that occur in wetlands, agroforestry and riparian zones. At a complete landscape scale the challenge is to deal with the typical patchwork of different land uses. We are therefore looking at how water flows between different landscape units such as forests, heaths, crops, set-aside, or pasture. As well as taking on the challenge of studying the physical interactions in multi-land use catchments, we are also looking in a more holistic way at the coupling between hydrology, ecology and socio-economic processes. Finally, at the continental to global scale we continue to contribute to research into large-scale land-atmosphere interactions. Our recent work has been on the development of multi-source and combined energy, water and CO_2 models, and the improved use of remote sensing techniques.

Specific challenges in water quality are driven by the growing concern about the degree to which we may be polluting our freshwater resources, thereby jeopardising their ability to sustain human and ecological requirements. Much of the pollution in our aquatic environment is transported by sediments and so we have formed a new group to address this issue. We are also looking at micro-pollutants: these occur at very low concentrations, but many of them are unidentified and have unknown consequences for human and ecological health. Changes in soil chemical condition, caused by the application of agricultural chemicals, and SO_2 and NO_x deposition, can also affect water quality. At the whole catchment scale, water quality modelling faces a similar challenge to physical process modelling, i.e. the development of distributed water quality models which can cope with heterogeneous areas.

In the field of water resources and hydrological extremes, we are concentrating more effort on the development of consistent and reliable ways of estimating groundwater recharge. This subject is particularly important given the recent interest in re-assessing the UK's freshwater resources. A key impediment to progress is the lack of understanding of surface-groundwater interactions: another new team is therefore looking at the basic processes governing these interactions.

Regional and global freshwater resources are very poorly quantified so we have put greater effort into the collation of hydrological data and modelling that are required to improve water resources assessment. In flood and drought prediction the problem of non-stationarity in hydrological time series (rainfall and river flows) needs to be taken into account. Current methods assume no long-term trend, a risky assumption given the human influences on river flows and recent evidence of climate change. Both water resource and extreme event assessment also need to address the issue of uncertainty: no data or models are ever without error, so water resource and flow frequency estimation and forecasting must have their uncertainties accurately identified. IH scientists are taking a leading role in addressing these resource and extreme event prediction issues.

Finally, low flows in rivers are occurring more frequently as a result of the combined effects of low rainfall and groundwater abstraction. These low flows can have important effects on aquatic ecology. To address this issue we have strengthened the team researching the interface between hydrology and ecology. Initial projects are quantifying the effects of low flows on fish populations and on the hydrological conditions required to sustain wetlands.

The main body of this report presents selected examples of some of our work in the above areas. The publications appendix contains an impressive list of our complete written output and I encourage readers to scrutinise that literature to assess the true quality and extent of our contribution to hydrological science.

Jim Wallace

Director's Introduction

This report concentrates on scientific issues in hydrology. An overview of the entire science programme of the Centre for Ecology and Hydrology (CEH), its organisation, funding and performance, is contained in the complementary CEH annual report. Organisational and managerial changes within and around IH have provided the opportunity to review our scientific foci. These reviews have led to the formation of new scientific groupings and to greater interactions between hydrologists and ecologists. The emerging research agenda, which is described below, is set in the context of water related issues which are of increasing concern at both national and international scales.

Until quite recently water has been assumed to be available in adequate quantities at a national scale; the main UK issues were therefore to do with water quality. However, the recent spate of exceptionally dry years in the UK has brought the issue of water quantity to the fore and shown politicians and the public that fresh water is not an inexhaustible resource. There are clearly areas of the UK where demand can sometimes outstrip supply.

Another major change to the supply/demand debate relates to a more recent expectation that fresh water will meet not only human needs but also those of the environment. These include support for ecological systems such as the plants and animals in wetlands, and fish and invertebrates in rivers and lakes.

The above issues require some essential hydrological information. The size of the water resource needs to be identified as well as its variation in both space and time. Rainfall and river flows are comparatively well measured in Britain but the rate of recharge to our aquifers, especially those in the south of England that supply much of the local water demand, is not well known. The requirement of each user sector needs to be known. Agricultural, industrial and domestic demands are comparatively easy to estimate, however it is much harder to assess environmental and ecological needs. It is also important to calculate how resources (and demands) may change in the future. Will widespread changes in land use alter water yields to rivers, reservoirs and aquifers? Will climate change sufficiently to affect these resources? Will

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

CEH Core Strategic Programme

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

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

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

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

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

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

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

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

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

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

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

One of the most important, yet least understood, parts of the hydrological cycle is the interface between the physical water system in the soil and the physiological water system within vegetation. Because of its sub-surface position and small size, this soil:root interface is one of the least studied parts of the entire soil-plant-atmosphere system. Most attention has focused on the factors determining the rate of water supply to a root, and much less ton how roots secure new supplies of water by extension into new soil zones and by subsequent root proliferation. The importance of the soil:root system in controlling evaporation and drainage and, hence, factors influenced by them such as plant growth, water resources and land-atmosphere interactions, is now widely recognised.

Soil and soil/ vegetation interactions

UPTAKE OF WATER BY ROOTS IN AGROFORESTRY

Models of water uptake will help define successful agroforestry systems

The sustainability of agriculture in the semi-arid tropics can be enhanced by agroforestry unless competition for water between trees and neighbouring crops results in unacceptable loss of yield. To ensure success therefore requires better knowledge of the processes controlling the partitioning of water uptake between trees and crops.

Competition for water is most easily avoided if trees extract water from below the rooting zone of the crop, using deeply-penetrating vertical roots. However, where deep reserves of water are not accessible, patterns of water uptake do not fit this ideal. A comparison of sap flow in lateral and vertical roots of silky oak *(Grevillea robusta)* trees in an agroforestry system in Kenya, measured using heat balance gauges, showed that uptake occurred almost entirely through lateral roots when the surface layer of the soil was wet and the subsurface was much drier (Figure 1). This type of behaviour should be reflected in the planning and management of agroforestry schemes where such conditions are common. Figure 1 also shows that the competitive effects of trees may be exacerbated when such strong gradients in soil moisture occur, because water was siphoned downwards by the tree root system, potentially depriving the crop of water - a reversal of the phenomenon of hydraulic lift.

To model the partitioning of water between trees and crops mechanistically, the resistance of roots to the entry of water must be quantified. This value was measured *in situ* for roots of *G. robusta* and maize in Kenya using a high pressure flow meter to measure the hydraulic conductances of roots. Improved estimates of root length are needed to reduce variation in the data. These may be achieved using the fractal properties of root branching.

Contact: John Roberts

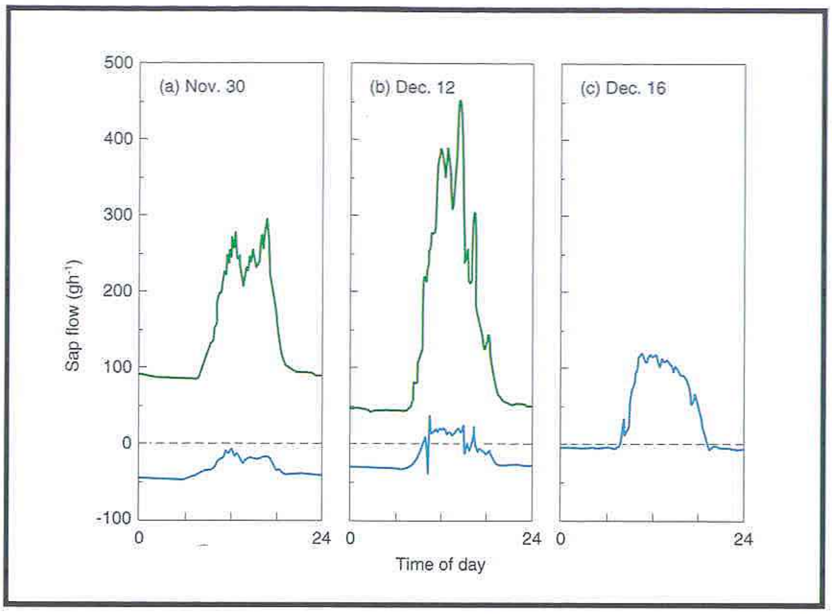


Figure 1. Sap flow in a 30-mm diameter lateral root (solid line) and a 15-mm diameter vertical root (dashed line) of a Grevillea robusta *tree on three days in 1996. Sap flow towards the trunk is positive; flow towards root tips is negative. In (c), all lateral roots of the tree had been cut, forcing uptake through vertical roots.*

SOIL-CANOPY INTERACTIONS IN SPARSE VEGETATION

Most of the world's vegetation grows as mixtures of species where the ground cover is low and there are large areas of bare soil. To predict how these sparse vegetation canopies interact with the atmosphere requires new models known as soil-vegetation-atmosphere transfer schemes (SVATS). The best SVATS describe canopy behaviour using independently acting environmental factors, and allow for a maximum of two sources (usually a canopy with underlying bare soil). At IH we have replaced this empirical approach with physiological parameterisation to include a model of photosynthesis and allow feedback between the canopy and the fluxes.

Typical flux variations in a Sahelian savannah in Niger, West Africa, are shown in Figure 2 demonstrating that the bush transpiration is largest and bare soil evaporation is very small; this means that the sensible heat flux originating from the dry bare soil is very high. The bushes exhibit an interesting diurnal pattern, with positive heat fluxes during the morning dropping sharply to reach negative values of down to –200 W m^{-2} in the afternoon. During these hours the bushes are using energy originating from the relatively hot grasses and bare soil to maintain their high levels of transpiration.

These results show that large quantities of energy are transferred from the soil and ground cover vegetation to the bush canopy which enhances its transpiration rate. Similar interactions may also occur for CO_2, with respired CO_2 from the soil affecting concentrations around the vegetation canopies and hence their carbon fixation and growth.

Contact: Anna Verhoef

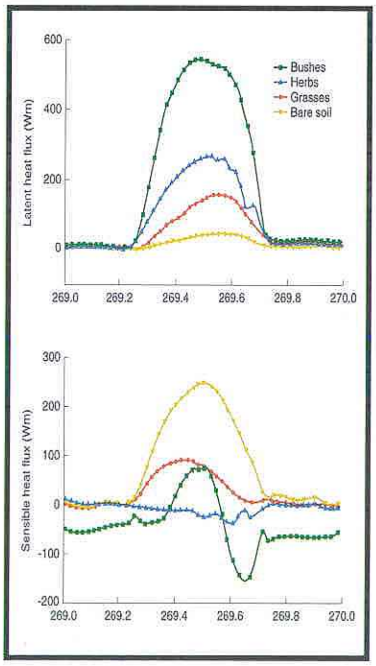


Figure 2. Latent and sensible heat fluxes of the four savannah surface components

Land use and land use change both influences, and is constrained by, the availability of fresh water. Government initiatives such as the planned doubling of afforested area in England, the pressure for alternative renewable energy sources, the European Commission's Common Agricultural Policy reforms and the recognition of the need for sustainable management of interdependent land and water resources provide many scientific challenges. The Institute's projects within this Programme Area have both national and regional dimensions, highlighted by current work in the UK, in Europe and in Asia.

Land use science

In wetter parts of the UK energy coppice should not have a serious impact on water resources

Gauges for measuring sap flow were used to allow calculation of transpiration rates. Here the gauges are fitted to one-year old poplar stems.

HYDROLOGICAL EFFECTS OF SHORT ROTATION ENERGY COPPICE

Poplar (*Populus* spp.) and willow (*Salix* spp.) are increasingly being grown in Europe as short rotation coppice (SRC) to produce biomass as a sustainable source of energy. The clones selected for biomass plantations are highly productive and use more water than the agricultural crops they replace. There is concern therefore that widespread plantation of SRC might result in reduced aquifer recharge and diminished river flows, particularly in drier areas. Funding has been made available from the Energy Technology Support Unit (ETSU) on behalf of the Department of Trade and Industry to provide information on the potential hydrological impacts of SRC before it is widely planted in the UK. Colleagues from the British Geological Survey have also investigated effects on water quality, especially nitrate leaching.

Extensive measurements have been made mainly on the poplar clone Beaupré (*Populus trichocarpa deltoides*) at two SRC plantations in southern England . Direct estimates of transpiration and interception loss have been made and additional environmental, plant physiological, and biometric data collected. These results provide insights into the mechanisms controlling the water use of SRC. When incorporated into new mathematical models of the daily transpiration and interception loss the measurements confirmed that water use of poplar and willow SRC is high - higher than that reported for other major agricultural crops and broadleaved trees, and second only to pine forest. The high water use of SRC results from its high transpiration rate. For poplar this is typically 500 mm a year, compared with 350 and 390 mm a year for conventional ash and beech forest, respectively. The high value for poplar is a consequence of its high aerodynamic and stomatal conductances and an efficient, adaptable root system. The stomatal conductances remain high even when atmospheric humidity deficits are large and when there are significant soil water deficits. However, the stomatal conductances do eventually reduce very rapidly, in response to a large soil water deficit. The interception loss from poplar SRC over the growing season is about 21% of the rainfall and the annual interception loss, including the unleafed period, is about 14% of the annual rainfall. These values are typical of conventional broadleaved woodland.

The main hydrological implications of these findings are:

- Extensive SRC plantations may result in reduced stream flows and reduced peak flows, except in the unlikely event of it replacing coniferous forest. The size of the reduction will be dependent upon the rainfall, the proportion of the catchment converted and the land use that the SRC replaces.
- Large scale plantation of SRC in the driest parts of the country could result in the annual net recharge to aquifers and drainage to rivers and streams being reduced by up to 80 mm where a grassland catchment is wholly converted to SRC.
- During the summer, SRC may cause springs and ephemeral streams to dry up sooner and for longer, with smaller catchments being at greatest risk because of their smaller potential for storage.
- In general, nitrate leaching should be less than from land under intensive agriculture.

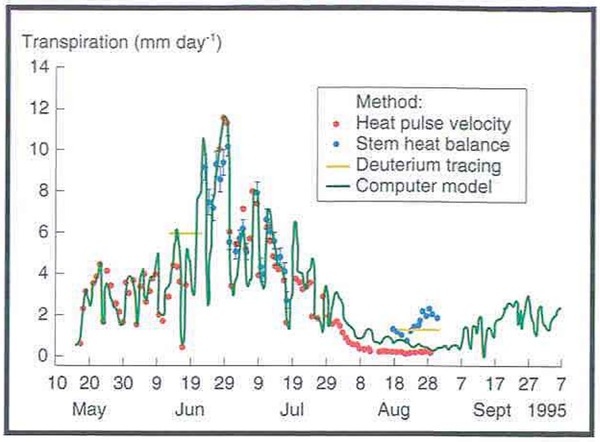


Figure 3. Daily transpiration of poplar SRC, compared with transpiration predicted by a mathematical model

However, in the south east, nitrate concentrations are critically dependent upon the difference between rainfall and evaporation. Where this difference is less than about 150 mm, even for low rates of nitrate leaching, concentrations of nitrate in the water draining beneath SRC could reach the limit for drinking water.

In the light of these effects, it would be wise for extensive plantation of SRC to be in the wetter parts of the country where its high water consumption will not have potentially serious consequences for the water resources. In these areas, and where the solar radiation is not limiting, high yields would be expected.

In drier parts of the country only a small proportion of a catchment should carry short rotation coppice

Contact: Robin Hall

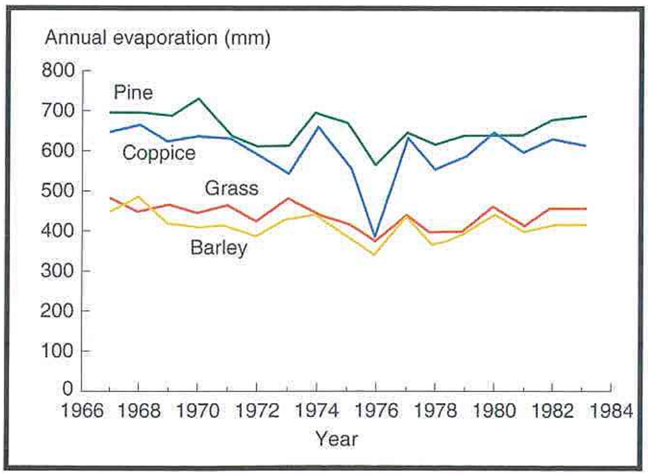
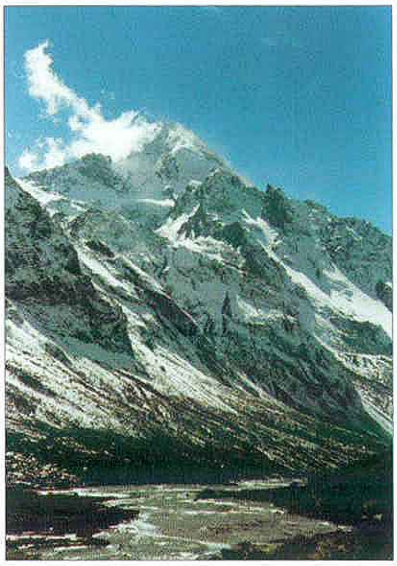


Figure 4. Model estimates of annual water use of SRC compared to three other land uses



HIMALAYAN RIVER SEDIMENTS

The main sources of sediment in Himalayan rivers are glacial deposits, landslides and intensively cultivated hillslopes. These sources produce immense volumes of material making river sedimentation one of the major river management problems of the region. Himalayan rivers are important for water supply, hydropower generation and irrigation to the densely populated lowlands. High sediment loads cause problems such as siltation of reservoirs, blockage of river channels, reduction in the quality of water supplies, and degradation of biological habitats.

Sustainable management of Himalayan rivers must incorporate qualitative and quantitative understanding of sediment regimes. This requires a detailed knowledge of the rate of sediment supply, the characteristic size and shape of the sediment particles, hillslope and channel sediment storage and the downstream transport of particles.

The characteristics of coarse sediment in channel deposits and the suspended sediment concentrations are related to the source area and the transport processes into, and along, the rivers. First- and second-order tributaries link source areas and the river network while the main rivers provide the transport route from the mountains to the lowlands. The characteristics of the sediments in these locations indicate the dominant sediment sources and the down-river transport rates.

Surveys of coarse sediments (>11 mm) in tributary streams have been undertaken in six river basins from the Pindar in NW India to the Tamur in eastern Nepal. In each basin the surveys extended from the intensively farmed Middle Mountains to the glaciers of the High Himalaya. The logistics of working in these remote regions can be difficult but even so 151 streams were surveyed, generating a unique data base.

These measurements show that regional influences predominate, with lesser impacts exercised by geology and land-use within the catchments. This reflects the regional contrast in precipitation regime, with the monsoon more intense and of longer duration in the east but more snowfall occurring in the west. Orographic effects also produce regional variations with areas of high rainfall on the southern facing, lower slopes of the major mountain massifs. The higher rainfall regions have greater river flows which increase sediment transport in the rivers. This explains the more mobile, but better sorted, deposits with larger and more rounded particles found in the eastern regions.

Sediment surveys were also undertaken along two major Himalayan rivers, Upper Ganges (NW India) and Trisuli (central Nepal) from the piedmont zone to the glaciers. The size and shape of particles were measured at regular intervals down the rivers in addition to systematic surveys of the sediments on individual bars and the micro-topography of the deposits.

Similar downstream trends in the size, roundness and sorting of the sediments were identified in both rivers but major impacts were more obvious where landslides occur. The micro-topography changes, with landslide deposits losing their fluvial lens shapes and becoming a chaotic mass of sediment. Bench forms eventually develop as the river attempts to become re-established.

Six major river basins in the Hindu-Kush Himalaya surveyed for major sediment sources and land covers

The results from these surveys explain the characteristics of sediment deposits found in tributaries and show the processes of downstream transport in the main rivers. River basin models are being developed to link the tributaries to the main river, to estimate sediment loads and the likely changes resulting from future environmental change.

Contact: Dick Johnson

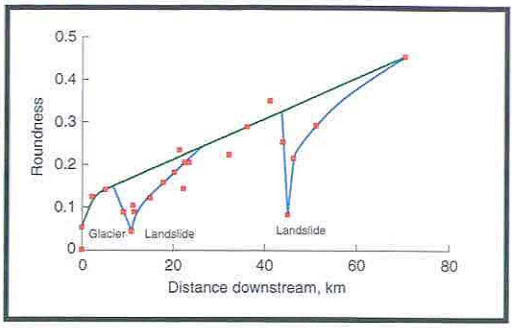


Figure 5. Downstream gradient of sediment roundness in the River Pindar (NW India)

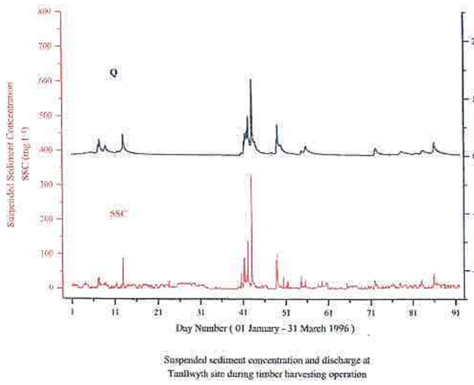
IMPACT OF PARTICULATE OUTPUTS ASSOCIATED WITH TIMBER HARVESTING IN THE UK

Increased river sediment yields associated with forestry are likely to be particularly significant during harvesting. Extensive tree planting took place in the UK during the 20 years after the Second World War, with many forests now reaching maturity. This makes it important to understand the dynamics of particulate outputs arising from modern timber harvesting practices to avoid potential adverse impacts.

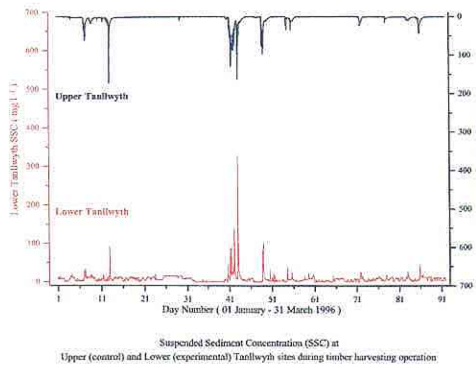
The long-term record of sediment fluxes within the IH experimental catchments at Plynlimon provided the foundation for a research project, commissioned by the Environment Agency, to investigate the impact of particulate outputs associated with timber harvesting. The existing monitoring network was intensified to encompass typical harvesting operations used in England and Wales, which normally involve the felling of 10-15 ha plots using a range of methods depending on specific site conditions. Previous investigations at Plynlimon, following the felling of a large proportion of a sub-catchment, needed to be expanded since that particular operation was not typical of modern forestry practice.

The main study site for this project was a 13 ha plot in the Nant Tanllwyth catchment. Suspended sediment concentrations were monitored continuously at a number of experimental and control sites using WISER (Wallingford Integrated System for Environmental monitoring in Rivers) incorporating turbidity measurement and automatic sample collection. In parallel, a detailed record was built up of the harvesting operation (Jan-June 1996) involving three separate techniques appropriate to the variable site conditions.

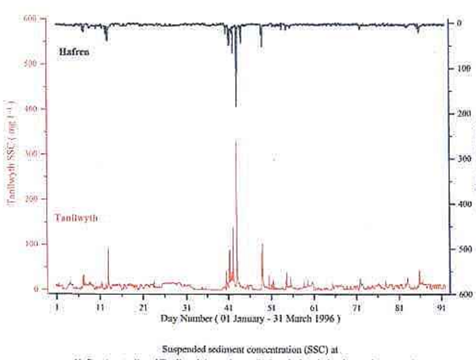
Suspended sediment yields for 1995 and 1996 increased by 83% (from 24 to 44 t km^2 y^{-1}) in the felled Tanllwyth catchment but by only 44% (from 16 to 23 t km^2 y^{-1}) in the adjacent Hafren catchment which, although afforested, was not influenced by harvesting operations. During 1996, the average suspended sediment concentration in the Nant Tanllwyth above and below the harvesting site was 4 and 9 mg l^{-1} respectively, while at control sites on the upper and lower Hafren the average suspended sediment concentrations were 5 and 7 mg l^{-1} respectively. These results indicate enhanced particulate outputs associated with the felling operation. Intensive site investigations have identified the main sources of this material. Other work has



SSC at Hafren (control) and Tanllwyth (experimental) sites



SSC at upper (control) and lower (experimental) Tanllwyth sites



SSC and discharge at Tanllwyth site

Figure 6. Suspended sediment concentrations (SSC) during timber harvesting at Plynlimon sites

Specialist machinery designed for use in erosion sensitive areas can be used to remove timber debris from upland river channels with minimum disturbance of the bed.

concentrated on bed-load yields, impacts on gravel composition and the development of methods for rapid physical impact assessment.

Causes and mechanisms of the particulate outputs associated with timber harvesting identified by this intensive research programme at Plynlimon are supported by additional investigations at other harvesting sites to give a broad view upon which to base recommendations for prevention, amelioration and assessment of these impacts.

Contact: Graham Leeks

COMBINING HYDRO-ECOLOGICAL, AGRICULTURAL AND SOCIO-ECONOMIC MODELLING (CHASM)

Data from Zimbabwe have been used to demonstrate the rationale for improving benefits assessment and evaluation procedures for rural water supply projects. Most rural water supply projects are evaluated using cost-effectiveness analysis. This means that some sort of target is set (for example, supply x households with water, or construct y boreholes in this area), then the cost to the public agency of meeting this objective is sought. The costs are then compared and a particular option is selected.

The principal weakness of cost effectiveness analysis, particularly in the appraisal of water projects, is that only an indirect evaluation of project benefits is made. CHASM analyses are identifying and attempting to quantify the many extended benefits, market-multiplier effects and non-market or environmental benefits that rural water supply projects often provide, but which are usually left out of the appraisal process. Ultimately, this research will provide the theoretical framework for an improved evaluation of the benefits of enhanced water supply. By matching the economic value of the different benefits of rural water supply projects decision makers will be able to choose a rural water supply option that provides maximum benefits to the community given existing cost constraints.

Similar research is under way in conjunction with the natural resource economists at ICARDA (International Centre for Agricultural Research in Dry Areas) in Syria. This initiative has been looking at ways of identifying and quantifying the multiple productive uses that small amounts of water are put to, often "informally" within households in dry areas, to enhance fresh water and income security at the household level.

The CHASM project has also reviewed research on modelling the interaction of the physical, social and economic processes which influence the use and management of natural resources. This review led to the identification of Bayesian Belief Networks (BBNs) as a modelling approach to facilitate interdisciplinary data analysis. A preliminary assessment of the potential of BBNs using data from case studies in the UK and in dryland areas has confirmed that this approach can overcome many of the problems that have beset integrated modelling in the past. BBNs allow variables representing system behaviour to be formally linked even if their relationships are uncertain or ill-defined. Models can then be developed and tested even when the relationship between physical and socio-economic dynamics is poorly understood or when the only understanding is expert opinion.

Contact: Dominic Waughray

CEH scientists are developing methodologies to improve the integration of physical and economic research

Adequate supplies of fresh water are essential to meet public, industrial and agricultural demands and to maintain freshwater ecosystems. The Institute's research in this area seeks to provide an understanding of the main controls on the temporal and spatial variability of both the quantity and quality of freshwater resources. Further to this process-level understanding, the Institute aims to build predictive models capable of decision and planning support at the whole catchment scale.

Freshwater resources

GLOBAL WATER SCARCITY: AFRICAN CASE STUDY

Adequate supplies of fresh water are essential to support all aspects of human life. Society uses water in many ways: domestically for hygiene and food preparation, in industry, in agriculture, for transport and energy production. Global water consumption has increased sevenfold since the beginning of the 20th century and, as the demand continues to grow, it is vitally important that this precious resource is safeguarded from future over-exploitation.

Many national statistics give an illusion of abundant fresh water supplies. However, water resources are not evenly distributed and often the local demand for water exceeds the local availability of the resource. National figures tend to mask problems of water stress which occur frequently in areas of high population and/or low precipitation.

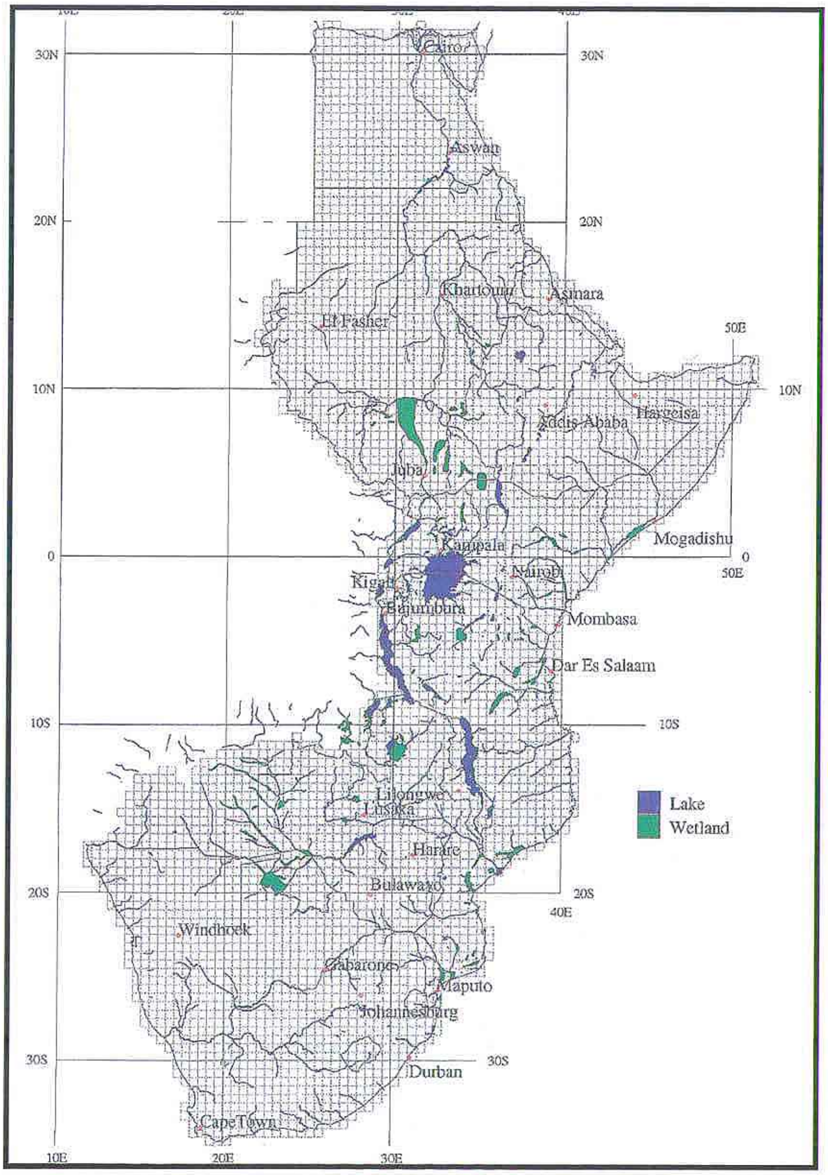
The Institute has been investigating spatial variability of water resources to determine indicators of water stress. Innovative - yet practical - methods have been derived for illustrating the local availability of water. By representing the annual, or seasonal, water resources on a grid basis, other spatial data sets such as land-use or urbanisation, can be used to derive indicators of water stress. Combined with digital elevation data, the grids can also be used to model the accumulation of flow within a river's natural drainage system. Such information not only enables the water resource to be calculated at any location but also provides a method for estimating the resource at regional or national scale. The example illustrated opposite is from Africa but IH has also applied the methodology in Europe.

Decision makers and planners need to identify countries or regions most at risk from the socio-economic disruption resulting from water scarcity, or those areas which are likely to experience water scarcity in the future. To help this process, the Institute has worked with the British Geological Survey and designed user-friendly software to display results. The basic approach relies on a 0.5° by 0.5° grid which allows the spatial variability in both the availability of water and the demands for water to be represented. This differs from most previous studies which have often only examined country-wide aggregates of resources and demand. Several global datasets at this grid resolution are now available, providing some of the input data needed, with the possibility of extension to worldwide coverage.

The approach includes the following key elements:

- A consistent methodology is applied in each grid cell, across all countries and regions.
- The individual grid cells are linked to model the flow patterns of the natural drainage basins. The drainage basin is the logical unit for examining resources, allowing problems of transfers between countries sharing the same basin to be considered.
- Within each grid cell the surface water resources are assessed using the Institute's PDM rainfall-runoff model. Both the locally-generated runoff and that arriving from upstream are considered. Seasonal and year-to-year variations in the surface water flows are taken into account to assess the amount of water which is actually available for use at a given level of reliability. The effects of lakes, reservoirs and wetlands and of water consumed and return flows are included in assessing the surface water availability.
- Groundwater availability in each grid cell, taking into account water quality, is also assessed and added to the surface water availability to provide an estimate of the total water availability for the cell.

Figure 7. Main hydrological features of the area studied, together with the grid squares used in the model

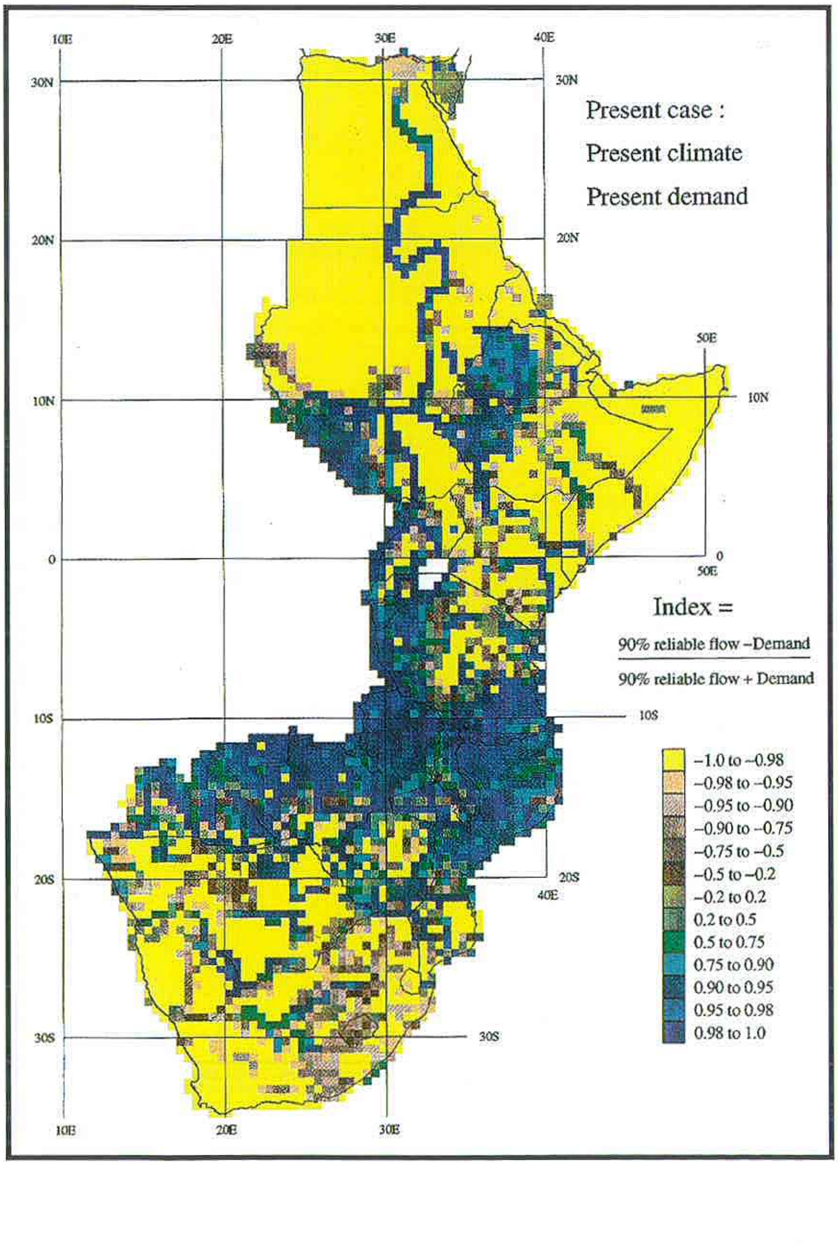


- Water demands, including those for human and livestock consumption, industry and irrigation, are assessed and compared to the water availability for the cell to derive a series of indices of water abundance or scarcity for each grid cell.

- Factors such as population growth, urbanisation, economic development and climate change are putting increasing stress on water resources. The model allows the examination of a range of scenarios of change, or combinations of scenarios, to estimate the magnitude of possible future water resources problems.

- The results are presented in a geographical information system, with user-friendly software providing a visual index of water surplus or scarcity in different regions.

Figure 8. Example of results for a water availability index based on surface flow reliability and estimated current demands



Initially, the method has been tested on a major portion of eastern and southern Africa (Figure xx). It includes 20 countries and parts of four others in an area representing about half of the continent. Figure xx shows an example of the output. This particular index compares the estimated water requirements in each grid square under present conditions with flows of a given reliability (90%). As might be expected, the index suggests that current demands cannot be met from surface flows alone across major parts of eastern and southern Africa, except near to major rivers and in the equatorial region and the Ethiopian Highlands.

Contacts: Gwyn Rees, Frank Farquharson

GROUNDWATER RECHARGE IN CENTRAL SPAIN

Groundwater levels have fallen drastically (up to 35 m) in the La Mancha region of Spain since the 1970s due to increasing abstraction for irrigation. The Guadiana river and the Tablas de Daimiel groundwater discharge wetland have dried up, despite measures to reduce abstraction. The situation had been exacerbated by a series of years with below average rainfall and the management of the groundwater resource is hampered by a lack of knowledge of the annual recharge.

Under the framework of EFEDA II (European Field Experiment in a Desertification-threatened Area) in collaboration with the Complutense University of Madrid and the University of Castilla-La-Mancha, the water balance method was used to study recharge at two agricultural sites - Tomelloso (dry farmed arable and vineyard) and Barrax (dry farmed and irrigated arable). The soils have a very hard caliche layer at about 0.8 m and special methods were required to obtain profile water content and soil water potential measurements using a neutron probe and tensiometers to a depth of 9m. Observations were made for one year through to August 1995. At Barrax, a specially designed borehole tensiometer was used to measure water potential at depths of 2.6 m to 11.6 m.

Over the study period, the rainfall totals at the Tomelloso and Barrax sites were 143 mm and 169 mm respectively, only 33% and 48% of the long term averages of 427 and 354 mm. As a result, there was no infiltration below 0.6 m on the dry farmed plots, and no recharge. However, in years with more 'normal' rainfall, some of the water infiltrating will reach the caliche layer at 0.6 - 1 m depth where it will percolate through cracks and fissures to depths beyond the reach of the roots of annual crops, and become recharge. The total evaporation from the vineyard was only 121 mm during the course of the study, showing that vines can produce a yield even while using remarkably little water. The soil between the vines is cultivated frequently, creating a mulch which reduces soil evaporation and minimises transpiration losses from

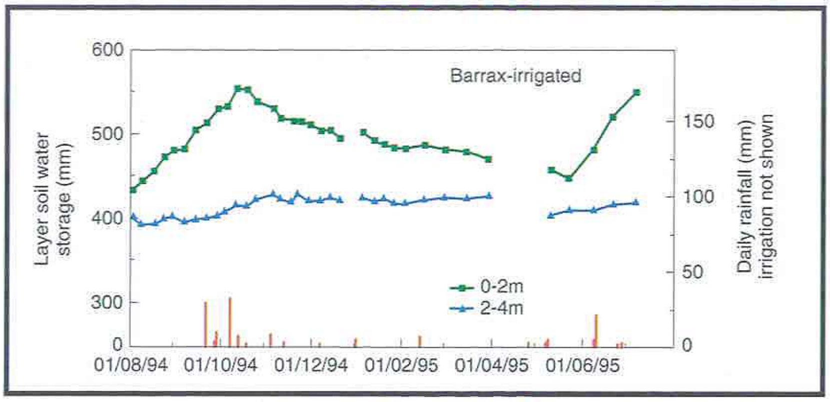


Figure 8. Soil water storage in the 0-2 m and 2-4 m layers

weeds. Recharge is much more likely beneath well managed (weed free) vineyards than from beneath annual, or forage crops, which have higher transpiration rates because of their greater overall leaf area. In contrast to the roots of annual crops, vine roots penetrate the hard caliche layers, but the observed rates of water uptake were very low.

As a result of irrigation in the summers of 1994 and 1995, there were large increases in storage in the 0-2 m layer and evidence of drainage to below 4 m depth. During 1994, the storage increase below the root zone (0.6 m) was 110 mm, indicating excessive application of irrigation water. The very deep wetting of the profile as a result of irrigation was confirmed by the profiles of total hydraulic potential shown in Figure 5 for the period 2 May to 27 July 1995. There is clearly scope for reducing water use through improved irrigation scheduling methods. The introduction of drip irrigation could also lead to large water savings, particularly if driplines were buried.

Contact: Ragab Ragab

Investigating recharge in dry areas of Spain shows potential for saving valuable irrigation water.

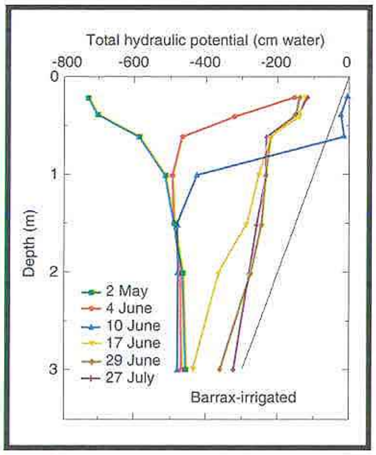


Figure 9. Profiles of total hydraulic potential following the start of irrigation in 1995. Ponding was observed on the caliche layer on 10 June.

ESTIMATION OF ANNUAL RIVER MASS LOADS

Modern computing systems and recently developed software allow synergistic application of large UK river flow and quality databases for the systematic calculation of 'best' river mass load estimates

Hydrochemical and sediment budgets are key diagnostic tools at a wide range of scales, from small upland catchments, through lowland catchments and estuaries, to coastal waters, shallow seas and beyond. IH has investigated the usefulness of existing national databases in providing information on pollutant fluxes, or river mass loads.

The Harmonised Monitoring Scheme (HMS) aims to fulfil the UK's obligation, as signatory to the Oslo and Paris Conventions, to monitor river pollutant loads entering the sea and to identify long-term trends. Each year, the former Department of the Environment collated river flows and determinand concentrations and stored the data in the HMS database, and reported to the Oslo and Paris Commissions who monitor the land-based discharges of contaminants to the North Sea.

Recent inspection of the HMS database revealed that, since 1988, fewer daily mean flows had been returned than in previous years (see Figure 10). As part of a DETR-commissioned study, the HMS database was enhanced with daily mean flow data from the National River Flow Archive which IH maintains as one of the major components of the National Water Archive at Wallingford.

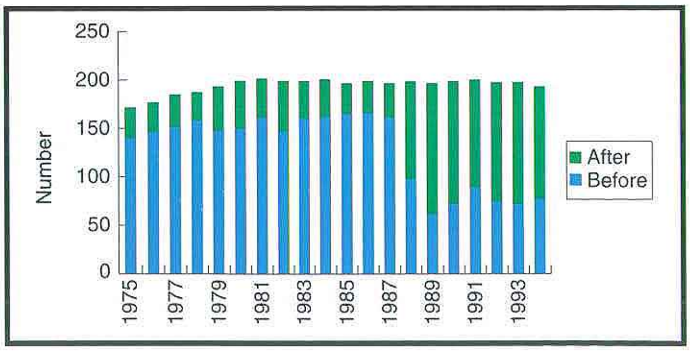


Figure 10. Number of HMS sites with daily mean flows on the HMS database before and after enhancement from the NRFA

Previous work had confirmed that an estimation algorithm which uses additional information from a continuous flow record often gives more precise river mass load estimates than when the HMS database is used in isolation.

For the coastal zones and determinands listed in Box 1, and using special software, the DETR-funded study enabled — for the first time — the systematic estimation of river mass loads from the synergistic application of the NRFA and HMS national databases.

An important aspect of the quality of a time series of aggregated annual river loads for a group of catchments is its temporal consistency. Where the data from a set of catchments for a coastal zone changes through time, or where the number of concentration or flow values is too low in a given year for a reasonable estimate to be made, the annual mass load for a given catchment can be relatively crudely estimated as the product of a mean flow and a mean concentration derived from data for other years or a nearby catchment (Method X).

Figure 11 shows the time series of annual mass loads for inorganic nitrogen aggregated for all 163 near-tidal-limit HMS catchments in Great Britain. The Method X component in this case is modest and does not vary much from year to year, enabling reasonably confident further analysis for trends and relationships with other environmental variables.

Box 1 Coastal zones and selected determinands

Coastal zones:	Atlantic, Irish Sea, Celtic Sea, English Channel and North Sea	
Determinands:	Suspended solids	Cadmium (dissolved and suspended)
	Ammoniacal-N (NH_3-N)	Copper (dissolved and suspended)
	Nitrite-N (NO_2-N)	Lead (dissolved and suspended)
	Nitrate-N (NO_3-N)	Total mercury
	Total nitrogen (NH_3-N + NO_3-N + NO_2-N)	Nickel (dissolved and suspended)
	Orthophosphate (PO_4-P)	Zinc (dissolved and suspended)
	Total phosphorus	Arsenic (dissolved and suspended)
	Gamma-HCH (Lindane)	

Unfortunately, the quality of mass load time series for some of the other HMS determinands is not so good. For example, for determinands where a relatively high proportion of concentrations are recorded as 'less than' values, estimates of mass loads can be very uncertain and further analysis, e.g. for trends, is probably not worthwhile.

Furthermore, the number of HMS samples can be small (e.g. less than 12 per year) or seasonally biased, leading to annual mass load estimates for a particular site which may be grossly in error. For some combinations of (i) aggregations of HMS catchments and (ii) determinand, the Method X component can be large and very variable between years, making further analysis difficult.

Work is under way to investigate relationships between river mass loads and other environmental factors, such as climate, land-use and atmospheric deposition, using the HMS and other databases. The quality of river mass load estimates derived from river flow and quality measurement networks and databases provides a useful focus for assessing the adequacy with which the objectives of such networks and databases are being met.

Contact: Ian Littlewood

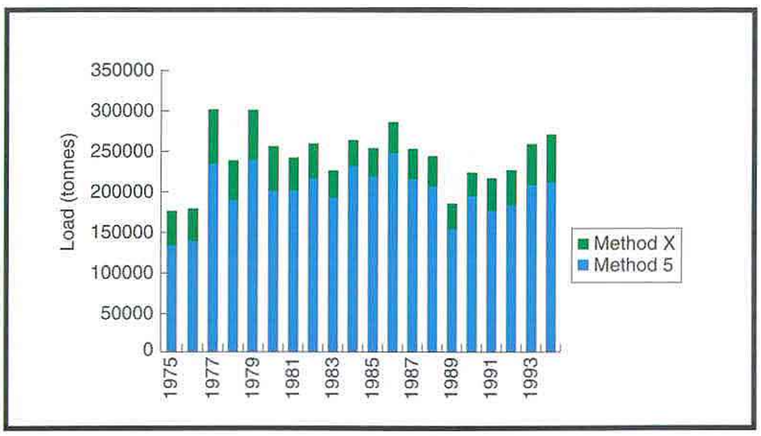


Figure 11. Annual total inorganic nitrogen load ((NH_3-N + NO_3-N + NO_2-N) from HMS catchments (Great Britain), 1975-1994)

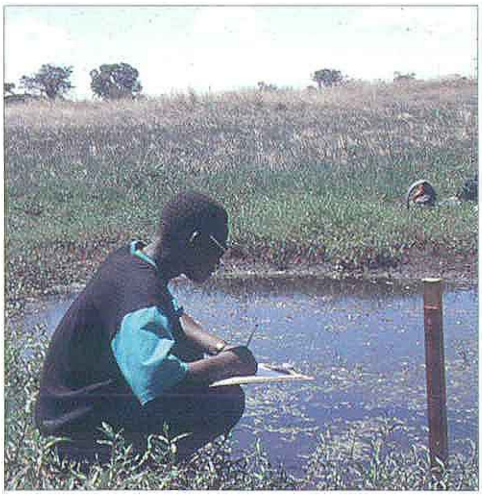
Biodiversity is a measure of the variability of genes, species and ecosystems. High variability is essential to support the ecological processes which keep the planet fit for life, providing our food, water to drink, air to breathe, medicines and much of what we call "quality of life". Understanding of biodiversity is required to build sound national and international policies on ecosystem conservation and the sustainable use of natural resources. Part of the CEH Biodiversity Programme is focusing on the way the hydrology of wetlands responds to improvement management.

Biodiversity

Wetlands are an important genetic reservoir for many plants, invertebrates and birds

DAMBO PROCESSES INTEGRATION EXPERIMENT

Seasonally inundated wetlands, known as dambos in southern Africa, play a significant role in the regional hydrological cycle. They are a vital water reserve for many small-scale farmers, sustaining agriculture during the periods of drought that occur frequently in this part of the world. The Dambo Processes Integration Experiment is a three-year study to quantify the hydrological processes occurring within dambos in Zimbabwe and to understand their influence on downstream flow regimes, particularly how these regions might be affected by their utilisation for agriculture. Measurements show that, on average, 90% of annual rainfall is lost from the study catchment through evaporation. Preliminary results suggest that dry season evaporation losses from the centre of the dambo exceed those from the wooded upslope regions because throughout the dry season the water-table is maintained closer to the soil surface in the valley bottom.



Monitoring water level changes in a dambo wetland, Zimbabwe

PEVENSEY LEVELS, SUSSEX

The Pevensey Levels, near Eastbourne in Sussex, are a wetland of international ecological value and has an English Nature pilot Wildlife Enhancement Scheme, which encourages farmers to adopt environmentally friendly practices, including maintenance of high ditch water levels. University College London, supported by the Environment Agency and the Institute, is researching the hydrological functioning of the Levels to determine the sustainability of such water management strategies. Data on rainfall, drainage pumping rates, energy fluxes and evaporation, river flows and groundwater levels have been used to model the water balance of the Levels. The data will be used to determine the hydrological consequences of various water management scenarios and the effects of climate change.

IUCN FRESHWATER POLICY FOR WETLAND CONSERVATION

Founded in 1948, the International Union for Conservation of Nature is a union of some 900 States, government agencies and a diverse range of non-governmental organisations from 136 countries. A key component of IUCN is its Wetlands Conservation Programme, which coordinates a range of field projects in Latin America, Africa and Asia. From 1993-1995, IH provided a Freshwater Management Advisor, based in Switzerland, to ensure that IUCN activities concerned with the conservation, management and sustainable use of freshwater ecosystems and their biodiversity were scientifically and technically sound and based on interdisciplinary cooperation. We continue to provide technical assistance in the development of IUCN policy on freshwater and river basin management.

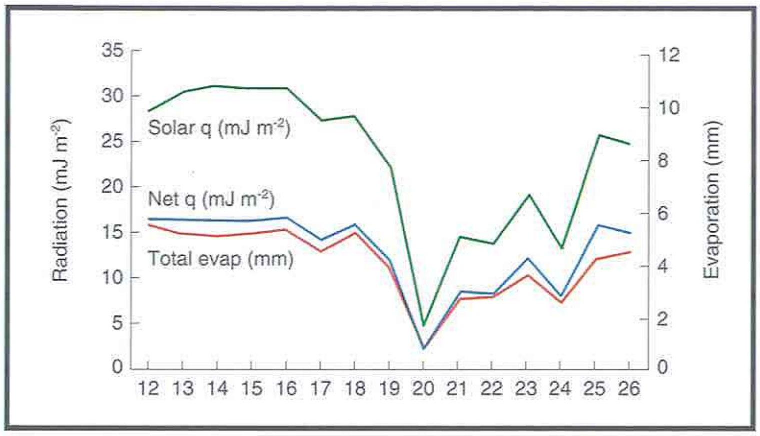


Figure 12. Energy flux, Pevensey Levels, June 1996

ECONOMIC VALUATION OF WETLANDS

Today, most development decisions are made on economic grounds. Hence the goods and services provided by wetlands must be given a quantitative value if wetland conservation is to be considered along with alternative uses of the land itself or the water which feeds the wetland. For many products, such as fish or timber, there is a world market which allows easy calculation of worth of the wetland. The value of a particular wetland function, such as water quality improvement, may be calculated from the cost of building a treatment works to perform the same processes. However, it is much more difficult to value the aesthetic beauty of wetlands as no market exists.

In developing countries the global benefits of wetland conservation are often overlooked unless mechanisms, such as debt-for-nature swaps are involved. To address these problems, the Institute, in collaboration with the University of York, has produced a guide for planners and decision makers on the economic valuation of wetlands for the Ramsar* Convention.

Contact: Mike Acreman

Conflicts between human and ecological needs from wetlands can only be resolved through better understanding of their hydrological behaviour

* *Convention on Wetlands of International Importance*, signed at Ramsar, Iran, in 1971.

The continuing requirement for legislation, at national and international level, to protect the natural environment and human health from anthropogenic pollutants must be underpinned by an understanding of the sources, movement and fate of pollutants in natural ecosystems. Since water provides the key pollutant transport vector, water quality studies at IH are central to this CEH programme. The wide range of pollutants of current concern dictates that studies are conducted in uplands and lowlands but must be considered at a catchment scale to provide for sustainable and integrated management.

Pollution assessment and control

Studies on acidic and acid-sensitive spruce forest at Plynlimon, mid-Wales, show water quality impacts are relatively short-lived... concern still remains over long-term loss of calcium

THE EFFECTS OF TREE HARVESTING ON STREAM WATER QUALITY

There has been much concern within the water industry over the combined effects of acid deposition and conifer plantation on stream water quality in upland Britain. Certain areas receive very high loads of acidic pollutants from industrial emissions. This deposition is enhanced by aerodynamically rough forest canopies which can increase the capture of acid pollutants by up to 90%. Many of these forests, planted in the 1940s, are now reaching maturity and are ready to be harvested. Harvesting may eliminate the enhanced capture of pollutants but it also disrupts the cycling of nutrients between the soil and forest biomass and may generate nitric acid, which may in turn lead to stream acidification and aluminium leaching with detrimental effects on stream ecology. On a decadal time scale, modelling predictions suggest further deterioration in stream water quality due to the uptake of base cations by the forest biomass. Tree felling and replanting operations are set to expand over the next decade and the need to assess and limit their impact on water quality has become urgent.

In conjunction with ITE Bangor, IH have been assessing the implications of conifer harvesting and replanting on upland stream water quality in a study centred on the experimental catchments at

Plynlimon, mid-Wales. The aim is to identify 'best practice' management strategies and develop a model and guidelines for environmental impact assessment. The programme is half-way to completion and emphasis remains on the measurement of variations in water quality with felling and replanting for a wide range of major, minor and trace elements. Over the past year monitoring has followed three approaches:

- Long-term weekly sampling of rainfall, cloud water and the main streams draining the upper River Severn. This provides a long term perspective on changes in pollutant inputs and stream water chemistry and sets a context against which to assess chemical variation at other sites with shorter records. In the Afon Hore, for example, tree-felling-induced nutrient releases to the stream (Figure 1) declined to background levels within five years of felling; there was no significant stream acidification associated with this period. At other sites, where soil water is a major component of flow, a depression in pH and increased aluminium concentrations have been observed. The gradual decline in amplitude of winter peaks in nitrate concentration in the Upper Hore is caused by the accumulating drought from summer 1992 until the drought-breaking storms of

Figure 13. Long-term stream chemistry data from two sites on the Afon Hore at Plynlimon showing the effects of major tree harvesting on pH, nitrate, potassium and aluminium. The orange trace is for samples collected downstream of the felled area while the blue trace shows data for water draining the area upstream of the felling.

autumn 1995. The wetting-up of the catchment in late 1995 and re-activation of nitrifying bacteria results in the observed large winter peak in nitrate concentration.

- Surface runoff from small ephemeral streams and groundwater from a series of associated boreholes have been monitored at felling and control sites on soils characteristic of upland areas (podzols, gleys and brown earths). Recent data show nitrate and potassium release in surface runoff as a consequence of felling at both the gley and podzol sites. For the gley site, there have been very large increases in dissolved organic carbon (+15 mg l^{-1}), nitrate (+8 mg NO^3 l^{-1}, potassium +3 mg l^{-1}), ammonium and phosphate (+1 mg l^{-1} each). For the podzol, the main changes are for nitrate (+11 mg NO^3 l^{-1}) and potassium (+0.4 mg l^{-1}). There is little evidence of chemical change in the groundwaters, except for the podzol site where a modest increase in nitrate has been observed.

- A broad regional survey has been undertaken of 65 upland streams in Wales draining felled and mature forest sites on a spectrum of soil types under both storm and baseflow conditions. Preliminary analysis of the 375 samples collected to date demonstrates the great variability in water quality from site to site and between the main soil types: brown earth sites appear to 'leak' the most nitrate. The results do, however, suggest that sites felled between six months and three years prior to sampling have elevated concentrations of the nutrients nitrate, potassium and phosphate compared to other sites.

The absence of an increase in acidity or a significant increase in the leaching of aluminium with tree harvesting for the Hore, small streams and regional survey sites is encouraging. It would appear that although nutrient cycling within the forest system is interrupted and promotes leakage of nitrate from the soil, any release of hydrogen ions into the stream-waters and/or release of aluminium is overcome by the concentration of base-rich groundwaters to the main streams.

The results indicate that the effects of forest felling and replanting on less than the decadal scale are relatively short-lived and the water quality changes are probably not a major cause for environmental concern. Questions still remain over the long term sustainability of upland forestry, given the loss of calcium. These issues demand continued monitoring of forest ecosystems and the questions raised may only be fully addressed once second rotation plantations are well established.

Contact: Colin Neal

Slow transport of pesticides by matrix flow suggests significant quantities may reach groundwater 10-30 years after application

PESTICIDES IN THE CHALK AQUIFER

Concerns over groundwater contamination by pesticides have led to the implementation of a joint Institute of Hydrology/British Geological Survey field study. This study has focused on the fate and behaviour of herbicides applied to wheat fields overlying the chalk aquifer of Hampshire to discover if pesticides reach the chalk aquifer and if so, by what process and in what concentrations?

There is recent evidence that a small proportion of herbicide does transverse the soil layer and enter the chalk above the water table. Laboratory sorption and degradation studies have shown little potential for pesticide concentrations in the chalk to decline: hence herbicide which escapes the soil horizon is likely to eventually reach the groundwater.

Monitoring groundwater through boreholes and sampling chalk pore water by shallow coring shows that the herbicides studied moved through the chalk in two ways: preferentially through fissures (by-passing the matrix) and through the fine matrix pores (piston flow). This is consistent with the conceptual view of the chalk aquifer as a dual porosity/permeability system. The matrix route was found to be dominant. Preferential flow to the groundwater only occurred where the water table was close to the soil surface (4-5 m), and then only occasionally for short periods after significant rainfall. By this pathway small quantities of the applied herbicide Chlorotoluron were able to reach the shallow groundwater within 10 days of application. These conclusions were confirmed using a bromide tracer (Figure 14). The almost total recovery of the tracer suggests that although small amounts do move via preferential means, the vast majority is transported within the fine pores of the chalk matrix. In contrast, where the water table was much deeper (17 m), no pesticides have been detected in the groundwater although they are present in the chalk unsaturated zone above the groundwater.

Hydrological data from the field site confirms the dual water flow hypothesis (Figure 15). At the upper site with a deep water table, chalk hydraulic potentials at 3 m depth responded to rainfall but do not permit fissures or fractures to hold water. Consequently, peak fluxes are delayed as water moves slowly through the chalk matrix. At the lower site with its shallow water table, capillary rise means that the matrix of the chalk above the water table is largely saturated. Therefore hydraulic potentials in response to the same rainfall are less negative and the movement of the peak water flux down the profile is more rapid. Water is thought to move down the surfaces of chalk blocks as thin-film flow since the large fissures/fractures would still not hold water under these tensions. It is calculated that significant pesticide concentrations could reach the groundwater through the chalk matrix between 10 and 30 years after application at this site, depending on the depth to the groundwater.

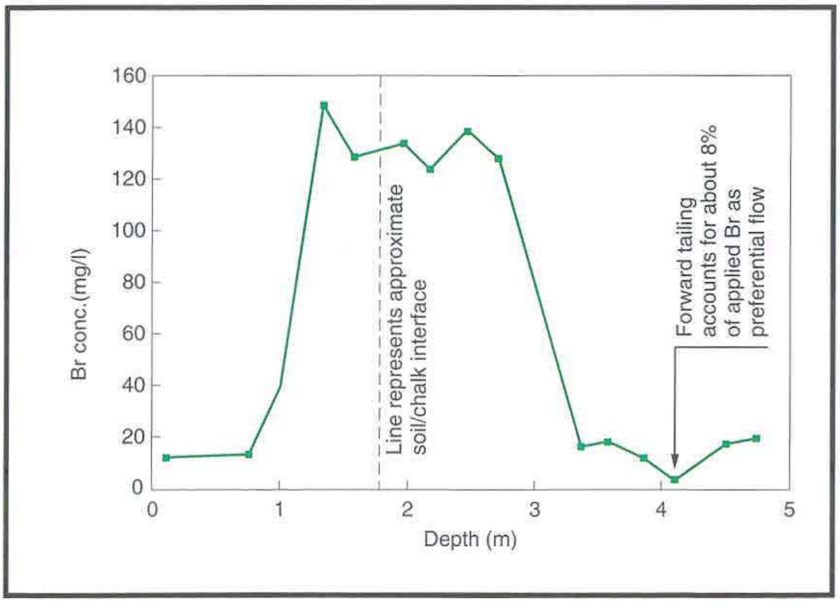


Figure 14. Bromide concentration profile with depth for the lower site

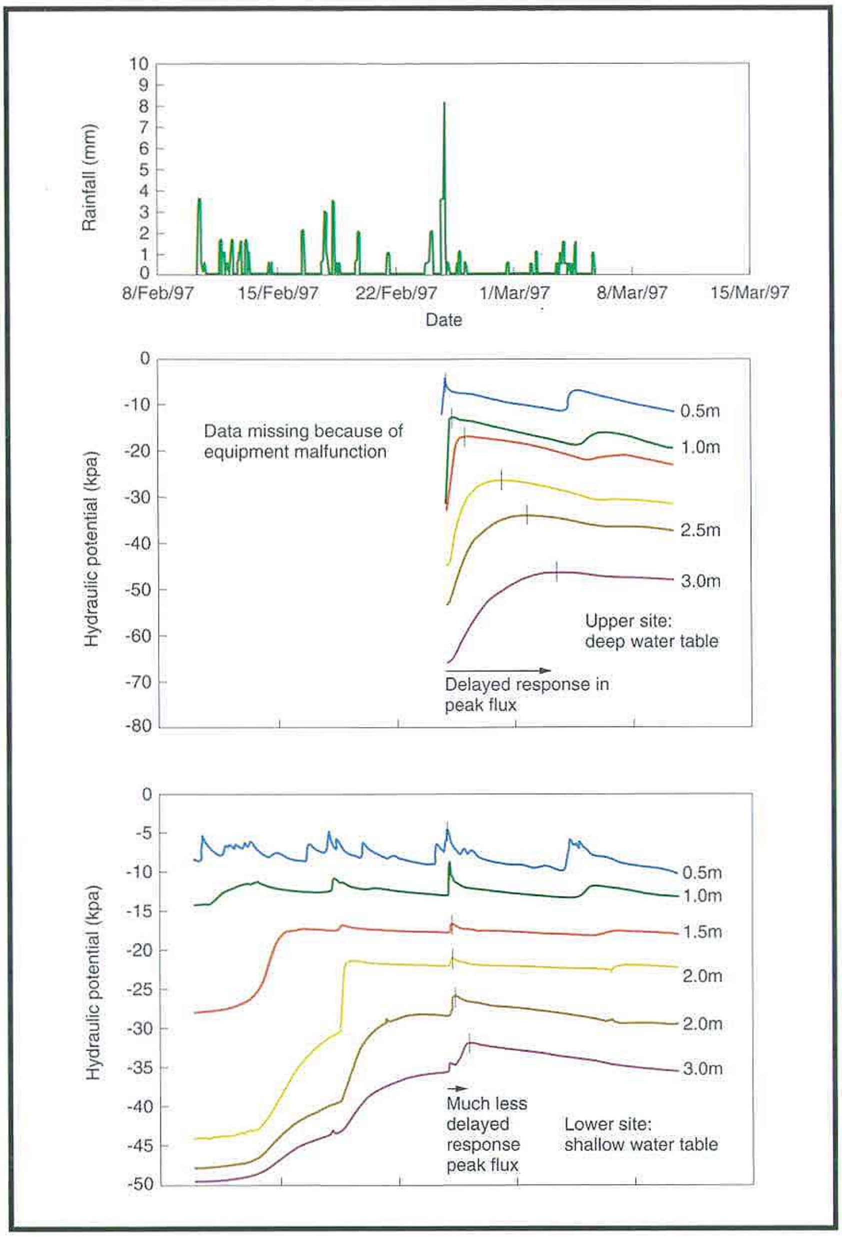


Figure 15. Different flow processes between upper and lower site

Laboratory studies with groundwater samples show that degradation of the pesticide once in the aquifer is spatially and temporally very variable. In addition, incomplete degradation is likely to leave persistent by-products which may remain within the aquifer for many years.

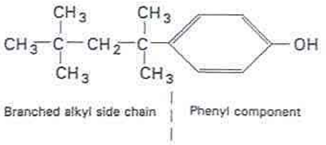
Contact: Atul Haria

BEHAVIOUR OF OESTROGENIC SUBSTANCES IN RIVERS

The release of oestrogenic compounds (those that turn males into hermaphrodites) into the environment is an issue of increasing concern in the developed world. Several different groups of xenobiotic compounds have been shown to possess an oestrogenic potential. There is still controversy over whether these compounds could be affecting human fertility. There is evidence, however, that fish in British rivers are being affected, as shown by the increase in the proportion of hermaphrodites being found (although it should be noted that fish are always likely to be more sensitive to oestrogen than humans).

A major class of chemical which has been implicated as a likely cause are alkylphenols emanating from some sewage treatment works as by-products of non-ionic surfactants used routinely in industrial and domestic cleaners. Concentrations up to 100 mg l^{-1} have been detected in polluted rivers. In addition, the female steroids themselves, oestradiol and oestrone have been found in sewage effluent. As yet no one knows how these different groups of oestrogenic compounds behave when they enter the freshwater environment. How these compounds persist or partition within the freshwater environment will affect their ecotoxicological impact.

The behaviour of one of these oestrogenic chemicals, octylphenol, in freshwater and sediment samples has been studied at IH and found to have a strong attraction to bed sediments,



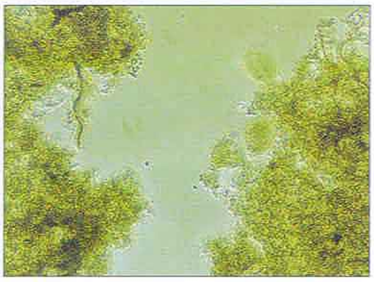
The octylphenol isomer, derived from a commonly used surfactant which acts like oestrogen.

particularly those with a high organic carbon content and small particle size. Being lipophilic, it may enter the food chain by being ingested (along with the sediments) by small benthic organisms, which are themselves eaten by other organisms. Degradation studies have shown octylphenol to be moderately persistent. Figure 16 shows the biodegradation of octylphenol by micro-organisms in a sample of river water from the River Calder (near Wakefield, Yorkshire).

As the residence time of water in many British rivers is not usually longer than seven days, these results indicate that much of the compound would remain intact during its transit down the river. Octylphenol has a strong affinity for the suspended sediments found in the industrial reaches of the Aire and Calder rivers. These suspended sediments consist largely of aggregates of decaying organic material, very probably originating from the nearby sewage works. It is predicted that high levels of these compounds will concentrate where the sediments settle at low velocity zones in the river. In unpolluted rural river reaches, where the suspended sediments in summer are composed largely of algae, there is much weaker sorption of octylphenol. In these situations most of the compound will remain free in the water.

The results show that when an oestrogenic compound like octylphenol is discharged into a river its behaviour will vary depending on the river type. Much work remains to be done to increase our understanding of this new and critical issue which may threaten the wildlife in our rivers.

Contact: Andrew Johnson



Water from the River Aire (x 100 magnification).

Some compounds are shown to remain largely undegraded in their transport down rivers and may accumulate in sediments

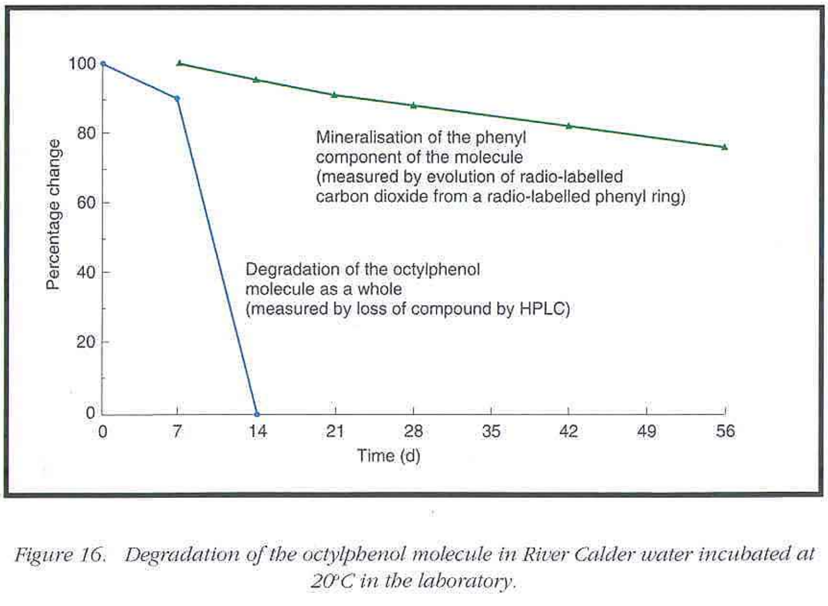


Figure 16. Degradation of the octylphenol molecule in River Calder water incubated at 20°C in the laboratory.

Storm rainfall can culminate at the catchment scale in extreme river flows and the associated risk of flooding and environmental degradation. This risk is related to the spatial and temporal pattern of storm rainfall. Understanding the variation of rainfall, and of its frequency of occurrence, over space and time is thus of fundamental importance to flood hazard assessment.

Environmental risks and extreme events

RAINFALL MAPPING IN UPLAND AREAS

The objective of this study is to provide improved extreme rainfall estimates at any location in the UK

Extreme rainfall frequencies remain the basis on which flood risks are assessed in the UK and elsewhere. Rainfall frequency estimation at IH is based on the analysis of annual maximum rainfall totals of various durations (from 1 hour to 8 days). The index to be mapped across the UK is the median of annual maximum rainfalls at a site, or RMED. This index is used together with the FORGEX rainfall frequency method[1] to provide design rainfall estimates at any location in the UK, as part of the Flood Estimation Handbook research funded by MAFF.

For a given duration, raingauges with at least ten years of record are selected to provide the observed data. For durations of 1, 2, 4 and 8 days, a total of 5591 raingauge records are available from Great Britain, and 267 from Northern Ireland.

Despite the large number of gauges available for the mapping, their spatial distribution is rather uneven, with high densities in lowland areas but much less in the uplands, especially in Wales and Scotland. Moreover, in Scotland, the gauges are mainly situated in the glens and may not be representative of the mountainous areas. Ordinary mapping methods such as an interpolation technique known as kriging are inadequate.

Topographic information was included in the interpolation to improve the mapping of RMED in upland areas. Rainfall is known to be closely related to topography, particularly in mountainous areas. Topographic variables are calculated from a Met. Office digital terrain model (DTM) which covers Great Britain, complemented in Ireland by an extract from the US Geological Survey's worldwide DTM.

The mapping method has three steps:

- A regression model is fitted to the observed values of RMED. A four-variable equation was fitted using the gauges in upland areas (south-west England, Wales, north-west England and the Highlands of Scotland). It explains between 57% (RMED-1day) and 75% (RMED-8day) of the variance of RMED in Britain. The variables are: distance to the sea (to the west and south-west directions), average elevation around the raingauge, and "obstruction to the west". The last is an index of the obstruction due to mountains situated to the west. These variables reflect the direction of the prevailing winds (westerly and southwesterly) which bring frontal rainfall to the UK. A different four-variable equation, using the same topographical variables but in different directions, has been fitted to the gauges in Northern Ireland, explaining from 64% (RMED-1day) to 71% (RMED-4day) of the variance.
- At the site of each raingauge, the difference between the regression estimate and the observed RMED (residual) is calculated. The pattern across the country indicates the remaining variability of the rainfall statistic which is not explained by the regression model. This reflects effects such as the rainshadow behind the Grampian mountains in Scotland. Interpolating these residuals (using kriging) gives an estimate of the correction to apply to the regression model to improve its estimate of RMED.
- The regression estimates are then combined with the interpolated residuals to give a final estimate of RMED for every point on the national 1-km grid. The improvement over ordinary interpolation is particularly noticeable in upland regions, where the effect of relief on rainfall appears on the final map.

Contact: Christel Prudhomme, Duncan Faulkner

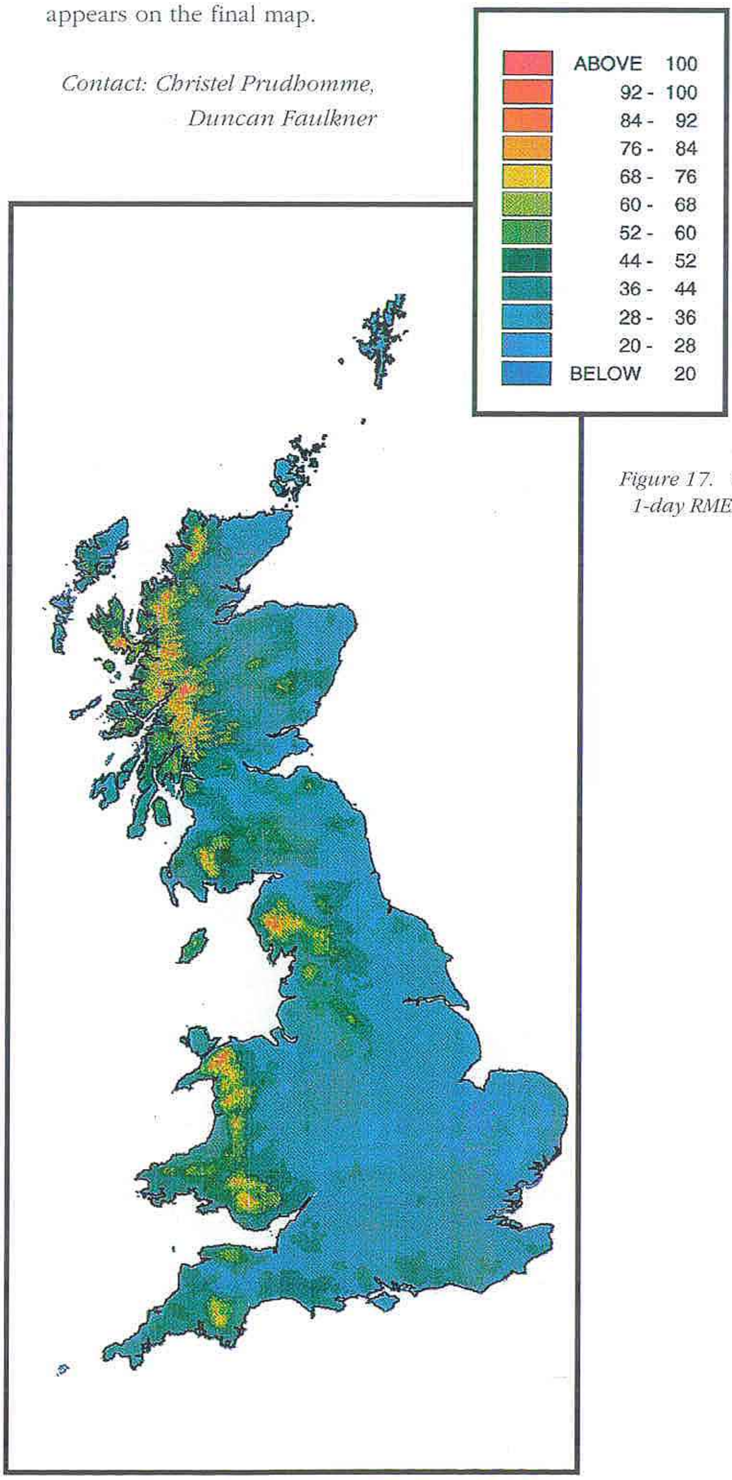


Figure 17. Combined 1-day RMED in mm

It is now accepted that man-made influences, such as emission of greenhouse gasses and land use change, have a profound and global influence on the climate. However, the representation of the earth's surface in climate models remains rudimentary and the incorporation of exchanges of carbon, energy and water, is still in its infancy. In parallel, the interpretation of the climate model output to identify the impact on human and natural systems requires thorough understanding of how these systems work. There is therefore an increasing need for measurements and modelling in the major biomes of the world to develop both the climate models and the impact assessment.

Global change

Certain areas consistently receive more rainfall in any one season than others. Why is this?

PERSISTENCE OF RAINFALL IN THE SAHEL

In the Sahel, as in all semi-arid regions, soil moisture controls the partition of incoming radiant energy into sensible and latent heat fluxes. Over 50% of rainfall in this region comes from organised convective systems, such as line squalls. Embedded within these systems are individual rain cells which cause considerable variability in rainfall in both time and space. In turn, this variability in rainfall causes spatial inhomogeneity in the soil moisture.

Rainfall observations taken as part of the HAPEX-Sahel study show a remarkable persistence of the spatial patterns of rainfall which can lead to the season's total rainfall varying by a factor of two over as little as 10 kilometres.

A feedback hypothesis has been proposed to relate the persistence of the rainfall patterns to surface fluxes as the soil dries out after rain. For the first day or two after a rainfall event, evaporation from bare soil is high, and soil albedo and temperature are low. On longer time scales, leaf area develops rapidly in areas of high antecedent rainfall whilst deep soil moisture ensures high rates of transpiration. These effects combine to produce both higher evaporation and net radiation in areas of higher rainfall. As a consequence, variability in sensible heat flux is less than that in evaporation. These horizontal gradients in the surface energy

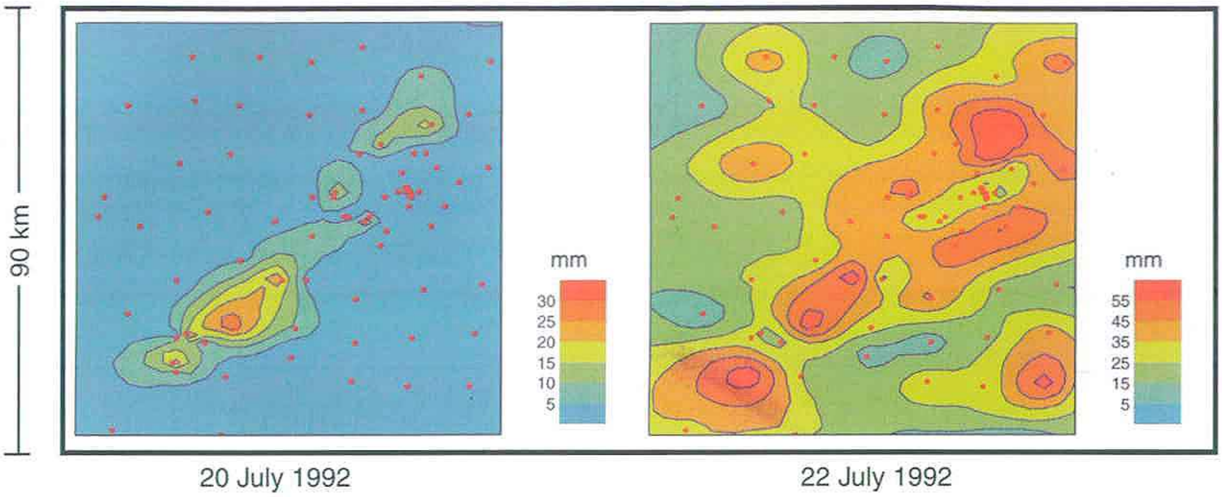


Figure 18. An example of rainfall persistence: isohyets calculated from the rain gauge network (red dots) over the HAPEX-Sahel study area in Niger. Rainfall patterns from the squall line on 22 July are characterised by "bulls eyes" coinciding with wet areas from the storm two days previously.

balance cause marked changes in the humidity in the atmospheric boundary layer above wet and dry areas (confirmed from aircraft observations taken over the region during HAPEX-Sahel).

When meteorological disturbances cross a region with pronounced evaporation patterns due to antecedent rainfall (see Figure 18), the differences in the boundary layer above wet and dry surfaces may significantly influence the dynamics in the passing disturbance, with preferential development of intense storm cells in areas which were previously wet. The surface thus acts as a positive feedback over a series of rainfall events at convective length scales of less than 15 km.

Rainfall patterns such as this have dramatic effects on the local people living in semi-arid regions like the Sahel. In some cases, entire villages may experience crop failure whilst their near-neighbours have reasonable yields. It is therefore of considerable practical interest to understand — and be able to predict — this effect. More detailed investigations are in hand using a fine scale numerical model to study the causes of rainfall persistence.

Contact: Chris Taylor

THE CLIMEX PROJECT

Boreal ecosystems may be quite sensitive to rising atmospheric CO_2 concentrations and the increased temperatures expected from the associated enhanced greenhouse effect. Of particular importance are the net impacts of such climatic changes on ecosystem bio-geochemistry. Ecosystem-scale study of bio-geochemistry is vital for:

- Understanding the overall ecosystem functioning in response to global change; and
- identifying and quantifying the effects on adjacent systems manifest as feedbacks to atmospheric greenhouse gas concentrations and as effects on aquatic ecosystems downstream.

From numerous plant and pot scale studies of individual ecosystem compartments in laboratories and in field chambers, a plethora of climate change impacts have been identified. Effects on plants often vary with species and the effects of individual processes in ecosystem bio-geochemical fluxes may oppose each other, making it difficult to predict net effects at the ecosystem or landscape scale.

Monitoring a complete ecosystem in glasshouses provides a unique way of investigating potential CO_2 enrichment and temperature increases

Whole-ecosystem manipulation experiments represent the only tool by which ecosystem response can be measured and with which whole-ecosystem models can be tested. Such models are a key to future negotiations on CO_2 emissions control policy and yet they remain untested at a scale consistent with their structure.

Increased CO_2 and temperature are expected to affect boreal forest ecosystems at many levels. Hence the EU funded a major pilot facility in Norway in which IH was able to cooperate with Scandinavian colleagues. At the individual plant level, elevated CO_2 is expected to promote increased stomatal closure and decreased stomatal density thereby increasing leaf water use efficiency. This leads to increased soil moisture manifest in higher water drainage for the same precipitation. Conversely, in some species, elevated CO_2 may increase leaf area so as to nullify the effect of decreased stomatal density on the transpiration loss of the whole plant. Increased temperature may also increase evapotranspiration to offset the expected increase in drainage flux.

Increased temperature and a longer growing season will tend to increase the volume of standing biomass and annual litter production. We also expect elevated CO_2 to stimulate plant growth even though nutrient availability is low. While nutrient availability may further decrease as a result of increased growth, increased temperature is expected to oppose this effect by stimulating decomposition of litter and mineralization of nutrients, especially of N. These responses should occur rapidly, i.e. within a few years. While soil and plant respiration will increase, fixation of C in biomass plus litter is expected to exceed total respiration, making the system a net sink of CO_2-carbon. Mineralized N will largely be taken up by the increased plant and microbial biomass, so that leaching of inorganic N into drainage water will remain low. The more rapid cycling of N may also lead to increased soil emissions of N_2O, NO and NO_2. These relatively rapid changes in the biotic compartments are expected to be followed by slower changes in the large, recalcitrant pools of humidified soil organic matter.

To test these hypotheses, the atmospheric CO_2 concentration has been increased to 560 ppmv and air temperature increased by 3-5°C at an enclosed afforested headwater catchment in southern Norway (Figure 19). Treatment began in April 1994. Within three years, elevated temperatures have caused a significant increase in soil N mineralisation. This extra nitrogen helps to sustain increased plant growth caused by elevated CO_2, higher temperatures and longer growing season, but also promotes increased nitrogen export in stream water. Photosynthetic capacity of new leaves of trees and shrubs have not changed significantly. Carbon-to-nitrogen ratios of new leaves also remain unchanged, except in *Pinus sylvestris* needles, where they have decreased, perhaps due to reduced light in the greenhouse. There is no evidence for slower decomposition of litter produced at higher CO_2.

The results suggest that in a boreal afforested ecosystem subjected to a climate change corresponding to earlier global circulation model projections for 2040, mineralisation rates of soil organic matter increase in response to higher temperature. Increased availability of N may further lead to a shift in plant species adapted to higher soil N levels. The fraction of the extra mineralised N that ends up in stream

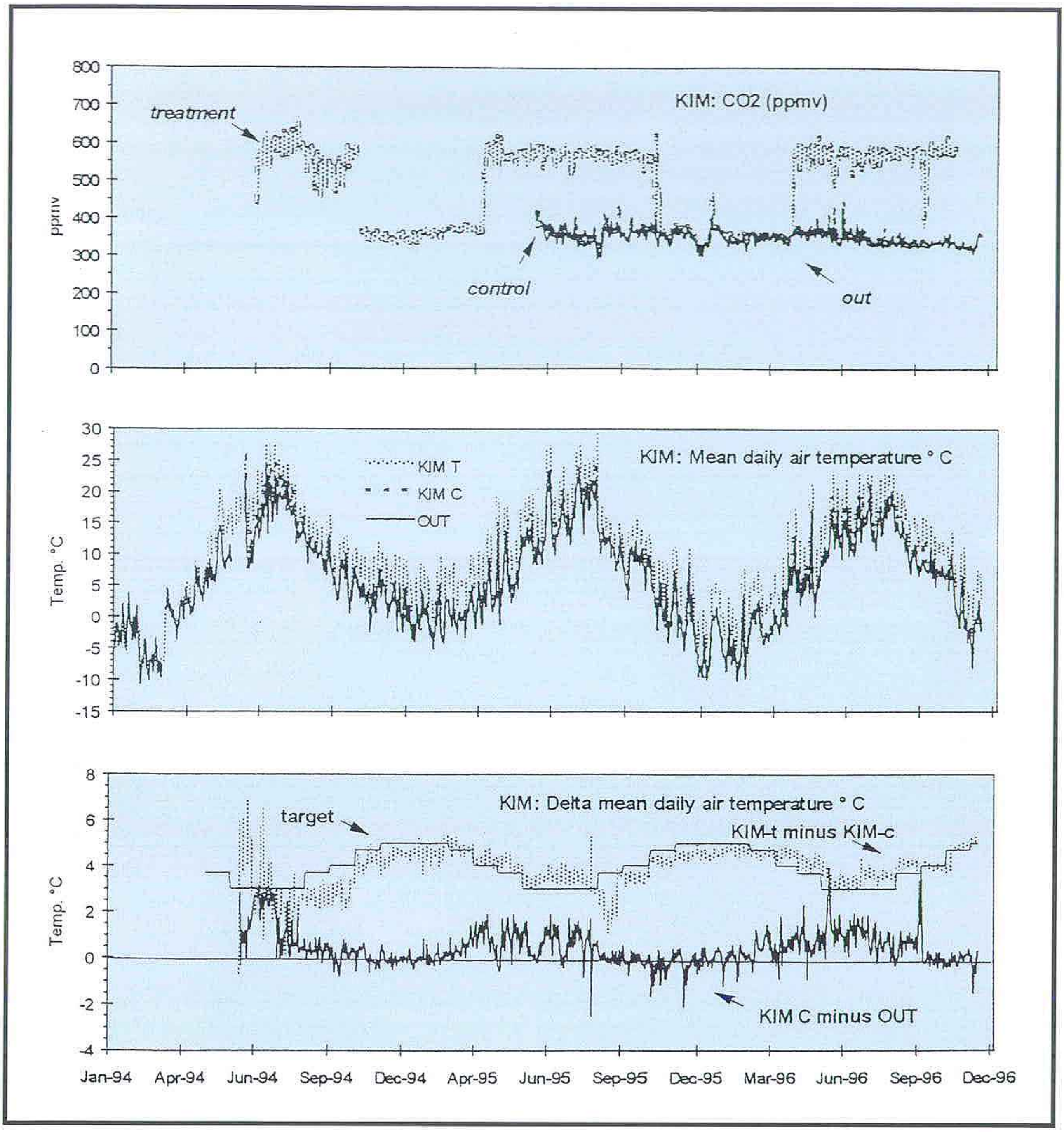


Figure 19. Effects of artificial increases in CO_2 concentration and temperature in an enclosed forest system, part of the CLIMAX experiment in southern Norway

water is small, but comprises a doubling in nitrate concentrations in runoff. In areas impacted by acid deposition such as southernmost Norway, such increased nitrate will be accompanied by cationic aluminium and H^+ and may exacerbate acidification of surface waters. Furthermore, increased nitrogen supply to coastal marine waters may cause nutrient imbalance with algal blooms and other undesirable effects.

Contact: Alan Jenkins

WATER AND CARBON IN TROPICAL BIOMES

Understanding the carbon budget of tropical forests is essential if we are to understand how the global carbon budget remains in balance. The Institute of Hydrology, the University of Edinburgh and the Brazilian National Institute for Amazonian Research (INPA) have addressed this issue by making continuous measurements of water and CO_2 fluxes, climate and soil moisture at a forest site near Manaus, Brazil since 1995.

Both water vapour and CO2 fluxes are measured using the eddy correlation method. This method is tested and works well during daylight hours, but there is some doubt whether fluxes are measured accurately in the stable conditions usually found at night. This is not important for water vapour because evaporation is small during the night, but CO_2 respiration fluxes do not depend on solar radiation and continue for 24 hours a day. It is important to understand how these nocturnal eddy correlation measurements relate to respiration fluxes and to identify under what atmospheric conditions the measurements may be unreliable.

The eddy correlation fluxes have therefore been linked to those on atmospheric processes obtained by using a tethered balloon to make simultaneous measurements of CO_2 concentrations in the nocturnal atmospheric boundary layer. The tethered balloon lifted an airline above the forest to heights of up to 250m and air was pumped back to a gas analyser on the ground. A wide range of conditions were found to occur, leading to varied behaviour of the surface fluxes and in-canopy CO_2 storage. The atmospheric concentrations were greater than predicted by the surface flux data, a discrepancy which may be due to spatial variability of the nocturnal flux caused by river valleys, forest edges and storm damage.

Contact: Alistair Culf

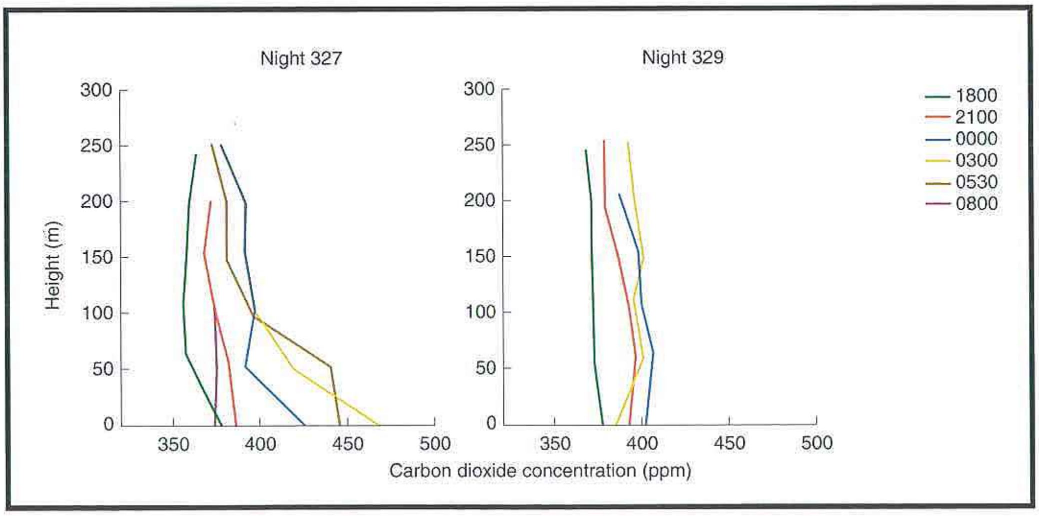


Figure 20. Atmospheric profiles of carbon dioxide above tropical forest for two nights, illustrating the effects of different atmospheric conditions. On Night 327 there was substantial storage of CO_2 in the lowest 150 m of the boundary layer whilst on Night 329 the profile was mixed throughout the night up to 250 m because of afternoon rainfall and the formation of mist.

Laboratories, libraries, collections, instrumentation, remote sensing, software design, data warehouses - all are being affected positively by the information revolution that is given a semblance of order by the World Wide Web. IH makes an important contribution to generic science that supports the CEH nine programme areas and to enabling the widest possible public to access research results by modern information technology. Key achievements during the year have been:

- *An advanced intranet written by local staff at Wallingford has drawn wide interest in NERC because of its efficiency gains.*
- *Transfer function software (IHACRES) for river modelling, written in collaboration with the Australian National University, has been released.*
- *Licensed use of our rainfall radar display system (HYRAD) continues to grow.*

Integrating generic science

USING SATELLITE RADAR TO MONITOR SURFACE SOIL MOISTURE

Synthetic aperture radar (SAR) can detect changes in the dielectric properties of soils which in turn are directly affected by the moisture content of the soil. Data from SARs can be routinely acquired as they can operate successfully through thick cloud cover and at night. Even from satellite altitudes they can readily detect variations in backscattered microwave energy within small land units such as fields. Previous work was on the variability of soil moisture, vegetation and surface roughness within selected fields, giving a better understanding of the factors controlling radar backscatter. However, at the field scale, surface soil moisture can be very variable due to local variations in soil type and thickness combined with differences in drainage, both natural and artificial, which in turn are affected by micro-topography. Current studies are therefore taking place at the catchment scale, which is more commonly needed for hydrological applications. Catchment studies are better matched to the large areal coverage afforded by satellite sensors and are less affected by local variations in soil moisture.

Catchment studies are better matched to the large area coverage by satellite sensors and less affected by local variations in soil moisture. Radar data offers a way forward.

The European Space Agency commissioned IH to investigate soil moisture measurement capabilities and accuracy of the SAR operating on the current ERS-2 satellite. In addition, IH has looked at the usefulness of the low resolution SAR products which will become available on the next generation European satellite, ENVISAT.

Validation of the SAR soil moisture information is taking place both in the upper Thames basin, as representative of temperate climates, and in Zimbabwe, which has marked wet and dry seasons. For the UK test area, detailed rainfall distribution comes from combining existing raingauge measurements with ground-based weather radar using a spatially distributed water balance model. The soil moisture distribution within the soil profile is measured at a number of sites each week with neutron probes and at 15-minute intervals with an automatic soil water station. On days when satellite data are acquired,

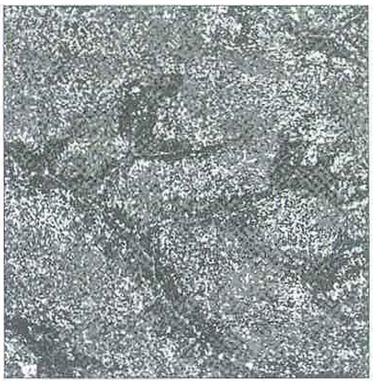


Figure 21. ERS-1 SAR images of the River Mnondo dambo system, Zimbabwe. The image above is for the dry season (July 1994); dambo areas appear as dark (low backscatter) regions around the branching stream system which is depicted by a thin bright line. The wet season image below (March 1996) shows dambos appearing brighter than drier interfluves, a reversal of the dry season relationship.

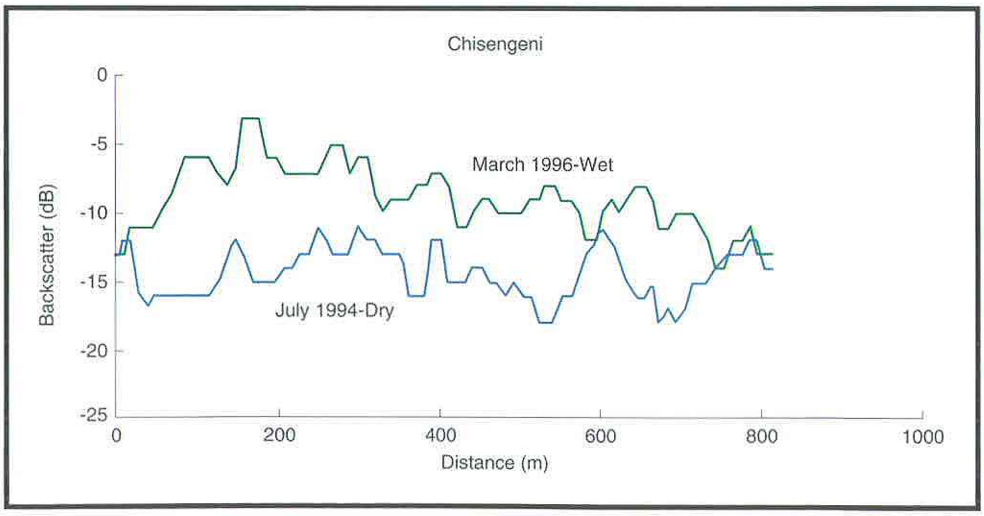


Figure 22. Profile across Chisengeni dambo (Y-shaped feature near centre of Figure 1) showing >5dB increase in backscatter between dry and wet seasons.

intensive field measurements are carried out at 50 sites distributed within the catchment to measure surface soil moisture and to determine the effects of different vegetation cover and soil roughness.

Results from Zimbabwe show that seasonal changes in soil moisture within dambos (gently-sloping headwater catchment areas) comprising sparse grasslands can be detected with satellite radar as large variations in backscatter, typically in the range 5-10dB. At a larger scale, surface moisture variations resulting from individual storm cells have been detected which means it may be possible to use such satellite derived measurements in regional scale hydrological and energy budget models. Multi-date ERS SAR of the Thames basin have been used to denote current land use patterns, an essential precursor to the modelling of soil moisture.

Contact: Ken Blyth

COMBINED H_2O AND CO_2 FLUX SYSTEM

The close association between transpiration and photosynthesis, plus keen interest in CO_2 budgets and their link to climate change, is creating a strong demand for instruments able to measure the fluxes of both water vapour and CO_2 from vegetation.

The current state of the art are closed-path gas analyser systems. These pipe air from a sonic anemometer array to a infrared gas analyser that has high power requirements and needs regular maintenance for recalibration and replacement of gas scrubbing chemicals. Furthermore, the time lag between the measurement of vertical windspeed and gas concentration is less than ideal, as is the problem of contamination of the pipe walls and attenuation of the high frequency information by friction in the pipe.

To remove these obstacles, an integrated, open-path, low power instrument for both water vapour and CO_2 flux measurement is under a three stage development at IH. This is based on IH's well-known Hydra system. The stage one prototype evaporation instrument is currently undergoing field trials. This incorporates the Hydra's miniature hygrometer into a commercial 3-D sonic anemometer. The logging system is being adapted to take advantage of the improved computer technologies now available.

The amount of CO_2 in air is typically only 5% of that of water vapour. The second stage of development is, therefore, to achieve significant improvements to the resolution and stability of the current open-path infrared gas analyser, before CO_2 flux measuring capability can be incorporated in the third stage.

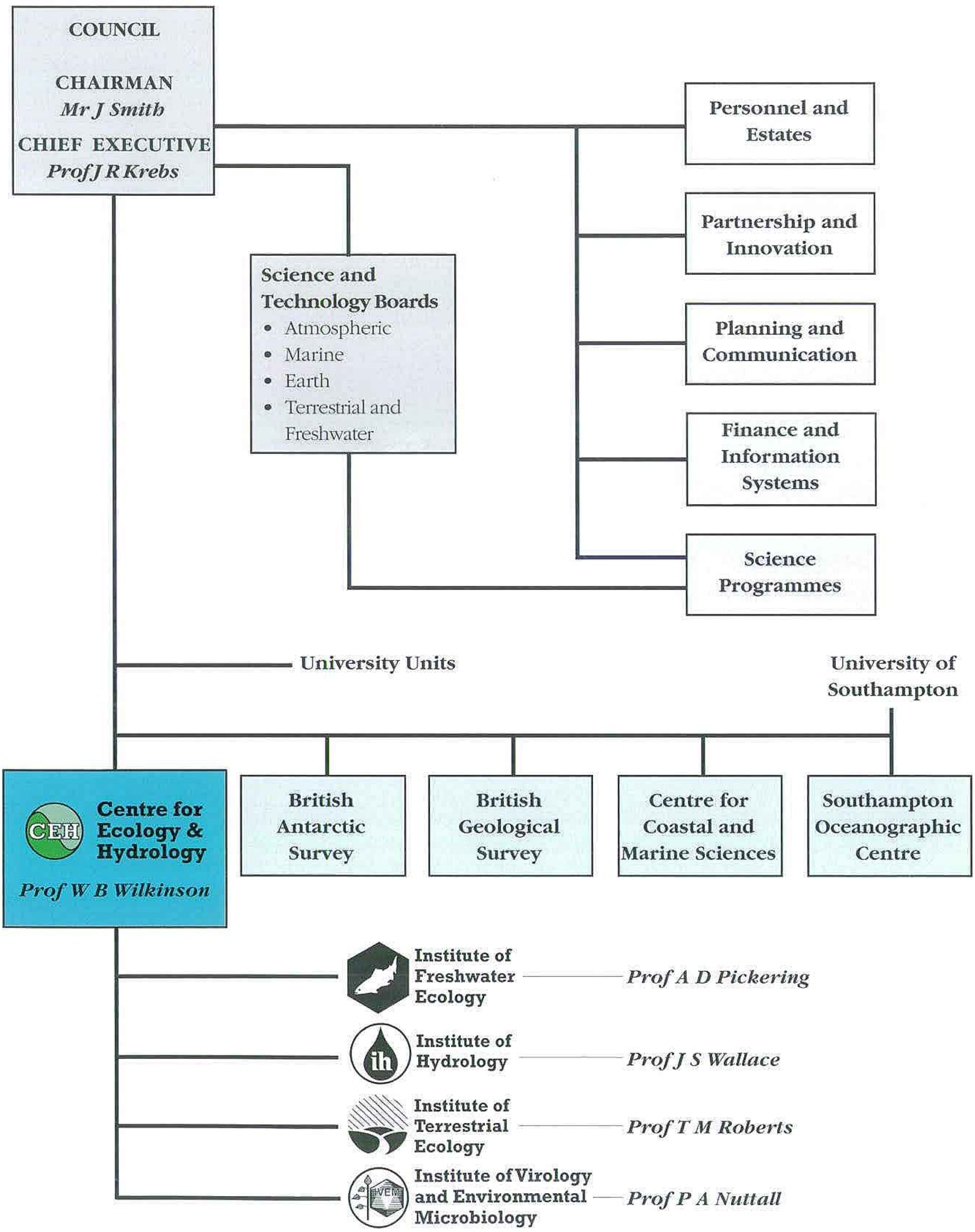
When completed, the instrument will be able to operate unattended for much longer periods than the current closed path system and, being purpose-built and without the need for ancillary equipment, be both cheaper and easier to buy operate.

Contact: David McNeil

A miniature hygrometer of the type used in the Hydra has been incorporated into a commercial 3-D sonic anemometer.

APPENDIX I

NERC structure



IH Staff Structure

Director
J S Wallace
I J Dwyer (PA); *V Lynch* (PS)

Deputy Director
F M Law

Information & Scientific Services
F M Law

- **Infrastructure** — *N R Runnalls*
- **National Water Archive** — *M L Lees*
- **Data & software systems** — *R V Moore*
- **Communications** — *C Kirby*
- **Library** — *S B Wharton*

Water Quality
A Jenkins

- **Catchment waterquality modelling** — *D B Boorman*
- **Hydrochemical processes** — *R J Williams*
- **Sediment interactions** — *P S Naden*
- **Experimental catchments** — *J A Hudson* (Wales), *R C Johnson* (Scotland)
- **Analytical chemistry** — *M Neal*
- **Thematic science management** — *G J L Leeks*

Bio-Physical Processes
J H C Gash

- **Global processes** — *R J Harding*
- **Regional environmental change** — *J W Finch*
- **Agricultural hydrology** — *C H Batchelor*
- **Vegetation & soil processes** — *J M Roberts*
- **Instrumentation** — *J D Cooper*

Risks & Resources
A Gustard

- **Low flow, ecology & wetlands** — *M C Acreman*
- **Flood, rainfall & climate analysis** — *D W Reed*
- **Hydrological systems modelling** — *R J Moore*
- **Surfacewater groundwater systems** — *A F Calver*
- **Water resource modelling** — *F A K Farquharson*

Administration Support
S M Pryde

- **Finance & accounts** — *S L G Barter*
- **Personnel & estate** — *W C Barnett*

INFORMATION & SCIENTIFIC SERVICES

Frank Law (Deputy Director & *Division Head*)
SandieButterfield (*Secretary*)

Roger Moore (Data & software systems)

Kevin Black *Software development*
Richard Alexander
David Hill

Anne Roberts *Software operations*
Isabella Tindall
Jeff Parker
Susan Jennings
Andrew Tidmarsh

Scientific remit

To provide the technology to ensure the Institute's science thrives. More specifically, the Division is structured:

- to collate, quality control, interpret and publish time series and spatial datasets that describe the hydrological cycle and its variability;
- to reveal the common features of environmental datasets by utilising advanced information technology;

to program to commercial standards the scienctific findings of the Institute as well as publishing them in printed and electronic form;

to provide professional library services to IH staff and to achieve the status of the leading UK hydrosciences collection.

***Martin Lees* (National Water Archive)**
Terry Marsh
Dave Morris
Samantha Green
Oliver Swain
Felicity Sanderson
Jackie Carr

***Celia Kirby* (Communications)**
John Griffin
Rob Flavin

***Sue Wharton* (Library)**
Pam Moorhouse

***Chris Bottrell* (Computing policy)**

***Penny Kisby* (IAHS Press)**
Frances Watkins

Henry Gunston (DFID coordinator & IH Training Officer)

Neil Runnalls (Marketing & business development manager)

WATER QUALITY

SCIENCE REMIT

To understand the processes that control surface water quality and, by their representation within computer models, provide tools for improving water quality through environmental management. Research priorities are:

to understand and develop models of key processes that determine river water quality at catchment scale;

to models the impacts of anthropogenic influences on water quality.

***Alan Jenkins* (Division Head)**
Sue Beresford (*Secretary*)

***David Boorman* (Catchment water quality modelling)**
Gareth Roberts
David M Cooper
Andrew Eatherall
Rob Collins
Beate Gannon
Catherine Sefton

***Richard Williams* (Hydro-chemical processes)**
Colin Neal
Andrew Johnson
Atul Haria
Helen Jarvie
Craig White

***Pam Naden* (Sediment interactions)**
Ian Littlewood
Carol Watts
Jeremy Wilkinson

***Margaret Neal* (Analytical chemistry)**
Lal Bhardwaj
James Dodd
Martin Harrow
Linda Hill
Heather Wickham

***Jim Hudson* (Experimental catchments)**
(Plynlimon)
Phil Hill
Sean Crane
Sue Hill
Alan Hughes
(Stirling)
Dick Johnson
David Price
Rachel Bronsdon

Graham Leeks (Thematic science management)
Howard Oliver
Ian Dwyer
Stephen Marks
Paul Wass

to understand the fate and behaviour of chemicals as they move from catchment surfaces to surface and groundwaters;

To determine sediment source areas and quantify sediment mass balances throughout entire river systems;

to develop procedures for chemical analysis of water samples and methods for continuous monitoring of water quality using in-stream sensors.

BIO-PHYSICAL PROCESSES

***John Gash* (Division Head)**
Biddy Hawker (*Secretary*)

Richard Harding (Global processes)
Eleanor Blyth
Alistair Culf
Colin Lloyd
Chris Huntingford
Chris Taylor

***John Roberts* (Vegetation and soil processes)**
Mark Robinson
Robin Hall
Martin Hodnett
Sam Boyle
Nick Jackson
Mark Smith

SCIENCE REMIT

To improve quantiative understanding of the physical and biological processes in the terrestrial hydrological cycle, from local to global scales, including interaction with human activities. Research priorities are:

to measure and model the surface fluxes of water, energy and carbon in the major terrestrial biomes, the interactions between the land surface and the atmosphere, and to identify the sensitivities of the hydrological and climate systems to anthropogenic and natural changes.

to investigate strategies for sustainable and environmentally acceptable agricutlural and natural resource management practices;

to measure and model the effects of vegetation and soil processes on evaporation, carbon and soil water fluxes.

to develop new measurement methods and instruments for hydrology; specialised drilling and hydrogeological interpretation.

Anne Verhoef
Rebecca Hopkins

***Charles Batchelor* (Agricultural hydrology)**
John Bromley
Chris Lovell
Ragab Ragab
Jeremy Cain
Paul Rosier
Dominic Waughray

***Jon Finch* (Regional environmental change)**
David Biggin
Ken Blyth
Eleanor Burke

***J David Cooper* (Instrumentation)**
Andy Dixon
Dave McNeil
Roger Wyatt
Mike Stroud
Jonathan Evans
Geoff Wicks

***Alan Warwick* (Workshop)**
John White
Geoff Walley

RISKS & RESOURCES

SCIENCE REMIT

To provide advanced techniques for flood and low flow estimation, for forecasting extreme events, and for assessing the availability of water resources. Research priorities are:

to determine the impact of environmental change on the reliability of existing and proposed schemes, including the impact of artificial influences such as land use change and resource development.

developing procedures for estimating and forecasting

***Alan Gustard* (Division Head)**
Sandra Smith (*Secretary*)

***Mike Acreman* (Low flow, ecology & wetlands)**
Andy Young
Ann Sekulin
Craig Elliott
Gwyn Rees
Karen Croker
Mike Dunbar
Gwynneth Cole
Julia Dixon
Clare Round
Ian Gowing

***Duncan Reed* (Flood, rainfall & climate analysis)**
David Marshall
Nick Reynard

Alice Robson
Lisa Stewart
Adrian Bayliss
Duncan Faulkner
Christel Prudhomme
Doerte Jakob

precipitation rates using radar and raingauge information.

to develop techniques for assessing the impact of river flow rgimes and channel morphology on freshwater ecology and the hydrological functions of wetlands.

Bob Moore **(Hydrological systems modelling)**
David Jones
Roger Austin
Vicky Bell

Ann Calver (Surface-groundwater systems)
Dick Bradford
Sue Crooks
Rob Lamb
Sue Morris
Helen Davies

Frank Farquharson **(Water resource systems)**
Jeremy Meigh
John Packman
Kevin Sene
Tony Andrews
Helen Houghton-Carr
Matthew McCartney
Val Bronsdon
Ned Hewitt
Emma Tate

ADMINISTRATION

Stuart Pryde
(Head of Administration)

Simon Barter **(Finance & Resource Management)**
Angie Dickerson
Huw Thomas
Thelma Gibson
Anita Napper
Lyn Ross
Val Lambert

Bill Barnett (Personnel & Estate)
Sue Fenton *(Personnel)*
Trish Sanders
Eileen Younghusband

Melanie Purvey and Anke Watson *(Reception)*

Heather Turner *(Typing Services)*
Jocelyn Cowley
Brenda Hall

John Fraser *(Site services)*
Denise Dolton
Ivor Standbridge
John Spencer
Harold Jones
Julie Butcher
Andy Sweetland *(Stores)*

Further details on staff qualifications and job descriptions may be obtained from our WWW pages (see back cover)

APPENDIX 3

CEH Core Strategic Research Programmes

Soil and soil/vegetation interactions

Project 1.1 Physicochemical processes affecting soil-water interactions
Issue 1.1.1 Solid-solution partitioning of chemical species
Project 1.3 Physical and physiological processes controlling soil water balances
Issue 1.3.1 Soil-root interactions at the individual plant root and stand scale
Issue 1.3.2 Soil-plant-atmosphere flux transfers in mixed vegetation
Issue 1.3.3 Root-soil-water interactions adjacent to fluctuating water tables

Land use science

Project 2.2 Land use systems
Issue 2.2.3 Land use manipulation to minimise adverse impacts
Issue 2.2.4 Hydrological impacts of land use change
Issue 2.2.5 Holistic catchment studies
Issue 2.2.6 Development of water resource management strategies
Project 2.4 Landscape function and modelling
Issue 2.4.3 Integrated modelling of land use processes including social and economic variables

The urban environment

Project 3.4 Urban water dynamics, risk and hazard
Issue 3.4.2 Floods and pollution flushes

Freshwater resources

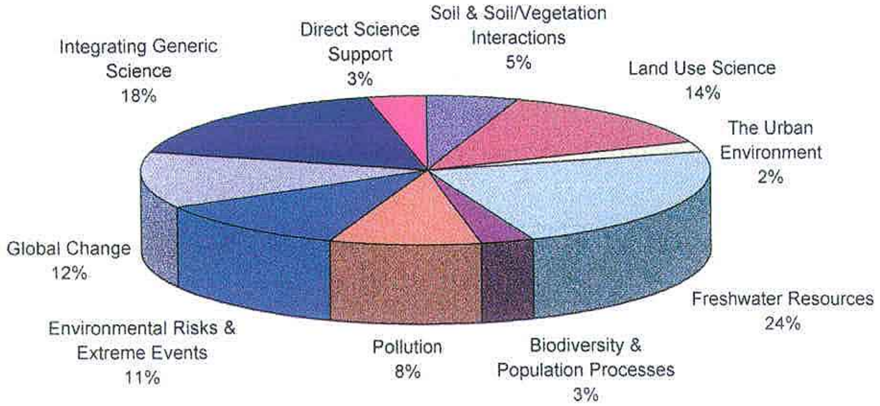
Project 4.1 Surface-groundwater interactions
Issue 4.1.1 The recharge-runoff division
Issue 4.1.2 The river-aquifer boundary and floodplain issues
Issue 4.1.3 Wetland interactions
Issue 4.1.4 Integrated catchment-scale analysis
Project 4.2 Statistical modelling of resource availability
Issue 4.2.1 Estimation of resource availability at ungauged sites
Issue 4.2.2 Drought frequency estimation
Project 4.3 Water resource modelling capabilities
Issue 4.3.1 Improvement of representation of hydrological systems in catchment models
Issue 4.3.3 Integrated decision support facility
Project 4.4 Integrated water quality modelling
Issue 4.4.1 Quantifying point sources
Issue 4.4.2 Catchment models: diffuse sources
Issue 4.4.3 In-stream water quality monitoring
Issue 4.4.5 Modelling uncertainty
Project 4.5 Integrated biotic response modelling
Issue 4.5.1 Flow resistance in channels and river ecosystems health
Issue 4.5.2 Integration of models of water quantity, quality and biotic variability

Biodiversity and population processes

Project 5.1 Biodiversity characterisation, pattern and monitoring
Issue 5.1.6 Biodiversity in rivers
Project 5.4 Conservation and restoration of biodiversity
Issue 5.4.5 Wetland management and restoration

Pest and disease control

Project 6.5 Distribution of pathogens in freshwater
Issue 6.5.1 Monitoring and risk assessment of pathogens in freshwater



Breakdown of IH research activity by CEH Core Strategic Programme

Pollution assessment and control

Project 7.2 Acidifying pollutants
Issue 7.2.5 Surface water and catchment-scale impacts
Issue 7.2.6 Modelling
Issue 7.2.7 Critical loads
Project 7.4 Toxic metals
Issue 7.4.1 Transport and deposition
Project 7.5 Organic pollutants
Issue 7.5.1 Monitoring
Issue 7.5.4 Physico-chemical processes controlling transport in soils and waters
Issue 7.5.5 Catchment-scale processes

Environmental risks and extreme events

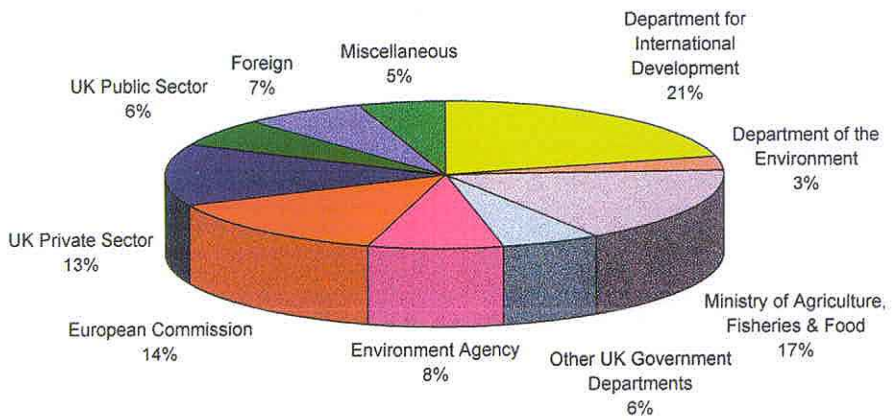
Project 8.1 Risk assessment and estimation of floods and other extreme events
Issue 8.1.1 Mainstream research
Issue 8.1.2 Generic solutions to 'joint probability' problem
Issue 8.1.3 Collective risk for environmental extremes
Issue 8.1.4 Continuous simulation modelling for flood estimation
Project 8.2 Real-time flow and water quality forecasting and decision support systems
Issue 8.2.2 Development of real-time flow forecasting models for arid regions
Issue 8.2.3 Development of improved water quality forecasting models
Issue 8.2.4 Real-time flood forecasting for gauged and ungauged catchments
Project 8.3 Understanding and modelling the role of rare events on ecological systems
Issue 8.3.1 Rare events and ecological processes

Global change

Project 9.1 Greenhouse gas budgets and cycles
Issue 9.1.4 Exchange mechanisms in high-latitude wetlands
Project 9.2 Land-atmosphere-ocean interactions
Issue 9.2.1 Improved hydrological representations within GCMs
Issue 9.2.2 Land surface-climate interactions: tropical deforestation and desertification
Issue 9.2.3 Snow-melt and routing models for northern latitudes
Issue 9.2.4 The use of macroscale hydrological models to validate GCMs
Issue 9.2.5 Dynamic ecosystem modelling
Project 9.3 Forecasting and detecting the impacts of global change
Issue 9.3.1 Regional hydrology and freshwater quality
Issue 9.3.2 Climate impacts on species populations and distributions
Issue 9.3.5 Ecosystem responses to elevated CO_2 concentrations

Integrating generic science

Project 10.1 Environmental assessment, economics and history
Issue 10.1.1 Improved methodology for quantitative prediction of environmental impacts
Project 10.2 Remote sensing
Issue 10.2.1 Algorithm development
Issue 10.2.2 Ground reference and scaling up
Issue 10.2.5 Regional scale evaporation
Project 10.3 Instrumentation
Issue 10.3.1 Intelligent sensor clusters
Project 10.6 Databases and reference collections
Issue 10.6.1 Integrity and accessibility of databases and collections within CEH
Issue 10.6.3 Environmental management
Project 10.7 Biometrical applications, research and development
Issue 10.7.1 Biometrical collaboration
Issue 10.7.2 Application and development of biometrical methods



Customer composition of IH science programme

APPENDIX 4

Publications

1996
Refereed publications

Acreman, M.C. 1996. Environmental effects of hydro-electric power generation in Africa and the potential for artificial floods. *J. CIWEM* **10**, 429-434.

Acreman, M.C. 1996. The IUCN Sahelian floodplain initiative – networking to build capacity to manage Sahelian floodplain resources sustainably. *Int. J. Wat. Resour. Devel.* **12**, 429-436.

Acreman, M.C. and **Elliott, C.R.N.** 1996. Evaluation of the River Wey restoration project using the Physical HABitat SIMulation (PHABSIM) model. *Proc. MAFF Conf. of River and Coastal Engineers, Keele.* 1.2.1-1.2.14

Acreman, M.C. and Hollis, G.E. (Eds) 1996. *Water management and wetlands in sub-Saharan Africa.* IUCN, Gland, Switzerland. 249pp

Alvalá, R.C.S., Gielow, R., **Wright, I.R.** and **Hodnett, M.G.** 1996. Thermal diffusivity of Amazonian soils. In: Gash, J.H.C., Nobre, C.A., Roberts, J.M. and Victoria, R.L. (Eds) *Amazon-ian Deforestation and Climate.* John Wiley & Sons, Chichester. 139-150.

Arnell, N.W. and **Reynard, N.S.** 1996. The effects of global warming on river flows in Great Britain. *J. Hydrol.* **183**, 397-424.

Avila, A., **Neal, C.** and Terradas, J. 1996. Climate change implications for streamflow and streamwater chemistry in a Mediterranean catchment. *J. Hydrol.* **177**, 99-116.

Batchelor, C.H. and **Wallace, J.S.** 1996. Hydrological processes in dryland degradation and integrated catchment resource management. *UNEP Desertification Control Bulletin* **27**, 27-34.

Batchelor, C.H., **Lovell, C.J.** and Murata, M. 1996. Simple micro-irrigation techniques for improving irrigation efficiency on vegetable gardens. *Agric. Wat. Manag.* **32**, 37-48.

Bullock, A. and **McCartney, M.P.** 1996. Wetland and river flow interactions in Zimbabwe. In: *IAHS Publ. No.238,* 305-321.

Cabral, O.M.R., McWilliam, A.-L.C. and **Roberts, J.M.** 1996. In-canopy microclimate of Amazonian forest and estimates of transpiration. In: Gash, J.H.C., Nobre, C.A., Roberts, J.M. and Victoria, R.L. (Eds) *Amazonian Deforestation and Climate.* John Wiley & Sons, Chichester. 207-219.

Calder, I.R. and **Hall, R.L.** 1996. Comment on: 'Interception of Tropical Rain Forest: Performance of a Canopy Water Balance Model' by V.C. Jetten. *Hydrol. Procs.* **11**, 671-685.

Calder, I.R., Hall, R.L., Rosier, P.T.W., Bastable, H.G. and Prasanna, K.T. 1996. Dependence of rainfall interception on drop size, 2: Experimental determination of the wetting functions and two-layer stochastic model parameters for five tropical tree species. *J. Hydrol.* **185**, 379-388.

Calver, A. 1996. Development and experience of the 'Tate' rainfall-runoff model. *Proc. ICE Water, Maritime & Energy* **118**, 168-176.

Calver, A. and **Lamb, R.** 1996. Flood frequency estimation using continuous rainfall-runoff modelling. *Phys. & Chem. of the Earth* **20**, 479-483.

Collins, R.P. and **Jenkins, A.** 1996. The impact of agricultural land use on stream chemistry in the Middle Hills of the Himalayas, Nepal. *J. Hydrol.* **185**, 71-86.

Cooper, D.M. and **Roberts, G.** 1996. Nitrate leaching from a small catchment in central England. *Soil Use & Manage.* **12**, 181-189.

Culf, A.D., Esteves, J.L. and da Rocha, H.R. 1996. Radiation, temperature and humidity over forest and pasture in Amazonia. In: Gash, J.H.C., Nobre, C.A., Roberts, J.M. and Victoria, R.L. (Eds) *Amazonian Deforestation and Climate.* John Wiley & Sons, Chichester. 175-191.

da Rocha, H.R., Nobre, C.A., Bonatti, J.P. and **Wright, I.R.** 1996. A vegetation-atmosphere interaction study for Amazonian deforestation using field data and a single column model. *Q. J. R. Meteorol. Soc.* **122**, 567-594.

da Rocha, H.R., Sellers, P.J., Collatz, G.J., **Wright, I.R.** and Grace, J. 1996. Calibration and use of the SiB2 model to estimate water vapour and carbon exchange at the ABRACOS forest sites. In: Gash, J.H.C., Nobre, C.A., Roberts, J.M. and Victoria, R.L. (Eds) *Amazonian Deforestation and Climate.* John Wiley & Sons, Chichester. 459-471.

de Souza, J.R.S., Pinheiro, F.M.A., de Araujo, R.L.C., Pinheiro, H.S. and **Hodnett, M.G.** 1996. Temperature and moisture profiles in soil beneath forest and pasture areas in eastern Amazonia. In: Gash, J.H.C., Nobre, C.A., Roberts, J.M. and Victoria, R.L. (Eds) *Amazonian Deforestation and Climate.* John Wiley & Sons, Chichester. 125-137.

Elliott, C.R.N., Willis, D.J. and **Acreman, M.C.** 1996. Application of the Physical Habitat Simulation (PHAMSIM) model as an assessment tool for riverine habitat restoration techniques. *Ecobydraulics 2000,* 2nd Internat. Symp. on Habitat Hydraulics, Quebec. B607-B618

Faulkner, D.S. 1996. Characteristics of recent flood-producing rainfalls in relation to the Flood Studies Report design event method. *Meteorol. Appl.* **4**, 259-268.

Fisch, G., **Culf, A.D.** and Nobre, C.A. 1996. Modelling convective boundary layer growth in Rondonia. In: Gash, J.H.C., Nobre, C.A., Roberts, J.M. and Victoria, R.L. (Eds) *Amazonian Deforestation and Climate.* John Wiley & Sons, Chichester. 425-435.

Forti, M.C., **Neal, C.** and **Robson, A.J.** 1996. Modelling the long term changes in stream, soil and groundwater chemistry for an acid moorland in the Welsh uplands: the influence of variations in chemical weathering. *Sci. Tot. Environ.* **180**, 187-200.

Gash, J.H.C., Nobre, C.A., **Roberts, J.M.** and Victoria, R.L. (Eds) 1996. *Amazonian Deforestation and Climate.* John Wiley & Sons, Chichester. 611pp.

Gash, J.H.C., Nobre, C.A., **Roberts, J.M.** and Victoria, R.L. 1996. An overview of ABRACOS. In: Gash, J.H.C., Nobre, C.A., Roberts, J.M. and Victoria, R.L. (Eds) *Amazonian Deforestation and Climate.* John Wiley & Sons, Chichester. 1-14.

Gash, J.H.C. and **Culf, A.D.** 1996. Applying a linear detrend to eddy correlation data in real time. *Bound. Layer Meteorol.* **79**, 301-306.

Gash, J.H.C., Wright, I.R., Hodnett, M.G., Oyama, M.D., **Culf, A.D.** and Ubarana, V.N. 1996. The water budget of Amazonian forest and pasture. Second International Conference on the Global Energy and Water Cycle, Washington DC, 196.

Gaze, S.R. 1996. Water balance of farmer-managed millet and fallow-savannah on sandy soils in South West Niger. PhD Thesis, Dept of Soil Science, University of Reading.

Gibbins, C.N., Jeffries, M.J., Soulsby, C. and **Elliott, C.R.N.** 1996. Modelling instream flow needs: the effects of a water transfer scheme on macroinvertebrate communities in the receiving River Wear. *Ecobydraulics 2000,* 2nd Internat. Symp. on Habitat Hydraulics, Quebec. B431-B443

Green, S. 1996. 1995 Hydrological Review. In: Marsh, T.J. (Ed.) *1995 Yearbook. Hydrological Data UK Series.* Institute of Hydrology.

Green, S., Sanderson, F.J. and **Marsh, T.J.** 1996. Evidence for recent climatic instability in rainfall and runoff patterns in the Celtic regions of Western Europe. Proc. First Interceltic Colloq. *Hydrology and Water Management,* Rennes, Brittany, 73-84.

Gustard, A. 1996. Analysis of River Regimes. In: Petts, G.E. and Calow, P. (Eds) *River Flows and Channel Forms.* 32-52.

Hall, R.L., Calder, I.R., Nimal Gunawardena, E.R. and **Rosier, P.T.W.** 1996. Dependence of rainfall interception on drop size, 3: implementation and comparative performance of the stochastic model using data from a tropical site in Sri Lanka. *J. Hydrol.* **185**, 389-407.

Harding, R.J., Taylor, C.M. and **Finch, J.W.** 1996. Areal average surface fluxes from mesoscale meteorological models – the application of remote sensing, 59-76. In: Stewart, J.B., Engman, E.T., Feddes, R.A. and Kerr, J. (Eds) *Scaling up using remote sensing.* John Wiley & Sons Ltd, Chichester, 59-76.

Harding, R.J. and Pomeroy, J.W. 1996. The energy balance of the winter boreal landscape. *J. Climate* **9**, 2778-2787.

Haria, A.H. 1996. Identification of preferential flow processes in a sandy loam soil from southern England: lysimeter studies and modelling. MRes thesis, Centre for Earth and Atmospheric Sciences, University of Reading.

Hauhs, M., **Neal, C.**, Christophersen, N., Hooper, R.P. and McCulloch, J.S.G. 1996. Modelling in environmental studies. *Sci. Tot. Environ.* Spec. Issue 185pp

Hauhs, M., **Neal, C.**, Hooper, R.P. and Christophersen, N. 1996. Summary of a workshop on ecosystem modelling: the end of an era? *Sci. Tot. Environ.* **183**, 1-5.

Hearne, J., **Johnson, I.W.** and Armitage, P. 1996. Determination of ecologically acceptable flows with seasonal changes in the density of macrophyte. *Reg. Rivers: Research & Manage.* **9**, 177-184.

Hodnett, M.G., Oyama, M.D., Tomasella, J. and Marques Filho, A.d.O. 1996. Comparisons of long-term soil water storage behaviour under pasture and forest in three areas of Amazonia. In: Gash, J.H.C., Nobre, C.A., Roberts, J.M. and Victoria, R.L. (Eds) *Amazonian Deforestation and Climate.* John Wiley & Sons, Chichester. 57-77.

Hodnett, M.G., Tomasella, J., Marques Filho, A.d.O. and Oyama, M.D. 1996. Deep soil water uptake by forest and pasture in Central Amazonia: predictions from long-term daily rainfall data using a simple water balance model. In: Gash, J.H.C., Nobre, C.A., Roberts, J.M. and Victoria, R.L. (Eds) *Amazonian Deforestation and Climate.* John Wiley & Sons, Chichester. 79-99.

Houghton-Carr, H.A. and **Farquharson, F.A.K.** 1996. Models for optimal management of the total water resources of a river basin. Proc. First Interceltic Colloq. *Hydrology and Water Management,* Rennes, Brittany, 427-434.

Huntingford, C. 1996. A note on the similarity groups of the Penman-Monteith big leaf model. *Bound. Layer Meteorol.* **79**, 307-312.

Jarvie, H.P., Burt, T.P., Parker, A. and Rae, J.E. 1996. The use of sediment mineralogy to identify sources of suspended sediment in the River Windrush. *Annales Geophys.* **14**, Suppl. II.

Jenkins, A., Boorman, D.B. and **Renshaw, M.** 1996. The UK Acid Waters Monitoring Network: an assessment of chemistry data, 1988-93. *Freshwater Biol.* **36,** 169-178.

Johnson, A.C., Haria, A.H., Bhardwaj, C.L., Williams, R.J. and Walker, A. 1996. Preferential flow pathways and their capacity to transport isoproturon in a structured clay soil. *Pesticide Sci.* **48**, 225-237.

Kirby, C. 1996. Remote sensing for hydrology: at an impasse or pushing forward? *EOS: Trans. Amer. Geophys. Union* **77** 454-455.

Kirchner, J.W., Hooper, R.P., Kendall, C., **Neal, C.** and Leavesley, G. 1996. Testing and validating environmental models. *Sci. Tot. Environ.* **183**, 33-47.

Kuchment, D.S., Demidov, V.N., **Naden, P.S., Cooper, D.M.** and **Broadhurst, P.** 1996. Rainfall-runoff modelling of the Ouse basin, North Yorkshire: an application of a physically-based distributed model. *J. Hydrol.* **181**, 323-342.

Law, F.M. 1996. Limits to surface water development in South East England. Proc. Conf. *Water Environment '96* Supply and demand – a fragile balance. CIWEM, London. 37-51

Littlewood, I.G. and **Marsh, T.J.**

1996. Reassessment of the monthly naturalised flow record for the River Thames at Kingston since 1883 and the implications for the relative severity of historical droughts. *Reg. Rivers: Research & Manage.* **12**, 13-26.

Lloyd, C.R. 1996. Tundra soil-vegetation-atmosphere climate interaction. Conf. on ecosystem studies in the Ny-Ålesund area, NySMAC, Norsk Polar Institutt, Oslo, 35-36.

Lloyd, J., Kruijt, B., Hollinger, D.Y., Grace, J., Wong, S.C., Francey, R.J., Kelliher, F., Farquar, G.D., Schulze, E.D., Miranda, A.C., Miranda, H.S., **Wright, I.R.**, **Gash, J.H.C.** and Vygodskaya, N.N. 1996. Vegetation effects on the isotopic composition of atmospheric CO_2 at local and regional scales: theoretical aspects and a comparison between rain forest in Amazonia and a boreal forest in Sibera. *Australian J. Plant Physiol.* **23**, 371-399.

Maidment, D.R., **Calver, A.**, **Eatherall, A.** and Fraczek, W. 1996. A spatially distributed unit hydrograph based on a response velocity field. *Hydrol. Procs.* **10**, 831-844.

Maitelli, G.T. and **Wright, I.R.** 1996. The climate of a riverside city in the Amazon Basin: urban-rural differences in temperature and humidity. In: Gash, J.H.C., Nobre, C.A., Roberts, J.M. and Victoria, R.L. (Eds) *Amazonian Deforestation and Climate.* John Wiley & Sons, Chichester. 193-206.

Marsh, T.J. 1996. The 1995 drought: evidence for climatic instability? Tech. Note 656. *J. ICE Water, Maritime & Energy* **118**, 189-195.

Marsh, T.J. 1996. The 1995 Drought in the context of the recent hydrological volatility. In: *1995 Yearbook.* Institute of Hydrology, Wallingford. 25-34.

Marsh, T.J. 1996. *Guide to Hydrometric Data Management.* British Standards Institution, London.

Marsh, T.J. 1996. River flow and groundwater level records – the instrumented era. In: Branson, J. (Ed.), *Palaeohydrology: context, components and application.* British Hydrological Society Occasional Paper No. 7, 7-24.

Marsh, T.J. (Ed.) 1996. *1995 Yearbook. Hydrological Data UK Series.* Institute of Hydrology.

Marsh, T.J. and Turton, P.S. 1996. The 1995 drought – a water resources perspective. *Weather,* **51** 46-53.

McWilliam, A.-L.C., Cabral, O.M.R., Gomes, B.M., Esteves, J.L. and **Roberts, J.M.** 1996. Forest and pasture leaf-gas exchange in South West Amazonia. In: Gash, J.H.C., Nobre, C.A., Roberts, J.M. and Victoria, R.L. (Eds) *Amazonian Deforestation and Climate.* John Wiley & Sons, Chichester. 265-285.

Meigh, J.R., Farquharson, F.A.K. and Sutcliffe, J.V. 1996. A worldwide comparison of regional flood estimation methods and climate. *Hydrol. Sci. J.* **42**, 225-244

Morris, D.G. and **Flavin, R.W.** Flood risk map for England and Wales. *Institute of Hydrology Report No. 130.*

Neal, C., Smith, C.J., Jeffery, H.A., Harrow, M.L. and **Neal, M.** 1996. Dissolved chromium pollution in rainfall and surface waters in mid-Wales during the mid 1980s. *Sci. Tot. Environ.* **188**, 127-138.

Neal, C. 1996. Towards lumped integrated models of complex heterogeneous systems. *Sci. Tot. Environ.* **183**, 115-124.

Neal, C., Smith, C.J., Jeffery, H.A., Jarvie, H.P. and **Robson, A.J.** 1996. Trace element concentrations in the major rivers entering the Humber estuary, N.E. England. *J. Hydrol.* **182**, 37-64.

Nobre, C.A., **Gash, J.H.C., Roberts, J.M.** and Victoria, R.L. 1996. The conclusions from ABRACOS. In: Gash, J.H.C., Nobre, C.A., Roberts, J.M. and Victoria, R.L. (Eds) *Amazonian Deforestation and Climate.* John Wiley & Sons, Chichester. 577-595.

Onof, C., **Faulkner, D.S.** and Wheater, H.S. 1996. Design rainfall modelling in the Thames catchment. *Hydrol. Sci. J.* **41**, 715-733.

Ormerod, S.J., Brewin, P.A., Buckton, S.T., **Jenkins, A.**, Juttner, I., Siren, A.M. and Wilkinson, S.M. 1996. Investigating the biodiversity of Himalayan hillstreams. In: Singh, R.B. and Haigh, M.J. (Eds), *Sustainable reconstruction of highland and headwater regions.* Oxford & IBH Publishing Ltd, New Delhi, India.

Patrick, S., Battarbee, R. and **Jenkins, A.** 1996. Monitoring acid waters in the UK: an overview of the UK Acid Waters Monitoring Network and summary of the first interpretative exercise. *Freshwater Biol.* **36**, 131-150.

Post, D.A., Jakeman, A.J., **Sefton, C.E.M.** and Howarth, S.M. 1996. Using a lumped parameter rainfall-runoff model to predict the daily streamflow of ungauged catchments from regional relationships between landscape attributes and hydrologic response. Fall Meet. Suppl. *EOS: Trans. Amer. Geophys. Union* **77**, F233.

Ragab, R., Cooper, D.M., Harris, G.L. and Catt, J.A. 1996. Simulated nitrate leaching under winter wheat grown on a structured clay soil considering bypass flow. *J. Hydrol.* **182**, 157-173.

Ribeiro, A., Victoria, R.L., Martinelli, L.A., Meneira, M.Z. and **Roberts, J.M.** 1996. The isotopic composition of atmospheric water vapour inside a canopy in Amazonian forest: vertical and diurnal variation. In: Gash, J.H.C., Nobre, C.A., Roberts, J.M. and Victoria, R.L. (Eds) *Amazonian Deforestation and Climate.* John Wiley & Sons, Chichester. 163-173.

Roberts, G. and **Harding, R.J.** 1996. The use of simple process-based models in the estimate of water balances for mixed land use catchments in East Africa. *J. Hydrol.* **180**, 251-266.

Roberts, J.M., Cabral, O.M.R., da Costa, J.P.R., **McWilliam, A.-L.C.** and Sá, T.D.d.A. 1996. An overview of the leaf area index and physiological measurement during ABRACOS. In: Gash, J.H.C., Nobre, C.A., Roberts, J.M. and Victoria, R.L. (Eds) *Amazonian Deforestation and Climate.* John Wiley & Sons, Chichester. 287-306.

Robson, A.J. and **Neal, C.** 1996. Water quality trends at an upland Welsh site. *Hydrol. Procs.* **10**, 183-203.

Robson, A.J., Neal, C., Currie, J.C., Virtue, W.A. and Ringrose, A. 1996. The water quality of the Tweed and its tributaries. *Institute of Hydrology Report No. 128.*

Sanderson, F.J. 1996. Hydrological diary. In: *Hydrological Data UK, 1995 Yearbook.* Institute of Hydrology, Wallingford. 23-24.

Sá, T.D.d.A., da Costa, J.P.R. and **Roberts, J.M.** 1996. Forest and pasture conductances in southern Pará, Amazonia. In: Gash, J.H.C., Nobre, C.A., Roberts, J.M. and Victoria, R.L. (Eds) *Amazonian Deforestation and Climate.* John Wiley & Sons, Chichester. 241-263.

Scudder, T. and **Acreman, M.C.** 1996. Water management for conservation of the Kafue flats, Zambia and the practicalities of artificial flood releases. In: Acreman, M.C. and Hollis, G.E. (Eds), *Water management and wetlands in sub-Saharan Africa.* IUCN, Gland, Switzerland. 101-106.

Sene, K.J. 1996. Meteorological estimates for the water balance of a sparse vine crop growing under semi-arid conditions. *J. Hydrol.* **179**, 259-280.

Smith, D.M. and **Allen, S.J.** 1996. Measurement of sap flow in plant stems. *J. Exper. Botany* **47**, 1833-1844.

Stewart, J.B. 1996. Extrapolation of evaporation at time of satellite overpass to daily totals, In: Stewart, J.B., Engman, E.T., Feddes, R.A. and Kerr, J. (Eds) *Scaling up using remote sensing.* John Wiley & Sons Ltd, Chichester, 245-255.

Stewart, J.B., Engman, E.T., Feddes, R.A. and Kerr, J. (Eds) *Scaling up using remote sensing.* John Wiley & Sons Ltd, Chichester, 255 pp

Taylor, C.M. 1996. The influence of mesoscale variability on the atmosphere. PhD thesis, Reading University.

Tomasella, J. and **Hodnett, M.G.** 1996. Soil hydraulic properties and van Genuchten parameters for an oxisol under pasture in central Amazonia. In: Gash, J.H.C., Nobre, C.A., Roberts, J.M. and Victoria, R.L. (Eds) *Amazonian Deforestation and Climate.* John Wiley & Sons, Chichester. 101-124.

Verhoef, A., **Allen, S.J.**, De Bruin, H.A.R., Jacobs, C.M.J. and Heusinkveld, B.G. 1996. CO_2 and water vapour fluxes from a Sahelian savanna. *Agric. For. Meteorol.* **80**, 231-248.

Verhoef, A. 1996. Surface energy balance of shrub vegetation in the Sahel, PhD thesis, Department of Meteorology, Wageningen Agricultural University, The Netherlands.

Verhoef, A., Van den Hurk, B.J.J.M., Jacobs, A.F.G. and Heusinkveld, B.G. 1996. Thermal soil properties for a vineyard (EFEDA-I) and a savanna (HAPEX-Sahel) sites. *Agric. For. Meteorol.* **78**, 1-18.

Wallace, J.S. 1996. The water balance of mixed tree-crop systems. In: Ong, C.K. and Huxley, P.A. (Eds), *Tree-crop interactions – a physiological approach.* CABI, Wallingford. 189-233.

Williams, R.J., Brooke, D.N., Clare, R.W., Matthiessen, P. and Mitchell, R.D.J. 1996. Rosemaund pesticide transport study 1987-1993. *Institute of Hydrology Report No. 129*

Worrall, F., Parker, A., Rae, J.E. and **Johnson, A.C.** 1996. Equilibrium adsorption of isoproturon on soil and pure clays. *European J. Soil Sci.* **47**, 265-272.

Wright, I.R., **Gash, J.H.C.** and da Rocha, H.R. 1996. Modelling surface conductance for Amazonian pasture and forest. In: Gash, J.H.C., Nobre, C.A., Roberts, J.M. and Victoria, R.L. (Eds) *Amazonian Deforestation and Climate.* John Wiley & Sons, Chichester. 437-458.

Wright, I.R., Nobre, C.A., Tomasella, J., da Rocha, H.R., **Roberts, J.M.**, Vertamatti, E., **Culf, A.D.**, Alvalá, R.C.S., **Hodnett, M.G.** and Ubarana, V. 1996. Towards a GCM surface parameterisation for Amazonia. In: Gash, J.H.C., Nobre, C.A., Roberts, J.M. and Victoria, R.L. *Amazonian Deforestation and Climate.* John Wiley & Sons, Chichester. 473-504.

Xue, Y., **Bastable, H.G.**, Dirmeyer, P.A. and Sellers, P.J. 1996. Sensitivity of simulated surface fluxes to changes in land surface parameterizations – a study using ABRACOS data. *J. Appl. Meteorol.* **35**, 386-400.

Other publications

Acreman, M.C. 1996. Economic valuation of wetlands and its role in wise use. *Proc. 6th meeting of the Conf. of the Contracting Parties, Brisbane, Australia,* **10/12 A**, 56-65. Ramsar Convention, Gland, Switzerland.

Acreman, M.C. 1996. IUCN. Review of the Niger Delta Environmental Survey, preliminary report, phase 1.

Acreman, M.C. 1996. The environmental effects of reservoir development and management in Africa. Proc. Internat. Conf. on *Aspects of conflicts in reservoir development and management,* City University, London.

Acreman, M.C. and **Fey, N.** 1996. Brochure – groundwater and river resources action programme on a European scale (GRAPES).

Acreman, M.C., Howard, G. and Pirot, J.-Y. 1996. Reconciling water resources management and wetland conservation: a key challenge for Ramsar in the 21st Century. *Proc. 6th meeting of the Conf. of the Contracting Parties, Brisbane, Australia,* **9/12**, 2-8. Ramsar Convention, Gland, Switzerland.

Andrews, A.J., **Reynard, N.S.** and Hatatule, A. 1996. A grid based method to assess the variability of water resources in Southern Africa. XII Journées Hydrologiques De l'Orstom, Montpellier, France.

Andrews, A.J. and Mkhandi, S. 1996. Southern Africa FRIEND time series and spatial databases. XII Journées Hydrologiques De l'Orstom, Montpellier, France.

Austin, R.M. and **Moore, R.J.** 1996. Evaluation of radar rainfall forecasts in real-time flood forecasting models. Proc. workshop on Integrating radar estimates of rainfall in real-time flood forecasting, *Quaderni Di Idronomia Montana* **16**, 19-28.

Austin, R.M. 1996. Improved methods of snowmelt forecasting. Report on Environment Agency Seminar. *Circulation* **52**, 12-15.

Batchelor, C.H., **Lovell, C.J.**, Chilton, J. and Mharapara, I. 1996. Development of collector well gardens. Proc. 22nd WEDC Conf. *Reaching the unreached: challenges for the 21st century"* – Conference preprints **I**, 28-30.

Batchelor, C.H., **Lovell, C.J.**, **Butterworth, J.A.** and **Waughray, D.K.N.** 1996. Integrated catchment management in dryland areas. EU Conference on Mediterranean

Desertification, Crete (Abstract).
Batchelor, C.H., **Lovell, C.J.** and Murata, M. 1996. Water use efficiency of simple subsurface irrigation systems. Proc. 7th Internat. Conf. on Water and Irrigation, Tel Aviv, Israel, 88-96.
Bell, V.A. and **Moore, R.J.** 1996. A water-balance rainfall model for flood forecasting using weather radar, satellite infra-red and surface weather observations: an assessment over Southern Britain. In: *HS11 – Remote Sensing in Hydrology*, EGS XXI General Assembly, The Hague, The Netherlands. (Abstract).
Besien, T.J. 1996. The sorption of Isopruturon to aquifer sediments. *Proc. COST 66 Workshop*, Stratford-upon-Avon, UK. 33-34.
Besien, T.J., **Williams, R.J.** and Jarvis, N.J. 1996. Simulation of water movement and herbicide behaviour in a heavy clay soil using the MACRO model. European Geophysical Society, XXI General Assembly, The Hague, The Netherlands, *Annal. Geophys.* **14** Suppl. II, C317.
Black, K.B. 1996. Computing. *Working in Natural Sciences*, DfEE, ISBN 0 86110 700 4 (WI 25).
Boorman, D.B., **Jenkins, A.** and **Collins, R.P.** 1996. Rainfall-runoff data and modelling in the Likhu Khola Catchment, Nepal. In: Chalise, S.R. and Khanal, N.R. (Eds), ICIMOD/UNESCO Internat. Conf. on *Ecohydrology of high mountain areas*, Kathmandu, Nepal, Extended abstract, 139-142.
Bromley, J., Llamas, R., Cruces, J., Dolz, J., Thornes, J.B. and Imeson, A. 1996. EFEDA II – Desertification and groundwater: overview of the groundwater crisis in the Upper Guidiana Basin. EU Conference on Mediterranean Desertification, Crete (Abstract).
Calver, A. and **Lamb, R.** 1996. Flood frequency estimation using continuous rainfall-runoff modelling. Paper presented at the European Geophysical Society General Assembly, The Hague, May 1996. *European Geophysical Society General Assembly*. (Abstract).
Collins, R.P. 1996. Modelling the nitrogen cycle in Nepal. *Mapping Awareness* **10**, 16-18.
Collins, R.P., **Jenkins, A.**, **Boorman, D.B.** and **Whitehead, P.G.** 1996. Streamwater acidification in response to anthropogenic pollution inputs at forested and cultivated catchments in the Middle Hills, Nepal. In: Chalise, S.R. and Khanal, N.R. (Eds), ICIMOD/UNESCO Internat. Conf. on *Ecohydrology of high mountain areas*, Kathmandu, Nepal, Extended abstract, 147-149.
Croker, K.M. and **Rees, H.G.** 1996. HydrA European Atlas of small scale hydropower potential. Publicity brochure (in English & Spanish).
Dixon, J.M. 1996. FRIEND – Northern European Project. Minutes of Steering Committee Meeting Number 4. UNESCO, Paris.
Dixon, J.M. 1996. FRIEND Progress Report (Sept 1995-Sept 1996).
Dolman, A.J., Kabat, P., Ashby, M., Noilhan, J., Calvet, C., Delire, C., **Gash, J.H.C.**, **Wright, I.R.**, Jochum, A. and Nobre, C.A. 1996. Modelling studies supporting the planning of the Large Scale Biosphere Atmosphere Experiment in Amazonia (LBA). 2nd Internat. Conf. on *The global energy and water cycle*, Washington DC, 197.
Eatherall, A. 1996. User notes for the MAFF small area statistics agricultural census, LOIS working note No. 5, Institute of Hydrology.
Fattorelli, S., Borga, M. and **Moore, R.J.** 1996. Storms, floods and radar hydrology. In: R. Casale (ed.), Hydrological and hydrogeological risks, Proc. European Commission, 1st Review Meeting, Brussels, EUR 16799 EN, 233-245.
Faulkner, D.S. 1996. Focusing on a Celtic region: rainfall frequency in south-west England. Poster with abstract in *Hydrologie dans les pays celtiques*. Proc. 1st Inter-Celtic Colloquium on Hydrology and Water Management, Rennes, Britanny.
Flavin, R.W. 1996. Institute of Hydrology Software – packaged science. *Water and Sewerage Journal*, **Summer 1996**, 19-21.
Gash, J.H.C. and **Nobre, C.A.** 1996. Climatic effects of Amazonian deforestation. International Congress on Environment and Climate, Rome, 117. (Abstract).
Gash, J.H.C. 1996. Review of "Space and time scale variability and interdependencies in hydrological processes" by R A Feddes. *Int. J. Clim.* **16**, 1423-1424.
Gooddy, D.C., Chilton, P.J., Stuart, M.E., **Williams, R.J.**, **Johnson, A.C.**, **Besien, T.J.** and **White, C.** 1996. Preferential flow and the transport of herbicides in the chalk of Southern England. *Proc. COST 66 Workshop*, Stratford-upon-Avon, UK. 187-188.
Gustard, A. 1996. Implementation, achievements and further plans for the Northern European FRIEND project. In: *Hydrology of the Hindu Kush-Himalayas*, Report of Regional Workshop, Kathmandu, Nepal.
Gustard, A. 1996. Water resource availability and use in the UK. Conference on *Water Management and Use*, London.
Gustard, A. 1996. Implementation, achievements and further plans for the Northern European FRIEND project. In Proc. UNESCO IHP internat. symp. *Rivers and people in Southeast Asia and the Pacific – partnership for the 21st Century*.
Gustard, A. and **Runnalls, N.R.** 1996. Summary by Workshop Rapporteurs. In: Water Resources in Europe – the Future. Proc. of a Euro-Workshop, Marlow, UK.
Hill, D.R. and Bellamy, S.P. 1996. Search mechanisms for querying the time dimension in 4-D GIS. Proc. 1st Internat. Conf. on Geocomputation, University of Leeds, **1**, 405-420
Hill, D.R. 1996. Access to the Rivers Data Centre. *LOIS Newsletter* No. 10.
Houghton-Carr, H.A. 1996. Micro FSR V2.2 Release Notes, 30pp.
Irving, K.M., **Young, A.R.** and **Bullock, A.** 1996. Low flow estimation in artificially influenced catchments. Reports 4, Micro LOW FLOWS V2.1. Training course manual, 70pp.
Jenkins, A., **Wilkinson, R.J.** and **Collins, R.P.** 1996. Hydrochemical characteristics of headwater streams in the Middle Hills and High Mountains of the Himalayas, Nepal. In: Chalise, S.R. and Khanal, N.R. (Eds), ICIMOD/UNESCO Internat. Conf. on *Ecohydrology of high mountain areas*, Kathmandu, Nepal, Extended abstract, 163-165.
Jennings, S.E. 1996. (Ed.) Software Newsletter.
Jennings, S.E. 1996. WINFAP: hydrology frequency analysis package (Brochure).
Johnson, A.C., **White, C.**, **Besien, T.J.**, **Williams, R.J.**, Worrall, F. and Walker, A. 1996. The potential of incorporated organic matter to reduce pesticide leaching. *Proc. COST 66 Workshop*, Stratford-upon-Avon, UK. 55-56.
Johnson, R.C. and **Collins, R.P.** 1996. Developments in a methodology of classifying sediments in Himalayan rivers. In: Chalise, S.R. and Khanal, N.R. (Eds), ICIMOD/UNESCO Internat. Conf. on *Ecohydrology of high mountain areas*, Kathmandu, Nepal, Extended abstract, 61.
Law, F.M. and **Gunston, H.M.** 1996. Dam failures. *Dams & Reservoirs* **6**, 6
Law, F.M. 1996. Forgotten flows?

Circulation **52**, 18.

Law, F.M. 1996. United Kingdom National Report on IHP Related Activities. Twelfth Session of the Intergovernmental Council, Paris.

Law, F.M. 1996. Water conservation and supply – Minutes of evidence and appendices (First Report). House of Commons Environment Committee, 26th June.

Lees, M.L. 1996. Optimizing freshwater data monitoring networks including links with modelling. Country paper of the UK. *In: Optimizing freshwater data monitoring networks.* Proc. EurAqua Second Technical Review Meeting, Paris, October 1995. 205-244.

Linder, W., Noilhan, J., Berger, M., Bluemel, K., **Blyth, E.M.**, Boulet, G., Braud, I., Dolman, A.J., Fiedler, F., Grunwald, J., **Harding, R.J.**, van der Hurk, B., Jaubert, G., Mueller, A. and Ogink, M. 1996. Inter-comparison of surface schemes using EFEDA flux data. Report, CNRM, France, 1-42.

Marsh, T.J. and **Green, S.** 1996. Entry to Digest of Environmental Statistics 1996.

Marsh, T.J. 1996. Getting to grips with drought in the UK. *NERC News*, Summer 1996, 16-18.

Martin de Santa Olalla, F., Gil, A., **Bromley, J.**, **Batchelor, C.H.**, Brasa, A. and Legorburo, A. 1996. Sustainable agricultural water use. EU Conference on Mediterranean Desertification, Crete (Abstract).

McCartney, M.P. 1996. A concept note on the modelling of dambo hydrology. Institute of Hydrology, Wallingford.

McCartney, M.P. 1996. A study of dambo hydrology in southern Africa. Upgrade report to Higher Degree Committee at the University of Reading, 44pp.

McCartney, M.P. 1996. Technical Note 3: A pedological survey of the grasslands research catchment at Marondera, Zimbabwe: implications of soil characteristics for catchment hydrology. 103pp.

Meynell, P-J., Pirot, J-Y. & **Acreman, M.C.** 1996. Guidelines for aid agencies for improved conservation and sustainable use of tropical and sub-tropical wetlands. *OECD Guidelines on Aid and Environment*, No.9. Organisation for Economic Cooperation and Development, Paris, France. 72 pp

Moore, R.J. and **Bell, V.A.** 1996. A grid-based flood forecasting model using weather radar, digital terrain and Landsat data. Proc. workshop on Integrating radar estimates of rainfall in real-time flood forecasting, *Quaderni Di Idronomia Montana* **16**, 97-105.

Moore, R.J. 1996. Aspects of uncertainty, reliability and risk in flood forecasting systems incorporating weather radar. In: *Risk, Reliability and Robustness of Water Resources Systems*, 3rd IHP/IAHS George Kovacs Colloquium, UNESCO, Paris.

Moore, R.J. 1996. Management and prevention of crisis situations: floods, droughts and institutional aspects. UK paper to EurAqua Third Technical Review, Rome.

Moore, R.J. 1996. Snowmelt flooding. MAFF *Flood and Coastal Defence* newsletter, 5-6.

Moore, R.J. 1996. Weather Radar and Storm and Flood Hazard. In: R. Casale (ed.), Hydrological and hydrogeological risks, Proc. European Commission, 1st Review Meeting, Brussels, 30-31 January 1995, EUR 16799 EN, 23-36.

Moore, R.V. 1996. The establishment and operation of national and Eastern Cape rural water supply planning, monitoring and evaluation (M&E) units. Visit report (18 October-18 November).

Naden, P.S. and **Broadhurst, P.** 1996. From small watersheds to large basins: a scheme based on classification, generalisation and routing. International GCIP/MAGS workshop on scaling in hydrometerological/hydrological processes and models, Victoria, Canada (Abstract).

Naden, P.S., **Crooks, S.M.** and **Broadhurst, P.** 1996. Impact of climate and land use change on the flood response of large catchments. *Proc. 31st MAFF Conf. of River & Coastal Engineers*, Keele, 2.1.1-2.1.16.

Neal, C. 1996. Review of "Changing river channels" edited by Gurnell, A. and Petts, G. *Sci. Tot. Environ.* **187**, 163-164.

Ormerod, S.J., Buckton, S.T., Brewin, P.A., **Jenkins, A.**, **Johnson, R.C.** and Suren, A. 1996. Biodiversity, chemistry and structure in streams of the Nepalese Himalaya. In: Chalise, S.R. and Khanal, N.R. (Eds), ICIMOD/UNESCO Internat. Conf. on *Ecohydrology of high mountain areas*, Kathmandu, Nepal, Extended abstract, 197-200.

Ragab, R. 1996. Soil hydraulic conductivity: issues in measuring, predicting and upscaling. In: *European workshop on advanced methods to determine hydraulic properties of soils*, Thurnau, Germany. University of Bayreuth. 75 (extended abstract).

Ragab, R. 1996. Constraints and applicability of irrigation scheduling under limited water resources, variable rainfall and saline conditions. Report on Theme III. In: Smith, M., Pereira, L.S., Berengena, J., Itier, B., Goussard, J., Ragab, R., Tollefson, L. and van Hofwegen, P. (Eds). *Irrigation scheduling: from theory to practice.* ICID/FAO Water Report No. 8. 149-165.

Ragab, R. 1996. Current activity on crop water requirements and related themes. *Irrigation News* **25**, 43-44.

Ragab, R., El Quosy, D., van den Broek, B. and Santos Pereira, L. (Eds) 1996. *Workshop on Crop-water-environment models*, ICID 16th Congress, Cairo. 301 pp.

Rees, H.G. 1996. Hydra offers rapid assessment of hydropower potential. *ESHA Info.* No.18.

Roberts, A.M. 1996. HYREX Conference. *Circulation* **52**, 9-10.

Roberts, A.M. 1996. Pollutant transport in soils and rocks. Brochure describing results of NERC Special Topic.

Smith, D.M., Jarvis, P.G. and Odongo, J.C.W. 1996. Water use by Sahelian windbreak trees. In: Buerkert, B., Allison, B.E. and von Oppen, M. (Eds), *Wind Erosion in West Africa: the problem and its control.* Margraf Verlag, Weikersheim, Germany. 115-128.

Smith, M., Pereira, L.S., Berengena, J., Itier, B., Goussard, J., **Ragab, R.**, Tollefson, L. and van Hofwegen, P. (Eds) 1996. *Irrigation scheduling: from theory to practice.* ICID/FAO Water Report No. 8, 384 pp.

Vardavas, I., Prastacos, P., Bolle, H., **Bromley, J.**, Devereux, B. and De Bruin, H.A.R. 1996. Desertification and climatic change impacts in the Messara Valley. EU Conference on Mediterranean desertification, Crete. *Abstract.*

Wilcox, D.A., **Besien, T.J.**, **Johnson, A.C.** and **Haria, A.H.** 1996. Isoproturon transport through upper chalk cores. Abstract, *Proc. COST 66 Workshop, Pesticides in the Soil and the Environment*, Stratford-upon-Avon, UK.

Wilkinson, W.B., **Law, F.M.**, **Gustard, A.** and Armitage, P. 1996. Environment Committee. First Report: Water Conservation and Supply. House of Commons Session 1996-1997. Minutes of evidence and appendices, 178-204.

Commissioned research reports

Alvalá, R.C.S., Calvet, J.C., Jaubert, G., Noilhan, J. and Wright, I.R. 1996. Mapping surface parameters for mesoscale modelling in forested and deforested south-western Amazonia. Report to ODA
Batchelor, C.H. 1996. Management of environmental resources through community-based initiatives: mission to prepare a project memorandum. Report to ODA.
Batchelor, C.H. 1996. Western India Rainfed Farming Project: report on a visit during September 1996. No. 96/12. Report to ODA
Bayliss, A.C. 1996. Catchment characteristics for flood estimation: completing a preliminary set for England & Wales. Flood Estimation Handbook Note 23. Report to MAFF
Bayliss, A.C. and Scarrott, R.M.J. 1996. Catchment characteristics for flood estimation: indexing catchment urbanization using gridded spatial data. Flood Estimation Handbook Note 24, 38pp. Report to MAFF
Bell, V.A. and Moore, R.J. 1996. A water-balance storm model for short-term rainfall forecasting using weather radar, satellite infra-red and surface weather observations: an assessment over south west Britain. Contract Report to MAFF, Document HYREX1/IH/2, Version 1.0, February 1996, 60pp.
Blackie, J.R., Houghton-Carr, H.A., McCartney, M.P., Moores, J.P. and Davies, H.N. 1996. The Trinity Catchment Study: Final Report. Report to Jersey Public Services Department.
Bradford, R.B. and Moores, J.P. 1996. Bath Hot Springs: Analysis and Interpretation of Flow and Temperature Data. Report to the NRA.
Bromley, J., Robinson, M. and Dixon, A.J. 1996. Evaluating sub-surface water losses in a cut-over peatland: Thorne Moors, South Yorkshire. Confidential report for Levingtons plc.
Bromley, J., Bergkamp, G., Burke, S., Casado, M., Cruces, J., Doltz Ripollés, J., Gomez Valentin, M., Harrison, A., De La Hera, A., Hodnett, M.G., Imeson, A.C., Llamas, M.R., Lopez Bermuda, F., Martiniz, L., Sanchez Juny, M., Thornes, J., Urbano Martin, A. and Young, A.R. 1996. EFEDA-2: hydrology group. Contract No. EV5V-CT93-0282. Final report to CEC.
Bullock, A. and Farquharson, F.A.K. 1996. Mozambique: Zambezi Hydropower Feasibility. Confidential report to ODA
Bullock, A. and Farquharson, F.A.K. 1996. ODA Technology, Development and Research (TDR) Water Sector Strategy: W1 – improve the assessment, development and management of water resources. Report to ODA
Cain, J.D. 1996. Literature review on evaporation, rainfall interception and scale issues. Report to the Meteorological Office
Cain, J.D. 1996. Simulating soil water balance and groundwater recharge of fallow site in Niger using the FRLM model. Report to ODA
Calver, A., Lamb, R. and Gannon, B. 1996. Comparison of flood frequency curves derived from continuous rainfall-runoff modelling and from data analysis. Report to MAFF
Calver, A. 1996. Rainfall-runoff modelling for flood frequency estimation – strategy and progress. Project Note FD0404. Report to MAFF.
Cole, G.A. and Rees, H.G. 1996. Long-range study on water supply and demand in Europe: UK. 63pp. Report to International Centre for Water Studies.
Cole, G.A. and Rees, H.G. 1996. The establishment of a Regional Data Centre of the European Water Archive for the European Territory of the former Soviet Union. INTAS Periodic Report No. 1, 1 October 1995 - 30 September 1996.
Collins, R.P. and Jenkins, A. 1996. Soil Moisture Monitoring and Hydrological Response. In: Jenkins, A. (Ed.) *The CLIMEX project:* Climate Change Research Report 8/1996 for CEC
Crooks, S.M., Naden, P.S., Broadhurst, P. and Gannon, B. 1996. Modelling the flood response of large catchments: initial estimates of the impacts of climate and land use change, 66 pp. Report to MAFF
Danks, P.W. and Morris, S.E. 1996. Estimation of river discharge and velocities for the Upper Ivel, near Stotfold, Bedfordshire. Vols I and II. Reading Agricultural Consultants.
Davies, H.N. and Robinson, M. 1996. An appraisal of water levels at Thorne Moors SSSI, 1992-96. Report to English Nature.
Dixon, A.J. 1996. Burnham Beeches groundwater monitoring 18th April 1995-19th March 1996. Report to the City of London Corporation
Dixon, A.J. 1996. Hydrogeological investigation of Packards South Section of Hatfield Moors, South Yorks. Report to Levington Horticulture
Dixon, A.J. 1996. Hydrogeological investigation of Earley Town Council Burial Ground. Report to Earley Town Council
Dixon, J.M. 1996. Provision of River Flow Data to the North and Irish Seas (FRIEND). Progress Report April 1996 - September 1996 to DOE.
Dixon, J.M. and Rees, H.G. 1996. Provision of river flow data to the North and Irish Seas (FRIEND). Progress Report Oct 95-March 96 to DOE.
Dunbar, M.J., Elliott, C.R.N., Acreman, M.C. and Gustard, A. 1996. Ecologically acceptable flows Phase II. Volume 1: Habitat time series analysis. R&D Technical Report W19 to the Environment Agency.
Elliott, C.R.N., Johnson, I.W., Sekulin, A.E., Dunbar, M.J. and Acreman, M.C. 1996. Guide to the use of the Physical Habitat Simulation System, Environment Agency Release version. R&D Technical Report W20 to the Environment Agency.
Evans, J.G. 1996. Contract: River Basin Management Project: Chile Contract Reference: CNTR 93 2083 A, Visit Report No. 6 to ODA
Faulkner, D.S. 1996. Summary of UK rainfall data gathered for the FEH. Flood Estimation Handbook Note 28, 3pp. Report to MAFF
Faulkner, D.S., Mackay, N.G., Onof, C.J., Reed, D.W. and Wheater, H.S. 1996. A review of some recent flood-producing rainfalls. Report to MAFF.
Finch, J.W., Calver, A., Harding, R.J. and Ragab, R. 1996. Manual for estimating mean annual recharge at drift-free sites on the chalk and Permo-Trias sandstone aquifers. R&D Report 49 for the Environment Agency
Forsius, M., Alveteg, M., Jenkins, A., Johansson, M., Kleemola, S., Lukewille, A., Posch, M., Sverdrup, H., Syri, S. and Walse, C. 1996. Dynamic model applications at selected ICP-IM sites. In: Kleemola, S. and Forsius, M. (Eds) *5th Annual Report of the UN ECE ICP-IM.* Finnish Environment Institute, Helsinki. 25-38.
Gash, J.H.C., Roberts, J.M. and Nobre, C.A. 1996. The Anglo-Brazilian Amazonian Climate Observation Study (ABRACOS): Final Report on Phase II. Report to ODA

Green, S. and Marsh, T.J. 1996. River Flows in the Lebanon. Report on ODA Resource Centre project for the Litani River Authority.

Hall, R.L., Allen,S.J., Rosier, P.T.W., Smith, D.M., Hodnett, M.G., Roberts, J.M., Hopkins, R., Davies, H.N., Kinniburgh, D.G. and Gooddy, D. C. 1996. Hydrological effects of short rotation energy coppice. ETSU Report B/W5/00275/REP, 226pp. Report to Department of Trade & Industry

Hearne, J., Johnson, I.W. and Armitage, P. 1996. Determination of ecologically acceptable flows with seasonal changes in the density of macrophyte. R&D Technical Report W48 to the Environment Agency.

Houghton-Carr, H.A. 1996. Flood Estimation Handbook Vol. 4 – Restatement of the FSR Rainfall Runoff Method: list of source documents. Flood Estimation Handbook, Note 19, 17pp. Report to MAFF

Jackson, N.A., Wallace, J.S., Smith, D.M. and Roberts, J.M. 1996. Water balance of agroforestry systems on hillslopes – Phase II. Annual Report to the Forestry Research Programme, September 1996.

Jenkins, A. 1996. (Ed.) The CLIMEX project: results from the second year of treatment, May 1995 – December 1995. NIVA, Oslo. 5-6.

Jenkins, A., Renshaw, M., Helliwell, R.C., Sefton, C.E.M., Ferrier, R.C. and Swingewood, P. 1996. Modelling surface water acidification in the UK: application of the MAGIC model to the UKAWMN. Report to the Department of the Environment

Jones, D.A. 1996. An evaluation of a Bayesian scheme for model updating and forecasting using a rainfall-runoff model. Report to MAFF

Lamb, R. and Gannon, B. 1996. The establishment of a database of hourly catchment average rainfall and flow for flood frequency estimation by continuous simulation. Report to MAFF.

Law, F.M. and Austin, B.N. 1996. Assessment of yield for the River Medway (Bewl Water). Confidential Report to SAUR UK

Law, F.M. and Austin, B.N. 1996. Confidential assessment of resource yield for two water companies.

Lees, M.L. 1996. Design for a monitoring network for the EEA area. Surface freshwater – quality. Report PO4/95-100. European Topic Centre on Inland Waters.

Lees, M.L. and Marsh, T.J. 1996. Inventory of water resource monitoring networks – determine requirements for density, sampling frequency, analytical methods, quality assurance schemes, data storage and estimate costs: surface freshwater – quality. Project MW3. Report to the European Topic Centre on Inland Waters, European Environment Agency

Lees, M.L. and Marsh, T.J. 1996. River flow monitoring in the EU. Determine the requirements for density, sampling frequency, analytical methods, quality assurance schemes, data storage and estimate costs. Report P04/95-96. European Topic Centre on Inland Waters.

Lovell, C.J., Batchelor, C.H., Waughray, D.K.N., Semple, A.J., Mazhangara, E., Mtetwa, G., Murata, M., Brown, M.W., Dube, T., Thompson, D.M., Chilton, P.J., MacDonald, D.M.J., Conyers, D. and Mugweni, O. 1996. Small-scale irrigation using collector wells. Final Report to ODA

Macdonald, A.M., Calow, R.C., Andrews, A.J. and Appiah, S. 1996. Groundwater management in drought prone areas of Africa. Northern Ghana. Technical Report WC/96/25. Overseas geology series. Report to ODA

Maddock, I.P., Dunbar, M.J., Holland, C. and Gowing, I.M. 1996. Habitat Mapping and PHABSIM site selection on the River Wylye. Report to Environment Agency South Western Region.

Marsh, T.J. (Ed.) 1996. Monthly hydrological summaries of Great Britain. Twelve monthly reports on hydrological conditions throughout Great Britain (by the Institute of Hydrology and British Geological Survey) for the Department of the Environment.

Marsh, T.J. and Carr, J. 1996. The archiving and checking of the 1931-73 Lebanese river flow data. ODA British Partnership Scheme project. Report to ODA

Marshall, D.C.W. 1996. Flood volume estimation II. Flood Estimation Handbook Note 26. Report to MAFF

Marshall, D.C.W. and Reed, D.W. 1996. Flood volume estimation I. Flood Estimation Handbook Note 18. Report to MAFF

Mazhanghara, E., Mtetwa, G., Dube, T., Lovell, C.J. and Batchelor, C.H. 1996. Small-scale irrigation using collector wells: Collector Well Garden Performance 1995 Winter Season.

Meigh, J.R. 1996. Water resources database for the Directorate of Water Management, Syria. UNDP, 10pp.

Moore, R.J. 1996. A river flow forecasting system for Rajasthan. In: Modernisation of hydro-meteorological observations in Rajasthan. Phase A – Final Report, Ex 2276 (130pp plus tables, appendices and maps) for Wallingford Water

Moore, R.J. 1996. Alpine study tour on snow cover monitoring. In: Blackie, J.R. and Robinson, M. (ed.), The Jizera Mountains: Training for Data Acquisition and Evaluation. Progress Report 1995-96. Management Unit of the Ministry of Environment of the Czech Republic, Water Quality Monitoring Programme – CS9002/22.06 – Wat/28 Contract Number: 28/Ser/5, Appendix E. Report to the EU Phare Programme

Moore, R.J., Harding, R.J., Austin, R.M., Bell, V.A. and Lewis, D.R. 1996. Development of improved methods for snowmelt forecasting. R&D Note 402, 192pp. Report to the National Rivers Authority

Moore, R.J. 1996. Storms, floods and radar hydrology, Contract No. EV5V-CT92-0182, 209pp. Report to Commission of the European Communities

Moore, R.V. and Bellamy, S.P. 1996. Establishment of a Hydrological Information System for Water Resources planning, development and management – Interim Report. Commissioned report for Jabatan Pengairan Dan Saliran, Malaysia.

Morris, D.G. and Hermans, E. 1996. Methods of flood risk mapping. Report to the Environment Agency.

Neal, C., Wilkinson, R.J. and Reynolds, B. 1996. The impact of conifer harvesting and replanting on upland water quality, R&D Progress Report P2/i502/5 to the Environment Agency

Ragab, R. 1996. Modelling surface runoff generation and flow. A literature review. Groundwater recharge in semi-arid zones. Report to ODA

Reed, D.W. 1996. Catchment characteristics for flood frequency generalisation. Flood Estimation Handbook Note 21, 7pp. Report to MAFF

Reed, D.W. 1996. Implementation of flood frequency estimation procedures. Flood Estimation Handbook Note 30. Report to MAFF

Reed, D.W. 1996. The FSR design event method and its treatment within the FEH research programme. Flood Estimation

Handbook Note 20, 4pp. Report to MAFF

Reed, D.W. 1996. Urban effects on catchment flood behaviour and their treatment in the FEH. Flood Estimation Handbook Note 29. Report to MAFF

Rees, H.G. and Cole, G.A. 1996. Estimation of renewable water resources in the European Union. Report submitted to CEC: Eurostat.

Rees, H.G. and Gustard, A. 1996. Estimation of renewable water resources in the European Union. Interim Report to the CEC Eurostat Programme. Report to the CEC

Rees, H.G., Cole, G.A. and Gustard, A. 1996. Surface water quantity monitoring. Topic No. 3: Inland Waters. ISBN 92-9167-002-2. Report to the European Environment Agency

Reynard, N.S. 1996. Changes in surface water availability. In: Hulme, M. (ed.) Climate Change and the SADC Region: an exploration of some potential impacts and implications. Report to WWF International

Reynard, N.S. 1996. Climate change scenarios – generation of a potential evaporation baseline and scenarios for the EC. In: Arnell, N. (ed.). Impact of climate change on hydrological regimes and water resources in Europe. Report to CEC (project EV5V-CT93-0293).

Reynard, N.S., Reed, D.W., Marsh, T.J. and Naden, P.S. 1996. Trends and changes in rainfall patterns, runoff and flow frequencies. In: Samuels, P. (ed.), Implications of climate change for flood and coastal defence research. Advisory report to MAFF

Robson, A.J. and Reed, D.W. 1996. Non-stationarity in UK flood records. Flood Estimation Handbook Note 25. Project FD0409, 37pp + appendices. Report to MAFF

Round, C.E. and Young, A.R. 1996. A review of data available for Yorkshire reservoirs. GREAT-ER Working Note No. 1. Report to ECETOC

Round, C.E. and Young, A.R. 1996. Calculation of daily mean flows at the monitoring sites in the Yorkshire Ouse Pilot Study. GREAT-ER Working Note No. 2. Report to ECETOC

Scarrott, R.M.J. and Bayliss, A.C. 1996. Catchment characteristics for flood estimation: indexing lakes and reservoirs using gridded spatial data. Flood Estimation Handbook Note 27. Report to MAFF

Sene, K.J., Down, K.D. and Parks, Y.P. 1996. HYDATA Dissemination 1995/96. Report 96/3 to ODA.

Sene, K.J. and Marsh, T.J. 1996. Hydrometric monitoring in the Lebanon – Interim report on installation and training. Confidential report to the British Parnership Scheme – Beirut, for ODA

Sene, K.J. and Houghton-Carr, H.A. 1996. ODA/JAU Know How Fund Aral Sea Project. Final Report No. 96/ for ODA

Smith, D.M., Jackson, N.A., Roberts, J.M. and Wallace, J.S. 1996. Root quantity, activity and below-ground competition in *Grevillea robusta* agroforestry systems. Annual Report to the ODA Forestry Research Programme.

Stewart, J.B. 1996. Interim Report on ERB CI1*CT940059 for 1995. Commissioning Agent: CEC.

Tate, E.L. 1996. Hydrological study of the River Tame at Stalybridge. A preliminary investigation for the feasibility of navigation in the reach. Report to Allott and Lomax Consulting Engineers

Wallace, J.S., Allen, S.J. and Milne, R. 1996. Combined growth and water use modelling of mixed vegetation. Project T06060P2. Report to Director, CEH

Wallace, J.S. and Mobbs, D.C. 1996. Modelling light interception, micro-climatic interactions and their effect on crop yield in agroforestry systems using the ERIN and HyPAR models. In: Lawson, G.J., Cannell, M.G.R., Mobbs, D.C., Crout, N.M.J., Muetzenfeldt, R., Wallace, J.S., Gregory, P.J., Thomas, T.H., Jagtap, S., Ludlow, A.R., Cobbina, J., Arah, J., MacDonald, K.J., Taylor, J., Sharp, L., Wiggins, G., Flynn, L., Livesley, S., Willis, R.W. and Friend, A.D. Agroforestry modelling and research coordination. ITE Edinburgh. Annual Report to the ODA Forestry Programme. 58-72.

Waughray, D.K.N., Mazhangara, E.M. and Lovell, C.J. 1996. Generating economic benefits in dryland areas: exploiting basement aquifers for small-scale irrigation schemes. Report to ODA

Waughray, D.K.N. and Dube, T. 1996. Small scale irrigation using collector wells: Pilot Project – Zimbabwe. An environmental economic reconnaissance. Report to ODA

Waughray, D.K.N., Mazhangara, E., Mtetwa, G., Mtetwa, M., Dube, T., Lovell, C.J. and Batchelor, C.H. 1996. Small-scale irrigation using collector wells: Pilot Project – Zimbabwe. Return to Households Survey Report to ODA

Wilkinson, R.J. and Jenkins, A. 1996. The UK contributions to the international Cooperative programme on integrated monitoring of air pollution effects on ecosystems. 38 pp. Report to Department of the Environment,

Young, A.R., Round, C.E. and Croker, K.M. 1996. An evaluation of low flow estimation in Scotland, SNIFFER. Report to Edinburgh Hydro Systems Ltd

Young, A.R. and Round, C.E. 1996. Institute of Hydrology Work Programme. GREAT-ER Working Note No. 3. Report to ECETOC

Young, A.R. and Sekulin, A.E. 1996. Naturalised river flow records of the Essex Region. Phase III final report to the EnvironmentAgency

Young, A.R. 1996. Surface water studies. EFEDA II – hydrological response to land-use change and over-exploitation of water resources in a semi-arid area of Spain. Final Report to Directorate General XI of the CEC

Zarour, H.I., McKenzie, A.A., Stuart, M.E. and Meigh, J.R. 1996. Hydrological monitoring in Palestine: Status and Planning of the National Programme, 31pp. Report to Palestinian Water Authority

1997
Refereed publications

Up to the time of going to press

Allen, S.J., **Roberts, J.M.**, **Smith, D.M.**, **Jackson, N.A.** and Lawson, G.J. 1997. Simulating the interaction between tree cover and crop temperature in integrated agroforestry models. *Agroforestry Forum* **8**, 20-23.

Andrews, A.J. 1997. The Southern African FRIEND database. In: Oberlin, G. (Ed.), FRIEND Third Report: 1994-1997, Cemagref, France. 45-49.

Arah, J. and **Hodnett, M.G.** 1997. Approximating soil hydrology in agroforestry models. *Agroforestry Forum* **8**, 17-20.

Barbier, E., **Acreman, M.C.** and Knowler, D. 1997. *Economic valuation of wetlands: a guide for policy makers and planners. Ramsar Convention, Gland, Switzerland.*

Blyth, E.M. 1997. Representing heterogeneity at the Southern Super Site with average surface parameters. *J. Hydrol.* HAPEX-Sahel Special Issue **188-189**, 869-877.

Blyth, K. 1997. An assessment of the capabilities of the ERS satellites' active microwave instruments for monitoring soil moisture change. *Hydrol. & Earth System Sci.* **1**, 159-174.

Blyth, K. 1997. Floodnet: A tele-network for acquisition, processing and dissemination of earth observation data for monitoring and emergency management of floods. *Hydrol.Procs.* **11**, 1359-1375.

Boorman, D.B. and **Sefton, C.E.M.** 1997. Recognising the uncertainty in the quantification of the effects of climate change of hydrological response. *Climatic Change* **35**, 415-434.

Brilly, M. and **Gustard, A.** 1997. FRIEND '97: *Regional hydrology: concepts and models for sustainable water resource Management.* LOC Proceedings of poster presentations, Ljubljana. *Acta hydrotech.* **15/19**, 177pp

Brilly, M. and **Gustard, A.** 1997. FRIEND '97: *Regional hydrology: concepts and models for sustainable water resource Management.* LOC Proceedings of oral presentations, Ljubljana. *Acta hydrotech.* 15/18 (1997), 203pp

Bromley, J., Edmunds, W.M., Fellman, E., Brouwer, J., **Gaze, S.R.**, Sudlow, J. and Taupin, J.-D. 1997. Estimation of rainfall inputs and direct recharge to the deep unsaturated zone of southern Niger using the chloride profile method. *J. Hydrol.* HAPEX-Sahel Special Issue **188-189**, 139-154.

Bromley, J., Brouwer, J., Barker, A.P., **Gaze, S.R.** and Valentin, C. 1997. The role of surface water redistribution in an area of patterned vegetation in a semi-arid environment, south west Niger. *J. Hydrol.* **198**, 1-29.

Bullock, A., **Andrews, A.J.** and Mngodo, R. 1997. Regional water resources and drought assessment in Southern Africa. In: Oberlin, G. (Ed.), FRIEND Third Report: 1994-1997, Cemagref, France. 149-157.

Bullock, A., Mkhandi, S., Hughes, D.A., Andrews, A.J., Kachroo, R. and Mngodo, R. 1997. Southern African FRIEND – international collaboration in the hydrological science of flow regimes. In: S1 – Sustainability of Water Resources Under Increasing Uncertainty; 5th Scientific Assembly of the IAHS, 23 April – 3 May 1997, Rabat, Morocco. *IAHS Publ. No. 240*, 133-143.

Burke, E.J., Gurney, R.J., Simmonds, L.P. and Jackson, T.J. 1997. Calibrating a soil water and energy budget model with remotely sensed data to obtain quantitative information about the soil. *Wat. Resour. Res.* **33**, 1689-1697.

Burke, E.J. and **Stewart, J.B.** 1997. Test of a sensible heat flux – radiometric surface temperature relationship for HAPEX-Sahel. *Bound. Layer Meteorol.* **84**, 329-337.

Calow, R.C., Robins, N.S., Macdonald, A.M., Macdonald, D.M.J., Gibbs, B.R., Orpen, W.R.G., Mtembezeka, P., **Andrews, A.J.** and Appiah, S. 1997. Groundwater management in drought-prone areas of Africa. *Int. J. Water Resour. Development* **13**, 241-261.

Calver, A. 1997. Recharge response functions. *Hydrol. and Earth System Sci.* **1**, 47-53.

Cosby, B.J., Ferrier, R.C., **Jenkins, A.**, Emmett, B.A., Wright, R.F. and Tietema, A. 1997. Modelling the ecosystem effects of nitrogen deposition: Model of Ecosystem Retention and Loss of Inorganic Nitrogen (MERLIN). *Hydrol. and Earth System Sci.* **1**, 137-158.

Cuença, R.H., Brouwer, J., Chanzy, A., Droogers, P., Galle, S., **Gaze, S.R.**, Sicot, M., Stricker, H., Angulo-Jaramillo, R., **Boyle, S.A.**, **Bromley, J.**, Chebhouni, A.G., **Cooper, J.D.**, **Dixon, A.J.**, Fies, J., Gandah, M., Gaudu, J., Laguerre, L., Soet, M., Steward, H.J., Vandervaere, J. and Vauclin, M. 1997. Soil measurements during the HAPEX-Sahel Intensive Observation Period. *J. Hydrol.* HAPEX-Sahel Special Issue **188-**

189, 224-266.
Culf, A.D., Fisch, G., Malhi, Y. and Nobre, C.A. 1997. The influence of the atmosphere boundary layer on carbon dioxide measurements over tropical forest. *Agric. For. Met.* **85**, 149-158.
De Bruin, H.A.R. and **Verhoef, A.** 1997. A new method to estimate displacement height. *Q. J. R. Meteorol. Soc.*, **82**, 159-164.
Dolman, A.J., Bessemoulin, P. and **Culf, A.D.** 1997. Observations of boundary layer development during the HAPEX-Sahel intensive observation period. *J. Hydrol.* HAPEX-Sahel Special Issue **188-189**, 998-1016.
Dolman, A.J. and **Blyth, E.M.** 1997. Patch scale aggregation of heterogeneous land surface cover for mesoscale meteorological models. *J. Hydrol.* **190**, 252-268.
Dolman, A.J., **Gash, J.H.C.**, Goutorbe, J.P., Kerr, Y.H., Lebel, T., Prince, S.D. and Stricker, J.N.M. 1997. The role of the land surface in Sahelian climate: HAPEX-Sahel results and future research needs. *J. Hydrol.* HAPEX-Sahel Special Issue **188-189**, 1067-1079.
Downing, T., Ringius, L., Hulme, M. and **Waughray, D.K.N.** 1997. Adapting to climate change in Africa. *Mitigation & Adaptation Strategies for Global Change* **2**, 19-44.
Eatherall, A. 1997. Modelling climate change impacts on ecosystems using linked models and a GIS. *Climatic Change* **35**, 1-18.
Emmett, B.A., Cosby, B.J., Ferrier, R.C., **Jenkins, A.**, Tietema, A. and Wright, R.F. 1997. Modelling the ecosystem effects of nitrogen deposition: Simulation of nitrogen saturation at a Sitka spruce forest, Aber, Wales. *Biogeochem.* **38**, 129-148.
Evans, J.G., Wass, P.D. and **Hodgson, P.** 1997. Integrated continuous water quality monitoring for the LOIS Rivers Programme. *Sci. Total Environ.* **194/195**, 111-118.
Evans, J.G., Wass, P.D. and **Hodgson, P.** 1997. Integrated continuous water quality monitoring for the LOIS river programme. *Sci.Tot.Envir.* Special Issue **194/195**, 112-118.
Faulkner, D.S., **Arnell, N.W.** and **Reynard, N.S.** 1997. Everyday aspects of climate change in Europe. *Proc. 6th BHS National Hydrology Symposium*, Salford, 8.1-8.8.
Finch, J.W., **Ragab, R.** and **Harding, R.J.** 1997. A simple method for estimating mean annual groundwater recharge for drift-free areas of the chalk and Permo-Triassic sandstone aquifers in the UK. *J. CIWEM* **11**, 357-362.
Finch, J.W. 1997. Monitoring small dams in semi-arid regions using remote sensing and GIS. *J. Hydrol.* **195**, 335-351.
Forsius, M., Alveteg, M., Bak, J., Guardans, R., Holmberg, M., **Jenkins, A.**, Johansson, M., Kleemola, S., Rankinen, K., **Renshaw, M.**, Sverdrup, H. and Syri, S. 1997. *Assessment of the effects of the EU acidification strategy: dynamic modelling on integrated monitoring sites: first results, 40 pp.* Finnish Environment Institute, Helsinki.
Fox, I.A. and **Johnson, R.C.** 1997. The hydrology of the River Tweed. *Sci. Tot. Environ.* Special Issue **194/195**, 163-172.
Franks, S.W., Beven, K.J., Quinn, P.F. and **Wright, I.R.** 1997. On the sensitivity of soil-vegetation-atmosphere transfer (SVAT) schemes: equifinality and the problem of robust calibration. *Agric. For. Meteorol.* **86**, 63-75.
Freeman, C., Lock, M.A., Hughes, S., Reynolds, B. and **Hudson, J.A.** 1997. Nitrous oxide emissions and the use of wetlands for water quality amelioration. *Environ. Sci. Technol.* **31**, 2438-2440.
Galéa, G. and **Prudhomme, C.** 1997. Regimes synthesis, modelization and display: QdF approaches and regionalization (in French). In: Oberlin, G. (Ed.), FRIEND Third Report: 1994-1997, Cemagref, France. 99-108.
Gardner, R. and **Jenkins, A.** 1997. *The Himalayan Crisis.* Cassell, London.
Gash, J.H.C. and Nobre, C.A. 1997. Climatic effects of Amazonian deforestation: some results from ABRACOS. *Bull. Amer. Meteorol. Soc.* **78**, 823-830.
Gash, J.H.C., Kabat, P., Amadou, M., Bessemoulin, P., Billing, H., **Blyth, E.M.**, De Bruin, H.A.R., Elbers, J.A., Friborg, T., Harrison, G., **Holwill, C.J.**, **Lloyd, C.R.**, Lhomme, J.P., Moncrieff, J.B., Monteny, B.A., Puech, D., Sögaard, H., Tuzet, A. and **Verhoef, A.** 1997. The variability of evaporation during the HAPEX-Sahel Intensive Observation Period. *J. Hydrol.* HAPEX-Sahel Special Issue **188-189**, 385-399.
Gaze, S.R., Brouwer, J., Simmonds, L.P. and Bouma, J. 1997. Measurement of surface redistribution of rainfall and modelling its effect on water balance calculations for a millet field on sandy soil in Niger. *J. Hydrol.* HAPEX-Sahel Special Issue **188-189**, 267-284.
Givone, P., **Gustard, A.** and Oberlin, G. 1997. Regional hydrology, integrated water management, and some futures for FRIEND. In: Oberlin, G. (ed.), FRIEND Third Report: 1994-1997, Cemagref, France. 371
Goutorbe, J.P., Lebel, T., Dolman, A.J., **Gash, J.H.C.**, Kabat, P., Kerr, Y.H., Monteny, B., Prince, S.D., Stricker, J.N.M., Tinga, A. and **Wallace, J.S.** 1997. An overview of HAPEX-Sahel: a study in climate and desertification. *J. Hydrol.* HAPEX-Sahel Special Issue **188-189**, 4-17.
Gustard, A. 1997. Future directions for Northern European FRIEND. In: Oberlin, G. (ed.), FRIEND Third Report: 1994-1997, Cemagref, France. 391-392.
Gustard, A., Blazkova, S., Brilly, M., Demuth, S., **Dixon, J.M.**, Lanen, H.A.J.v., Llasat, C., Mkhandi, S. and Servat, E. 1997. FRIEND '97 – Regional Hydrology: Concepts and Models for Sustainable Water Resource Management. Proc. Conf., Postojna, Slovenia, ISBN 1-901502-35-X. *IAHS Publ. No. 246*, 363pp.
Gustard, A., Novicky, S., Demuth, S., Tallaksen, L., Lanen, H.A.J.v., Clausen, B., Kasparek, L., Miklanek, P., Majercakova, O., Fendekova, M., Kupszyk, E., Radsuk, L. and Czamara, W. 1997. Low flows and droughts in Northern Europe. In: Oberlin, G. (ed) FRIEND Third Report: 1994-1997 Cemagref, France. 132-148
Gustard, A. and **Elliott, C.R.N.** 1997. The role of hydro-ecological models in the development of sustainable water resources. In: S1 – Sustainability of Water Resources Under Increasing Uncertainty; 5th Scientific Assembly of the International Association of Hydrological Sciences, Rabat, Morocco. *IAHS Publ. No. 240*, 407-417.
Gustard, A., **Rees, H.G.**, **Croker, K.M.** and **Dixon, J.M.** 1997. Using regional hydrology for assessing European water resources. In: FRIEND '97 – *Regional Hydrology: Concepts and Models for Sustainable Water Resource Management. IAHS Publ. No. 246*, 107-115.
Hall, R.L. and **Allen, S.J.** 1997. Water use of poplar clones grown as short-rotation coppice

at two sites in the UK. In: Bullard, M. J., Ellis, R. G., Heath, M.C., Knight, J. D., Lainsbury, M.A. and Parker, S.R. (Eds), Biomass & Bioenergy Crops. *Aspects of Applied Biology* **49**, 163-172. Assn of Applied Biologists, Wellesbourne, Warwick.

Hall, R.L. and **Hopkins, R.** 1997. Technical note: a net-rainfall gauge for use with multi-stemmed trees. *Hydrol. & Earth System Sci.* **1**, 213-315.

Harding, R.J., **Blyth, E.M.** and **Taylor, C.M.** 1997. Issues in the aggregation of surface fluxes from a heterogeneous landscape: from sparse canopies up to the GCM grid scale. In: van Gardingen, P.R., Foody, G.M. and Curran, P.J. (Eds) *Scaling-up: from cell to landscape. (Society for Experimental Biology, Seminar Series: 63).* Cambridge University Press. 229-252.

Hill, D.R. 1997. Distributing Geographical Information Systems and data using Java and the Internet, *Proc. 2nd Internat. Conf. on Geocomputation,* University of Otago, New Zealand, 319-326.

House, W.A., Leach, D.V., Long, J.L.A., Cranwell, P., **Smith, C.J.**, **Bhardwaj, C.L.**, Meharg, A., **Ryland, G.P.**, Orr, D.O. and Wright, J. 1997. Micro-organic compounds in the Humber rivers. *Sci. Tot. Environ.* Special Issue **194/195**, 357-371.

Huntingford, C. and Cox, P.M. 1997. Use of statistical and neural network techniques to detect how stomatal conductance responds to changes in the local environment *Ecol. Modelling* **97**, 217-246.

Jacobs, A.F.G. and **Verhoef, A.** 1997. Soil evaporation from a sparse natural vegetation estimated from Sherwood numbers. *J. Hydrol.* HAPEX-Sahel Special Issue **188-189**, 443-452.

de Jager, J.M., Vermes, L.P. and **Ragab, R.** (Eds) 1997. Sustainable irrigation in areas of water scarcity and drought. Proc. International Workshop organised by ICID and BNCID, Oxford. 257 pp.

Jarvie, H.P., **Neal, C.** and Tappin, A.D. 1997. European land-based pollutant loads to the North Sea: an analysis of the Paris Commission data and review of monitoring strategies. *Sci. Tot. Environ.* Special Issue **194/195**, 41-58.

Jarvie, H.P., **Neal, C.**, Leach, D.V., Ryland, G.P., House, W.A. and **Robson, A.J.** 1997. Major ion concentrations and the inorganic carbon chemistry of the Humber rivers. *Sci. Tot. Environ.* Special Issue **194/195**, 285-302.

Jarvie, H.P., **Neal, C.** and **Robson, A.J.** 1997. The Geography of the Humber catchment. *Sci. Tot. Environ.* Special Issue **194/195**, 88-99.

Jenkins, A., Ferrier, R.C. and Cosby, B.J. 1997. A dynamic model for assessing the impact of coupled sulphur nitrogen deposition scenarios on surface water acidification. *J. Hydrol.* **197**, 111-127.

Jenkins, A., **Renshaw, M.**, Helliwell, R.C., **Sefton, C.E.M.**, Ferrier, R.C. and Swingewood, P. 1997. Modelling surface water acidification in the UK. Application of the MAGIC model to the Acid Waters Monitoring Network. *Institute of Hydrology Report No. 131.*

Jenkins, A. and **Wilkinson, R.J.** 1997. Anthropogenic impacts on stream chemistry. In: Gardner, R. and Jenkins, A. (Eds), *The Himalayan Crisis.* Cassell, London.

Johnson, A.C., Worrall, F., **White, C.**, Walker, A., **Besien, T.J.** and **Williams, R.J.** 1997. The potential of incorporated organic matter to reduce pesticide leaching. *Toxicol. & Environ. Chem.* **58**, 47-61.

Johnson, R.C. and Black, A.R. 1997. The effects of forestry on low flows in Scotland and Northern Ireland. In: Sustainability of water resources under increasing uncertainty. Proc. Rabat Symp. *IAHS Publication No. 240,* 125-132.

Kirby, C. 1997. Catchment behaviour and bacteriological quality of rural water supplies, Southern Zimbabwe, *Proc. BHS 6th Nat. Hydrology Symposium,* 4.41-4.47.

Lamb, R. and Beven, K.J. 1997. Using interactive recession curve analysis to specify a general catchment storage model. *Hydrol. and Earth System Sci.* **1**, 101-113.

Langan, S.J., Wade, A.J., Smart, R., Edwards, A.C., Soulsby, C., Billett, M.F., **Jarvie, H.P.**, Cresser, M.S., Owen, R. and Ferrier, R.C. 1997. The prediction and management of water quality in a relatively unpolluted major Scottish catchment: current issues and experimental approaches. *Sci. Tot. Environ.* **194/195**, 419-435.

Law, M., **Wass, P.D.** and Grimshaw, D. 1997. The hydrology of the Humber catchment. *Sci. Tot. Environ.* Special Issue **194/195**, 119-128.

Leduc, C., **Bromley, J.** and Schroeter, P. 1997. Water table fluctuation and recharge in a semi-arid climate: some results of the HAPEX-Sahel Hydrodynamic Survey (Niger). *J. Hydrol.* HAPEX-Sahel Special Issue **188-189**, 123-138.

Leeks, G.J.L., **Neal, C.**, **Jarvie, H.P.**, Casey, H. and Leach, D.V. 1997. The LOIS river monitoring network: strategy and implementation. *Sci. Tot. Environ.* **194/195**, 101-109.

Lewis, D.R., **Williams, R.J.** and **Whitehead, P.G.** 1997. Quality simulation along rivers (QUASAR): an application to the Yorkshire Ouse. *Sci. Tot. Environ.* **194/195**, 399-418.

Lloyd, C.R., Bessemoulin, P., Cropley, F.D., **Culf, A.D.**, Dolman, A.J., Elbers, J., Heusinkveld, B., Moncrieff, J.B., Monteny, B. and **Verhoef, A.** 1997. A comparison of surface fluxes at the HAPEX-Sahel fallow bush sites. *J. Hydrol.* HAPEX-Sahel Special Issue **188-189**, 400-425.

Lloyd, J., Kruijt, B., Hollinger, D.Y., Grace, J., Francey, R.J., Wong, S.C., Kelliher, F.M., Miranda, A.C., Farquhar, G.D., **Gash, J.H.C.**, Vygodskaya, N.N., **Wright, I.R.**, Miranda, H.S. and Schulze, E.D. 1997. An alternative interpretation of the appropriateness and correct means for the evaluation of CO_2 recycling indices. *Australian J. Plant Physiol.* **24**, 399-405.

Marengo, J.A., Nobre, C.A. and **Culf, A.D.** 1997. Climatic impacts of the "friagens" in forested and deforested areas of the Amazon basin. *J. Appl. Meteorol.* **36**, 1553-1566.

Marsh, T.J. and **Sanderson, F.J.** 1997. A review of hydrological conditions throughout the period of the LOIS monitoring programme, considered within the context of the recent UK climatic volatility. *Sci. Total Environ.* **194/195** (Special LOIS issue), 59-69.

Moncrieff, J.B., Massheder, J.M., De Bruin, H.A.R., Elbers, J., Friborg, T., Heusinkveld, B.G., Kabat, P., Scott, S., Sogaard, H. and **Verhoef, A.** 1997. A system to measure fluxes of momentum, sensible heat, water vapour and carbon dioxide. *J. Hydrol.* HAPEX-Sahel Special Issue **188-189**, 589-611.

Moncrieff, J.B., Monteny, B., **Verhoef, A.**, Friborg, T., Kabat, P., De Bruin, H.A.R., Sogaard, H., Jarvis, P.G. and Billing, H.

Sahel Special Issue **188-189**, 563-588.

Monteny, B.A., Lhomme, J.P., Chehbouni, A., Amadou, M., Troufleau, D., Brunel, J.P., Bessemoulin, P., Sicot, M., Galle, S., **Lloyd, C.R.** and Said, F. 1997. Les interactions surface continentale-atmosphere en milieu sahelien. Passage de l'echelle stationnelle a l'echelle regionale. X[e] journées hydrologiques, Orstom, September 1994 (Conference), 287-301.

Monteny, B.A., Lhomme, P.-J., Chehbouni, A., Troufleau, D., Amadou, M., Sicot, M., Galle, S., Saïd, F., **Verhoef, A.** and **Lloyd, C.R.** 1997. The rôle of the Sahelian biosphere in the water and CO_2 cycle during the HAPEX-Sahel experiment. *J. Hydrol.* HAPEX-Sahel Special Issue **188-189**, 516-535.

Moore, R.V. 1997. The logical and physical design of the Land Ocean Interaction Study database. *Sci. Total Environ.* **194/195** (Special LOIS issue) 137-146.

Neal, C. 1997. Comments on "Influence of autocorrelation and measurement errors on interpretation of solubility diagrams". *Soil Sci. Soc. of Amer. J.* **61**, 330-331.

Neal, C., House, A., **Jarvie, H.P.**, **Leeks, G.J.L.** and Marker, A.H. 1997. Conclusions to the special volume concerning UK fluxes to the North Sea, Land Ocean Interaction Study, river basins research, the first two years. *Sci. Tot. Environ.* **194/195**, 467-477.

Neal, C. and **Robson, A.J.** 1997. Integrating variations of soil adsorbed cations into a cation exchange model. *Sci. Tot. Environ.* **199**, 277-292.

Neal, C., Robson, A.J., Harrow, M., Hill, L., Wickham, C.L., Bhardwaj, C.L., Tindall, C.I., Ryland, G.P., Leach, D.V., **Johnson, R.C., Bronsdon, R.K.** and Cranston, M. 1997. Major, minor, trace element and suspended sediment variations in the River Tweed: results from the LOIS core monitoring programme. *Sci. Tot. Environ.* **194/195**, 193-205.

Neal, C., Hill, T., Alexander, S., Reynolds, B., Hill, S., **Dixon, A.J.**, **Harrow, M.L.**, **Neal, M.** and **Smith, C.J.** 1997. Streamwater quality in acid sensitive UK upland areas, an example of potential water quality remediation based on groundwater manipulation. *Hydrol. and Earth Systems Sci.* **1**, 185-196.

Neal, C., **Robson, A.J.**, Shand, P., Edmunds, W.M., **Dixon, A.J.**, Buckley, D.K., **Hill, S.**, **Harrow, M.L.**, **Neal, M.** and Reynolds, B. 1997. The occurrence of groundwater in the Lower Palaeozoic rocks of upland Central Wales. *Hydrol. and Earth Systems Sci.* **1**, 3-18.

Neal, C., **Robson, A.J.** and Christophersen, N. 1997. Towards coupling hydrological, soil and weathering processes within a modelling perspective. In: Saether, O.M. and de Caritat, P. (Eds), *Geochemical processes, weathering and groundwater recharge in catchments,* Balkema, Rotterdam. 329-380.

Neal, C., **Robson, A.J.**, **Jeffery, H.A.**, **Harrow, M.L.**, **Neal, M.**, **Smith, C.J.** and **Jarvie, H.P.** 1997. Trace element inter-relationships for the Humber rivers: inferences for hydrological and chemical controls. *Sci. Total Environ.* **194/195** (Special LOIS issue) 321-343.

Neal, C., House, W.A., **Leeks, G.J.L.** and Marker, A.H. 1997. UK fluxes to the North Sea, Land Ocean Interaction Study (LOIS): river basins research, the first two years 1993-1995. *Sci. Total Environ.* **194/195** (Special LOIS issue), 1-4.

Neal, M., **Neal, C.** and Brahmer, G. 1997. Stable oxygen isotope variations in rain, snow and streamwaters at the Schluchsee and Villingen sites in the Black-Forest, South-West Germany. *J. Hydrol.* **190**, 102-110.

Noilhan, J., Lacarrè, P., Dolman, A.J. and **Blyth, E.M.** 1997. Defining area-average parameters in meteorological models for land surfaces with mesoscale heterogeneity. *J. Hydrol.* **190**, 302-316.

Polarski, M. 1997. Distributed rainfall-runoff model incorporating channel extension and gridded digital maps. *Hydrol. Procs* **11**, 1-11.

Prudhomme, C. and Galéa, G. 1997. The typology of the regional QdF models, FRIEND '97. Proc. Conf., Postojna, Slovenia; *IAHS Publ. No. 246*, 75-78.

Prudhomme, C. and Galéa, G. 1997. Non-stationary regimes: the QdF model's behaviour – FRIEND '97. Proc. Conf., Postojna, Slovenia, *IAHS Publ. No. 246*, 267-276.

Ragab, R., **Finch, J.W.** and **Harding, R.J.** 1997. Estimation of groundwater recharge to chalk and sandstone aquifers using simple soil models. *J. Hydrol.* **190**, 19-41.

Ragab, R. and Hamdy, A. 1997. Reuse of saline and waste waters for irrigation: major issues on water, crop and soil management, environment protection and health safety. *Proc. Int. Conf. on Water Management, Salinity and Pollution Control Towards Sustainable Irrigation in the Mediterranean Region,* Valenzano (Bari), Italy, **I**, 101-143.

Rees, H.G., **Croker, K.M.**, **Reynard, N.S.** and **Gustard, A.** 1997. Estimation of renewable water resources in the European Union. FRIEND '97 – *Regional Hydrology: Concepts and Models for Sustainable Water Resource Management.* Proc. Conf., Postojna, Slovenia. *IAHS Publ. No. 246*, 31-38.

Rees, H.G. 1997. HYDRA – Rapid assessment of small scale hydropower potential. *World Directory of Renewable Energy Suppliers and Services 1997.*

Rees, H.G. 1997. International FRIEND Group Databases. In: Oberlin, G. (ed.), FRIEND Third Report: 1994-1997, Cemagref, France. 31-32.

Rees, H.G. 1997. The FRIEND European Water Archive. In: Oberlin, G. (ed.), FRIEND Third Report: 1994-1997, Cemagref, France. 33-37.

Reynard, N.S., **Andrews, A.J.** and **Arnell, N.W.** 1997. The derivation of a runoff grid for southern Africa for climate change impact analyses. FRIEND '97 – *Regional Hydrology: Concepts and Models for Sustainable Water Resource Management.* Proc. Conf., Postojna, Slovenia. *IAHS Publ. No. 246*, 23-30.

Reynolds, B., **Jenkins, A.**, Chapman, P.J. and **Wilkinson, R.J.** 1997. Stream hydrochemistry of the Khumbus Annapurna and Langtang regions of Nepal. In: Bando, R. and Tartini, G. (Eds) *Top of the World Environmental Research: Mount Everest Himalayan Ecosystem.* Ecovision world monograph series.

Roberts, G. 1997. The influence of sampling frequency on streamflow chemical loads. *J.CIWEM* **11**, 114-118.

Robson, A.J. and **Neal, C.** 1997. A summary of regional water quality for Eastern UK rivers. *Sci. Tot. Environ.* **194/195**, 15-38.

Robson, A.J. and **Neal, C.** 1997. A summary of regional water quality for Eastern UK rivers. In: UK fluxes to the North Sea, Land Ocean Interactions Study (LOIS): river basins research, the first two years. Neal, C., House, W.A., Leeks, G.J.L., Marker, A.H. (Eds). *Sci.Tot.Envir.* Special Issue **194/195**, 15-37.

Robson, A.J. and **Neal, C.** 1997. Regional Water Quality of the River Tweed. Special Issue *Sci. Tot. Environ.* **194/195**, 173-192.

Sefton, C.E.M. and **Boorman, D.B.** 1997. A regional investigation of climate change impacts on UK streamflows. *J. Hydrol.* **195**, 26-44.

Smith, D.M., **Jackson, N.A.** and **Roberts, J.M.** 1997. A new direction in hydraulic lift: can tree roots siphon water downwards? *Agroforestry Forum*, **8**, 23-26.

Smith, D.M., Jarvis, P.G. and Odongo, J.C.W. 1997. Aerodynamic conductances of trees in windbreaks. *Agric. For. Meteorol.* **86**, 17-31.

Smith, D.M., Jarvis, P.G. and Odongo, J.C.W. 1997. Energy budgets of windbreak canopies in the Sahel. *Agric. For. Meteorol.* **86**, 33-49.

Smith, D.M., Jarvis, P.G. and Odongo, J.C.W. 1997. Sources of water used by trees and millet in Sahelian windbreak systems. *J. Hydrol.* **198**, 140-153.

Taylor, C.M., **Harding, R.J.**, Thorpe, A.J. and Bessemoulin, P. 1997. A mesoscale simulation of land surface heterogeneity from HAPEX-Sahel. *J. Hydrol.* HAPEX-Sahel Special Issue **188-189**, 1040-1066.

Taylor, C.M., Saïd, F. and Lebel, T. 1997. Interactions between the land surface and mesoscale rainfall variability during HAPEX-Sahel. *Monthly Weather Review* **125**, 2211-2227.

Tindall, C.I. and **Moore, R.V.** 1997. The Rivers Database and the overall data management for the Land Ocean Interaction Study programme. *Sci. Total Environ.* **194/195** (Special LOIS Issue), 129-135.

Valente, F., David, J.S. and **Gash, J.H.C.** 1997. Modelling interception loss for two sparse eucalypt and pine forests in central Portugal using reformulated Rutter and Gash analytical models. *J. Hydrol.* **190**, 141-162.

Verhoef, A., McNaughton, K.G. and Jacobs, A.F.G. 1997. A parameterization of momentum roughness length and displacement height for a wide range of canopy densities. *Hydrol. & Earth System Sci.* **1**, 89-91.

Verhoef, A., De Bruin, H.A.R. and Van den Hurk, B.J.J.M. 1997. Some practical notes on the parameter kB-1 for sparse canopies. *J. Appl. Meteorol.* **36**, 560-572.

Verhoef, A. 1997. The effect of temperature differences between porometer head and leaf surface on stomatal conductance measurements. *Plant,Cell & Environ.* **20**, 641-646.

Wai, M.M.K., Smith, E.A., Bessemoulin, P., **Culf, A.D.**, Dolman, A.J. and Lebel, T. 1997. Variability in boundary layer structure during HAPEX Sahel wet-dry season transition. *J. Hydrol.* HAPEX-Sahel Special Issue **188-189**, 965-997.

Wallace, J.S. and **Batchelor, C.H.** 1997. Managing water resources for crop production. *Phil. Trans. Roy. Soc. Lond.* **352**, 937-947.

Wallace, J.S. and **Holwill, C.J.** 1997. Soil evaporation from Tiger-bush in Niger. *J. Hydrol.* HAPEX-Sahel Special Issue **188-189**, 426-442.

Wass, P.D., **Marks, S.D.**, **Finch, J.W.**, **Leeks, G.J.L.** and **Ingram, J.K.** 1997. Monitoring & preliminary interpretation of in-river turbidity and remote sensed imagery for suspended sediment transport studies in the Humber catchment. *Sci. Tot. Environ.* **194/195**, 263-283.

Webb, B.W., Phillips, J.M., Walling, D.E., **Littlewood, I.G.**, **Watts, C.D.** and **Leeks, G.J.L.** 1997. Load estimation methodologies for British rivers and their relevance to the LOIS RACS(R) programme. *Sci. Tot. Environ.* Special Issue **194/195**, 379-389.

Whitehead, P.G., **Williams, R.J.** and **Lewis, D.R.** 1997. Quality simulation along river systems (QUASAR): model theory and development. *Sci. Tot. Environ.* Special Issue **194/195**, 447-456.

Wilkinson, W.B., **Leeks, G.J.L.**, Morris, A. and Walling, D.E. 1997. Rivers and coastal research in the Land Ocean Interaction Study. *Sci. Tot. Environ.* Special Issue **194/195**, 5-14.

Worrall, F., Parker, A., Rae, J.E. and **Johnson, A.C.** 1997. A study of the adsorption kinetics of isoproturon on soil and subsoil. *Chemosphere* **34**, 71-86.

Worrall, F., Parker, A., Rae, J.E. and **Johnson, A.C.** 1997. A study of the sorption kinetics of isoproturon on soil and subsoil: the role of dissolved organic carbon. *Chemosphere* **34**, 87-97.

Worrall, F., Parker, A., Rae, J.E. and **Johnson, A.C.** 1997. The role of earthworm burrows in pesticide transport from ploughlands. *Toxicol. & Environ. Chem.* **61**, 211-222.

Yeo, A.R., Flowers, T.J., **Ragab, R.** and Pearce, G.R. 1997. The role of crop salt tolerance in the development of an integrated management plan for irrigation with saline water. In: Wastewater re-use in irrigated agriculture session, *Proc. Int. Conf. on Water management, salinity and pollution control towards sustainable irrigation in the Mediterranean Region*, Valenzano (Bari), Italy, **IV** 19-35.

Other publications

Batchelor, C.H. 1997. Community-based water development: putting research into practice. DFID *Water*, Issue 4.

Batchelor, C.H., **Cain, J.D.**, **Farquharson, F.A.K.** and **Roberts, J.M.** 1997. Improving water utilisation from a catchment perspective. System-Wide Initiative on Water Management (SWIM) meeting, Nairobi, 5-6 May 1997, 32pp.

Bell, V.A. and Moore, R.J. 1997. A water-balance storm model for short-term rainfall and flood forecasting at the catchment scale. EGS 22nd General Assembly, Vienna. *Annales Geophysicae* **15**, Pt 1, Suppl. I, C237. Abstract.

Burke, E.J. 1997. Using a modelling approach to predict soil hydraulic parameters from passive microwave measurements for both bare and cropped soils. PhD Thesis, University of Reading.

Cain, J.D. and **Ragab, R.** 1997. Accounting for sub-grid heterogeneity through aggregation of input parameters in a catchment scale water balance model. EGS 22nd General Assembly, Vienna. *Annales Geophysicae* **15**, Pt II, Suppl. II, C337. Abstract.

Calder, I.R. and **Hall, R.L.** 1997. Comment on 'Interception of tropical rain forest: performance of a canopy water balance model' by V. G. Vetten (In *Hydrol. Procs.* 10: 671-685 (1996)). *Hydrol. Procs* **11**, 225-226.

Dorcey, A. Steiner, A., **Acreman, M.C.** & Orlando, B. (Eds) 1997. *Large dams: learning from the past, looking at the future.* Proc. workshop. IUCN, Gland, Switzerland; World Bank, Washington DC, USA. 146 pp

Fey, N. 1997. Economic valuation of wetlands: key concepts for policy makers and planners. (Brochure in English, French & Spanish).

Finch, J.W. 1997. Land cover mapping for a groundwater recharge study in South West Niger. Proc. Remote Sensing Society Conf., Reading, 422-427.

Flavin, R.W. 1997. Answers to correspondents – "How long does it take water in Lake Victoria to flow the 3800 miles down the River Nile to the sea". In: *Daily Mail*, 4th September.

Franks, S.W., Beven, K.J. and **Lamb, R.** 1997. Assessing the utility of distributed data in constraining the behaviour of hydrological models in the Wijlegemse subcatchment. In: F.P. De Troch et al. (Eds.), *Spatial and temporal soil moisture mapping from ERS-1 and JERS-1 Data and macroscale hydrological modelling*, Final Research Report, EC Environment Research Programme, Climatology and Natural Hazards, EV5V-CT94-0446, Laboratory of Hydrology and Water Management, University of Ghent, 334-358.

Gunston, H.M. 1997. Hydrological History from an Industrial Source: Joseph Glynn, John Trickett and Pumping at Pode Hall, 1830 to 1835. Poster paper to East of England Regional Industrial Archaeology Conference, Stretham, Cambridge.

Gunston, H.M. 1997. The flow record from Wendover Springs – historical interests of the National Water Archive. Poster paper at conference *Defining a new research agenda for waterways history*, UMIST, Manchester.

Gunston, H.M. 1997. Industrial archaeology and historical hydrology. *Industrial Archaeology News*, **100**, 10-11.

Gunston, H.M. and **Rosier, P.T.W.** 1997. St Helena hydrology catchment management study: catchment management and cloud water deposition on St Helena. DFID *Water*, Issue 5, 10.

Gunston, H.M. 1997. The flow record from Wendover Springs – Historical interests of the National Water Archive.

Hall, R.L. and **Allen, S.J.** 1997. Water use of poplar clones grown as short-rotation coppice at two sites in the United Kingdom. In: *Biomass and Energy Crops* – Proc. Conf. *Aspects of Applied Biology* **49**, 163-172.

Harding, R.J. 1997. Data for calibration and verification of land surface models at high latitudes. Proc. ACSVS Workshop, Bracknell, November, 1996.

Hudson, J.A., **Crane, S.B.**, **Hill, P.J.**, **Hughes, W.A.**, **Robinson, M.**, Reynolds, B., Brittain, S.A., Wood, M.J., Beaumont, W.R.C. and Tipping, E. 1997. Upland forestry canopy closure: its implications for chemistry, hydrology and ecology. CEH Integrating Fund progress report, October 1997.

Jacobs, A.F.G., **Verhoef, A.** and De Bruin, H.A.R. 1997. Sensible heat flux from sparse vegetation estimated from Nusselt number. In: Proc. EGS XXI General Assembly. *Phys. & Chem. of the Earth.* **21**, 107-110.

Jenkins, A. 1997. A catchment based modelling scheme for prediction of bacterial water quality and hazard assessment. In: Maier, E.A., Lightfoot, N.F. and Ramaekers, D.A. (Eds), Measurement and Testing Programme, Technical feasibility of an *a priori* measurement approach for managing bathing water quality. Workshop in Sitges, Spain, Report EUR 17801 EN (ISSN 1018-5593), 12-15.

Jenkins, A. 1997. Book Review of Environmental Hydrology edited by Vijay P. Singh. *Earth Surf. Procs and Landforms* **22**, 189-192.

Jennings, S.E. 1997. HYDATA – Hydrological database system. (Brochure).

Jennings, S.E. 1997. PC-QUASAR: Quality Simulation Along Rivers. (Brochure).

Jennings, S.E. 1997. RIVPACS III: River InVertebrate Prediction And Classification System. (Brochure).

Jennings, S.E. 1997. Software Newsletter.

Lamb, R. and **Calver, A.** 1997. Flood frequency estimation by continuous rainfall-runoff modelling. Paper to BHS Pennines Group meeting on *Development and Practical Applications of Frequency Analysis* (Abstract).

Lamb, R. and **Calver, A.** 1997. Towards generalised flood frequency estimation using continuous rainfall-runoff modelling. Proc. European Geophysical Society XXII General Assembly, Vienna. Session HS11.2, Pt II. *Annales Geophys.* (Abstract).

Law, F.M. 1997. Book review of *Hydraulic Structures*, 2nd Edition, by Prof Paul Novak, A.I.B. Moffatt, C. Nalluri and R. Narayan, E. & F.N. Spon, London. *J. Hydrol.* **191**, 370.

Law, F.M. 1997. Book review of *Jersey Weather and Tides* by Peter Manton, Seaflower Books, Jersey. *Climatol. Observers Link* **326**, 47-47.

Law, F.M. and **Gunston, H.M.** 1997. Dam failures. *Dams & Reservoirs* **7**, 27

Law, F.M. 1997. Report on IHP-related activities in the UK. *Circulation* **53**, 7-9.

Littlewood, I.G., Gergov, G. and **Hodgson, P.** 1997. UK-Bulgarian environmental research on sediment transport in rivers. *Circulation* **55**, 10-11.

Marsh, T.J. 1997. Readers' Forum: The UK drought and climate change. *Weather* **52**, 354-355.

Marshall, D.C.W. and Davie, N.J.

1997. Relationship between FSR and FEH indices of catchment urbanisation. Flood Estimation Handbook Note 36.

McCartney, M.P. 1997. Technical Note 5: Application of hydro-chemistry to an investigation of the hydrology within the grasslands research catchment at Marondera, Zimbabwe.

Moore, R.J., **Bell, V.A.**, **Austin, R.M.** and **Harding, R.J.** 1997. Developments in snowmelt modelling for flood forecasting. Proc conf. *The Snow Resources of Scotland*, Bridge of Allan, Scotland. Scottish Natural Heritage, 12pp.

Moore, R.J. 1997. Flood hazard research within the European Commission 1987 to 1996. First International RIBAMOD work-shop: Current policy and practice, River basin modelling, management, and flood mitigation: the challenge for European cooperation, 13-15 February 1997, Delft, The Netherlands, 16pp.

Moore, R.J. and **Jones, D.A.** 1997. Linking hydrological and hydrodynamic forecast models and their data. In: Casale, R., Havno, K. and Samuels, P. (eds.). Ribamod: River basin modelling, management and flood mitigation. Concerted action. Proc. First Expert Meeting, Copenhagen, EUR 17456 EN, European Commission, 37-56.

Naden, P.S. 1997. Towards whole catchment modelling. *MAFF Newsletter*, **10** (1).

Naden, P.S. 1997. Continental-scale hydrological models: charting the future. WMO/IAHS Workshop at Institute of Hydrology. World Climate Research Programme 1997. WMO, Geneva.

Neal, C. 1997. Review of *The freshwater imperative* edited by Naiman, J.J., McKnight, D.M. and Stanford, J.A., *J. Hydrol.* **191**, 364-365.

Nobre, C.A. and **Gash, J.H.C.** 1997. Desmatamento muda clima da Amazônia. *Ciência Hoje* **22** (128), 32-41.

Prudhomme, C. and Galea, G. 1997. Discharge-duration-Frequency model: an efficient synthetic model for the regionalisation of hydrological regimes. XVII Annual Amer. Geophys. Union Hydrology days, Fort Collins, Colorado, 375-386.

Ragab, R. 1997. Inter-plant competition and complementarity for water resource capture in natural and agro-ecosystems. Proc. Conf. *Modelling inter-plant competition in natural and agro-ecosystems*, Wageningen, The Netherlands. 1-21 (invited paper).

Ragab, R., **Austin, B.N.** and Albergel, J. 1997. Hydrology of semi-arid Mediterranean catchments with hill reservoirs: an overview and some preliminary results from a Tunisian catchment. Proc. Conf. *Water in the Mediterranean*, Istanbul, Turkey. 1-12.

Ragab, R. and **Cain, J.D.** 1997. Aggregation of input parameters for catchment scale model and its implication to model validation. In: Workshop W3, 5th IAHS Assembly, Rabat, Morocco (abstract).

Ragab, R., **Sene, K.** and **Austin, B.N.** 1997. A decision-support system for hill reservoirs in the semi-arid zone of the Mediterranean periphery. EGS 22nd General Assembly, Vienna. *Annales Geophysicae* **15**, Pt II, Suppl. II, C338. Abstract.

Rees, H.G. 1997. FRIEND '97 – Report of the third international conference of FRIEND at Postojna, Slovenia, 1-3 October 1997. *IAHS Newsletter No. 62, IAHS Press.*

Roberts, G. and **Williams, R.J.** 1997. A review of the treatment of household wastes and the characterisation of sewage effluents. Institute of Hydrology.

Sene, K.J. 1997. Hydrology and Water Resources. Paper given at *Environment Somalia*. SOAS, London. (Abstract).

Stewart, J.B., De Bruin, H.A.R., Garatuza-Payan, J. and **Watts, C.J.** 1997. Use of satellite data to estimate hydrological variables for Northwest Mexico. Proc. 21st Annual Conf. of Remote Sensing Society, 'Remote Sensing in Action', 11-14 Sept. 1995, University of Southampton, 91-98, 91-97.

Tinnion, M. and **Moore, R.J.** 1997. The UK Environment Agency North East Region's river flow forecasting and warning system (RFFS). In: J. Handmer (ed.), *Flood warning: issues and practice in total system design.* Flood Hazard Research Centre, Middlesex University, 37-46.

Wallace, J.S. 1997. Modelling component transpiration in mixed plant communities. Proc. Internat. Evapotranspiration and Irrigation Scheduling Conference, San Antonio, 585-591.

Waughray, D.K.N., **Lovell, C.J.**, **Moriarty, P.M.** and **Batchelor, C.H.** 1997. Productive water points. *ICID British Section News & Views* **24**, 11-13.

Commissioned research reports

Acreman, M.C. (Ed.) 1997. Groundwater and River Resources Action Programme on a European Scale (GRAPES). ENV4 CT95-0186. First Annual Report to the European Commission

Acreman, M.C. and Adams, B. 1997. Low flow, groundwater and wetland interactions – a scoping study. Report to the Environment Agency (W112), UKWIR and NERC

Allen, S.J. 1997. Microclimate modification in spaced tree canopies. Chapter 9 in Agroforestry Modelling and Research Coordination (G. J. Lawson *et al.*). Project R5652. Final Report to ODA

Arah, J. and Hodnett, M.G. 1997. Handling soil hydrology in agroforestry models. Chapter 4 in Agroforestry Modelling and Research Coordination (G. J. Lawson *et al.*). Project R5652. Final Report to ODA

Austin, B.N. and Law, F.M. 1997. Yield Analysis for Arlington Reservoir. Report to South East Water

Austin, R.M., Bell, V.A., Jones, D.A. and Moore, R.J. 1997. River Calder flood warning improvements: RFFS model network. 39pp. Report to the Environment Agency.

Batchelor, C.H., Cain, J.D., Hilton, J., McNally, S., Sheail, J. and Waughray, D.K.N. 1997. CHASM: Combined Hydro-ecological, Agricultural and Socio-economic Modelling. First Progress Report of CEH Integrating Fund CHASM Project.

Batchelor, C.H. and Rosier, P.T.W. 1997. Report on a visit to the KAWAD Project watersheds. Report No. 97/7 to DFID.

Bayliss, A.C. 1997. Catchment characteristics for flood estimation: indexing catchment size, configuration, altitude, steepness and aspect. Flood Estimation Handbook Note 32. Report to MAFF

Bayliss, A.C. 1997. The validation and update of the IH Flood Peak Database.Flood Estimation Handbook Note 38. Report to MAFF

Boorman, D.B. and Williams, R.J. 1997. River Almond Water Quality Study. Part 2: Scenario Analysis. Report to the Scottish Environment Protection Agency, East Region.

Boorman, D.B. and Williams, R.J.

1997. River Almond Water Quality Study. Part I: Model Development + Appendices. Report to the Scottish Environment Protection Agency, East Region.

Bradford, R.B. and Faulkner, D.S. 1997. Review of floods and flood frequency estimation in permeable catchments. 50pp. Report to MAFF

Bromley, J., Robinson, M. and Dixon, A.J. 1997. Evaluating subsurface water losses in a cutover peatland: Thorne Moors, South Yorkshire. Confidential report for Levingtons plc.

Bullock, A., Gilman, K., McCartney, M.P., Waughray, D.K.N., Blyth, K. and Andrews, A.J. 1997. Hydrological strategy to develop and manage African wetland resources for sustainable agricultural use. 173pp. Report to Food and Agricultural Organization of the United Nations (FAO)

Cain, J.D. 1997. Integrated natural resource management – a review of scientific approaches. Report for CEH Integrating Fund CHASM Project

Cain, J.D. 1997. Simulating the soil water balance with special reference to groundwater recharge in two sub-catchments in Zimbabwe using the FRLM model. Second Project Report to ODA.

Croker, K.M., Young, A.R. and Sekulin, A.E. 1997. Development of low flow facilities for Scotland and Northern Ireland. SNIFFER. Interim Report to December 1996.

Crooks, S.M. and Naden, P.S. 1997. Assessment of the EPIC model for predicting water colour, 31 pp. Report to Yorkshire Water.

Culf, A.D., Gash, J.H.C. and Fisch, G. 1997. Combined carbon, water and energy balances of tropical biomes – atmospheric boundary layer studies. TIGER Report III.1/5A.

Davies, H.N. and Robinson, M. 1997. An appraisal of water levels at Thorne Moors SSSI 1992-96. Report for English Nature.

Dent, J.D., Forsyth, G., Pearson, I., Sene, K.J. and Pietersen, K. 1997. Establishment and operation of planning, monitoring and evaluation units and integration of ex-Transkei and ex-Ciskei water supply data into the information system: annual report to EU and to Department of Water Affairs and Forestry, South Africa

Dixon, A.J. 1997. Peat survey and groundwater monitoring of Packards South Sections 3 & 4 of Hatfield Moors S. Yorks. Report to Levington Horticulture

Dunbar, M.J., Elliott, C.R.N., Gowing, I.M. and Acreman, M.C. 1997. Ecologically Acceptable Flows Phase II. Volume 4: River Sector-scale Extrapolation. R&D Technical Report W34. Report to the Environment Agency.

Evans, J.G. 1997. Contract: River Basin Management Project: Chile Contract Reference: CNTR 93 2083 A, Visit Report No. 9 to ODA

Farquharson, F.A.K., Gunston, H.M. and Calder, I.R. 1997. Integrated water resource management in Southern Africa – an overview of relevant UK supported research. Water Resources Occasional Paper No. 2, 20pp. Report to DFID

Gilman, K. 1997. Interim Report on progress of hydrological evaluation of reedbed re-creation at Ham Wall, Somerset. Contract report to Somerset County Council, RSPB and NERC.

Gustard, A. and Cole, G.A. 1997. Advances in regional hydrology through East European Cooperation. 42pp. Final Report to Commission of European Communities.

Gustard, A. 1997. Pan European Studies, p52-58. GRAPES – First Annual Report, DGXII to CEC.

Haverkamp, R., Bouraoui, F. and Ragab, R. 1997. GRAPES, Groundwater and River resources Action Programme on a European Scale. First annual report by the vadoze zone modelling group. EU Progress Report.

Hills, S. 1997. IH Digital Terrain Model of Northern Ireland: Data Problems and Quality Control. Flood Estimation Handbook Note 33. Report to MAFF

Houghton-Carr, H.A. 1997. Bulyanhulu Gold Mine Tanzania: review of hydrological baseline study and preliminary assessment of surface water resources (plus appendix of hydrological data). Report to Dames and Moore

Houghton-Carr, H.A. 1997. Restatement of the FSR Rainfall-Runoff Method: first draft. Flood Estimation Handbook Volume 4. Report to MAFF

Hudson, J.A., Roberts, G., Eatherall, A., Jolankai, G., Kwadijk, J. and Perk, v.d.M. 1997. INCAMOD – integrated catchment models for supporting water management decisions, 73 pp. EC Contract Nos. ENV4-CT95-0187 and IC20-CT96-0023. Report to the EC

Hughes, S., Dowrick, D.J., Brittain, S.A., Reynolds, B., Hudson, J.A., Hill, P.J., Crane, S.B., Hughes, W.A. and Freeman, C. 1997. The Cerrig yr Wyn wetland manipulation study. Final report for 2nd phase, Contract WEP 120/100/6. CEH, ITE (Bangor) & IH (Plynlimon). Report to the Welsh Office

Institute of Hydrology 1997. Development of improved methods for snowmelt forecasting. Annual Progress Report to the Scottish Office for the period November 1996 to October 1997. 23pp. Contract Report to the Scottish Office

Jackson, N.A., Smith, D.M., Roberts, J.M. and Wallace, J.S. 1997. Water balance of agroforestry systems on hillslopes – Phase II. Annual Report to DFID/FRP 96-97.

Jakob, D. 1997. Catchment daily rainfall time series: some details. Flood Estimation Handbook Note 34. Report to MAFF

Jakob, D. 1997. Comparison of FSR regions and FEH Note 35 regions. Flood Estimation Handbook Note 37. Report to MAFF

Jakob, D. 1997. Proposing regions for flood frequency analysis. Flood Estimation Handbook Note 35. Report to MAFF

Jenkins, A. and Renshaw, M. 1997. An assessment of the EU acidification strategy B1 scenario and the timing of emission reductions using the MAGIC model at UKAWMN sites. (contract no. EPG 1/3/84), 13 pp. Contract report for the Department of the Environment, Transport and the Regions

Jenkins, A. and (Editor) 1997. CLIMEX project: Results from the third year of treatment, May 1996-December 1996. Contract ENV4-CT95-0185. ISBN 82-577-3315-6. Final report to the EU

Jones, D.A. 1997. Prospects for Bayesian analysis in FEH work. FEH Note No. 22, 5pp. Report to MAFF

Kirby, C. 1997. IH/BGS collector well garden experiment, Romwe catchment, Chivi District of Masvingo Province, Zimbabwe, Visit reports to DFID.

Marks, S.D. 1997. The impact of particulate outputs associated with timber harvesting (January-March 1997). P2/i465/18 17 pp. Quarterly progress report to the Environment Agency

Marsh, T.J. (Ed.) 1997. Hydrological Summaries of Great Britain. Twelve monthly reports on hydrological conditions throughout Great Britain for the Department of the Environment, Transport and the Regions.

Marsh, T.J. and Littlewood, I.G.

1997. The 1995 drought and limited drought-break: hydroclimatological background and potential impact on river mass loads. In: Post-drought flush effects upon river water quality and sediment transport in upland and lowland catchments. Report to the Environment Agency

Morris, S.E. 1997. Catchment characteristics for flood estimation: indices of catchment wetness. Flood Estimation Handbook Note 31. Report to MAFF.

Naden, P.S., Calver, A., Samuels, P.G. and Ash, J. 1997. Whole Catchment Modelling: the basis for an integrated approach to catchment management, 83 pp. Report to MAFF

Price, D.J., Calder, I.R. and Hall, R.L. 1997. Water balance of African lakes. Report to ODA

Price, D.J. 1997. Water balance of African lakes; Final Project Summary Report. Report to ODA

Price, D.J., Calder, I.R. and Hall, R.L. 1997. Water resource modelling for large catchments. Technical Report to ODA

Price, D.J. 1997. Water resource modelling for large catchments. Project Summary Report for ODA

Ragab, R. 1997. The Hydrologic Evaluation of Landfill Performance (HELP) Model – an overview & evaluation report. Report to the Environment Agency.

Ragab, R. and Austin, B.N. 1997. HYDROMED – programme of research on hill reservoirs in the semi-arid zone of the Mediterranean periphery. An overview of hydrological models and processes. EU Progress Report

Ragab, R. and Brookes, C. 1997. Hydrology of landfill sites under different soil and vegetation types. Report to the Environment Agency.

Rees, H.G. and Cole, G.A. 1997. Estimation of renewable water resources in the European Union. 101pp + Annexes. Report to CEC: Eurostat.

Renshaw, M. and Jenkins, A. 1997. Techniques for critical load assessment in China, 30 pp. A report under contract to UNECIA Ltd

Roberts, A.M. 1997. IH lowland catchment database facility: Pang catchment data management plan. Technical Note No. 1 In: Acreman, M.C (Ed) Groundwater and River Resources Action Programme on a European Scale (GRAPES). First Annual Report to the European Commission. ENV4 CT95-0186

Robins, N.S., Calow, R.C., MacDonald, A.M., Macdonald, D.M.J., Gibbs, B.R., Orpen, W.R.G., Mtembezeka, P., Andrews, A.J., Appiah, S. and Banda, K. 1997. Groundwater management in drought-prone areas of Africa. British Geological Survey Technical Report WC/97/57, Overseas Geology Series, 26p.

Sefton, C.E.M. and Jenkins, A. 1997. Hydrochemical Modelling – MAGIC Applications. In: Stevens, P.A., Ormerod, S.J., Reynolds (Eds). Final Report on the Acid Waters Survey for Wales, Vol. I, p. 153-195. Report to the Welsh Office, Environment Agency, Forestry Commission and Countryside Council for Wales (Subcontracted by the Institute of Terrestrial Ecology, Bangor).

Sene, K.J. and Davies, H.N. 1997. A brief review of rating equations for river flow gauging stations in the Guadiana Basin. Report to CEC GRAPES

Sene, K.J. 1997. Hydrometric monitoring in the Lebanon, final report, October 1997 (No. 97/06). Report to DFID

Sene, K.J. 1997. Review of CWSS-related databases for Eastern Cape Province. Report to EU and Department of WaterAffairs and Forestry, South Africa

Sene, K.J. 1997. St Lucia watershed and environmental management project – training for Hydata Software, No. 97/03. Report to ODA

Smith, D.M., Jackson, N.A. and Roberts, J.M. 1997. Root quantity, activity and below-ground competition in *Grevillea robusta* agroforestry systems. Research Project R6363. Annual Report to the Forestry Research Programme, DFID

Stevens, P.A., Allott, T.E.H. and Crane, S.B. 1997. Lakes – chemistry and biology. In: Final Report on the Acid Waters Survey for Wales, Vol 1, Main Text (Eds. P.A. Stevens, S.J. Ormerod and B.Reynolds), p 138-152. Report to the Welsh Office, Environment Agency, Forestry Commission and Countryside Council for Wales

Stevens, P.A., Reynolds, B., Ormerod, S.J., Skotnicki, A., Brewin, P.A., Renshaw, M., Neal, C., Norris, D.A., Lowe, J.A.H., Hudson, J.A. and Crane, S.B. 1997. Stream chemistry. In: Stevens, P.A., Ormerod, S.J., Reynolds (Eds). Final Report on the Acid Waters Survey for Wales, Vol. I, 25-71. Report to the Welsh Office, Environment Agency, Forestry Commission and Countryside Council for Wales (CEH/ITE, Bangor).

Waughray, D.K.N. and Marsh, T.J. 1997. Chapter 7. Economic Impacts of the Hot Summer of 1995 'The Water Sector'. In: Palutikof, J., Subak, S. and Agnew, M. (Eds) *Economic Impacts of the Hot Summer and Unusually Warm Year of 1995* CRU/SERGE. Report to the Department of the Environment.

Wilkinson, R.J., Reynolds, B. and Neal, C. 1997. The impact of conifer harvesting and replanting on upland water quality, R&D Progress Report P2/i502/6 to the Environment Agency

Wilkinson, R.J., Reynolds, B. and Neal, C. 1997. The impact of conifer harvesting and replanting on upland water quality, R&D Progress Report P2i502/7 to the Environment Agency

Location of CEH sites

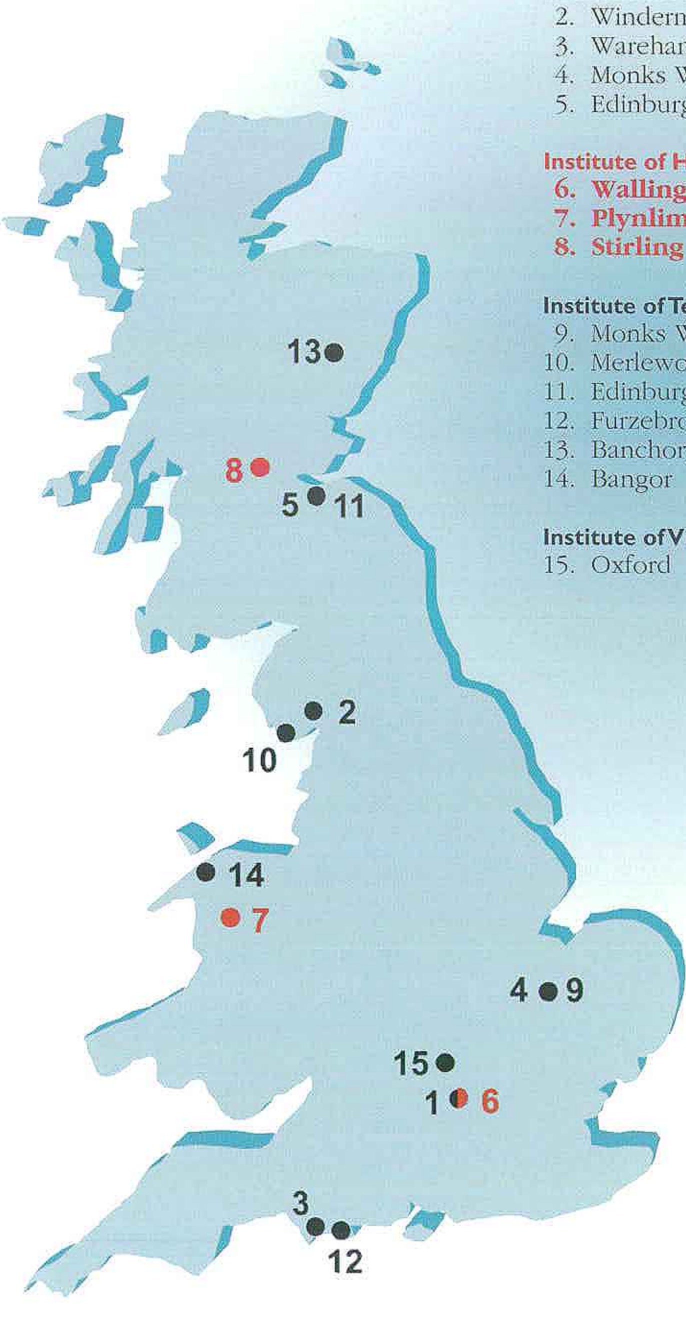
Centre for Ecology and Hydrology
1. Wallingford

Institute of Freshwater Ecology
2. Windermere
3. Wareham
4. Monks Wood
5. Edinburgh

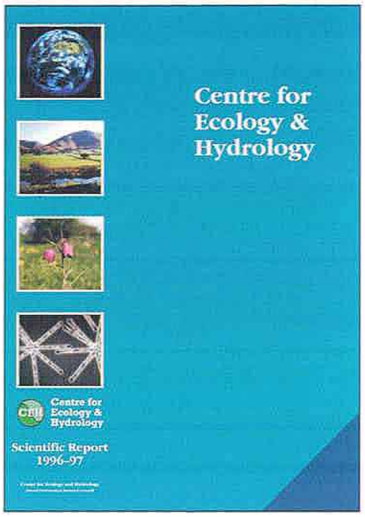
Institute of Hydrology
6. **Wallingford**
7. **Plynlimon**
8. **Stirling**

Institute of Terrestrial Ecology
9. Monks Wood
10. Merlewood
11. Edinburgh
12. Furzebrook
13. Banchory
14. Bangor

Institute of Virology and Environmental Microbiology
15. Oxford

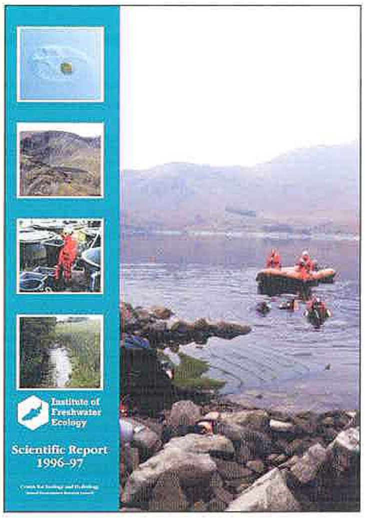


CEH REPORT RANGE 1996–97



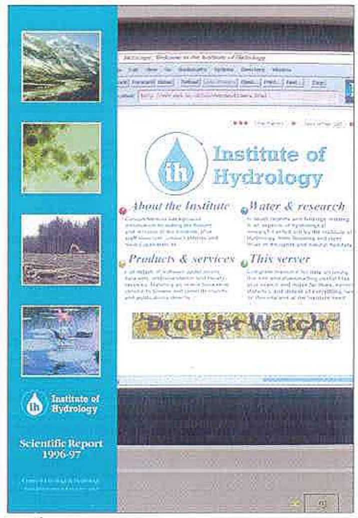
Centre for Ecology & Hydrology

http://www.nmw.ac.uk/ceh



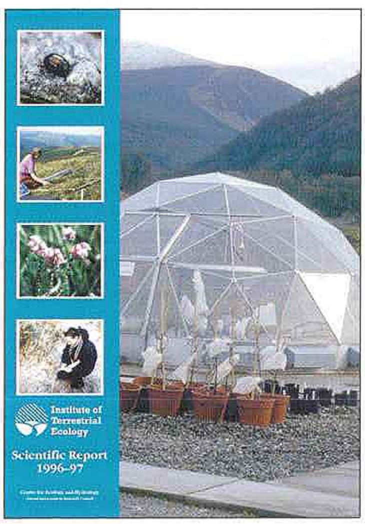
Institute of Freshwater Ecology

http://www.ife.ac.uk/



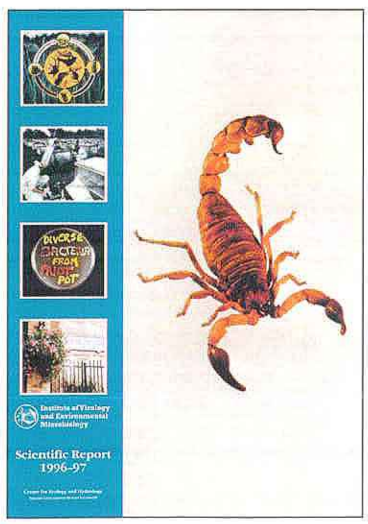
Institute of Hydrology

http://www.nwl.ac.uk/ih



Institute of Terrestrial Ecology

http://www.nmw.ac.uk/ite



Institute of Virology and Environmental Microbiology

http://www.nox.ac.uk/

Centre for Ecology & Hydrology

ISBN 1 85531 189 5

Institute of Hydrology
Wallingford, Oxon OX10 8BB, United Kingdom
Telephone: +44 (0) 1491 838800 Fax: +44 (0) 1491 692424
Email: web@ua.nwl.ac.uk
Internet: http://www.nwl.ac.uk/ih