Interagency Research Committee on the Hydrological Use of Weather Radar

First Report

October 1991 - February 1993

Interagency Research Committee on the Hydrological Use of Weather Radar

First Report

October 1991 - February 1993

Report prepared on behalf of the Committee
by the Institute of Hydrology

Institute of Hydrology
Crowmarsh Gifford
Wallingford
Oxon
OX10 8BB

March 1993

Preface

I am pleased to present to the sponsoring agencies, and to all others who have an interest in the development of weather radar for hydrological use, our first report. This covers the period since the establishment of the Committee in October 1991, when the Committee experienced and enjoyed an excellent initiation as part of a Radar Research Workshop at Lancaster.

The period under review has seen the achievement of major milestones on the UK weather radar scene. The completion of the UK network was marked by the opening of the Cobbacombe radar by the Minister of Agriculture in the autumn of 1991. The Committee was particularly pleased to see the announcement by NERC of the HYREX (HYdrological Radar EXperiment) Special Topic which will enable a significant new thrust into fundamental research of weather radar as a remote sensing device and the investigation of rainfall processes and their link to runoff response. Our predecessor Committee (the NERC Steering Committee on the Hydrological Application of Weather Radar) had prepared the HYREX proposal and the new Committee will follow its progress with considerable interest. I wish the research groups every success with their endeavours.

However, the Committee also has concerns for the future well being of data produced by weather radars in the UK and in particular for the full exploitation of the detailed information that they can provide. The UK has pioneered the operational use of weather radar and established itself as a world leader. All regions of the NRA use it operationally for flood forecasting and the public can see pictures of rainfall almost nightly on the BBC television weather forecasts produced by the Meteorological Office. Potentially the UK could have had one of the longest and most comprehensive archives of weather radar data in the world. Unfortunately, large parts of these data have been destroyed because the hydrological requirements of data archiving do not match those for meteorological science, and data for hydrological applications are continuing to be lost. The MAFF Coastal and Flood Defence Research Advisory Committee chaired by Mr Peter Ackers has also recognised the need for an archive. The Committee is particularly keen to see progress in the development of an archive and associated policies for data preservation.

Many members of the Committee contribute to international activities, which plays a significant role in enhancing the status of British work in this field. I am grateful to all members of the Committee for their enthusiastic support of the Committee's work and their pioneering contributions to weather radar developments. The Committee has had a successful and flourishing reincarnation and faces the future with vitality.

Dr Peter D. Walsh
Chairman

Contents

1. BACKGROUND TO THE COMMITTEE

The Interagency Research Committee on the Hydrological Use of Weather Radar was established in 1991 as the successor to the NERC Steering Committee on Hydrological Applications of Weather Radar. The NERC Committee was initiated in 1986 following the North West Weather Radar Project which had established the UK as a world leader in this field. Dr Browning (Met Office) approached Mr Fish (Chairman, NERC) to create a forum for the exchange of ideas between research, applications and commercial exploitation of weather radar. The Committee was formalised by Dr McCulloch (Director, IH) and met first in March 1986 under the chairmanship of Dr Rodda (IH). Dr Walsh took over as chairman in 1988 and the UK continued to command a very high reputation internationally, playing an important role in European programmes such as EPOCH. A successful national meeting held in 1989 resulted in publication of *Weather Radar and the Water Industry* by the British Hydrological Society.

However, as the Committee's relationship and reporting lines with NERC had become unclear, a meeting was held on 5 November 1990 attended by Professor Knill (Chairman, NERC), Dr Tinker (Director, Terrestrial and Freshwater Sciences, NERC), Professor Wilkinson (Director, IH) and members of the Committee to resolve these matters. Professor Knill recommended that the Committee should be recast as an interagency committee to include SERC and the Scottish Office in addition to the agencies already represented. He received agreement from the agencies concerned for new Terms of Reference and a new title.

The final meeting of the NERC Steering Committee was held on 3 October 1991 during a workshop at the University of Lancaster set up by Committee members. The first meeting of the new Interagency Committee was held during the same workshop on 4 October 1991.

2. MEMBERSHIP AND TERMS OF REFERENCE

Professor Knill invited membership to the Committee from interested agencies and the following agreed to provide representation:

Meteorological Office,
Ministry of Agriculture, Fisheries and Food (MAFF),
National Rivers Authority (NRA),
Natural Environment Research Council (NERC),
Science and Engineering Research Council (SERC),
Scottish Office and
Water Services Association.

The Department of the Environment, whose membership of the NERC Committee had been limited to receiving papers, declined the invitation stating that its interests were covered by other agencies. MAFF also agreed to cover Welsh Office interests.

Dr Walsh was appointed chairman to provide continuity since he had been chairman of the NERC Committee. It was proposed that the chairmanship should be rotated around the agencies with two year appointments. NERC's Institute of Hydrology (IH) agreed to continue the tradition of providing the secretariat for the Committee.

The Constitution and Terms of Reference of the Committee were agreed by the agencies represented and are given in Appendix A.

The constitution of the committee allows for up to four members (with at least two from Higher Education Institutions (HEIs) and/or research organisations) to be co-opted for a two year period at the invitation of the Committee. Professor Cluckie from the University of Salford and Dr Illingworth from the University of Manchester Institute of Science and Technology (but now at the University of Reading), were invited to join the Committee and duly accepted. The remaining two places were not filled but Dr Shepherd of the States of Jersey Resources Recovery Board was invited to attend meetings as an observer.

The complete membership list is given in Appendix B.

3. OVERVIEW OF THE COMMITTEE'S ACTIVITIES

The Committee has met four times, in October 1991, March 1992, September 1992, and February 1993.

Committee's interests and reporting

The first task undertaken by the Committee was to define the boundaries of its field of interest. Given the Committee's title, meteorological research will only be considered as far as it is required to make weather radar data hydrologically useful. Radars will include satellite and airborne equipment as well as ground-based radar. The interest from most of the agencies represented lies in local applications, such as flood forecasting. However, it was agreed that it is not possible to separate different scales of meteorological phenomena and that understanding of global processes will help local forecasting as well as being a fundamental part of hydrological science. Hence the Committee has a global perspective. Dr Walsh contributed to the work of the Interagency Atmospheric Radar Working Group in his capacity as Chairman of this Committee.

In view of the uncertainties that had existed in the NERC Committee, Members have confirmed their correct reporting lines within their respective agencies. A comprehensive address list has been compiled for circulation of reports and other material.

UK research priorities

The Committee decided that an important task was to produce a prioritised list of scientific projects which addressed basic and applied research needs. In March 1992 the NERC Committee published a document entitled *Opportunities for Radar Hydrometeorological Research during the 1990s: proposals for strategic research to address UK requirements*. This provided a comprehensive list of proposals. The Interagency Committee has selected from the list those projects of highest priority and classified them as either basic or applied research according to whether the research is required to acquire new knowledge of the fundamental aspects of the phenomena, or directed primarily towards practical aims. Appendix C provides the resulting classification of priority topics. The Committee plans to review current research against these priorities on a regular basis.

UK research capabilities

An inventory of UK capabilities in the field of Weather Radar has been compiled by the Committee and will include interested groups, their expertise and their equipment. The current list is given in Appendix D. This will be updated periodically.

World Meteorological Organisation, 9th Commission for Hydrology

Dr Walsh and Professor Collier were members of the UK delegation to the meeting of the 9th Commission in January 1993. Professor Collier was appointed as Rapporteur for Precipitation Estimation and Forecasting under the Working Group on Hydrological Forecasting and Applications for Water Management. The Committee will be supporting Professor Collier through direct contact with Members, and by round-table discussion at Committee meetings. Dr Walsh and Mr Moore are to co-author a paper with Dr Rodda, of the WMO, on *Use of Weather Radar Data for Hydrological Forecasting*.

4. UK RESEARCH ACTIVITIES

A major new programme of fundamental research on hydrological aspects of weather radar, the HYdrological Radar EXperiment (HYREX), was initiated in 1992. Full details follow in Section 5.

The Meteorological Department at the **University of Edinburgh** are engaged in a study of orographic enhancement of precipitation in Scotland. Radar data from Corse Hill in southern Scotland are being used together with raingauge data to study the enhancement of rainfall over complex terrain. Both individual case studies of heavy rainfall events, using hourly data, and analysis of long-period rainfall data are being carried out to understand the role of successive ranges of hills in orographic enhancement. Radar underestimates rainfall over and near hills where orographic enhancement is occurring and overestimates it to the lee of high ground. The analysis shows very pronounced rain shadow effects even in the lee of the first range of high ground, with current methods of estimating enhancement giving too great an amount in most circumstances. Modifications to the formulation being used at present are to be developed.

The propagation research group at the **University of Essex** performs research in the modelling of scattering of electromagnetic waves by hydrometeors. In particular they have extensive experience of analysing polarisation data from convective storms - mainly at S-band but also at X-band. They have just commenced a 2-year EC Environment Programme Contract entitled *Development of polarisation-diversity and Doppler radar data analysis for qualitative precipitation monitoring in severe weather*, including partners in Germany (1), Italy (3) and at the UK Meteorological Office, coordinated at Essex. The aim is to develop understanding of the use of Doppler and polarisation at C-band to improve, *inter alia*, rainrate measurement in severe storms. They are also contributing to an ESTEC contract on the study of rain-radar retrieval algorithms from space, lead by CRPE (France).

Radar studies at the **Joint Centre for Mesoscale Meteorology** involve the use of the multi-parameter Doppler radar situated at Chilbolton in Hampshire. This radar, with its 25 m antenna, is the largest steerable meteorological radar in the world and is able to make polarisation measurements of unrivalled purity. The radar is being used to implement and test new techniques to recognise and correct problems which cause large errors in the rainfall estimated from the current network radars. Examples are: the overestimate of rainfall due to melting snow (the 'bright band'), the overshooting of low level rain at large distances, the artificially high radar returns when hail is present, and the spurious returns from ground clutter and anomalous propagation. In addition, coupled atmospheric and hydrological models are being developed, in association with the Institute of Hydrology, to aid the understanding and short term forecasting of rainfall and its effects on runoff.

Work on the hydrological use of Weather Radar has been in progress at **Lancaster University** under the direction of Dr V K Collinge from 1985 to 1991, and under the joint direction of Professor Young

and Dr J R R McIlveen since then. With funding from the EC, North West Water and the NRA the group has studied the performance of the Weather Radar at Hameldon Hill (Lancashire) in comparison with routine and special gauges. The assessment factors have been examined in relation to orographic enhancement over local hills and a range of meteorological conditions, including strong convective instability. Current work includes the last, and detailed examination of the use of recursive time and space analysis techniques (including Kalman filtering) for optimising assessment factors and resultant calibration.

The **Meteorological Office** has continued to expand the UK radar network by the installation and commissioning of three radars in Scotland at the end of 1991 and the Cobbacombe radar during 1992. Coverage of the whole of the United Kingdom has now been achieved. The Cobbacombe radar, the first operational C-band Doppler radar in the United Kingdom, is currently undergoing pre-operational trials.

The FRONTIERS system was handed over from the research side of the Meteorological Office to the operations side, and is now managed by a group attached to the Central Forecast Office. Work with the NRA Thames and North West Regions to improve the availability of FRONTIERS forecasts from both a meteorological and hydrological point of view has been reported. So far it has been demonstrated that FRONTIERS forecasts are very useful as input to an operational flood forecasting model in frontal rainfall situations, but are not satisfactory in convective (including thunderstorms) rainfall. This work continues.

Research and Development to automate FRONTIERS forecasts and to develop improved procedures using artificial intelligence techniques is on-going. This work includes investigation of improvements to radar measurements of precipitation, including the use of estimates of the vertical reflectivity profile, bright-band correction procedures and raingauge representativity, use of object-oriented coding approaches to forecasting convection and improvements to the estimation of rainfall from visible and infrared satellite data. The aim is to introduce a new, fully automated version of FRONTIERS (NIMROD) within the next three years. Proposals for a tailored thunderstorm warning system to be developed under contract have been made. Work with the University of Salford to develop new techniques of estimating short duration Probable Maximum Precipitation using weather radar information, under contract to DOE, began on 1 October 1992.

At the **Institute of Hydrology** (IH) the start of the reporting period saw the completion of the Local Radar Rainfall Forecasting Study and, in November 1991, the operational deployment of the recommended method at the NRA's London Flood Warning Centre at Waltham Cross. A detailed assessment in conjunction with the national Frontiers product demonstrated the superiority of the local system for short-term, high resolution rainfall forecasting and their complementarity at higher lead times over larger areas. A two year evaluation study of the Local and Frontiers rainfall forecasting methods for use in flood forecasting models is scheduled for completion in April 1993. The evaluation is employing three lumped conceptual rainfall-runoff models and flow data from nine catchments of varied character in the Thames basin. A conditional probability forecast provides a point of reference from which to compare results obtained using the Frontiers and Local rainfall forecasts as input to the models. Small, rapidly-responding catchments appear to benefit most from the use of rainfall forecasts for flood forecasting.

In December 1992 the Interim Report to the NRA relating to the development of a distributed flood forecasting model, configured to use grid-square radar data and parameterised using a digital terrain model (DTM) and Landsat imagery, was completed. The model employs a DTM to infer isochrones automatically: these are used as the basis for routing runoff, generated from the radar grid square areas, to the basin outlet using a discrete kinematic wave formulation capable of reproducing both

advection and diffusion translation effects.

Work has continued on the use of radar data for storm hazard assessment for reservoir and drainage system design. The focus has been on the development of realistic temporal profiles of areal average rainfall for upland areas: the results suggest the need for updating design profiles in current use, particularly for long durations. A study to examine the response times of small catchments will complete its data collection phase, involving 15 river level recorders for catchments within a 76 km radius of the London Weather Radar, in March 1993. Preliminary results suggest that the lag and time to peak regression relations used in UK unit hydrograph design methods are biased towards large catchments, and for smaller catchments the importance of urban fraction is more dominant and shorter delay times are required.

Most recently, IH has supplied a Radar Hydrology kernel product to Thames Water Utilities to support urban stormwater management of the Beckton-Crossness catchment. This software combines radar preprocessing (clutter suppression and anomaly removal), calibration, rainfall forecasting and catchment averaging techniques previously developed by IH. The Radar Hydrology kernel, together with a Windows-based user display and management interface, has been christened HYRAD, and is currently being supplied to the NRA Yorkshire Region where it will be interfaced to the RFFS (River Flow Forecasting System) in support of region-wide flood warning.

Two projects are under way in the Water Resource Systems Research Unit of the **University of Newcastle-upon-Tyne**. One is using a stochastic space-time rainfall model to produce simulated radar data which is then fed into the SHE modelling system to determine characteristic hydrological responses of a catchment to spatially distributed rainfall. The second project, being undertaken by a Ph.D. Student, is to compare and contrast various approaches to modelling space-time rainfall in the context of real-time flood forecasting.

The Modified Turning Bands (MTB) model for space-time rainfall has been under continual development for the last four years, and has recently been used for the production not only of synthetic radar data, but also for the production of synthetic time-series such as may be observed at a network of tipping-bucket raingauges in a catchment. This has been used within the context described above to determine the effectiveness of the raingauge network in providing data for the calibration of the space-time rainfall model and for the distributed modelling of catchment response.

The Ph.D. project has been exploring various methodologies for the short-term modelling and forecasting of spatially distributed rainfall, and is now investigating the effectiveness of the ARNO model for the semi-distributed modelling of catchment response, given a spatially distributed rainfall input. The calibration of the ARNO model on the Tyne catchment is currently under way. Once completed, synthetic radar data generated by the MTB model will be used in conjunction with the ARNO model to assess the benefits of rainfall forecasts in real-time flood forecasting.

Current weather radar research projects at the **University of Salford** range from research into the development of operational procedures for drought management to real-time flood forecasting and the development of control strategies for urban drainage systems. The main research areas related to radar hydrology are

- improving the quality of radar rainfall data,
- real-time flood forecasting in rural catchments, and
- real-time modelling and control of urban drainage systems.

The Salford group commissioned a mobile vertically pointing X-band radar system in March 1993 which will be used to investigate bright-band dynamics and orographic effects in north-west England. Improved knowledge of all such processes is supporting the development of numerical procedures for improved real-time calibration of scanning weather radars. The X-band radars will be used in conjunction with a low-cost C-band hydrological scanning radar, which the group will commission in May 1993, to complement the existing Salford X-band radar. The C-band device is intended to be installed close to urban areas in order to provide high spatial and temporal resolution rainfall estimates to satisfy the stringent requirements of urban hydrological uses. Three research contracts (including one NERC studentship) are directly involved with these projects, with a second NERC studentship starting in October 1993.

Work on real-time flood forecasting models for use with weather radar data for urban catchments is continuing, with the development of a model for the Avon at Bristol which will be incorporated into the real-time forecasting system (WRIP) developed by the Salford group. Recent modelling developments include the physically realisable transfer-function (PTRF) which combines the advantages of the transfer-function approach with improved stability and response. Current research aims to fully test the PRTF model and develop a snow-melt component.

Current projects are attempting to develop urban drainage system (UDS) models which satisfy the requirements for real-time operation and utilise the high spatial and temporal resolution data provided by radar data. Active control algorithms for the on-line management of UDS are being investigated. The work is focusing on urban systems in north-west England, supported by industrial funding by North West Water Ltd.

The group is also conducting research into real-time drought management techniques, probable maximum flood / probable maximum precipitation studies (storm transposition, maximisation, flood modelling), and a water quality balance of the Irish Sea (macro-scale hydrological modelling).

The **SERC Rutherford Appleton Laboratory** (RAL) is responsible for the operation of the Chilbolton Radar Facility. The RAL Radio Communication Research Unit participates in a number of research programmes which utilise the Chilbolton Radar, funded by various agencies. Activities include:

• Olympus/ITALSAT propagation experiment	(Radio communication agency)
• Doppler system development	(NERC)
• HYREX: Use of polarisation-dependent phase changes for rainrate estimation	(NERC)
• Space radar validation (14 GHz)	(SERC)
• Validation of rain retrieval algorithms between 10 and 35 GHz	(CRPE)
• European consortium on flood hazard prediction	(EC)
• Cloud radar studies at 35 GHz	(SERC)
• Prototype low cost tropical radar for freezing height identification using Chilbolton based cross polar technique	(Radio communication agency)

The RAL Space Science Department has a programme of radar remote sensing. The main objectives

are to improve the interpretation of data from spaceborne radar systems. This programme involves the use of an airborne radar altimeter operating at X band (13.8 GHz) and the development of the 35 GHz experimental radar to be used on the Chilbolton dish for the Cloud Radar Studies (see above) in collaboration with RCRU and university groups.

A major activity at present is a detailed scientific examination (in collaboration with 6 university groups) of the overall feasibility of the use of millimetre-wave radar for examining the 3-dimensional structure of clouds from space. The study is primarily funded by SERC.

In March 1990 the Meteorological Office invited the **Thames and North-West Regions of the National Rivers Authority** to take part in a pilot operational service to receive and assess FRONTIERS rainfall forecasts. The initial trial period commenced on 1 October 1990 with duration of one year, later extended to 18 months. Unfortunately, it was an unusually dry period with very few events giving rise to significant river flows of the scale for which flood forecasting models have been calibrated. A decision was therefore taken in March 1992 to extend the trial for a further year.

The assessment comprised a subjective evaluation of the usefulness of the FRONTIERS forecasts by forecasters at the London and Manchester Weather Centres and an objective study of the effects of using FRONTIERS forecasts in flood forecasting models in the National Rivers Authority. In addition the Meteorological Office carried out their own analyses to test the quality of the FRONTIERS forecasts.

The final year of the project has given some much larger events to work with and will enable conclusions to be drawn as to how useful FRONTIERS forecasts will be for flood forecasting and warning. The final report is due in June 1993.

5. HYREX

The HYdrological Radar EXperiment (HYREX) was conceived by members of the NERC Committee. The aim of HYREX is to undertake fundamental research in two main areas. First, the science of weather radar as a remote sensing device, and second, investigation of the precipitation process and its link with runoff response. The former will involve the study of radar systems with different capabilities using various wavelengths and Doppler or dual polarisation facilities. The latter should achieve a better understanding of the structure of rainfall and other precipitation processes, as revealed by weather radar measurements, and will in turn support an improved understanding of runoff response at a range of scales in space and time.

The focus of the experiment will be southern England, making use of data from the Wardon Hill and Cobbacombe C-band network weather radars and the experimental S-band radar situated at Chilbolton. In addition, some projects will involve work in other areas of the country, for example the study of orographic intensification in north-west England.

A proposal to develop and undertake HYREX was presented to NERC in May 1991. HYREX received support from NERC's Advisory Committees in both the Terrestrial and Freshwater Sciences, which had taken the lead in promoting HYREX within NERC, and also in the Atmospheric Sciences.

In competition with other proposals NERC Council agreed to support HYREX under its Special Topic scheme with a provisional allocation of £750,000 over three years. To support HYREX, additional funds for capital infrastructure were provided by other agencies. NRA agreed to establish and maintain a dense raingauge network between the Chilbolton and Warden Hill radars and MAFF provided funds

towards setting-up of a database to hold the hydrological data, other than radar, to serve the HYREX community. The Meteorological Office agreed to provide radar data, radiosonde ascents, flights of its C-130 aircraft, and mesoscale model case studies. North West Water Ltd agreed to provide data from the C-band and vertically pointing X-band radars developed jointly by the Water Resources Research Group at the University of Salford and the McGill Weather Radar Observatory.

A Steering Committee of the HYREX Special Topic programme was set up, and includes five members of the Interagency committee. The Steering Committee held a meeting in November 1992 at which 13 project applications were discussed. Six proposals were recommended for funding, covering five of the six key research areas originally identified in the objectives of the HYREX Programme. A list of awards is given in Appendix E.

A two-day workshop is to be held in Shaftesbury on 6 and 7 April 1993 and will include a field visit to the Brue catchment, which has been chosen as the focus of the hydrological studies.

6. INTERNATIONAL RESEARCH ACTIVITIES

EC projects

September 1991 saw completion of the first project, on *Use of Weather Radar for the Alleviation of Climatic Hazard*, under the EC Climatology and Natural Hazards research programme. The occasion was marked by an international workshop on *Advances in Radar Hydrology* held in Lisbon, Portugal over the period 11-13 November 1991. The proceedings of this workshop are to be published by the E as a book in 1993. The first annual report for the second project, under the EPOCH programme, was submitted in March 1992 and a final report is due in early 1993. A specialist workshop on *Rainfall Estimation and Forecasting using Weather Radar* was convened in Athens, Greece from 25 to 26 June 1992 and attended by three UK delegates. A final seminar of the EPOCH project is to be held at the Institute of Hydrology in March 1993. Mr Moore has set up a third EC project, within the Environment Programme, entitled *Storms, Floods and Radar Hydrology*. This started in January 1993 with the involvement of eight European countries. A further E project within the Environment Programme, to be undertaken jointly by Essex University, the Meteorological Office, and teams from Germany and Italy, will look at polarisation diversity and Doppler radars, and the potential for using C-band radars in the UK network (see the Essex University entry under UK Research Activities).

The results of the COST 73 project have been published in the form of a book: D H Newsome (Ed) *Weather radar networking COST 73 Project/Final Report*. It recommends that an operational European network be established, and a Committee has been set up to take this forward. A COST 75 project on advanced radar systems, which includes Eastern European countries, began in January 1993. This will be chaired by Professor Collier until September 1993, when he will become Project Coordinator and Secretary, and Dr Meischner (DLR, Gennany) will take over the Chair.

Second International Symposium on Hydrological Applications of Weather Radar

The Second International Symposium on Hydrological Applications of Weather Radar was held in Hannover in August 1992. Five Members of the Interagency Committee attended along with 120 delegates from over 30 countries. In general the conference was a success but few papers contained any hydrology and many concentrated on Z-R relationships. This lack of advancement for hydrological use of weather radar served to confirm the UK's leading role in this area. At the symposium it was decided that the Third Symposium would be held in Brazil in 1995.

7. THE FUTURE

Scientific meetings and workshops

The Committee has begun planning two meetings. The first will be a workshop for the exchange of scientific ideas, similar to the Lancaster meeting in October 1991. Easter 1994 has been set as a provisional date and attendance will be by invitation. The second meeting will provide an opportunity for the scientific community to present their expertise to the UK consulting engineering community and to funding bodies such as the ODA, and to publicise the opportunities for applied research. This meeting is currently scheduled for Autumn 1994.

Membership and Committee meetings

At the meeting of the Committee in February 1993, Dr Walsh agreed to continue for a further term as Chairman, Mr Austin replaced Dr Acreman as Secretary, and the Committee resolved to coopt two further members to fill the vacancies available.

The next meeting of the Committee will be in September 1993.

APPENDIX A

Constitution

The Committee is constituted of members appointed by the following supporting agencies:

Meteorological Office	- 1
MAFF	- 1
NRA	- 2
NERC	- 1
SERC	- 1
Scottish Office	- 1
Water Services Association	- 1

and up to four members (of which at least two should be from Higher Education Institutes and/or research organisations) to be co-opted for a two year period at the invitation of the Committee. The Chairman is appointed from amongst the representatives of the supporting agencies for a two year term of office. The Secretary to the Committee is provided by the Institute of Hydrology.

Terms of reference

1. To identify research needs and opportunities

2. To recommend priorities for future research and to coordinate research activities

3. To seek funding for research.

4. To identify needs for and availability of data and to recommend archiving requirements.

5. To publicise and promote hydrological uses of weather radar.

6. To promote and establish international contacts.

7. To report on its work to the nominating bodies and the water industry generally.

APPENDIX B

Members

Dr P D Walsh (*Chairman*)	National Rivers Authority North West Region
Mr C G Collier	Meteorological Office Met Star Consultants
Dr A Donald	Scottish Office Environment Department
Mr R W Hatton	National Rivers Authority South West Region
Dr D Llewellyn-Jones	Science & Engineering Research Council Rutherford-Appleton Laboratory
Mr R J Moore	Natural Environment Research Council Institute of Hydrology
Mr B D Richardson	Ministry of Agriculture, Fisheries and Food Flood Defence Division
Mr J M Tyson	Water Services Association North West Water Ltd
Dr M C Acreman (*Secretary to Feb. 1993*)	Natural Environment Research Council Institute of Hydrology
Mr R M Austin (*Secretary from Feb. 1993*)	Natural Environment Research Council Institute of Hydrology

Coopted members

Dr A J Illingworth	University of Reading Joint Centre for Mesoscale Meteorology (formerly at University of Manchester Institute of Science & Technology Department of Pure and Applied Physics)
Professor I D Cluckie	University of Salford Department of Civil Engineering

Observers

Dr G Shepherd	States of Jersey Resources Recovery Board

APPENDIX C PRIORITY TOPICS FOR RADAR HYDROMETEOROLOGICAL RESEARCH

In March 1992 the Natural Environment Research Council's Steering Committee on Hydrological Applications of Weather Radar produced a report proposing a *UK strategy for Radar Hydrometeorological Research during the 1990s*. The purpose of the report was to identify both needs and opportunities presented by the availability of weather radar data for basic research. Applications of weather radar, particularly to flood forecasting, are already well advanced and in operational use within the National Rivers Authority.

The Interagency Research Committee on Hydrological Use of Weather Radar, which replaces the NERC committee, has reviewed the topics identified in the strategy report. These have been grouped into four themes, and assigned priorities in Tables 1 and 2. Each topic appears under one or both of the headings of basic and applied research, but a second entry in the same table is replaced with an asterisk. Topics which are, or are similar to, HYREX projects are labelled (H). A brief description of each topic is provided in the listing which follows the tables. Fuller descriptions are given in the strategy report, obtainable from Mr Roger Austin at the Institute of Hydrology, Wallingford, UK.

Table 1 *First priority research topics*

	Basic Research	Applied Research
A. Processes		
B. Measurement		
	1. Bright band. 2. Vertical pointing radar and cloud physical model reflectivity profile studies. (H) 3. Combined weather radar and satellite systems for global rainfall measurement.	1. * 4. The radar/raingauge representativeness problem. (H)
C. Modelling and forecasting		
	1. Development of distributed grid-based rainfall-runoff models for flow forecasting. 2. Radar based rainfall forecasts for use in flow forecasting models. (H) 3. Time and space discretisation of weather radar for flow forecasting. 4. Radar and satellite data for global scale modelling. 5. Radar, GIS and digital terrain models to investigate hydrological regimes. 6. Radar, areal rainfall estimation and flood forecasting.	1. * 2. * 7. Calibration of weather radar within flood forecasting models. 8. The use of weather radar in forecasting flows at ungauged sites.
D. Data analysis		
	1. Use of radar for design storm estimation. 2. Climatology of short period rainfall.	1. * 3. Probable maximum precipitation.

Table 2 Second priority research topics

Basic Research	Applied Research
A. Processes	
1. Weather radar and snowmelt processes at the basin scale.	1. *
2. Effect of urban areas on precipitation.	2. *
	3. Areal soil moisture deficit and actual evaporation estimation using radar.
B. Measurement	
4. The radar/raingauge representativeness problem. (H)	3. Combined weather radar and satellite systems for global rainfall measurement.
5. Climatologies of adjustment factors.	5. *
6. Scientific assessment of the potential of different radar systems. (H)	6. *
7. Radar measurement of snowfall.	7. *
8. High reflectivity gradients.	8. *
9. Wind drift.	13. Correction for attenuation.
10. Low level evaporation.	14. X-band radar systems.
11. Use of digital terrain models and GIS techniques.	15. Improving calibration using vertical pointing radar and raingauge networks.
12. Multiple beam scanning radar study.	
C. Modelling and forecasting	
7. Calibration of weather radar within flood forecasting models.	3. Time and space discretisation of weather radar for flow forecasting.
9. Tidally influenced flood forecasts using weather radar.	4. Radar and satellite data for global scale modelling.
10. The effect of catchment and storm conditions on flow response using rainfall-runoff models with radar as input.	6. Radar, areal rainfall estimation and flood forecasting.
11. The relative merits of continuous soil moisture accounting models and isolated event models for flood forecasting.	9. *
12. Physics-based distributed catchment models to investigate sensitivity of runoff response to storm type and basin factors.	10. *
	11. *
	12. *
	13. Improvements to rainfall-runoff modelling.
D. Data analysis	
3. Probable maximum precipitation.	4. *
4. The fractal structure of rainfall fields.	5. * (H)
5. Stochastic models of rainfall fields.(H)	7. Time-series analysis.
6. Information from radar patterns.	

BRIEF DESCRIPTIONS OF PRIORITY TOPICS

Topics are arranged by theme and number. Each entry comprises a heading, the priority rating(s) assigned to the topic, a brief description and, where appropriate, the reference number of the corresponding project description in *UK strategy for Radar Hydrometeorological Research during the 1990s*. Topics which are the same as, or similar to, HYREX projects are labelled (HYREX).

A. Processes

1. Weather radar and snowmelt processes at the basin scale. (BR2,AR2)

Radar would be used to estimate snowfall and melting level, in combination with ground survey and climatological measurements. A model of the snowmelt process coupled to a catchment runoff model would be used to study basin scale processes during snowfall events. (C2)

2. Effect of urban areas on precipitation. (BR2,AR2)

Rainfall pattern and intensity, and short-duration rainfall totals in particular, would be studied over urban areas, and for categories such as convective or frontal rainfall. (G4)

3. Areal soil moisture deficit and actual evaporation estimation using radar. (AR2)

Estimates of areal evaporation amounts could be improved by a knowledge of the spatial distribution of rainfall. Existing soil moisture/evaporation accounting models would be evaluated using a water balance approach and observed runoff data. (C3)

B. Measurement

1. Bright band. (BR1,AR1)

Development of techniques for the automatic detection of bright band would be supported by the use of dual polarization, fundamental research into types of precipitation within a storm, and models of the vertical profile of reflectivity as suggested in topic B2 below. (A6)

2. Vertical pointing radar and cloud physical model reflectivity profile studies. (BR1)

Vertical pointing radar would be used to measure, and validate models for, vertical reflectivity profiles. Bright-band, orographic, sampling, beam-overshooting and beam-filling corrections to C-band derived rainfall estimates would be computed from models and observations, and validated by a raingauge network. (A3) (HYREX)

3. Combined weather radar and satellite systems for global rainfall measurement. (BR1,AR2)

The feasibility of global scale systems for rainfall measurement, to support Global Circulation Models and hydrological macromodels, would be examined. Radar might be used to adjust and verify space-based observation, and to adjust models. Appropriate scale of measurement is an important consideration. (D1)

4. **The radar/raingauge representativeness problem.** (BR2,AR1)

   The effect of sub-grid inhomogeneity of the rainfall field on radar/gauge ratios could be quantified by comparing areal and individual totals from a high density gauge network for different synoptic types and gauge positions. (B1) (HYREX)

5. **Climatologies of adjustment factors.** (BR2,AR2)

   A quantitative approach to the identification of geographical areas of poor radar performance is needed which includes some discrimination of performance in different storm types. This is important in assessing the impact of changes to the radar on calibration systems. (B4)

6. **Scientific assessment of the potential of different radar systems.** (BR2,AR2)

   The potential of new developments in radar technology, such as Doppler and dual polarisation systems, should be investigated. (A1) (HYREX)

7. **Radar measurement of snowfall.** (BR2,AR2)

   A network of heated raingauges, an optical system for measuring snow, and surveys of lying snow would be used to explore the ability of radar to measure snowfall. (C1)

8. **High reflectivity gradients.** (BR2,AR2)

   High reflectivity gradients in time and space introduce measurement errors whose magnitude and frequency of occurrence, for frontal rainfall in particular, might be assessed using high resolution or 2km grid data. (A4)

9. **Wind drift.** (BR2)

   The HYREX facility would be used to quantify errors due to wind drift, and establish whether useful corrections could be made using Doppler or gradient winds. (B2)

10. **Low level evaporation.** (BR2)

    The effect of low level evaporation in reducing the rainfall measured by gauges used for radar calibration would be quantified, and might lead to a procedure for identifying and rejecting affected sites. (B3)

11. **Use of digital terrain models and GIS techniques.** (BR2)

    Digital terrain models can automatically identify areas in which the radar beam is obscured, and might be used to support more complex calibration methods. New GIS techniques could be developed to handle radar data and interface with models. Both could be used for fundamental studies of the failure of radar to measure rain at ground level under certain conditions. (D3)

12. **Multiple beam scanning radar study.** (BR2)

    Multiple beam data may be used to assist rainfall estimation in orographic terrain and improve radar calibration factors based on the lowest beam data. Vertical variation in rainfall amounts in different rainfall systems might also be investigated. (A2)

13. **Correction for attenuation.** (AR2)

Errors due to incorrect attenuation corrections, and the influence of bright band in particular, might be identified using different wavelengths, overlapping radars, and data from gauge networks. (A5)

14. **X-band radar systems.** (AR2)

X-band radars provide high resolution data suitable for urban applications and are relatively cheap and portable. Their role as a complement to conventional C-band radar needs to be explored. They can produce reliable rainfall measurements if complemented with distrometers, but research into optimal procedures for combination is at an early stage. (A7)

15. **Improving calibration using vertical pointing radar and raingauge networks.** (AR2)

Vertical pointing radar could be used to remove errors in radar data before calibration with raingauges (topics B1 and B2 above). Another approach would be to look for systematic spatial variations between radar and gauge observations, introducing variables such as the areal extent of rainfall and orographic enhancement to explain the data. (A9)

C. *Modelling and forecasting*

1. **Development of distributed grid-based rainfall-runoff models for flow forecasting.** (BR1,AR1)

There are a large number of avenues to explore in the formulation of distributed rainfall-runoff models based on radar grids. These include the description of runoff within a grid cell, the interaction (if any) between cells, and the use of GIS and digital terrain models to support efficient parameterisation. Comparison with conventional lumped models is required. (F1)

2. **Radar based rainfall forecasts for use in flow forecasting models.** (BR1,AR1)

Short term rainfall forecasts based on network (FRONTIERS) or local radar would be investigated in the context of flood forecasting. Attention would be given to forecasting convective storms, and to the robustness of flow forecasts. The information would be used to provide guidance in the issuing of flood warnings. (F10) (HYREX)

3. **Time and space discretisation of weather radar for flow forecasting.** (BR1,AR2)

The trade off between data resolution and forecast accuracy would be examined with respect to factors such as catchment size and type, synoptic conditions, radar data type and accuracy requirements. (E5)

4. **Radar and satellite data for global scale modelling.** (BR1,AR2)

The complementary rôle of raingauge, radar and satellite data in providing global data sets to support macromodels would be explored, as would suitable model structures for accommodating such data in point, small and large grid form. (D2)

5. **Radar, GIS techniques and digital terrain models to investigate hydrological regimes.** (BR1)

   GIS techniques, digital terrain models and spatially distributed hydrological databases offer tremendous scope for research on aspects of hydrological regimes such as the spatial variability of runoff in response to distributed radar rainfall. They also offer the prospect of incorporating detailed process understanding in more complex, but more complete, catchment models. (F4)

6. **Radar, areal rainfall estimation and flood forecasting.** (BR1,AR2)

   The accuracy of flow forecasts resulting from the use of a point raingauge measurement, different gauge-based areal rainfall estimators, and weather radar measurements would be examined. (F11)

7. **Calibration of weather radar within flood forecasting models.** (BR2,AR1)

   Instead of calibrating radar using a network of raingauges, and using the calibrated data as input to a rainfall-runoff model, the calibration might be performed implicitly within the model. (F6)

8. **The use of weather radar in forecasting flows at ungauged sites.** (AR1)

   Models for flow at ungauged sites would be developed to make use of recently available data sets on relief, soils and vegetation, and would be evaluated with particular reference to radar data. (F8)

9. **Tidally influenced flood forecasts using weather radar.** (BR2,AR2)

   Channel based flow models predominate over rainfall-runoff models in forecasting combined fluvial and tidal flooding in large estuaries, but there are many locations in which local runoff can be important, and the use of radar in such situations may improve the ability to forecast floods and lead to improved design procedures for flood alleviation works. (F9)

10. **The effect of catchment and storm conditions on flow response using rainfall-runoff models with radar as input.** (BR2,AR2)

    The impact on catchment flow response of factors such as antecedent soil moisture conditions, and the alignment and configuration of a catchment relative to a storm system moving across it, would be investigated using distributed radar data, and would lead to better formulated rainfall-runoff models. (F5)

11. **The relative merits of continuous soil moisture accounting models and isolated event models for flood forecasting.** (BR2,AR2)

    The impact on forecast accuracy of the use of continuous soil moisture accounting models or isolated event models, taking radar rainfall as input, would be assessed in simulation mode and using various forecast updating techniques. (F7)

12. **Physics-based distributed catchment models to investigate sensitivity of runoff response to storm type and basin factors.** (BR2,AR2)

    Processes influencing runoff response from catchments of different size and form would be investigated using a physics-based distributed catchment model, paying particular attention to spatially varying rainfall due to moving storms of different types, and to the time and space discretisation of the rainfall. The implications for radar data specification would be assessed. (F2)

13. Improvements to rainfall-runoff modelling. (BR2,AR2)

Relevant modelling techniques developed under other topics, such as snowmelt forecasting, the use of FRONTIERS and local radar rainfall forecasts, and various forms of calibration, will be used to develop fully distributed models based on radar data for real time applications. (F12)

D. Data analysis

1. Use of weather radar for design storm estimation. (BR1,AR1)

Topics include probable maximum probable precipitation (see D3), storm profiles, areal reduction factors and, in particular, estimation and regionalisation of storm duration-intensity-frequency. Raingauge data are required to supplement the relatively short records of radar data. (F3)

2. Climatology of short period rainfall. (BR1)

Radar data on a 5km grid would be used to study short-period storm duration, totals and return period. Radar pixel and co-located point raingauge rainfall frequencies would need to be compared, and return periods of areal totals would be of interest. There is a need for a long-term archive of higher resolution data to permit such studies on 2km or even 1km grids. (G1)

3. Probable maximum precipitation. (BR2,AR1)

Existing PMP fields for the UK are based on raingauge data. There is a need, for short durations in particular, to investigate the effect of high resolution radar data on accepted values, and to study the mechanisms by which these values might be approached or exceeded. Storm totals might also be studied in a Lagrangian frame, and the stationarity of particular storms investigated. (G2)

4. The fractal structure of rainfall fields. (BR2,AR2)

Research into the fractal structure of rainfall fields using radar data is important both in the mathematics of fractal processes and in the way natural phenomena exhibit fractal behaviour. (E2)

5. Stochastic models of rainfall fields. (BR2,AR2)

The good radar data sets available in the UK could be used to infer the spatial structure of rainfall fields or for the validation of existing stochastic models. (E3) (HYREX)

6. Information from radar patterns. (BR2)

Information characterising the type and stage of development of rainfall systems could be obtained from radar images using methods such as space-time correlation between data elements, or texture analysis. This might be used to improve calibration, infer development of the echo, highlight important features, and identify orographic effects. 4D data sets might also be studied. (E1)

7. Time-series analysis. (AR2)

Radar/gauge ratios are sometimes observed to change with time in a progressive manner, though with random fluctuations superimposed, due to changes in meteorological conditions. Time-series analysis should lead to a better understanding of this process. (E4)

APPENDIX D DIRECTORY OF UK EXPERTISE IN THE HYDROLOGICAL USE OF WEATHER RADAR

The contactee within each organisation is indicated with an asterisk.

Higher Education Institutions

University of Bristol

Department of Geography
University of Bristol
University Road
Bristol BS8 1SS

*Professor E C Barrett

University of Edinburgh

Department of Meteorology
University of Edinburgh
James Clerk Maxwell Building
The King's Buildings
Mayfield Road
Edinburgh
EH9 3JZ

*Dr C Duncan

University of Essex

Department of Mathematics
University of Essex
Colchester

*Professor A Holt
Dr V Brown
Dr R McGuinness

Department of Electronics Systems Engineering

Dr D H O Bebbington

University of Lancaster

Environmental Sciences Division
University of Lancaster
Bailrigg
Lancaster LA1 4YQ

*Dr J F R McIlveen		
Mr J Mann	(RS)	Calibration of radar performance in severe convective storms, topographical and other influences on behaviour of severe convective storms as observed by radar.
Ms J Thielen	(RS)	Observation of severe convective storms by weather radar and standard meteorological means, dynamical modelling of severe convective storms observed by radar.
Prof P C Young		
Mr M Lord	(RS)	Use of novel time and space analysis to improve real time calibration of weather radar.

University of Newcastle-upon-Tyne

Department of Civil Engineering
University of Newcastle-upon-Tyne
Newcastle-upon-Tyne
NE1 7RU

*Professor P E O'Connell		Spatial rainfall process modelling
D Mellor	(RS)	"

University of Reading

Department of Meteorology
(Joint Centre for Mesoscale Meteorology)
University of Reading
2 Earley Gate
Whiteknights
PO Box 239
Reading RG6 2AU

*Dr A J Illingworth		Estimating rainfall using Doppler and Polarisation radar techniques. Radar validation of satellite rainfall estimates.
Mr M Blackman	(RS)	Polarisation radar techniques.
Mr N Fox	(RS)	Aircraft verification of radar inferences.
Mr D Jones	(RS)	Satellite radiometer calibrations.
Dr V Marecal	(PDRA)	Mesoscale modelling of rainfall events.
Dr J Thomason	(PDRA)	Correcting vertical profiles of radar reflectivity.
Mr D Wilson	(RS)	Bright band analysis. Doppler techniques.

		Radar validation of satellite rainfall estimates.
Mr D Jones	(RS)	Calibrating satellite radiometer by radar comparisons.

University of Salford

Department of Civil Engineering
University of Salford
Salford
M5 4WT

*Professor I D Cluckie
Dr B Barber
Dr K A Tilford

Mr A Abes	(RS)	Active control of urban drainage systems using weather radar.
Mr B Austin	(RS)	PMP/PMF Modelling using radar storm transposition method.
Mr J Cox	(RS)	Real-time drought management strategies.
Mr R Griffith	(RS)	Engineering development of an urban flash flood expert system.
Mr Hajjam	(RS)	Radar hydrology and flood producing storms.
Dr D Han	(PDRF)	Low cost "C" band radar for urban hydrology. Vertical pointing X-band radar.
Dr R Norreys	(PDRF)	Water quality river impact model for river basin management. Real-time radar based large scale urban pipe network model.
Mr L Scott	(RS)	Real-time forecasting of tidal surges using non-orthogonal boundary fitted coordinate systems.
Ms S Towers	(RS)	Vertical reflectivity profiles and real-time calibration of scanning hydrological radars.
Mr O Wedgwood*	(RS)	Engineering development of a 'flash flood' expert system.
Mr A Wild	(RS)	Macro scale hydrological process modelling using remotely sensed data.
M J Yuan	(PGRA)	The hydrological use of weather radar data for design and rehabilitation of urban drainage systems.
Mr L Zhang	(PGRA)	Development of Dendritic real-time river basin model.

Professor C G Collier	Visiting Professor, Meteorological Office.
Dr G W Shepherd	Visiting Fellow, States of Jersey.

* Now with NRA North West Region

University of Strathclyde

Department of Pure and Applied Physics
University of Strathclyde
John Anderson Building
107 Rottenrow
Glasgow G4 0NG

*Dr J Crowther

Agencies and private companies

Meteorological Office

Met Star Consultants
Meteorological Office
Room 6/12 Sutton House
London Road
Bracknell RG12 2SY

*Professor C G Collier	Radar technology and installation. Radar data quality assessment. Rainfall and weather nowcasting and forecasting.
W K Wheeler	Radar sites, hardware and software
Dr P K James	Operational radar networking software, central processing including European radar networking, operational FRONTIERS
M Woodley	Radar data sales
R Brown	Forecasting using radar data, data quality control
Dr B J Conway	Artificial intelligence
Miss R B E Lilley	Doppler radar development
Dr K Browning	Mesoscale meteorological research

National Rivers Authority

Northumbrian Region

NRA Northumbrian Region
Eldon House
Regent Centre
Gosforth
Newcastle-upon-tyne
ME3 3UD

*D Archer	General research and operations, particularly flood warning and forecasting

Wessex Region

NRA Wessex Region
Rivers House
East Quay
Bridgewater
Somerset
TA6 4TS

*L Aucott "

South West Region
National Rivers Authority
Kestrel Way
Exeter EX2 7LQ

*R Hatton "

Thames Region
National Rivers Authority
Aspen House
Crossbrook Street
Waltham Cross
Hertfordshire EN8 8LX

*C Haggett "
P Borrows "
G Merrick "
B May "
M Crees "

North West Region
National Rivers Authority
PO Box 12
Richard Fairclough House
Knutsford Road
Warrington WA4 1HG.

*Dr S Walker "
I Pearse "
M Knowles "
O Wedgewood "

Anglian Region

NRA Anglian Region
Kingfisher House
Goldhay Way
Orton Goldhay
Peterborough
PE2 5ZR

*N Fawthrop	"
J East	"
S Dines	"
J Stanton	"

Severn Trent Region

NRA Severn-Trent Region
Sapphire East
550 Streetsbrook Road
Solihull
B91 9QT

*R Goodhew	"
C Dobson	"

Yorkshire Region

NRA Yorkshire Region
Rivers House
21 Park Square South
Leeds
LS1 2QG

*M Cottingham	"
S Pomeroy	"

Welsh Region

Rivers House
Plas-yr-Afon
St Mellons Business Park
St Mellons
Cardiff
CF3 0EG

*J Mosedale	"
D Cadman	"

Southern Region

Guidebourne House
Chatsworth Road
Worthing
W Sussex
BN1 1LD

Research Companies

Hydraulics Research Ltd
Crowmarsh Gifford
Wallingford
Oxfordshire OX10 8BA

*M Osborne	Application of radar data to urban drainage design.

Water Research Centre
Flankland Road
Blagrove
Swindon SN5 8YR

*M Green	Application of radar data to urban drainage design.

River Purification Boards

Forth River Purification Board
Clearwater House
Heriot Watt Research Park
Avenue North
Riccarton
Edinburgh EH14 4AP

*R J Sargent	Flood warning and forecasting

Tay River Purification Board
1 South Street
Perth PH2 8NJ

*J Anderson	Flood warning and forecasting

Tweed River Purification Board
Burnbrae
Mossilee Road
Galashiels TD1 1NF

*I Fox	Flood warning and forecasting

Clyde River Purification Board
Rivers House
Murray Road
East Kilbride
Glasgow G75 0LA

*J Curran	Flood warning and forecasting

Water service companies

North West Water Ltd
Dawson House
Great Sankey
Warrington

*J M Tyson	Application of radar data to urban drainage planning, design and control

Thames Water Utilities
Sewerage and Sewage Treatment Operations
Nugent House (Napier Court 5)
Vastern Road
Reading
Berkshire RG1 8DB

*N E Martin	Application of radar data to urban stormwater management

Yorkshire Water Ltd
2 The Embankment
Leeds LS1 4BG

*Dr A Mackam	Application of radar data to urban drainage planning, design and control

Research Councils

Natural Environment Research Council

Institute of Hydrology
Crowmarsh Gifford
Wallingford
Oxfordshire OX10 8BB

*R J Moore	Radar calibration, rainfall and flow forecasting
D A Jones	Radar calibration and rainfall forecasting
D S Hotchkiss	Radar rainfall forecasting
R Austin	Flow forecasting using radar
V Bell	Distributed flow forecasting using radar
K B Black	Radar database management and display software
Dr D W Reed	Point and areal rainfall statistics using radar data
E J Stewart	Areal reduction factors and design storm specification from radar data
D C W Marshall	Small catchment flood response times estimated using radar data

Unit of Thematic Information Studies
Natural Environment Research Council
Department of Geography
University of Reading
Whiteknights
PO Box 227
Reading RG6 2AB

*Mr I J McKendrick	Data structures from space radars with different orbits.

Science and Engineering Research Council

Rutherford-Appleton Laboratory
R25 Chilton
Didcot
Oxfordshire OX11 OQX

*Dr D Llewellyn-Jones

Government Departments

Ministry of Agriculture, Fisheries and Food

Eastbury House
30/34 Albert Embankment
London SE1 7TL

*Mr B D Richardson — Radar network policy and science administration

Field Drainage Experimental Unit

A D Muscutt — Small catchment flood response studies using radar data

Scottish Office

The Scottish Office
Environment Department
27 Perth Street
Edinburgh EH3 5RB

*Dr A Donald — Radar network policy and science administration

States of Jersey Resources Recovery Board

PO Box 86
Bellozanne Road
St Hellier
Jersey

*Dr G Shepherd — Radar network policy and science administration. Development of urban applications.

APPENDIX E HYREX SPECIAL TOPIC AWARDS

1. **Dr H S Wheater (Imperial College), Prof. V Isham (UCL), Prof. Sir David Cox (Oxford)**

   Spatial-temporal rainfall fields: modelling and statistical aspects.

   £117k

2. **Dr A J Illingworth (Reading), Mr J W F Goddard (RAL)**

   Verification of polarisation radar techniques for improving estimates of rainfall.

   £74k

3. **Prof. A J Thorpe, Dr M A Pedder (JCMM, Reading), Mr R J Moore (IH)**

   Methods for short-period precipitation and flow forecasting incorporating radar data.

   £107k

4. **Prof. P E O'Connell, Dr A V Metcalfe (Newcastle)**

   The development of a stochastic space-time rainfall forecasting system for real-time flow forecasting.

   £80k

5. **Mr R J Moore (IH)**

   Design of radar/raingauge networks for hydrological use.

   £53k

6. **Prof. I D Cluckie, Dr K A Tilford (Salford)**

   Radar hydrometeorology using a vertically pointing radar.

   £99k