Inter-Agency Committee on the Hydrological Use of Weather Radar

Fifth Report

2003 to 2005

Report published on behalf of the Committee by CEH Wallingford

CEH Wallingford
Crowmarsh Gifford
Wallingford
Oxon
OX10 8BB

June 2005

Preface

I am pleased to present to the organisations represented on the Committee and to the wider community of practitioners and researchers who have an interest in the development of weather radar for hydrological use, our fifth report. This covers the period 2003 to 2005 when we have seen advances in both the research and operational arenas that support the UK's Weather Radar Network and beyond.

Although research and development efforts continue to focus on improving the quality of radar information and the use of this information to improve rainfall and flood forecasting, the "take-up" of this technology by the operating agencies remains patchy. The main operational services that are underpinned by the Weather Radar Network are the National Severe Weather Warning and the Flood Warning Services. The organisations that are responsible for delivering these services continue to invest in Network modernisation and targeted research work, and tangible benefits of this investment can be demonstrated. However, only limited use is made of radar information to support other functions such as urban drainage, water supply, water resources, etc. In the area of urban drainage for example, due to no current requirement to provide flood warnings and the limited requirement to control drainage networks, there is limited demand for predictive or real-time radar data at present, but this may change in the future.

The potential that weather radar and related technologies offer needs to be recognised, understood and exploited across all relevant functions to meet existing and future business needs and this is where the Inter-Agency Committee can be of value. The advantage of having a national forum of leading researchers and practitioners that can meet regularly, exchange ideas and debate research and operational needs, should not be underestimated. By focusing on research needs and opportunities, data needs and availability, and through international collaboration the Committee continues to promote the hydrological uses of weather radar and helps bridge the gap between research and operational implementation for the benefit of all parties.

I would like to thank all the members of the Committee who have continued to play a full role in the Committee's activities both during and between our quarterly meetings: their support is much appreciated. Particular mention is due to Professor Anthony Holt who retired this year after over 10 years membership of the Committee. Anthony has been a leading ambassador for weather radar and related technologies both in the UK and across the World throughout his career. The work he led in Essex University has helped ensure that this country remains in the forefront of research in this area; we all wish Anthony well in his retirement.

Dr Chris Haggett
Committee Chairman (2003-2005)

Contents

1. Introduction

If we cast our eyes back to the 1960s and 1970s when the potential of weather radar for hydrological uses was first recognised in the UK, four important attributes were identified:

1. Radar could be processed in real-time, transmitted from site and displayed remotely,
2. Radar could measure areal precipitation over a large area of varying terrain,
3. Radar data could be used to improve the short-period quantitative forecasting of precipitation which could be used in turn to improve flood forecasts,
4. On-line hydrological forecasting using radar data was shown to be feasible.

Over the last 40 years we have seen impressive technological and scientific advances that have helped realise this potential, particularly in the first three areas listed above. However, the routine and widespread use of weather radar data in hydrological forecasting to support operational decision-making still eludes us. Despite significant research in this area, the operating agencies still have a lack in confidence to make the transition. The gap between the findings of the research community and the take-up of those findings by operational practitioners remains large.

It is not surprising then that the need to focus on ways to influence the greater use of weather radar by operating agencies to meet their service delivery requirements was the main driver of this session of the Committee's work. Identification of user requirements; suggested ways in which research findings can be "pulled through" to operational practice; and ways of raising the awareness of weather radar are key areas addressed in this report.

On a more positive note, during the period of this session investment in the National Weather Radar Network has continued. As the joint Met Office/Environment Agency National Radar Committee reports, almost every aspect of the Network has been modernised at a total cost of about £3m to the partners. By the end of 2004 it is estimated that 85% of the recommended developments set out by the then National Rivers Authority in 1995 have been implemented. This has "delivered tangible benefits in terms of radar capability and performance and has enabled radar data to be used in a wider range of services". In addition to this, the Environment Agency now routinely makes radar data available to up to 200 operational staff via the Hyrad display and processing system; and SEPA has adopted Hyrad for White Cart Water (Glasgow) with an interface to the RFFS-FloodWorks flood forecasting system.

There are important developments on the horizon that will help. In 2005 the UK's first dual polarisation radar will become operational in Kent and if successful could influence future enhancement plans for the entire Weather Radar Network. The Environment Agency will be launching two new important systems that will facilitate the wider provision of flood forecasting and warning services across England and Wales. These are the "National Flood Forecasting System" serving as an integrated forecasting facility and "Floodline Warnings Direct" which functions as a multi-channelled warning and information service. Greater public demand for accurate, reliable and timely flood warnings will drive the need for improved rainfall measurement and forecasts over the coming years. The NERC-funded FREE (Flood Risk from Extreme Events) research programme aims to investigate the scientific basis of both fluvial and coastal flooding. The meteorological, hydrological and coastal oceanographic communities will combine to address this activity, which represents the largest NERC-funded research programme (£6 million over five years) currently underway.

2. Community Plan – a review of Committee activities

2.1 Background and Aims

In the previous session the Committee addressed the following activities:

- Integration with NERC and National Programmes
- Providing co-ordinated UK support to current international projects
- Improved dissemination of information to the UK community

In this session the Committee focussed on ways to facilitate the greater use of weather radar and related technologies by operating agencies to meet their service delivery requirements; ways of facilitating more effective "pull through" of research findings into the operational arena; and on raising awareness of weather radar in the wider community.

2.2 Strategic Overview

Presented in the table below is a broad strategic outline of the activities pursued under the 2003-2005 Programme.

Strategic Area 1	**Strategic Area 2**	**Strategic Area 3**
Bringing research findings into operational use	Identifying and addressing service delivery needs of operating agencies	Raising awareness of weather radar in the wider community

This activity strategy aimed to help address the following terms of reference of the Committee:

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

2. To identify research needs and opportunities

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

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

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

2.3 Milestones and Deliverables

A number of key deliverables were identified under each Strategic Area, and a lead contact for each area assigned to report on progress against these deliverables. A brief report on the progress that has been achieved is presented below. Appendix 1 provides an outline milestone report whilst more detailed reports produced as deliverables feature as

Appendices 4 to 9. The Committee's constitution, terms of reference and membership are set down in Appendix 2 and 3.

2.4 Reports on Strategic Areas

2.4.1 Strategic Area 1 – Bringing research findings into operational use

(a) Identify examples of best practice in recent research work

The use of radar to measure precipitation continues to be a major area of research activity worldwide. In the UK Nimrod provides in real time quality-controlled radar estimates of rainfall. Research is moving in two directions. Firstly the enhancement of reflectivity-only based techniques using output from high resolution Numerical Weather Prediction (NWP) models to allow for the drift of precipitation with the wind as it descends, and to identify the melting level so improving techniques for adjusting the data for bright-band effects (see Mittermaier and Illingworth, 2003; Michelson *et al*., 2005). Secondly the operational introduction of polarisation diversity in the UK with the installation of the Kent radar offers the opportunity to investigate ways of improving data quality. Much work has been published on the ability of polarisation diversity radars to identify ground clutter, anaprop, bright-band enhancement and attenuation by rain and hail (for a brief review see Collier, 2002). In the UK these developments have focused upon the use of data from the S-band Chilbolton radar (see for example Goddard *et al*., 1994: Smyth and Illingworth, 1998). However, the Kent radar will operate at C-band and further research is necessary to ensure algorithms developed at S-band are effective at C-band.

The use of radar for short-period forecasting has similarly followed two distinct pathways. Nowcasting techniques based upon the advection of radar echoes are operational in Nimrod/GANDOLF, and have been successfully enhanced using wind fields from operational NWP mesoscale models (Golding, 2000). More recently the generation of heuristic forecasting procedures with some level of skill in predicting the growth and decay of the rainfall field have met with some success, and a procedure now known as STEPS is operational in the UK (Bowler *et al.*, 2004). In parallel with this activity the use of radar data as direct input to NWP models is receiving considerable attention. The use of both reflectivity (Macpherson *et al*., 1996) and radar radial winds (Rihan *et al*., 2005) are areas of active research in the UK, and show potential for improving forecast accuracy at lead times beyond those addressed by nowcasting techniques.

The use of radar as direct input to hydrological models continues to receive attention. It is clear in this area that the unusual error characteristics of radar estimates of precipitation necessitate the development of procedures for handling and estimating uncertainty. Robbins and Collier (2005) consider a methodology for assessing the impact of different observing systems on flows from an urban drainage model, and work is on-going at CEH and elsewhere to incorporate uncertainty into hydrological model structures.

Finally the use of measurements of attenuation along dual and single frequency microwave communication links for estimating path-integrated rainfall has been demonstrated (see Rahimi *et al.*, 2004). This technique compliments radar and offers the possibility of adjusting the radar reflectivity measurements for the effects of attenuation by rain in the beam.

References

Bowler, N.E.H., Pierce, C.E. and Seed, A. 2004. Development of a precipitation nowcasting algorithm based upon optical flow techniques. *J. Hydrology*, **288**, 74-91.

Collier, C.G. 2002. Developments in radar and remote sensing methods for measuring and forecasting rainfall. *Phil. Trans. R. Soc. Lond.*, **A360**, 1345-1361.

Goddard, J.W.F., Tan, J. and Thurai, M. 1994. Technique for calibration of meteorological radars using differential phase. *Electronic Letters*, **30**, 166-167.

Golding, B.W. 2000. Quantitative precipitation forecasting in the UK. *J. Hydrology*, **239**, 286-305.

Macpherson, B., Wright, B.J., Hand, W.H. and Maycock, A.J. 1996. The impact of MOPS moisture data in the UK Meteorological Office mesoscale data assimilation scheme. *Mon. Weather Rev.*, **124**, 1746-1766.

Michelson, D.B., Jones, C.G., Landius, T., Collier, C.G., Haase, G. and Heen, M. 2005. *Down-to-Earth* modelling of equivalent surface precipitation using multisource data and radar. *Quart. J. R.. Met. Soc*., **131**, 1093-1112.

Mittermaier, M.P. and Illingworth, A.J. 2003. Comparison of model-derived and radar-observed freezing-level heights: Implications for vertical reflectivity profile-correction schemes. *Quart. J. R. Met. Soc*., **129**, 83-96.

Rahimi, A.R., Upton, G.J. G. and Holt, A.R. 2004. Dual-frequency links – a complement to gauges and radar for the measurement of rain. *J. Hydrology*, **288**, 3-12.

Rihan, F.A., Collier, C.G. and Roulstone, I. 2005. Four dimensional variational data assimilation for Doppler radar wind data. *J. Comp. App. Math*., **176**, 15-34.

Robbins, G.L. and Collier, C.G. 2005. Assessing error in hydrological and hydraulic model output flows. *Atmos. Science Letters*, **6(1)**, 47-53.

Smyth, T.J. and Illingworth, A.J. 1998. Correction for attenuation of radar reflectivity using polarisation data. *Quart. J. R.. Met. Soc*., **124**, 2393-2415.

(b) Identify a process for "operational pull through" that researchers can follow

In common with some other areas of research, the IACHWR have concerns over the degree of implementation of research work undertaken. The scientific body of knowledge is advancing through research but the application of findings into the operational activities and day-to-day work of users of technology is lagging behind. Weather radar is by its very nature a complex and technical area and the application of new developments requires an appropriate level of knowledge, both in the new development and in existing systems, to enable users to make use of them. To improve the take-up of developments, it is suggested that researchers should pay more attention in the early stages of defining a project on how the findings may be used. Implementation plans form a part of some projects but often these are developed without clear definition of the stages for implementation and resources required. Examples of approaches to Project Planning and how implementation might be better considered are set out in Appendix 4 along with specific examples of good practice.

(c) Convene workshop bringing together research community and operating agencies

A workshop bringing together the research community and operating agencies was considered by the Committee. However, it was judged that a number of initiatives that related to the hydrological use of weather radar were in the process of being launched and it was not timely for the Committee to host a workshop within the Session being reported here. Instead, it was decided to convene a meeting to coincide with the Kent Radar launch and the publication of this Session Report and Bibliography.

(d) Engage in European research programmes (e.g. ACTIF, Framework6, COST717, etc)

The European Union Framework 5 Programme has now formally finished, although some individual projects still remain to be completed (e.g. CARPE DIEM). The European Workshop on New Tools for Flood Forecasting and Warning was held from 22-23 June 2004 in Helsinki. This Workshop reported the outcome of three Framework 5 projects:

MANTISSA	http://prswww.essex.ac.uk/mantissa/
MUSIC	http://www.geomin.unibo.it/orgv/hydro/music/
CARPE DIEM	http://carpediem.ub.es/

A CD containing the proceedings is available from the EU. Some of the papers dealt with radar data. The ACTIF Project, concerned with identifying best practice in flood forecasting and warning, held its second Workshop in Delft from 22-23 November 2004. Papers from this meeting are to be posted on the project web site in 2005: http://www.actif-ec.net/.

The first call for Framework 6 has been completed. In the floods area, one Integrated Project - FLOODSITE (http://www.floodsite.net/) - was awarded with a budget of 14 million euros over five years. It began on 1 March 2004. The key actions in FLOODSITE are:

- Research on sources of flooding, the effectiveness of defences and the impact of floods.
- Management of flood risks, from long-term planning to new technologies for flood warning.
- Developing knowledge from analysing real flood cases in Belgium, the Czech Republic, France, Germany, Hungary, Italy, the Netherlands, Spain and the UK.

No Networks of Excellence were successful. The second call for this programme has been made and a number of projects involving radar are in preparation.

COST 717 "Use of radar observations in hydrological and NWP models" is now coming to an end, and the final report is in preparation. A follow-on project, COST 731 "Propagation of Uncertainty in Advanced Meteo-Hydrological Forecast Systems", has been approved by the COST Technical Committee and the COST Senior Officials. This project will involve the use of high resolution NWP model output and radar. BALTRAD, a part of the WMO BALTEX Project, continues its work to establish and extend the radar network in and around the Nordic countries.

The results from many of these research programmes were reported at the European Conference on Radar in Meteorology and Hydrology (ERAD) held in Visby, Sweden, 6-10 September 2004.

In the UK the Flood Risk Management Research Consortium (FRMRC), led by EPSRC, is underway. The NERC-led FREE (Flood Risk from Extreme Events) Programme has been approved at a funding level of £6 million over five years.

The FREE research programme will bring together meteorologists, hydrologists and coastal oceanographers to investigate the mechanisms and science of extreme events leading to both fluvial and coastal flooding on time scales from minutes to seasons and beyond. This programme is just getting underway, and details of the research being undertaken will be decided by early 2006.

The FRMRC is now in progress, and it will deliver practical operational tools to aid flood forecasting and warning. The research being undertaken includes the search for methods of dealing with uncertainty in fluvial and urban flood forecasts, and the development of algorithms for extracting Quantitative Precipitation Estimates (QPE) from the new Kent polarisation diversity radar. This programme involves close stakeholder participation.

The European Flood Forecasting System (EFFS) was developed with EU funding by the EU Joint Research Centre (JRC), Ispra. The European Centre for Medium Range Weather Forecasting (ECMWF) operational ensemble precipitation forecasts are used as input to a distributed hydrological model covering the major catchments in Europe. The aim was to provide a system to warn of the likely occurrence of flooding some days in advance. It was meant to complement more local national systems. The EFFS is now being developed into a European Flood Advisory Service (EFAS), and involves the use of European wide weather radar data including data from the Nimrod system.

(e) Identify and prioritise new research opportunities to address the advancement of operational practice

New research opportunities to address the advancement of operational practice were considered by the Committee, under the leadership of Malcolm Kitchen (Met Office). The following statement was agreed.

The ideas below concern mainly the use of radar data in the measurement of surface precipitation (and to a lesser extent humidity). Research into forecasting techniques has not been considered here.

Near market academic research

Examples of academic research - either completed or planned in the Session period - which are 'near-market' (that it is considered to have the potential for almost direct implementation in the UK weather radar network) are set down below.

- Development of algorithms to estimate surface rainfall from dual-polarisation radar moments (subject of PhD work at Reading University sponsored by the Environment Agency/ Met Office) – to be implemented in operational processing of Kent radar data

- Development of a wind drift algorithm to be applied to operational radar data (subject of PhD work at Reading sponsored by the Environment Agency/Met Office but yet to be implemented on operational systems)

- Development of real-time adjustment procedure using data from microwave communications link (subject of NERC Connect-B project led by Essex University) – algorithms to be tested on radar data in real-time in parallel with operational gauge-adjustment scheme.

- Development of algorithms to estimate surface rainfall from dual-polarisation radar moments (subject of Bristol University project sponsored by EPSRC) – implementation path to be decided

- Assimilation of Doppler radial winds into high-resolution NWP (Salford University/Met Office)

"Near-operational" research opportunities

Examples of other opportunities for new "near-operational" research (a limited set in no particular order of priority or opportunity) are:

- Radar measurements of Boundary Layer Humidity

- Exploitation of synergy between different observation types to improve rainfall estimation. For example, the use of a network of disdrometers to assist in surface rainfall estimation from radar.

- Using pattern recognition methods to diagnose and correct radar data for the effects of radome attenuation.

- New methods of correcting radar data for the low-level growth of precipitation over hills using diagnostics from high-resolution NWP.

- Exploitation of new radar technology in hardware design

Scientific problems/opportunities

There are numerous physical effects which introduce uncertainty into the estimation of surface rainfall from radar, and hence could be considered to limit the advancement of Operational Practice (that is the use of weather radar data in hydrological applications). Almost all sources of uncertainty have been the subject of extensive international research efforts. Mitigation measures (mostly in the form of quality control and corrections applied in real-time to radar data) are already in place. The table below lists the sources of uncertainty in a rough order of magnitude, the perceived level of success achieved by existing mitigation (as in current Met Office processing) and the scope/opportunity for making further progress. Note that the relative importance of the different sources of uncertainty varies markedly case-to-case, between radar networks, and between different geographical regions. The table represents a viewpoint of the Committee and does not reflect any national or international consensus.

Source of uncertainty	**Current mitigation benefit**	**Likely opportunity benefit**
Bright Band	Corrected but significant residual errors	Large benefits but difficult to make progress
Orographic rainfall	Corrected but large residual errors in some cases over upland catchments	Benefits confined to upland areas – progress only likely through large numerical models
Uncertainty in Z-R transformation	None	40% residual uncertainty – progress through dual-polarisation

Attenuation	Corrected but unquantified residual errors in large storms	Some, but difficult to quantify – progress through dual-polarisation?
Compositing errors	Challenge is to make optimal use of all available data – extent to which current methods are sub-optimal is unknown	Unknown benefits but some progress should be possible
Radome attenuation	None – large errors are rare and confined to heavy convective rainfall	Some benefits should be relatively easy to obtain
Anaprop	Quality control processes in place but some large residual errors – mainly in no-rain events	Further progress may be very hard to win.
Detection efficiency	Challenge to improve and quantify everywhere in real-time.	Minor benefits for NWP but progress difficult (see also noise and interference)
Ground clutter	Quality control in place – some residual errors	Some opportunity to retrieve usable signals within areas of strong clutter
Hail	None – a problem only in severe convection	Detection problem likely to be addressed through dual polarisation. Correction problem much more difficult but potential benefits are high
Antenna imperfections and pointing	Limited corrections applied, but residual errors could affect performance of other corrections (bright band, beam blocking)	Some additional benefits should be relatively easy to obtain
Transient clutter (sea, birds, ships, trains, motor vehicles, aircraft)	No specific quality control in place except for sea clutter	Probably some scope for importing techniques from other radar applications (e.g. military target recognition/tracking). Benefits small and may be difficult to obtain
Wind drift	None – errors significant only at high resolutions and the smallest catchments	Some published methods already available – benefits likely to be small but relatively easy to obtain

Background radiation, noise and interference	None – normally affects ability to detect very light rainfall only	Some improvement in signal retrieval should be relatively easy to obtain.
Atmospheric refraction	None – affects performance of other corrections (bright band, beam blocking)	Benefits unknown - some improvement could be relatively easy to obtain.
Sampling issues (scan repetition rate, dwell time etc)	Challenge is to define optimal combination but unknown errors arising from use of sub-optimal	Probably not
Contradictions in information from different sources	Challenge is to define optimal method of combining different rainfall information (direct and indirect)	Opportunity benefit likely to increase as the quantity and diversity of information increases. Progress in some areas difficult (e.g. radar + gauge combination) but may be easier in others
Real-time estimation of uncertainty	Yes	Opportunity benefits high as probability forecasts NWP assimilation and risk-based approaches all require accurate estimates of uncertainty. Generalised approach is difficult.

Hydrological research opportunities for advancement of best practice

The following provides a selection of hydrological research opportunities where the use of weather radar data could advance best practice:

- Areal rainfall estimation using radar and/or raingauge data for catchment- and grid-based hydrological forecasting models
- Distributed hydrological forecasting models for use with weather radar for gauged and ungauged areas
- Data assimilation of radar and raingauge rainfall into hydrological forecasting models
- Characterisation of radar rainfall uncertainty and its propagation in probabilistic rainfall and flood forecasting models for risk-based flood warning decision-making
- Use of fine-resolution Numerical Weather Prediction model rainfall forecasts, incorporating radar data assimilation, in flood forecasting models

- Use of radar rainfall in flood/drought design and planning studies

- Use of radar rainfall in dynamic-stochastic space-time rainfall modelling for input to the continuous simulation approach to flood/drought design and planning

- Weather radar for urban stormwater management and design

(f) Collate information on existing research programmes in the field of weather radar and related technologies

Research progress over the Reporting Period is reviewed in Appendix 5 by research groups in six universities (Bristol, Essex, London: Imperial College and University College, Newcastle, Reading, Salford) together with CCLRC and CEH Wallingford. Reports are also provided by two UK Agencies: SEPA and the Met Office. A summary is provided below.

The **Bristol Group**'s work includes research on improved rainfall estimation using the vertical reflectivity profile (VPR), particularly to correct for the enhanced reflectivity due to melting snowflakes (the bright-band). Supported by a vertically pointing X-band radar and the Chilbolton radar, a new algorithm has been developed to detect the boundaries of the bright-band. A fuzzy logic based classification of hydrometeors is used in combination with a VRP correction algorithm. Research on quantisation of radar data and information loss has shown that, under certain conditions of data error, 3 bit data can be as satisfactory as 8 bit data. Ongoing work is being done under the EU project FLOOD RELIEF (concerned with a decision-support system integrating hydrological, meteorological and radar technologies) and the EPSRC Flood Risk Management Research Consortium under the real-time flood forecasting theme.

The **Essex Group**'s research concerns (i) the use of dual-frequency microwave links to estimate path-averaged rainfall corrected for attenuation and to detect sleet, (ii) detection of anomalous propagation by propagation modelling using NWP analysis information, and (iii) wind-field analysis using two Doppler radars and over oceans using the Windsat satellite equipped with polarisation sensitive radiometers.

Research of the **London Group** focuses on the use of weather radar to formulate stochastic space-time rainfall models for application in the continuous simulation approach to flood frequency analysis. Alternative methods are being investigated including Generalised Linear Models (GLMs) applied to daily raingauge network data, stochastic Poisson process models applied to short-term radar data, and hybrid methods that combine GLM and disaggregation to generate spatially correlated hourly data sequences.

The **Newcastle Group**'s research has focussed on rainfall forecasting by extrapolation methods and the use of radar rainfall in flood forecasting, both undertaken within the EU

MUSIC project. The former has concerned the development and assessment of a new spectral decomposition method of nowcasting; the research has considered the issues of field transformation, advection of features as a function of scale and ensemble forecasting. The latter concerned use of more accurate rainfall estimates and forecasts with uncertainty estimates with a rainfall-runoff model to provide hydrological forecasts with uncertainty estimates.

The **Reading Group**'s research - supported by the Chilbolton radar - concerned bright-band correction, wind-drift error correction using mesoscale model winds, and improved rain-rate estimation using polarisation radar. Nimrod's bright-band correction scheme uses the mesoscale model's estimate of the height at which the wet bulb temperature is zero as the height of the bright band. This has been checked using a vertical-pointing cloud radar and found to be a sufficiently accurate approximation. The wind-drift study demonstrated its importance, particularly at long-range, and developed an algorithm for correction which uses the vertical profile of wind from the mesoscale model. Polarisation radar can provide information on raindrop size which can be used to correct the coefficient in the reflectivity-rainfall relation, thereby improving rainfall estimation. A study using the Chilbolton radar indicates that averaging over an area of several km^2 is required to obtain sufficiently accurate estimates of the coefficient for operational use.

The **Salford Group**'s research work has involved comparison of the use of radar and raingauge data in a urban hydraulic model and a stochastic state-space model. A second topic concerns assimilation of Doppler radar radial winds into Numerical Weather Prediction (NWP) models to improve short-term forecasts.

The **CCLRC Group** are responsible for the Chilbolton Facilities for Atmospheric and Radio Research. This includes the 3 GHz polarisation-Doppler CAMRa radar used to support research on radial wind data assimilation in NWP (Numerical Weather Prediction) systems. The Facilities have also served a central role in the NERC Convective Storm Initiation Project. There is collaborative research with Essex and Salford on path-integrated rain-rate estimation using differential phase measurements from microwave links and with CEH involving the design and construction of a scintillometer for evaporation measurement.

The **CEH Wallingford Group** have extended their Hyrad system for the receipt, processing and display of radar data to accommodate NWP (rainfall and temperature) and MOSES -Met Office Surface Exchange Scheme – (soil moisture, evaporation and runoff) products and interface to new flood forecasting and warning systems. Proof of concept work has been done in collaboration with the Met Office on probabilistic rainfall and flood forecasting. A detailed assessment of Nimrod rainfall estimates for use in flood forecasting has highlighted consistency problems with the Hameldon radar data that require further investigation. A methodology for assessing the performance of rainfall forecasts, including ones in probabilistic form, has been formulated in a report and a PC tool. Work for Defra has investigated extreme rainfall and flood response for extreme historical storms having available radar data; a rainfall transformation tool has been developed to amplify storms for use in model destruction testing and modelled flood response experiments.

SEPA have an ongoing operational trial of the use of radar in flood forecasting, employing Hyrad and RFFS/FloodWorks configured to the White Cart catchment and using Corse Hill radar.

The **Met Office** is the principle operating authority for the UK weather radar network and has focussed its development effort over the Reporting Period on three areas: (i) re-engineering the data processing chain to centralise data processing and product generation in the new Radarnet IV system; clutter discrimination has also been improved; (ii) radar network development, with a new dual-polarisation radar in Kent and redeployment of the Wardon Hill radar to near Salisbury in progress and the prospect of a new radar in East Anglia; and (iii) increasing radar capability in the future to give Doppler wind support to NWP data assimilation, giving rise to a new PC-based radar signal processor (Cyclops-D).

2.4.2 Strategic Area 2 - Identifying and addressing service delivery needs of operating agencies

(a) Flood Forecasting and Warning

In Scotland

SEPA's Flood Warning Development Strategy (2001) identified two main areas for development:

- Improved access to radar data – SEPA should be moving towards real-time quantitative access to the 3 radars in Scotland. This is currently being trialled with Corse Hill radar. The use of these data may only increase as improvements are made to flood forecasting on fast response catchments and new flood warning schemes are introduced elsewhere.

- Improved radar coverage – the radar network in Scotland was never set up to provide the best coverage for flood warning. Therefore large areas of Scotland are left with poor radar coverage

See Appendix 6 for further details.

In England and Wales

The Environment Agency's National Weather Radar Strategy (2002) presents the following recommendations that are designed to ensure the continued provision and development of the Agency's Weather Radar Service and to meet the Agency's requirements for the period 2002-2012.

- Development of Met Office products to meet Agency needs, particularly relating to the new RadarNet IV centralised data processing and product generation system
- Implementation of the raingauge adjustment methodologies applied within the Met Office
- Investigation and selection of the radar adjustment techniques to be employed
- Development of the quality of data products
- Review of current historic radar data archives and analysis of the historic and future radar data archive requirements
- Implementation of additional radar base stations (e.g. Kent, East Anglian and NE England) and where agreed, relocation of existing stations (e.g. Wardon Hill)
- Evaluation of the effectiveness of the dual polarisation radar to be installed in Kent.

See Appendix 7 for further details.

In Northern Ireland

The Rivers Agency has been using raw single-site rainfall radar data in real-time flood response and analysis for around 10 years. This use comes at a relatively modest cost, but is becoming increasingly outdated and employs a DOS-based program that will not be developed because of insufficient demand. Corrected data products have not been taken up as this would result in a significant increase in cost. Standard replacement products of the Met Office and others do not meet vital requirements to have sub-catchment data and are significantly more expensive. The recent Met Office approach is targeted at fulfilling that need - the development, in parallel with EA Regions, is a GIS-based rainfall information system. Rivers Agency has looked at a number of possible software packages.

No decision as to what product should be used has been made as the Rivers Agency is considering adopting a Flood Warning policy similar to Floodline in the UK. Once a decision is made on the way forward with flood warning in Northern Ireland then the Rivers Agency can proceed with using products such as HYRAD or Envirometics. Whatever software is adopted the project is likely to involve additional investment and training of staff, but should produce a working operational system much superior to that being used at present.

(b) Urban Drainage

There should be benefits to be generated from the use of weather radar in the urban drainage area, and the use of weather radar data is imperative if spatial variation of rainfall is to be accurately assessed as part of a design process. The benefits are, in the short-term, more associated with the area of archive data for modelling purposes. Due to the current lack of the requirement to give flood warnings, and the limited requirement to control wastewater networks, there is not a great need currently for predictive or real-time radar data. However this may change in the future if planning timescales lengthen beyond the current 5 year AMP (Asset Management Plan) cycle, and the full potential of predictive real-time control is assessed.

Requirements to produce these benefits would be: -

- Improvements in calibration processes to ensure correction is made for bright band etc.
- Production of Industry agreed methodologies for the use of radar data.
- Demonstration projects to show the benefits of the use of weather radar.
- Long-term archive of high resolution radar data.

See Appendix 8 for further details.

(c) Other potential users of radar data

Rainfall data are generally required for assessment of reservoir levels and also for assessment of river flows for availability of water resources, and are related to an assessment of low flows.

The rainfall requirements are generally as follows: -

- Daily/Weekly Horizon data are used to assess availability of water resources relying on river flows.
- Advance warning of low flows therefore needs to have greater than 2-3 day lead-time forecasts due to the time-of-travel in water supply systems.
- Cumulative weekly/monthly rainfall data are required to assess total inflows to reservoirs.

Two developing areas of use for other meteorological products are for the Water Framework Directive, particularly relating to MOSES, and for the Bathing Water Signage project.

2.4.3 Strategic Area 3 - Raising awareness in the wider community

(a) Further development of the IAC web site

The IAC web site (www.iac.rl.ac.uk) has been actively developed during this session to publicise the work of the Committee and demonstrate the relevance of its work to the radar and hydrological communities. A new section on ‘Severe Storms’ has been added under the ‘Community Information’ heading, which includes radar images of the Halifax storm of 19 May 1989 and the London floods of 3 August 2004, together with an animated sequence of images from the Bracknell storm of 7 May 2000. Also included under the ‘Community Information’ heading are documents describing the EA National

Weather Radar Strategy and Water Utility Requirements for Weather Radar. There have also been further topics added to the ‘Committee Technical Note Series’ of presentations and documents. Finally, routine updates have been made to members’ details and various committee reports.

(b) Identify opportunities for raising awareness of radar e.g. linking into public awareness and other campaigns

The potential for raising public interest and awareness of the uses of weather radar has been considered. There was thought to be a general educational benefit to be gained in addition to opportunities to improve public awareness and understanding of flooding causes. The development of educational material such as a booklet, website information or a short video/CD suitable for children or adults will be explored in the next session.

(c) Exploit opportunities for publicising the role of weather radar in detecting and forecasting of severe weather/flooding events

The exploitation of weather radar has featured in a number of Research Council projects over the years. More recently the Joint Research Council/EA/Defra/UKWIR Flood Risk Management Research Consortium (FRMRC) contains sub-projects seeking to investigate algorithms for quantitative precipitation estimation from the new Kent polarisation diversity C-band, and the use of radar with flood forecasting models. The FRMRC is a near market project aimed at delivering operational tools and systems. In parallel with this activity the NERC-funded FREE (Flood Risk from Extreme Events: The science of flooding) is likely to include projects using radar data for nowcasting and within data assimilation systems. Both these projects will lead to papers in scientific journals and press releases on aspects of their work.

The Royal Meteorological Society (RMetS) continues to organise scientific meetings presenting the results of research using weather radar data. A recent example being the Symons Lecture and associated programme on convection held in May 2005. Undoubtedly further meetings will involve the exploitation of weather radar data. UK scientists will continue to present their work using radar data at a range of international meetings.

Popular lectures such as the annual British Association meeting will, from time to time, as in the past, continue to provide a platform for the applications of radar data. In addition, scientists will continue to use radar data in talks aimed at increasing the awareness of the public to meteorology and weather forecasting.

Finally, the Inter-Agency Committee provides a forum within which users of radar data may meet those involved in radar research. However, others also meet users charged with the operational use of radar data. These contacts will continue to raise the awareness of the utility of radar data. Perhaps the most influential presentation of radar imagery is that included in the weather forecasts broadcast by the BBC and commercial television companies.

(d) Review training needs and provision in operating agencies

As part of Strategic Area 3 for the Committee reporting period 2003-2005, a specific objective was to "review training needs and provision in operating agencies". A report on this review has been produced and is included here as Appendix 9. The following is a summary of the findings.

COST Action 75 (Collier, 2001) reported on a review of training and development in weather radar for its participating countries. The review suggested a standard training syllabus for undertaking work with weather radar, which included a number of core modules: principles of radar, microwave propagation, correction and quality control, precipitation estimation and related products, and radar maintenance and operational support.

The primary means of delivering training in weather radar in the UK for operating agencies is through the Met Office. This course "Introduction to Weather Radar" is tailored for the UK Agencies and their flood warning and forecasting staff. Much of the training course encompasses the proposed Module 4 from COST Action 75: radar estimation of rainfall, radar data processing and quality control, advantages and disadvantages of raingauges and radar, applications of radar and short-period rainfall forecasting (Nimrod and Gandolf).

The most advanced training course for hydrological uses of weather radar for European operating agencies to date was held at the University of Bristol in 1998. The European Commission funded Advanced Study course was held in 1998 on *Radar Hydrology for Real Time Flood Forecasting* (see Griffith *et al.,* 2001). The study course lasted ten days and covered more advanced and applied topics such as rainfall forecasting techniques and the use of radar in fluvial and urban flood forecasting.

In reviewing the level of training in the UK at present, training courses are clearly being delivered for the agencies that have an operational requirement for weather radar. This is usually at a basic level, i.e. introduction to weather radar for flood warning staff in the EA and SEPA. For agencies that do not have an operational requirement such as DARNI, the Water Utilities and the States of Jersey, there are as yet no requirements for training. However, it is clear that if the business requirement changes - i.e. flood warning in Northern Ireland or increased urban drainage modelling within the water utilities - then this will drive a need for training delivery within these agencies.

Therefore there are two main areas that the Committee should consider to ensure that operating agencies are catered for in the future:

- That agencies developing into new business areas are catered for with regard to training. At a basic level this could mean that the Committee makes available information about existing courses to the agencies developing into operational use of weather radar and that these courses meet their requirements.

- That the Committee consider ways of developing more advanced training courses for the hydrological use of weather radar, for flood forecasting, urban drainage and water supply modelling.

(e) Identify opportunities for raising awareness of weather radar in the urban drainage community

During the last twelve months or so there have been a number of opportunities taken for raising awareness of weather radar in the urban drainage community. A summary of these is:

- FWR / WaPUG Workshop on Urban Rainfall and Run Off. 30 April 2004
- Met Office Radar Data User Seminar – 26 May 2004.
- WaPUG R&D Workshop – WaPUG Autumn Meeting. Modelling with Radar Rainfall - How and Why? M. Dale and J. Lau, 11 November 2004, Blackpool
- Met Office Publication (in Draft) - Research Requirements for Weather Radar Data in Urban Drainage.

Most of these have been presentations to the Urban Drainage Modelling and Planning communities, with a mixture of Industry driven and Met Office events.

Due to the nature of the Urban Drainage Community, there are a number of key areas in which awareness needs to be raised to fulfil the potential of weather radar. These are:

- Asset Management
- Planning
- Operations
- Design of Capital Works

Forums that could impact on the wider drainage community are:

- Wastewater Planning User Group (WaPUG) – representing the Planning, Modelling and Design Communities, including water company staff and consultants.

- Water UK through the Sewerage Network representing all major UK wastewater service providers. This forum includes planning and operational staff.

- Other National and International Urban Drainage Conferences

- Opportunities will take the form of presentations of capabilities of weather radar to key individuals at User Conferences, and identification of Industry Needs at an early stage to ensure that the unique spatial benefits of weather radar are utilised as fully as possible.

3. Development in the next Committee Session

Important developments are anticipated in the coming years that will drive the need for and help deliver improved rainfall measurement and forecasting using weather radar.

(a) Meteorological forecasting aspirations

The UK Met Office is embarking on a major development in the field of short-term forecasting. The current mesoscale model runs with 12km resolution over the UK producing a forecast every six hours out to 36 hours. Starting May 2005 a higher resolution version will be run operationally every three hours with a resolution of 4km. By the end of the year this will be providing 'nowcasting' forecasts every 3 hours out to 9 hours with longer forecasts (up to 36 hours) every 6 hours. By the end of the decade it is anticipated that the 'nowcasting' forecasts will be every hour using a 1km model. Trials of the 4km version have already shown an increase in the skill of forecasting precipitation, which probably results from the better representation of the orography and the boundary between land and sea, as well as the explicit representation of major convective storms. It is also anticipated that the new polarisation radars will provide more reliable estimates of rainfall in real time accompanied by quantified errors in the rainrate estimates. A major challenge in these new versions of the model will be to improve techniques which continually assimilate observations and especially the high resolution radar observations into the model so that it has a better representation of the true state of the atmosphere to initialise each forecast run. These new techniques will also provide an indication of the confidence in the precipitation forecasts. By the end of the decade there is the real prospect of a significant improvement in the accuracy of precipitation forecasts and as a consequence a more widespread use in hydrological applications.

(b) The feed-through to hydrology

The year 2005 will see the Environment Agency able to implement, for the first time across all 8 regions of England and Wales, the use of weather radar for flood forecasting. The chain of Nimrod (radar, NWP and MOSES) products received, displayed, processed and analysed by Hyrad and time-series passed forward for use in flood forecasting systems operated in each region is a big step forward in operational practice.

Operational experience with these new products and systems is likely to bring new challenges for weather radar and its use in flood forecasting and warning. This may bring new demands for hydrological forecasting models that are distributed in form and capable of being applied to any location served with weather radar coverage, whether gauged or ungauged with regard to river flow.

The present focus on improving forecast accuracy through improved models and their inputs (including radar estimates and forecasts) is likely to broaden to encompass consideration of input and flow forecast uncertainty in support of risk-based decision-making for flood warning and control. Quality indicators available now for radar rainfall estimates, but in qualitative form, are likely to be deficient as a basis for new probabilistic products.

Improving the consistency of radar rainfall estimates will be the fundamental challenge underpinning advances in the use of weather radar for flood forecasting. Investigating the potential of new radars with dual-polarisation and Doppler capability and improved signal processors, together with new rainfall estimation algorithms that exploit their data, will provide important avenues for research and application over the Committee's next Reporting Period.

(c) Likely impact of changes to the regulatory framework

Through the enactment of the Civil Contingencies Act in 2004, the Government is seeking to improve the UK's resilience to disruptive challenges, ranging from local flooding to terrorist attack. The Act contains an expanded common definition of an emergency and has promoted environmental issues particularly flooding to the heart of the civil protection agenda. It is anticipated that the Act will stimulate greater demand for accurate, reliable and timely flood warnings across most of the UK and this in turn will drive the need for improved rainfall measurement and forecasts over the coming years.

Legislative change is seen as the missing catalyst for improvement in urban stormwater management using weather radar in the UK water utility sector and in flood warning for Northern Ireland. The potential realisable benefit of the UK weather radar network would be increased significantly by legislative change affecting responsibilities for flood management in these two areas.

(d) Anticipated outcomes of the FREE and FRMRC programmes

The NERC-funded FREE research programme aims to investigate the scientific basis of both fluvial and coastal flooding. The meteorological, hydrological and coastal oceanographic communities will combine to address this activity, which represents the largest NERC-funded research programme (£6 million over five years) currently underway. The outline research plan ranges from nowcasting (up to three hours ahead) to seasonal and climate forecasting, and seeks to clarify uncertainty in forecasting extreme events and associated flooding across this range of time scales. It presents a major opportunity for the UK research community to utilise weather radar data directly and within meteorological and hydrological data assimilation systems.

The FRMRC is an interdisciplinary research Consortium investigating the prediction and management of flood risk. It is funded by EPSRC, Defra/EA Joint R&D programme on Flood and Coastal Defence, UKWIR, NERC and the Scottish Executive. The FRMRC research programme aims to investigate the tools and techniques to support more accurate flood forecasting and warning, improvements to flood management infrastructure and reduction of flood risk to people, property and the environment. In addition, the FRMRC will establish a programme of high quality science that will enhance the understanding of flooding and improve the ability to reduce flood risk through the development of sustainable flood management strategies. The proposed research is addressed through eight research priority areas: Land use management, Real-time forecasting, Infrastructure management, Whole systems modelling, Urban flood management, Stakeholders and policy, Morphology and habitats and Risk and uncertainty. Each research priority area has been split into discrete work packages with deliverable products.

Currently the Defra/EA Theme Advisory Group (TAG) on Flood Forecasting and Warning manage a research programme of direct relevance to the operational side of the EA. It is likely that the TAG programme will be developed in the future taking cognisance of both FREE and the FRMRC outputs.

(e) Forward look to the next Committee session

The Committee will continue to focus on ways to influence the greater use of weather radar by operating agencies to meet their service delivery requirements in the next session. In particular, it will concentrate its efforts on monitoring and critically reviewing the significant research programmes and projects that will be in progress over the next 2 years, including FREE, FRMRC, SE Radar Project, CSIP, etc. The Committee will seek to guide the operational application of outputs and influence future research directions. Raising awareness of the work with radar and the benefits that can be obtained continues to be a challenge and thus will be the subject of the second strategic area in the coming session.

Strategic Area 1	**Strategic Area 2**
Monitor and critically review ongoing research programmes and projects with the view to guiding the operational application of their outputs and influencing future research directions	Raising awareness of hydrological applications of weather radar in the wider community

Appendix 1: Community Plan Milestone Report

Strategic Area 1 **Bringing research findings into operational use**	**Date achieved**
• Identify examples of best practice in recent research work - (Chris Collier)	Dec 2003
• Identify a process for "operational pull through" that researchers can follow - (Linda Aucott)	Dec 2003
• Convene workshop bringing together research community and operating agencies - (Bob Moore)	Oct 2004
• Engage in European research programmes (e.g. ACTIF, Framework6, COST717, etc) - (Chris Collier)	T.S.P**
• Identify and prioritise new research opportunities to address the advancement of operational practice - (Malcolm Kitchen)	Apr 2004
• Collate information on existing research programmes in the field of weather radar and related technologies - (Bob Moore)	T.S.P**

Strategic Area 2 **Identifying and addressing service delivery needs of operating agencies**	**Target date***
• Identify and document service delivery needs of the individual operating agencies - (Chris Haggett, Malcolm Kitchen, Mike Cranston, Noel Higginson, Graham Squibbs/Chris Collier)	Apr 2004
• Produce a report detailing collated requirements and identify and prioritise new research opportunities to address the service delivery needs of operating agencies - (Chris Haggett)	Dec 2004

Strategic Area 3 **Raising awareness in the wider community**	**Target date**
• Further development of the IAC web site - (John Goddard)	T.S.P**
• Identify opportunities for raising awareness of radar e.g. linking into public awareness and other campaigns - (Linda Aucott/Chris Haggett)	June 2004
• Exploit opportunities for publicising the role of weather radar in detecting and forecasting of severe weather/flooding events - (Malcolm Kitchen)	T.S.P**
• Review training needs and provision in operating agencies - (Mike Cranston)	Dec 2003
• Identify opportunities for raising awareness of weather radar in the urban drainage community - (Graham Squibbs)	Dec 2003

* Lead contacts will be required to produce progress reports for each work package at Committee meetings during the session.
**T.S.P = Throughout Session Period

Appendix 2: Committee Constitution and Terms of Reference

A2.1. Constitution

The Committee comprises members appointed by the following supporting agencies:

Met Office	1
Department for Environment Food and Rural Affairs (Defra)	1
Environment Agency (EA)	1
Natural Environment Research Council (NERC)	1
Council for the Central Laboratory of the Research Councils (CCLRC)	1
Scottish Environment Protection Agency (SEPA)	1
Department of Agriculture and Rural Development, Northern Ireland (DARD)	1
States of Jersey	1
Water UK	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 CEH Wallingford.

A2.2 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 3: Committee Membership

Dr Chris Haggett *(Chairman)*	Environment Agency
Ms Linda Aucott	Department of Environment, Food and Rural Affairs, Flood Management Division
Dr Steven Cole (*Technical Secretary*)	Natural Environment Research Council, Centre for Ecology and Hydrology, Wallingford
Professor Chris Collier *(co-opted)*	University of Salford, School of Environment and Life Sciences
Mr Mike Cranston	Scottish Environment Protection Agency
Dr John Goddard	Central Laboratory for the Research Councils, Rutherford Appleton Laboratory
Dr Dawei Han *(co-opted)*	University of Bristol, Department of Civil Engineering
Dr Noel Higginson	Hydrometric Section, Rivers Agency Department of Agricultural and Rural Development
Professor Anthony Holt *(co-opted)*	University of Essex, Department of Mathematical Sciences
Professor Anthony Illingworth *(co-opted)*	University of Reading, Joint Centre for Mesoscale Meteorology
Mr David Johnson	States of Jersey Public Services Department
Mr Malcolm Kitchen	Met Office
Mr Bob Moore	Natural Environment Research Council, Centre for Ecology and Hydrology, Wallingford
Mr Graham Squibbs	United Utilities North West

Appendix 4: Best Practice Guide for the Implementation of Research

Intended Audience

This guide is directed at researchers, research co-ordinators and organisations funding research.

Purpose

The purpose of this guide is to facilitate the pull-through and implementation of research projects so that advances in knowledge, science and technology are put into practical application. Research into weather radar and its hydrological use is of particular concern to this IAC but the challenge of getting any research implemented will have common features so this guide should have more general use.

Background

In common with some other areas of research, the IACHWR have concerns over the degree of implementation of research work undertaken. The scientific body of knowledge is advancing through research but the application of findings into the operational activities and day-to-day work of users of technology is lagging behind. Weather radar is by its very nature a complex and technical area and the application of new developments requires an appropriate level of knowledge, both in the new development and in existing systems, to enable users to make use of them. To improve the take-up of developments, it is suggested that researchers should pay more attention in the early stages of defining a project on how the findings may be used. Implementation plans form a part of some projects but often these are developed without clear definition of the stages for implementation and resources required. Examples of approaches to Project Planning and how implementation might be better considered are set out below.

Traditional Research Project Development

Figure 1 illustrates a traditional approach to developing a research project. It is common for the initial effort to concentrate on the project definition and organising funding and resourcing. Delivery of outputs of the research, particularly in projects that run for three to four years, may be seen as a secondary issue and one that can be delayed until the latter stages of the project. In reality, projects that take little account of the implementation of results until the final stages are unlikely to see them taken up and used except as references in other research.

There are a number of potential pitfalls to the uptake of research findings including:

- Applicability – does the research provide a solution to a user need? Starting with the premise that research is being undertaken to fill a gap in knowledge, the first stage is to understand who the user of that knowledge is.

- Functionality – does the result of the research successfully fill the knowledge gap and does it do the job it was intended to do? If research results do not provide a solution or an answer, or advance the state of knowledge in a significant way, it has no purpose.

- Technology – if results of research are delivered in a form that is incompatible with users' technological systems, there will be considerable barriers to getting them tested and users committed to incorporating them into their activities.

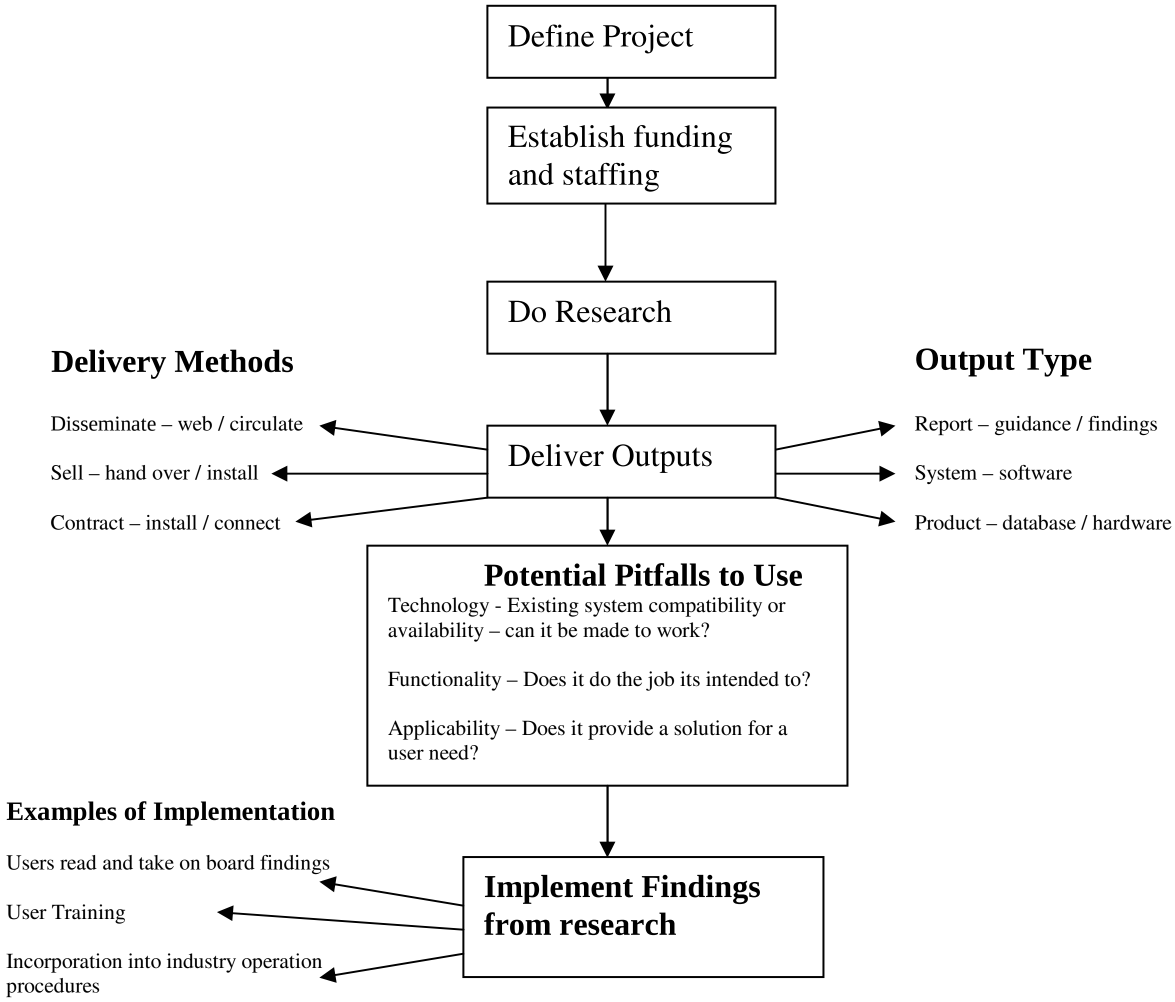


Figure 1 Traditional approach to research project development and potential pitfalls

Alternative approaches to developing research projects that improve the likelihood of pull-through and implementation

If the project definition or specification phase of research includes a set of objectives which the research is seeking to achieve, and one of these objectives is to ensure successful take-up of the findings, greater thought will have to be given at the inception phase to the final outcome of the work. Figure 2 shows two possible scenarios for the inception of research and how this may influence and lead to the development of an implementation plan. In both cases, the important feature is that pull-though of research is being considered even before the research work starts. This enables the research plan to build in the factors that will ensure good take-up of results.

This approach will also ensure that the research is well focused and, for the researcher, it will provide extra motivation and clarity of purpose.

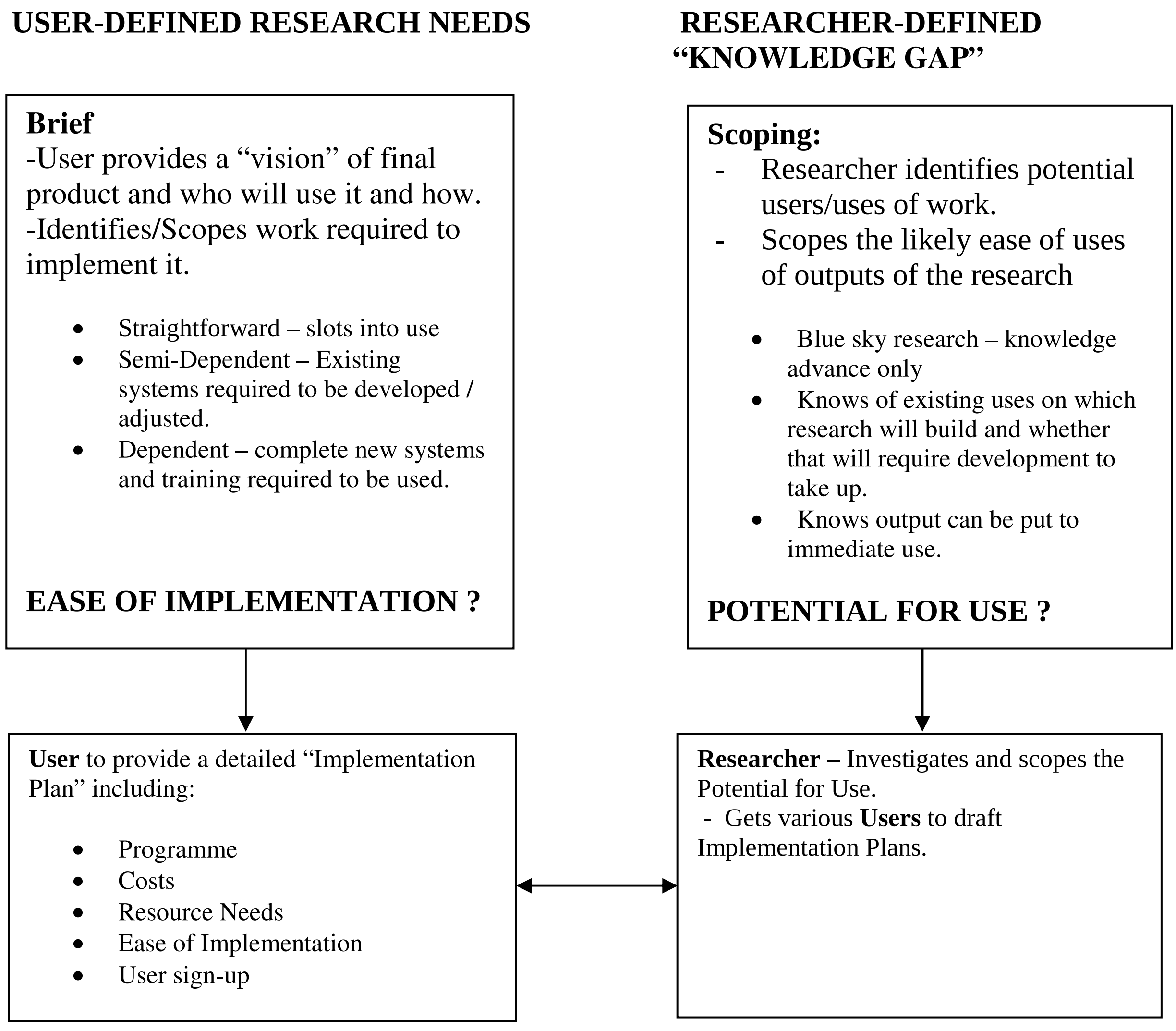


Figure 2 Alternative scenarios for the definition of research and development of an Implementation Plan

Conclusions - A Best Practice approach to pull-through of research

Figure 3 shows a route map that if followed will facilitate the operational pull-through of research. It is recommended that researchers, research co-ordinators and sponsoring organisations give full consideration to and incorporate the stages shown in the route map into their project plans.

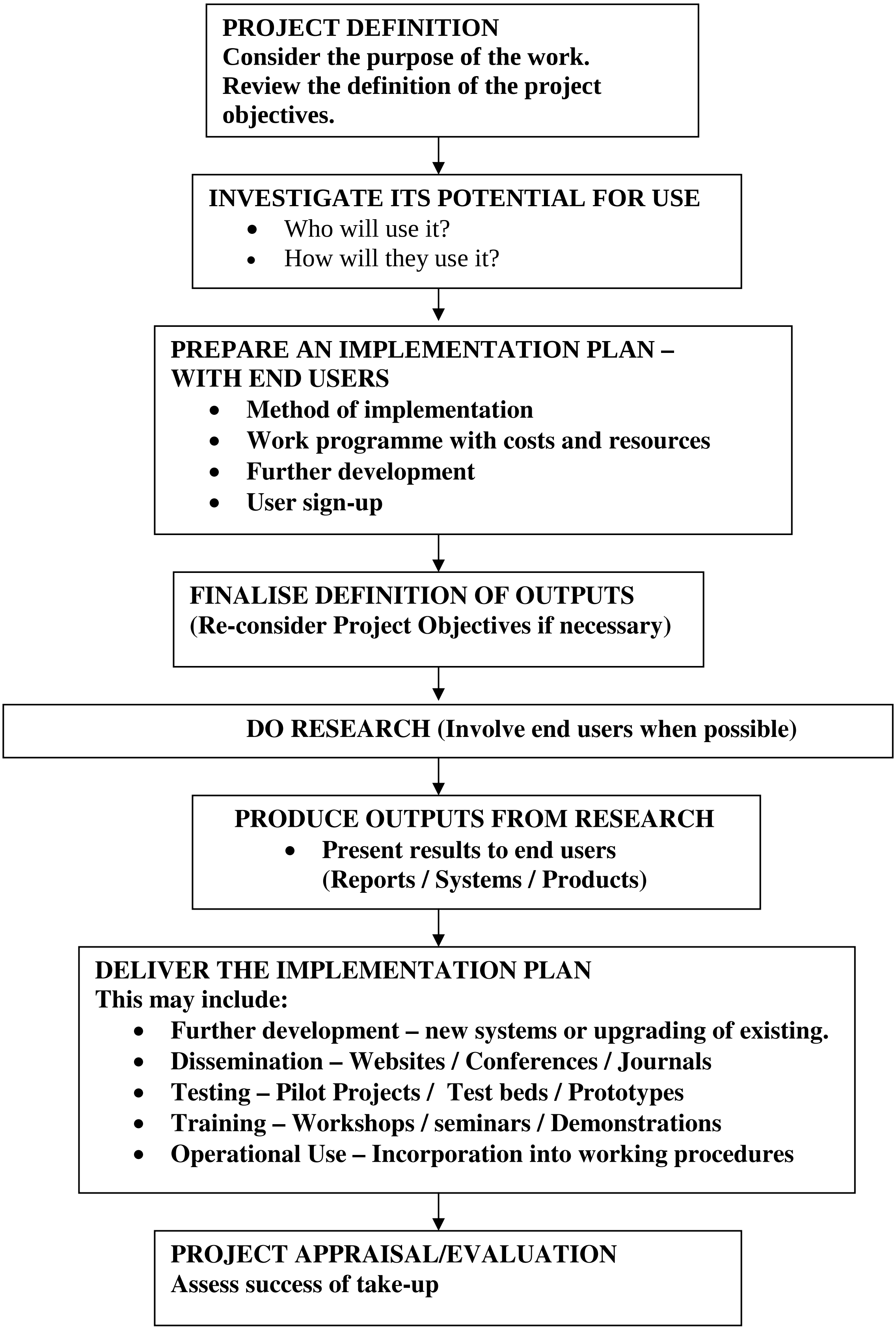


Figure 3 Route map for operational pull through of research

Examples of case studies where research has been successfully taken up and implemented into practice

1. Gandolf

The precipitation that accompanies convective storms poses significant problems for flood forecasters. Rainfall intensities often exceed 10mm h^{-1} and the spatial and temporal extents of precipitation are often very limited - a few square kilometres and about one hour. The difficulties entailed in providing timely flood warnings for such events are exacerbated in urbanised areas where catchment characteristics give rise to very rapid rainfall-runoff responses.

This problem is of particular concern to Thames Region of the Environment Agency whose responsibilities for flood warning cover river catchments in the vicinity of London. In common with other regions of the Agency, Thames Region employs computer models of catchment water balance that make forecasts of river discharge, given predictions of precipitation accumulation. The problem is obtaining accurate precipitation forecasts for convective situations.

In the early 1990s, Thames Region employed various rainfall radar extrapolation-based precipitation nowcasts for this purpose. These had a proven track record in forecasting frontal precipitation, but had, at times, demonstrated serious deficiencies in their treatments of convective precipitation. Thus, results from several Agency-Met Office collaborative studies (FOAG, 1992, 1993) led to the conclusion that the ability of FRONTIERS (the Met Office's nowcasting system in the 1990s) to "accurately forecast rainfall in…convective events…is generally poor".

The need to find an alternative approach to the prediction of convective rainfall became increasingly apparent following a number of serious floods caused by summer thunderstorms. This led the Agency and the Met Office to establish a joint research and development project to address this problem. The resultant Thunderstorm Warning Project explored the predictive skills of an Object-Orientated conceptual Model (OOM) of convection (Hand and Conway, 1995).

With the advent of such a model, an additional problem arose for the Agency, namely, the selection of the most suitable forecast (extrapolation or OOM) in any given weather situation. The choice of forecast must be based upon a full and reasoned evaluation of the prevailing weather conditions, and a knowledge of how well each forecast performs under those conditions. For this reason, the approach adopted in the Thunderstorm Warning Project was to deploy the OOM within an experimental, automated system called GANDOLF (Generating Advanced Nowcasts for the Deployment of Operational Land-based Flood forecasts). The system was capable of identifying and distinguishing frontal and convective precipitation, and of making an informed and objective decision as to which precipitation model should be used, given the prevailing weather conditions.

GANDOLF was fully integrated into Thames Region's operational flood detection and forecasting system following the completion of the research project in 1997. It has subsequently been subsumed into the Met Office's Nimrod nowcasting system that is widely used by all regions of the Environment Agency to support operational flood forecasting.

References

FOAG 1992. *Evaluation of FRONTIERS Forecast Precipitation Accumulation Final Report.* March, Met Office/NRA.

FOAG 1993. *FRONTIERS Evaluation of Radar-Based Rainfall and River Flow Forecasts, April 1992 to March 1993.* Met Office/NRA, 122pp.

Hand, W.H. and Conway, B.J. 1995. An object-orientated approach to nowcasting showers. *Weather and forecasting*, **10**, 327-341.

2. Radar estimates of rainfall at the ground in bright-band and non bright-band events

This work arose as part of a NERC-funded PhD student at the University of Reading who was looking at precipitation measurement using multiparameter radar. This involved looking at the structure of the bright-band. Key factors enabling pull-through to implementation were discussions with users, instigated at meetings of the IAC, on the relevance of the work in a operational environment.

The bright-band is a common occurrence in the UK. The present system for correcting it assumes there is always an enhanced radar return when the radar beam is dwelling at a height up to 600m below the zero degree isotherm as derived from the mesoscale forecast model; the standard algorithm then corrects for the overestimation of reflectivity from the melting snow and reduces the inferred rainfall rate at the ground. Such a method usually works well, but will fail on those occasions when a bright-band is absent. This happens during vigorous convection, when hail pellets occur instead of snow; in this case the high value of reflectivity observed at the melting layer is a good indication of heavy rain at the ground and should not be reduced by the bright-band correction algorithm. An analysis of high resolution vertical profiles, taken with the research Chilbolton radar in Hampshire, revealed that such occasions when a bright-band was absent could be recognised by an increased reflectivity (>30dBZ) at a height of 1.5km above the freezing level. Accordingly, the present operational bright-band algorithm correction scheme and its associated reduction of rainfall estimates is suppressed when the upper beam of the radar indicates a high value of reflectivity 1.5km above the freezing level.

Appendix 5: Reports from UK Research Groups and Agencies

Information on existing research programmes in the UK in the field of weather radar and related technologies is collated here for the Reporting Period. Reports are provided from research groups in six universities (Bristol, Essex, London: Imperial College and University College, Newcastle, Reading, Salford) together with CCLRC and CEH Wallingford. Reports are also provided from two Agencies: SEPA and the Met Office.

Reports from UK Research Groups

University of Bristol

The activities of the University of Bristol team on radar-related research are reported under the sub-headings of a review of recent work and on-going projects.

Review of recent work

(a) Quantitative weather radar and the effects of the vertical reflectivity profile. The variation of the vertical reflectivity profile (VRP) of rain is one of the major problems for quantitative precipitation estimation using weather radars. In particular, during stratiform rainfall a region of enhanced reflectivity associated with echoes from melting snowflakes causes overestimation of precipitation. This work is focused on the study of this region commonly known as the bright band. A new algorithm to detect the boundaries of the bright band from single-polarisation VRP has been developed. This algorithm has enabled the analysis of 1835 hours of vertically pointing X-band radar data and 1354 S-band Rang-Height Indicator (RHI) scans from the Chilbolton radar in order to study the characteristics of the bright band such as intensity, depth, height and variability at both frequencies. In addition, the differential reflectivity and the linear depolarisation ratio in the bright band are also included in the analysis. Using the results obtained, the Membership Functions (MF) of a Fuzzy Logic System (FLS) to classify hydrometeors have been proposed. The FLS receives as input parameters the conventional reflectivity factor, the differential reflectivity, the linear depolarisation ratio and the height of the hydrometeors and retrieves three types of hydrometeors: rain, snow and melting snow. The classification of rain and snow presents a high degree of uncertainty because of the large overlapping regions between the MF of both hydrometeors. The FLS is shown to perform a primary classification of melting snow because the depolarisation characteristics are distinct. By establishing the mean height of melting snow it is possible to modify the MF of the height of the hydrometeors in a more constrained way. A secondary classification is then performed with the new MF providing a much improved classification. The hydrometeor classification is followed by an algorithm to estimate the expected rain reflectivity from bright band contaminated reflectivity data. This correction is based on an idealised VRP typical of stratiform precipitation and obtained from the extensive analysis of the VRP at S-band frequencies.

(2) Quantisation issue. Quantisation is an approximation of a signal value by a whole multiple of an elementary quantity. Unlike the sampling process (providing the Nyquist frequency is above the maximum process frequency) this results in an irretrievable loss of

information since it is impossible to reconstitute the original analogue signal from its quantised version. Hence there is a tendency to use higher resolution digitising cards to convert data from analogue to digital signals. However, it is important to notice that despite extensive research in remote sensing technology, there exist many factors that influence the accuracy of the measured data. The research has shown that that whilst use of a longer quantisation length can reduce the overall errors caused by quantisation, this is only true when the data to be converted are error-free. If there are uncertainties in the data, a longer quantisation length may increase the overall error and reduce the data quality. A simple case study shows that 3 bit data can be as satisfactory as 8 bit data under some noise levels.

On-going projects

There are two ongoing projects.

(a) FLOOD RELIEF. A real-time decision-support system integrating hydrological, meteorological and radar technologies. Web site: http://projects.dhi.dk/floodrelief/.
FLOOD RELIEF is supported by the European Commission under the Fifth Framework Programme. It is undertaken by Bristol and six other European partners with complementary expertise covering development and application of numerical weather forecasting systems, flood forecasting systems, radar, data assimilation, uncertainty estimation, flood warning and decision-support tools. The FLOOD RELIEF project aims (i) to develop and demonstrate a new generation of flood forecasting methodologies which will advance present capabilities and accuracies and (ii) to make the results more readily accessible both to flood managers and those threatened by floods. This will be achieved by exploiting and integrating different sources of forecast information - including improved hydrological and meteorological model systems and databases, radar, advanced data assimilation procedures and uncertainty estimation - into a real-time flood management decision-support tool designed to meet the needs of regional flood forecasting authorities. The benefits expected from this project are increased accuracy of both quantitative precipitation forecasts and hydrological forecasts, and cost-effective implementations of numerical weather modelling for precipitation forecasts in a highly accessible internet-based forecast information system.

(b) EPSRC Flood Risk Management Research Consortium: Real-time flood forecasting theme. Work Package 3.3: Weather Radar and Remote Sensing. Web site: http://www.floodrisk.org.uk/.
This is a £5.5 million Engineering and Physical Sciences Research Council (EPSRC) initiative to combat the growing threat of flooding in the UK. FRMRC is an inter-disciplinary research consortium investigating the prediction and management of flood risk. The short-term delivery of tools and techniques to support more accurate flood forecasting and warning, improvements to flood management infrastructure and reduction of flood risk to people, property and the environment are the key issues in the consortium. Real-time forecasting is one of the Research Priority Areas (RPAs) in the FRMRC. This RPA includes the work package “weather radar and remote sensing”. This work package will seek to provide fundamental research and support to the new dual-polarisation

EA/Met Office radar to be sited at Kent. The aim is to extend techniques that have been proven at research level on very narrow beam non-attenuating S-band systems and identify their operational performance at operational network radar level.

University of Essex

At the University of Essex there have been three main areas of study concerning weather radar and associated techniques:-

- **Dual-frequency microwave links.** Research has continued on the use of these links for estimating path-averaged rainfall. Links in both the Bolton region and in Germany have been used. In addition to comparing link rainfall estimates with those from a number of gauges, work has focussed on the detection of sleet. The German link is radial from an X-band radar, and research has shown that the link data enables the radar data along the link to be corrected for attenuation, even in heavy rain.

- **Propagation modelling** has been developed using information from NWP analysis to identify regions in a radar PPI where anomalous propagation is to be expected.

- **Wind-field analysis**

  (i) Software has been developed to derive the horizontal wind-field from data from two operational Doppler radars belonging to the Civil Defence authority in the Emilia Romagna region of Italy.

  (ii) In conjunction with the Met Office, work has commenced on a study of data from Windsat, a satellite which carries a number of polarisation sensitive radiometers, and from whose data both wind speed and direction over the oceans should be derivable.

University of London (Imperial College and University College)

Research using weather radar data at Imperial College and University College London, in collaboration with CEH Wallingford, has been undertaken in the context of the Defra-funded project "Improved methods for national spatial-temporal rainfall and evaporation modelling". A range of research into rainfall simulation methods is underway, based on raingauge and radar data. Methods of single-site stochastic rainfall generation have been evaluated, using raingauge data, as a basis for the development of national procedures to simulate inputs to continuous simulation rainfall-runoff models for flood design. In parallel, procedures have been developed to simulate potential evaporation.

Modelling of spatial rainfall is being investigated using a suite of alternative methods:

a) Generalised Linear Models (GLMs) have been developed, based on daily data from UK raingauge networks, to represent stochastic sequences which incorporate spatial and temporal heterogeneity (i.e. location effects and climatic variability).

b) Stochastic models of spatial-temporal rainfall based on Poisson processes are being evaluated using a long historical dataset from the Chenies radar. This dataset has been de-calibrated and re-calibrated in an attempt to create a homogeneous 13 year sequence.

c) Hybrid methods are under development to take the daily data from GLM simulations and add spatial-temporal disaggregation to generate spatially correlated hourly data sequences. A simple disaggregation scheme is currently being tested for the River Lee catchment in north London.

A distributed rainfall-runoff model has been developed for the Lee catchment to allow the significance of different representations of spatial rainfall to be evaluated. These will include observed rainguage and radar data, and stochastically disaggregated sequences.

University of Newcastle

Research at the University of Newcastle Water Resource Systems Research Laboratory relevant to weather radar has concerned two topics: rainfall forecasting by extrapolation methods and use of radar rainfall in flood forecasting. These formed contributions within the EC MUSIC Project (http://www.geomin.unibo.it/orgv/hydro/music/).

(a) Radar precipitation extrapolation nowcasting methodologies. Stochastic or deterministic extrapolation of radar precipitation fields clearly offers useful alternative techniques to Numerical Weather Prediction (NWP) for short-term rainfall forecasts (rainfall nowcasting). The main calculation variable is often either raw reflectivity data from the radar or precipitation. Thus, compared with NWP, the computational load is reduced, allowing high resolution forecasts, assimilation issues are simplified, the time taken to make a forecast is reduced and certain formulations offer the possibility of stochastic ensemble forecasts.

Following a review of current literature, a new spectral decomposition nowcasting methodology was selected for implementation and testing. A range of key research issues were then identified. These included the choice of initial transformation to be applied to the rainfall field (e.g. log to transfer to a dBZ domain), the possibility of different scale feature advecting independently and the development of stochastic ensemble forecasts. A range of intercomparison tests were carried out between the various choices of methodology and the best formulation identified.

An intercomparison of deterministic nowcasting skill was carried out between four complex radar nowcasting models. These included the spectral decomposition methodology, an autoregressive model, a cell tracking model and a baseline advection scheme. This study provides a rare intercomparison of different classes of radar extrapolation nowcasting models. The results were found to be reasonably consistent between the three study areas (in northern Italy and Poland). Finally, an assessment was made as to the added value of satellite observations for the purposes of extending radar nowcasts.

(b) Flood forecasting. The aim of the EC MUSIC project was to develop a very short-term (1 to 6 hours) flood warning system applicable to small and medium size catchments and designed to improve upon the reliability, precision and lead time of existing flood forecasting and dissemination methodologies. Firstly, new rainfall estimation and forecasting techniques were developed and integrated using an innovative combination of radar, Meteosat and raingauge observations to provide improved accuracy and an estimate of the uncertainty. Secondly, a rainfall-runoff model was used to forecast the response of the land surface/river network to the rainfall, again providing a clear estimate of the forecast uncertainty. Finally, a highly flexible and interactive visualization system was developed to allow clear dissemination of the uncertain hydrological forecasts within a geographical context.

University of Reading

Research at the University of Reading of relevance to the hydrological use of weather radar concerns three topics, all benefiting from use of the Chilbolton radar.

(a) Bright band correction algorithms: The bright band correction scheme is crucial if accurate rainfall rates are to be inferred from radar. The Nimrod system used operationally by the Met Office assumes that the height of the bright band is given by the height in the operational mesoscale model at which the wet bulb temperature is zero. This scheme has been vigorously queried at international conferences with the claim that the model temperatures – particularly in the vicinity of fronts – are insufficiently accurate. An analysis of the one year's data of the height of the melting layer measured with a vertically-pointing cloud radar to an accuracy of 60m has been compared with the height in the mesoscale model. The root mean square error is only 150m and the bias 14m; much less than the depth of the melting layer, thus vindicating the Met Office technique.

(b) Correction for wind-drift errors in rainfall using mesoscale model winds: At longer ranges the radar samples the precipitation some distance above the ground. Because of the 'wind drift', the precipitation subsequently falls to ground with a considerable displacement which can be tens of kilometres. A careful radar study, comparing precipitation at different elevations, has (i) confirmed that the wind drift can be reliably estimated from the vertical profile of wind held in an operational mesoscale model and (ii) proposed an operational algorithm to correct for wind drift. .

(c)Better rainfall rates using polarisation radar: The first polarisation radar in the UK network should be operational in 2005. Currently, rainfall rate R is inferred from radar reflectivity Z by an empirical formula: $Z=aR^{1.6}$ with $a=200$. The additional parameters available from polarisation radar provide information on hydrometeor shape, and hence

raindrop size, and should lead to improved rainfall rates. Studies with the Chilbolton polarisation radar have shown that these new parameters are not accurate enough to be used at each individual radar gate but, by studying their characteristics over an area of several km^2, it is possible to infer the correct value of the empirical constant *a* to be used for that area. Work is progressing on operational implementation of such a scheme

University of Salford

Work at the University of Salford generally falls under the heading of the assimilation of weather radar data into hydrological and meteorological forecast models.

An urban hydraulic model (Hydroworks™) of the Bolton Town centre catchment, and a stochastic state-space model (Water Aspects) of the River Croal catchment have been used to test the impact of radar data on flow forecasts. Work to compare forecast flows prepared using radar data with those using other precipitation measurements has been carried out. The work using the stochastic state-space model is continuing within a NERC-funded project being undertaken in the River Croal catchment in cooperation with the University of Essex and RAL. This project will include work on the use of measurements of snow and sleet.

Doppler radar radial winds offer the opportunity to improve short-period numerical forecasts of precipitation through their impact upon NWP model dynamics. Such forecasts are of central importance to hydrological forecasting for rapid response catchments. Work to assimilate Chilbolton radial winds into the Met Office Unified Model using three dimensional variational analysis (3D-Var) is currently underway in cooperation with the Joint Centre for Mesoscale Meteorology at the University of Reading.

CCLRC

Work within CCLRC relevant to the hydrological use of weather radar concerns use of the Chilbolton remote sensing facility and research on microwave link supported measurement of rainfall and scintillometer measurement of evaporation.
(a) *Chilbolton Facilities*. CCLRC owns and operates the Chilbolton Facilities for Atmospheric and Radio Research. CFARR is a ground-based atmospheric remote sensing facility which supports the NERC atmospheric science, hydrology and Earth Observation communities. The combination of radars mounted on the 25 metre diameter dish together with other radars, lidars, radiometers and meteorological sensors provides the UK with a world-class set of facilities supporting a broad range of science. The 3 GHz polarisation-Doppler CAMRa radar has supported a NERC project to investigate the assimilation of Doppler radar wind information into the Met Office Unified Model using 3D-Var/4D-Var, leading to an improved representation of the initial condition for storm-scale forecasting. CFARR has also played a central role in the NERC Convective Storms Initiation Project,

with a successful pilot campaign held in the summer of 2004, and a full 3-month campaign planned for 2005.
2) *Microwave link and scintillometer research.* CCLRC are joint Principal Investigators on two NERC-funded projects. One, with the universities of Essex and Salford, involves the investigation of the use of differential phase measurements on microwave links to estimate path-integrated rainfall rate, and to provide a new technique for weather radar calibrations. CCLRC are responsible for design and construction of the 4 links, two of which are radial to the Met Office Hameldon Hill radar. The second project, with CEH, involves the design and construction of a scintillometer for evaporation measurement, initially in the Lambourn catchment.

Centre for Ecology & Hydrology Wallingford

Research and development relevant to weather radar at CEH Wallingford over the Session period is summarised under six headings below. Further information on most of these topics is available in the R&D Reports of the Joint Centre for Hydro-Meteorological Research (JCHMR) via the web site www.jchmr.org . A recent position paper on "Forecasting for Flood Warning", prepared at the invitation of the French Academy of Sciences, is of particular relevance (R.J. Moore *et al.*, C. R. Geoscience 337, 203-217, 2005).

(i) Hyrad: CEH's Hyrad (Hydrological RADar) system has been used as the Environment Agency's standard tool for receipt, processing and display of Met Office Nimrod products since July 2002. A support service has been provided over the Session period to the 200 users throughout England and Wales. The system has been configured to receive new products, notably the Numerical Weather Prediction (NWP) Model rainfall and temperature fields on a 15 km grid out to 1½ days and the MOSES-PDM soil moisture, evaporation, snow and runoff fields on a 5 km grid. Catchment average rainfall time-series can now be calculated and exported to flood forecasting systems in XML form. Hyrad has also been supplied to the Belgium Government as a pilot using the Demer Basin and to SEPA as a pilot using the White Cart Water (Glasgow); both systems interface to RFFS-FloodWorks flood forecasting systems.

(ii) Probabilistic ensemble forecasting: Collaborative work - with Met Office scientists in the JCHMR at Wallingford and the Bureau of Meteorology (Australia) - has combined the STEPS (Stochastic Ensemble Prediction System) with the PDM rainfall-runoff model to demonstrate the production of probabilistic rainfall and flood forecasts utilising a blend of weather radar, NWP and stochastic rainfall fields as input.

(iii) Use of Nimrod in Flood Forecasting: This project, jointly funded by the Environment Agency and Met Office, explored the feasibility of using the quality-controlled Nimrod radar rainfall for directly calibrating rainfall-runoff models. The study was restricted in scope to use the Hameldon Hill radar, catchments over the Upper Calder in Yorkshire and the PDM rainfall-runoff model. The study exposed problems with the consistency of the Nimrod radar rainfall estimates over time for the catchments

examined. For operational models calibrated using raingauge data and using radar-based rainfall forecasts to extend the lead-time of flood forecasts, there is a need to pay regard to any "rainfall representativeness factor" used in the rainfall-runoff model formulation and make appropriate adjustments if necessary.

(iv) Rainfall Forecast Performance Monitoring: This project, jointly funded by the Environment Agency and Met Office, developed methodology and a PC Tool to assess the performance of the Met Office's Daily Weather Forecast and Heavy Rainfall Warning products used by the Agency in support of flood warning. Raingauge, weather radar and NWP model estimates of rainfall were used as assessment reference sources. New methods were developed to compare different sources of rainfall forecast and to assess forecasts provided in probability form.

(v) Extreme rainfall and flood response: This work for Defra is part of a Met Office led consortium project on Extreme Rainfall and Flood Event Recognition. It is developing spatio-temporal rainfall datasets using radar and raingauge data from historical heavy rainfall events of convective, orographic and frontal type. A rainfall transformation tool has been developed that will allow a storm to be transposed over a catchment and modified in speed and direction, as well as shape and magnitude, to investigate rainfall-runoff model behaviour under artificially more extreme storm conditions. A set of case study storms and catchments are being used to investigate rainfall-runoff model performance at times of historical extremes and under artificially enhanced conditions within a "model destruction testing" framework. New methods of areal rainfall estimation for grid-square and catchment domains using radar and raingauge data are being explored in the context of the study.

(vi) Flood modelling for ungauged basins: This Environment Agency funded R&D project has flood modelling as its focus. It considers the use of radar and raingauge networks over areas with sparse or no river gauging station network, the importance of areal rainfall estimation for grid-square and catchment domains, and the implications for grid- and catchment-based soil moisture, groundwater, runoff and river flow modelling.

Reports from UK Agencies

SEPA

SEPA are carrying out a trial application of radar in flood forecasting for the White Cart flood warning scheme. The White Cart RFFS (River Flow Forecasting System) has been configured to take Corse Hill radar data in addition to the use of tipping bucket raingauges. The White Cart RFFS has been integrated into a Floodworks Shell environment and utilises Corse Hill radar data for flood forecasts via HYRAD.

Met Office

The Met Office is the principal operating authority for the UK weather radar network. Over the period 2003-04, development effort concerning weather radar operations has focussed on three areas.

(a) Re-engineering the data processing chain in line with Environment Agency and Met Office strategy. The main objective is to centralise data processing and product generation in a new system – Radarnet IV – in order to increase flexibility and reduce costs (Figure 1). Opportunities to improve the processing algorithms and incorporate new science have been limited. However, progress on clutter discrimination has much reduced the need for interpolation and enabled data from lower elevation scans to be more widely used.

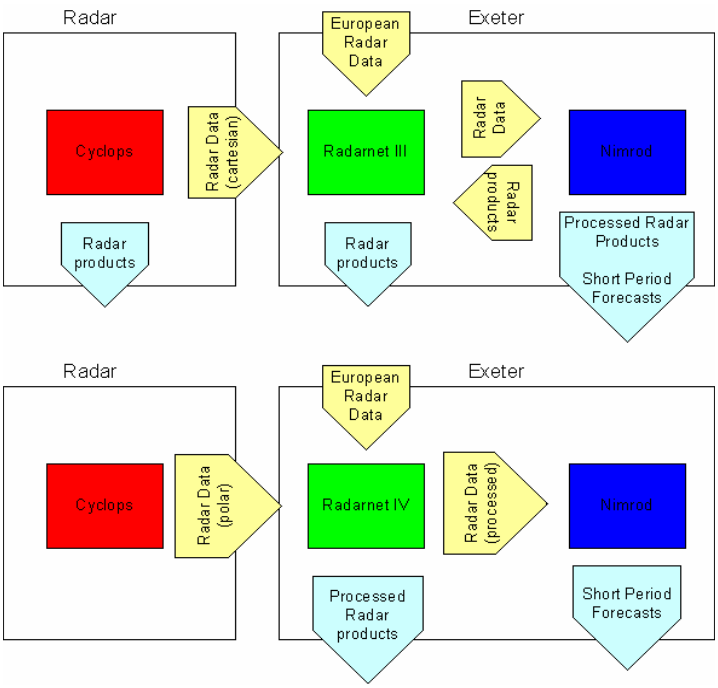


Figure 1 The new Radarnet IV centralised data processing and product generation system compared with the Radarnet III system it replaces

(b) Developing the network. In England and Wales the finances of the network are secure. Agency requirements to improve the quality, and especially the resolution of radar coverage, has resulted in a new radar installation in Kent and the redeployment of the Wardon Hill radar to a new site near Salisbury. Both radars are scheduled for installation in early 2005. Plans for a new radar installation in Northumberland are at a very early stage but prospects for a new radar in East Anglia look good at this time. In contrast, continued financial difficulties in Scotland and Northern Ireland have led to a cut back in maintenance cover on the existing radars. The threat to the Corse Hill radar site (near Glasgow) from wind farm development remains, but it has proved difficult to secure alternative sites for replacement radar(s). The UK network has otherwise been

successfully defended against detrimental wind farm development and frequency encroachment.

(c) Increasing the radar capability. The future role of weather radar as a principal source of data for high-resolution (1-4km) Numerical Weather Prediction Models is likely to have an increasing influence on development activities. The first manifestation is the renewed drive to obtain Doppler wind data from those radars in the network that have the necessary Doppler hardware. A new PC-based radar signal processor, Cyclops-D, has been developed and is currently undergoing initial tests in combination with a new receiver. This work has been hampered by the difficulties experienced in relocating the development radar from Bracknell to the new Met Office HQ site in Exeter. The new radar for Kent is being manufactured by DRS (formerly EEC) and will be the first operational dual-polarisation radar in the UK. The data from this radar will be carefully evaluated to see whether its novel features improve the measurement capability and justifies further investment in this technology.

In summary, this two-year period has seen development effort almost entirely focussed on new engineering, rather than implementation of new science. The Met Office and Environment Agency are currently discussing an investment strategy for the next ten years.

Appendix 6: SEPA - Operational Requirements of Weather Radar for Flood Warning

1. Introduction

SEPA's flood warning development strategy (2001) stated:

> '*Weather radar… allows hydrologists to download and view raw and quality controlled images and short and medium term forecasts. It does not allow hydrology to download quantitative data. Consequently, weather radar can only be used in a qualitative sense. Hydrologists view images to assess the spatial and temporal structure of rainfall and are therefore able to judge the scale and timing of storm events. Access to quantitative data would be of a potential benefit to flood forecasting as it would supplement SEPA's sparse telemetry raingauge network, allow SEPA to develop improved forecasting models, and greatly enhance SEPA's ability to forecast flooding arising from convective storms. It is proposed that options for improved access to radar data and for influencing the development of the weather radar network in Scotland should be explored and a preferred option identified.*'

Since 2001 a number of key developments have taken place in the use of weather radar for flood warning. In particular MIST has been replaced by Enviromet as the radar software used by hydrologists, HYRAD has been delivered to East Kilbride for use in the White Cart flood forecasting model, a national review and best practice guidance in flood forecasting has been carried out by consultants and a number of training and awareness initiatives have been provided for hydrologists.

This document details progress to date with regard to flood warning use of weather radar. The report will also identify future considerations regarding user requirements for the use of weather radar in Scotland.

2. Operational Review (2002)

In July 2002 a review was carried out into the operational use of weather radar for flood warning purposes. The review concluded with various recommendations and actions based on existing user requirements.

Action 1
Make sure all offices are aware of the potential benefits associated with the operation of the quality-controlled rainfall-radar product.

> *Update - only Nimrod quality controlled radar products are available in Enviromet.*

Action 2
Attempt to get Dingwall, Aberdeen and Galashiels all fully operational on MIST. Dingwall and Aberdeen have problems with file sources which have been rectified elsewhere. Galashiels require a new desktop computer for operation in the office.

Update – all hydrologists now have access to Enviromet through their own PC and web browser. The MIST product is redundant for SEPA usage.

Action 3

Training should be organised for duty officer staff in the operation and technical aspects of weather radar. The National Flood Warning Development Team have identified a national training scheme for flood warning – one of the modules has been identified for *radar meteorology*. This module includes radar technology, data processing, calibration and interpretation, benefits and limitations of operational practice and coverage, development and applications to flood warning. This training initiative should address this problem.

Update – 14 hydrologists attended the first Introduction to Weather Radar training course organised by the Met Office in January 2004. A further 12 hydrologists attended the second course in October 2004.

Action 4

Training may also address the lack of uncertainty in weather radar by flood warning duty officers. A study into the accuracy may also assist (see below).

Update – although some hydrologists attended the training course and more will in the future, there remains a lack of confidence in radar accuracy. This was discussed at a Workshop on Best Practice in Flood Forecasting in April 2004.

Action 5

MIST is essential to some Flood Watch services and of lesser importance to Flood Warning. Removal of this facility will have a detrimental affect on flood warning duties as a consequence. Either use of MIST should be continued or alternatives shall be found for the delivery of this information.

Update – all duty officers now have access to Enviromet through PC Internet browser. The MIST product is redundant for SEPA usage.

Action 6

It should be raised that any future development of MIST use or any new initiatives should consider providing constant real-time access to rainfall-radar and have a quicker operation time.

Update – Enviromet has near real-time displays available. There is no need to use a dial-up connection as with MIST.

Action 7

It should also be raised that any future development of MIST use or any new initiatives shall consider linking real-time rainfall estimates to hydrological models or Flood Watch procedures**.**

Update – firstly Enviromet has rainfall accumulations and forecast accumulations based on SEPA's Flood Watch boundaries (see Fig. 1). Also, HYRAD has been developed for use with the White Cart RFFS flood forecasting model. This will be run as a pilot project to evaluate the use of quantitative radar estimates for input into the

RFFS model. An FTP link is being established with the Met Office for transfer of the Corse Hill 1, 2 and 5 km data.

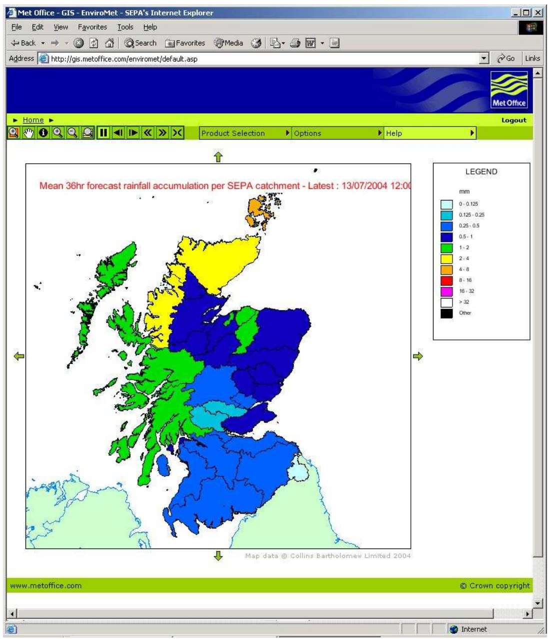


Figure 1 Enviromet display with SEPA Flood Watch boundaries

Action 8

Consider the development of methods for accessing quantitative rainfall radar estimates for both Flood Watch and Flood Warning schemes presently in use.

Update – post flood report evaluated radar estimates in the North East floods of 2002 (see Cranston, M., Kitchen, M. and Flynn, T. 2003. Benefits of using weather radar for flood warning in Scotland. Floods in Scotland, Volume of Extended Abstracts, Seminar organised by the Scottish Hydrological Group, 11-12).

Action 9

Investigate the potential delivery and benefits of quantitative rainfall radar for new flood warning areas.

Update – the production of the Best Practice Guidelines in Flood Forecasting provides scope for the investigation of use of rainfall radar.

Action 10

Investigate the possibility of a study into the accuracy of weather radar in Scotland or get the Meteorological Office to produce improved quality reporting procedures.

Action 11

Investigate alternative potential sources of weather radar, including the MARS system for small urban catchments.

3. Operational Requirements for Flood Warning (2003 – 2004)

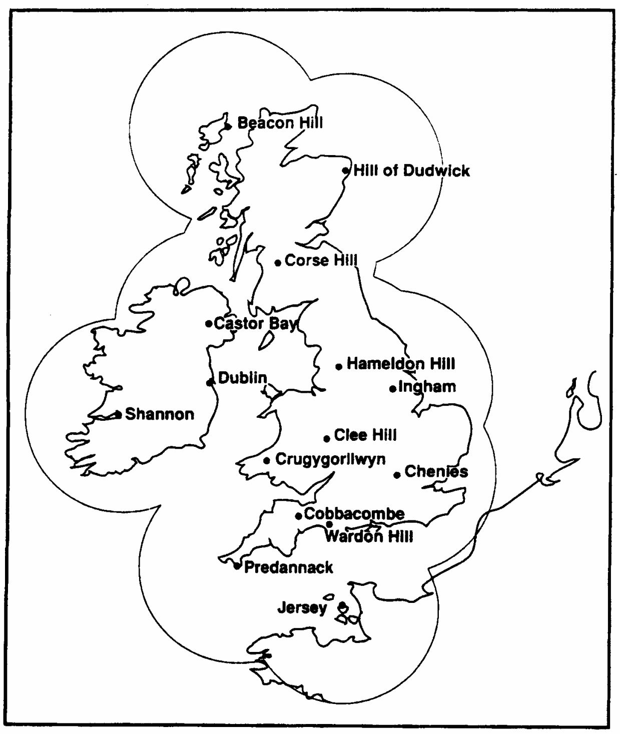
1) Enviromet

Enviromet has been an operational product available to SEPA since early-2004. Enviromet replaces MIST as SEPA's access to view weather radar. A number of other products are available within Enviromet including: Gandolf forecasting, MOSES and Flood Watch catchment accumulations (see Fig. 1). The Met Office is reviewing the availability of products that had been useful within MIST but which are not currently available within Enviromet, e.g. air temperatures and freezing levels.

2) Radar Network

The Met Office received a request to move the weather radar presently sited at Corse Hill to allow wind farm development to proceed in the area. The Met Office has produced a number of options for replacing Corse Hill. The preferred option is to install a replacement site at Holehead (North of Glasgow) and install new radar in the East of Scotland in Fife.

In terms of the effects on SEPA's existing flood warning service, the changes in the network will lead to a poorer service in one of SEPA's flood warning schemes (Nith). However, the proposals would lead to an improved coverage in flood warning schemes in Edinburgh, East Lothian, the Borders and Perthshire and also lead to improved information for Floodline services in the Central Belt, Edinburgh and Perth.



The poor coverage in some parts of the North of Scotland continues to be a problem. The lack of coverage in the Shetland Islands means Flood Watch services are restricted for the Islands. Also, the poor quality of radar data across the Highlands limits the use of the data in flood forecasting and warning.

3) White Cart RFFS-FloodWorks Flood Forecasting Model
HYRAD has been delivered as part of the recent upgrade to the RFFS-FloodWorks model for the White Cart. HYRAD is an advanced weather radar display system that provides real-time receipt of radar products, database and archiving facilities and a hydrological processing kernel for improved rainfall estimation and forecasting.

The Met Office is supplying Corse Hill radar data for a trial period (1km, 2km and 5km Nimrod actuals). This trial period will involve the evaluation of using radar as an input into the RFFS rainfall-runoff forecasting model.

4) Training and Awareness in Radar Meteorology
The Met Office ran a training course for SEPA flood warning duty officers in 2004 on ‘Introduction to Weather Radar’. It is hoped that this course can be run on an annual basis for flood warning staff. In addition, SEPA and the Met Office are supporting continued visits to the forecasting centre in Aberdeen for flood warning staff.

5) Best Practice in Flood Forecasting
A set of guidelines have been developed to assist SEPA in the selection of the best flood forecasting modelling approaches to use taking account of catchment response and flooding mechanisms. The guideline document provides a range of flowcharts, fact sheets, worksheets and schematics to guide towards best practice modelling approaches and takes account of the requirements for performance monitoring and catchment rainfall estimation from raingauges and weather radar.

6) User Requirements away from Flood Warning
At present there is a limited use outside of flood warning for weather radar. Two developing areas of use for other meteorological products are for the Water Framework Directive particularly relating to MOSES and for the Bathing Water Signage project.

4. Future Operational Requirements (2005 –)

As stated in the flood warning development strategy there are two main areas for development:

- Improved access to radar data – SEPA should be moving towards real-time quantitative access to the 3 radars in Scotland. This is currently being trialled with Corse Hill. The use of these data may only increase as we start to improve flood forecasting on fast response catchments and look to other catchments for new flood warning schemes.

- Improved radar coverage – the radar network in Scotland was never set up to provide the best coverage for flood warning. Therefore we are left with large areas of Scotland being left with poor radar coverage (54% of Scotland's land area of class 3 and 57% of Scotland's population covered by class 2 and below).

SEPA will continue to promote these potential developments as defined by business need and to implement advances in weather radar and other meteorological products and as funding permits.

Appendix 7: Environment Agency - Operational Requirements of Weather Radar for Flood Warning

1. Introduction

In 2002 the Environment Agency published its revised National Weather Radar Strategy that presents - *the recommendations which will ensure the continued provision and development of the Agency's Weather Radar Service and meet the changing needs and requirements of the Agency for the period 2002-2012.*

The recommended improvements and changes to the Weather Radar Service as set out in the Strategy are designed to assist the Agency in achieving its corporate targets. In particular to reduce the risk of flooding through the provision of flood warnings in good time so that they can be acted upon and therefore injury, death and damage are minimised. Access to current, forecast and archived weather radar data by the Agency's flood warning and forecasting teams will support the processes by which progress can be achieved.

The provision of good quality weather radar data will supplement the Agency's telemetered data thereby enhancing the flood forecasting capabilities through:

- Timely updates of forecast and radar actual precipitation data
- Potential for better calibration of the forecast models
- Post-event analysis which will assist the Agency in the future planning activities in the Flood Warning function

Wider access to and use of the weather radar historical data archive information will improve the Agency's ability to produce accurate forecasts and more effective warnings and is therefore considered to be a fundamental requirement to help progress this theme.

The revised Strategy builds on the developments that have occurred since the original National Weather Radar Strategy document of August 2000. The Agency has commissioned a number of projects that have contributed to the successful implementation of the original strategy outcomes: in particular the National Weather Radar Display System project. The Weather Radar Network Review Report of September 2001 has also identified the likely locations for additional future radars. This led to the subsequent plan for the implementation of a new radar base station in Kent, and at least two further radar base stations planned for installation in NE England and East Anglia. The Rainfall Measurement and Forecasting Guidelines link the requirements of weather radar coverage to flood forecasting in the Agency. The revised Strategy identifies further areas of coverage required and recommends that a second network review is undertaken to ensure the most beneficial radar network is installed to meet the Agency's coverage needs.

The products received by the Agency and how they are used are now under constant review and the Agency has some involvement in their development with the Met Office.

The Strategy recommends the need for an increased involvement in the product developments and recommends a more sustained and detailed approach in this area in the future.

2. National Weather Radar Strategy Outcomes

The Strategy identifies a number of outcomes that have been identified as being important to meet the Agency's short, medium and long term objectives.

Outcome 1 - Radar product development and data adjustment
Observed products:

- Influence and support the Met Office in the implementation and development of raingauge adjustment systems
- Continue with the implementation of the Raingauge Collaboration Project.
- Continue with the RadarNetIV and the respective radar product development schemes
- Agree and implement product performance targets and monitoring process for forecast and other value-added products
- Agree and implement product performance targets and monitoring process
- Influence/implement product development programme

Outcome 2 - National Weather Radar System Requirements and Architecture

- Produce a National Weather Radar Business Development Plan to detail current and future requirements and constraints
- Ongoing development of the Agency's National Weather Radar System through a co-ordinated system development programme
- Decommission in all regions the existing weather radar legacy systems

Outcome 3 - Availability of the Weather Radar Service
Reliability

- Ensure that a highly resilient communications link is installed between the Met Office Systems at Exeter and the National Weather Radar System at the Agency
- Develop and implement a disaster recovery plan
- Ensure that the Met Office maintain the required level of RadarNetIV data adjustments to meet the Agency's overall requirements
- Decommission the existing raw data serial lines from the radar base stations
- Provide an ultimate back-up contingency plan in order for the Agency to continue viewing weather radar data in the event of a total loss of the weather radar service.

Data format

- Investigate the data transfer methodology between the Met Office and the Agency radar systems and update as appropriate

Outcome 4 - Historic Data Archive

- Undertake a Regional Data Archive Pilot Assessment/Product Convergence
- Produce a National Agency Radar Archive Requirement Specification
- Develop the Agency's National Data Archive System
- Produce the Met Office Mass Archive System Requirements
- Implement Mass Archive System (if required)

Outcome 5 - Radar Funding

- Investigate the IPR Terms and conditions of Weather Radar Product Data
- Re-negotiate with the Met Office changes to the MoU
- Finalise a revised MoU covering Weather Radar

Outcome 6 - Extent of Coverage and the Development of the Radar Network

Develop Agency Coverage Requirements Methodology

- Undertake a Hydrological Study to establish and agree the proposed changes in the Time-to-Peak bands recommended to be used in the economic benefit assessment for wider radar coverage
- Undertake a second Met Office Network Review concentrating on areas of poor coverage.

New Installations

- Installation of a dual polarisation radar base station in Kent to assess dual polarisation for the future of the whole network
- Re-locate Wardon Hill Radar base station
- Installation of North East radar base station
- Installation of East Anglia radar base station
- Carry out further radar base station installations based on the outcome of the second Met Office Network Review

Radar Replacement

- Undertake a period of evaluation to assess the accuracy and operation of the dual polarisation radar installed in Kent
- Undertake a roll-out programme for dual polarisation to further radar base stations depending on the outcome of the evaluation period.

Appendix 8: Water Utility User Requirements for Weather Radar Data

Introduction

This report is intended to give an indication of the water utility requirements for weather radar data, both in real-time and archive form. It will look mainly at the area of urban drainage in wastewater systems, with only an outline assessment of water supply requirements.

Urban Drainage

The management of runoff from urban areas is a key activity of a water utility for which measurement of rainfall is critical.

The most useful aspect of weather radar is its ability to measure spatial variation of rainfall over relatively small areas. This is particularly important in urban areas with large impermeable surfaces and relatively short overland flow times. Hence weather radar information should be very useful in urban drainage situations as long as it is accurate and reliable. Another potential use is the forecasting abilities of weather radar related products.

Operational Uses of Weather Radar

Wastewater networks operate predominantly under gravity, which therefore means that there are relatively low maintenance and operational costs. There is little scope at present for control of the system. Controls that are in the network are generally simple, and are reactive, e.g. pumping stations with a switch on and off level, or controls based on a level in another part of the catchment. Hence there is currently very little requirement for weather radar data for operational control purposes. However there are some areas and developments for which weather radar data may be of benefit

There is currently no requirement to give advance flood warnings for potential wastewater flooding incidents to customers. Hence there is not the same requirement for predictive rainfall forecasts as there is for the Environment Agency who have to provide flood forecasts in Rivers.

Wastewater flooding generally relates to individual rainfall events, the size and intensity of which are difficult to predict. River flooding is related to longer duration events, often over several weeks, and therefore there is more possibility of predicting and damage limitation.

Weather Forecasting for Planned Operations

Possible uses could be in the area of weather forecasting for planned operations. Requirements would be to receive information relating to weather conditions prior to committing to carrying out certain site work. At least one water company has looked into this and has not found sufficient use to warrant the expense of receiving the data. However the data are used in other water companies to provide Control Centres with visibility of likely periods of high rainfall so they can decide whether to implement wet weather systems to downgrade alarms. It also gives them a view of how intense and how long the rain will last, and also provides operations staff with information on current rainfall patterns before entering sewers etc.

In summary it is considered that weather radar is useful for Operational activities.

Predictive RTC

The most significant area that weather radar would be of use is in the area of predictive real-time control (RTC). This works on the basis that controls are changed based on a prediction of rainfall rather than reacting to rainfall that has already fallen. There are very few systems in operation in the world, and none that the Committee is currently aware of in the UK. There are a number of issues relating to storm discharge consenting, abilities for accurate prediction and others that mean the advent of predictive RTC in the UK is a number of years off, and then only if there is sufficient desire in the water industry to make it happen. Saying that, there are systems in operation in the world, and it is currently possible to use weather radar for this purpose.

There is potential for additional benefits in linking RTC to water quality in the sewers. In this way diversion of weak effluent to watercourses may be possible, based on current water quality and a prediction of rainfall. Some research work has been carried out on this element, but more work is required on a real-time water quality sensor before this can come to fruition for anything, other than control using ammonia. There is an example of this in Bournemouth.

Research work has been carried out in the UK on the weather radar requirements for predictive RTC. There are still inadequacies in the ability of current weather radar methodologies to meet these requirements.

Assessment of Flooding Events

Most water utilities have procedures which assess the return period of rainfall events that have caused flooding, in particular foul flooding, in the networks. Because of the nature of the urban runoff, it is highly unlikely that there will be a raingauge close enough to the flooding location to adequately show the rainfall. Hence there is a need to use radar rainfall and raingauges to carry out the assessment. This is typically carried out after the rainfall event on archive data.

One water company has used their radar record to rationalise their flooding history data, by correlation of reported flooding with rainfall data. Their experience has been that the radar data correctly indicates when it is raining and gives subjective measure of whether the rainfall is hard or gentle. Correlation with raingauge data can generally give an example of typical intensities.

One other potential use of weather radar is to go one step further and use the radar data to model the impact of the rainfall on the wastewater network. Advantages of this would be for improvements in the calibration of models, and also to allow further evaluation of the actual flooding occurrence, to confirm whether the problem is really one of hydraulic inadequacy of the network. The logistics and radar requirements for this will be discussed further under the section “Design of Capital Projects and Modelling”.

Rainfall return period is a poor substitute measure for return period of flooding, as other factors such as storm movement, variations in intensity during the storm, antecedent conditions and other factors will impact on flooding. There is a need to have a means of assessing the return period of flooding, not just the return period of rainfall. A good radar rainfall archive linked with in-sewer monitoring could allow us to move towards this.

Prediction of rainfall for Water Quality Sampling Studies

It is the policy of some Water Utilities to trigger wastewater sampling in sewers based on the start time of a rainfall event. This requires accurate prediction of a rainfall event with the following typical parameters: -

Total rainfall > 10mm
Peak Intensity > 5mm h^{-1}

Currently these are difficult to predict and sampling opportunities are missed.

Design of Capital Projects and Modelling

With the possible exception of size-for-size sewer rehabilitation, all capital projects are modelled to some extent. Key areas of capital projects tend to be either related to Intermittent Discharge operation and/or Flooding.

Currently there is no Water Industry methodology for using spatial variability of rainfall in any design work, although some work has been carried out in the past looking at the possible impacts of spatial variation of rainfall on solutions. However when verifying models against flow survey data, spatial variation has to be taken into account.

Model verification

It is UK policy to hydraulically verify models against short-term flow survey. This requires measurement of rainfall with a raingauge density of one raingauge to between 2 and 4 km^2. In small catchments this is manageable, but in large catchments such as Manchester and London this requires an extremely large number of raingauges. For example, the Davyhulme catchment in Manchester covers 195 km^2 and would require in excess of 50 raingauges for full coverage. Equally there are issues when carrying out more long-term monitoring, as there is still a need to have the same raingauge density even if only monitoring at a few locations at the downstream of the system. The use of a mixture of weather radar data and raingauge data in these situations should bring benefits.

The Committee is aware of several locations where radar data have been used for verification purposes. These include

- Manchester circa 1990
- Beckton/Crossness in London 1990-1995
- Manchester/Salford 2000 (radar data obtained but not required).
- River Calder catchment, Yorkshire 2000

There may well be others.

The take-up of weather radar for verification purposes is hampered by: -

- No agreed methodology for calibration of data
- Concerns over accuracy of weather radar data
- Potential for loss of data
- Spatial resolution of data
- Lack of experience in use
- Lack of knowledge of radar

Potential benefits are: -

- Cost savings
- Convenience
- If radar data are archived then actual flooding events can be modelled without the need for local raingauges
- Could use radar data to fill in for raingauges that have failed

User requirements would be: -

- Temporal resolution of 5 minute intervals
- Spatial distribution of $4km^2$ or better. 1 km^2 preferred.
- Calibrated data against local raingauges
- Data in mm h^{-1} at each time-step.

The only water company with a reasonable archive of radar data believe that Met Office Nimrod data since 2000 gives very similar hyetographs to raingauge data in the area and is now of sufficient accuracy to use for this purpose.

Design of Capital Projects

Intermittent Discharges

For Intermittent Discharges, typically design is carried out based on long-term rainfall series, either developed stochastically and checked against raingauge data, or if a suitable record is available using raingauge data directly.

Typically the requirement is to analyse events occurring more frequently than once per year and, as explained previously, spatial effects are not analysed.

There are a number of reasons why analysis of spatial effects is becoming more necessary.

- In large catchments assumptions that rain will fall over the whole of the catchment at the same time mean that solution storage volumes will be over-estimated at the downstream end of catchments.
- In large catchments there can be as much as 300mm difference in annual rainfall per annum. Assuming the same rainfall, this will generally lead to either over-design or under-design at some locations.
- There is a need to assess the spill frequency of intermittent discharges as an “agglomeration”, i.e. effectively lumping the discharges together and analysing them as if they are one discharge. Modelling with point rainfall will not adequately address the variability of spilling events caused by spatial effects, and solutions will not produce the required overall spill frequencies.

All of the above suggest that spatial effects will need to be assessed.

Radar data could be used in the following ways: -

- If a sufficiently long archive dataset is available, directly as an input to models.
- If not, as calibration data for a stochastically-generated spatial dataset.

User Requirements would be: -

- Minimum 10 year dataset for direct use.
- Temporal resolution of 5 minute intervals
- Spatial distribution of $4km^2$ or better.
- Calibrated data with no bright band
- Data in mm h^{-1} at each time-step

Flooding Related Designs

Rainfall used in flooding related design concerns design storms using either Flood Studies Report or Flood Estimation Handbook methodologies. Due to the typical return periods of greater than 1 in 30 years used in flooding designs, it is difficult to see how radar rainfall will be used directly in flooding related design, except to check individual events that have been known to cause flooding, and possibly to assess particular spatial events. However for the same reasons as above there is a need for a design tool which takes into account spatial variation in rainfall.

Current Capabilities of Weather Radar

It is possible for a number of locations in the UK to obtain radar data at a $1km^2$ resolution at a temporal resolution of 5 minutes. It has been possible since the early 1990's to input weather radar data into industry standard hydraulic modelling packages. It is the considered view of the largest water industry user of weather radar that recent improvements made in the quality of weather radar data mean that data are now of sufficient accuracy to contemplate its use in quantitative analysis.

Conclusion

There should be benefits to be generated from the use of weather radar in the urban drainage area, and the use of weather radar data is imperative if spatial variation of rainfall is to be accurately assessed as part of a design process. The benefits are in the short-term more associated with the area of archive data for modelling purposes. Due to the current lack of the requirement to give flood warnings, and the general inability to control wastewater networks, there is not a great need currently for predictive or real-time radar data. However this may change in the future if planning timescales lengthen beyond the current 5 year AMP cycle, and the full potential of predictive real-time control is assessed. (Note: AMP is an Asset Management Plan. This is the 5 year cycle, enforced by regulation, that the water utilities work to. Once funding is confirmed at the start of a cycle, typically years one and two are used for planning and years three, four and five are for implementation.)

Requirements to produce these benefits would be: -

- Improvements in calibration processes to ensure correction is made for bright band etc.
- Production of Industry agreed methodologies for the use of radar data.
- Demonstration projects to show the benefits of the use of weather radar.
- Long-term archive of high resolution radar data.

Water Supply Requirements

Rainfall data are generally required for assessment of reservoir levels and also for assessment of river flows for availability of water resources, and are related to an assessment of low flows.

The rainfall requirements are generally as follows: -

- Daily/Weekly Horizon data are used to assess availability of water resources relying on river flows.
- Advance warnings of low flows therefore need to have greater than 2-3 day lead-time forecasts due to the time-of-travel in water supply systems.
- Cumulative weekly/monthly rainfall data are required to assess total inflows to reservoirs.

The requirements tend to be more related to improvements in medium-term forecasts of rainfall.

Appendix 9: UK Operating Agencies Training Requirements in Weather Radar

1. Introduction

The Inter-Agency Committee on the Hydrological Use of Weather Radar is committed to three strategic areas of activity for the 2003 to 2005 programme. These are:

Strategic Area 1 – *'Bringing research findings into operational use'*

Strategic Area 2 – *'Identifying and addressing service delivery needs of operating agencies'*

Strategic Area 3 – *'Raising awareness of weather radar in the wider community'*

As part of Strategic Area 3, a specific objective was to "review training needs and provision in operating agencies". This report presents the findings of this review.

2. Training Programmes

COST Action 75 (Collier, 2001) reported on a review of training and development in weather radar for its participating countries. The review suggested a standard training syllabus for undertaking work with weather radar, which included a number of core modules:

1. The Principles of Radar
- Instrumentation overview
- Simple signal processing
- Basic sampling theory
- The Radar Equation
- Calibration
- Digital signal processing

2. Microwave Propagation
- Basic scattering theory
- Attenuation and phase effects
- Refraction and ducting
- Anomalous propagation

3. Correction and Quality Control
- Hydrometeor type
- The vertical reflectivity profile
- Spurious echoes
- Identifying and removing propagation effects

- Quality indices

4. Precipitation Estimation and Related Products

- Radar networking
- Rainfall estimation
- Hail and graupel
- Snow
- Freezing rain
- Interpreting integrated instrumentation
- Nowcasting
- Radar data and models

5. Radar Maintenance and Operational Support

- Computer systems and devices
- Radar system design
- Radar components
- Characteristics of system performance
- Maintenance of component parts
- Test equipment
- Calibration

The review recommended that: (i) a common European set of radar case study data is established to provide the basis for use in training and development programmes; (ii) that a European summer school in weather radar meteorology is held for two weeks every two years to provide training in all the modules outlined; and (iii) that a standardised weather radar training package is developed for the World Wide Web for access by all participating COST countries, with specific examples from differing countries and product generation systems (Collier, 2001).

The primary means of delivering training in weather radar in the UK for operating agencies is through the Met Office. This course “Introduction to Weather Radar” is tailored for the UK Agencies and their flood warning and forecasting staff. Much of the training course encompasses the proposed Module 4 from COST Action 75:

- Radar estimation of rainfall
- Radar data processing and quality control
- Advantages and disadvantages of raingauges and radar
- Applications of radar
- Short-period rainfall forecasting (Nimrod and Gandolf)

The most advanced training course for hydrological uses of weather radar for European operating agencies to date was held at the University of Bristol in 1998. The European Commission funded Advanced Study course was held in 1998 on *Radar Hydrology for Real Time Flood Forecasting* (Griffith *et al.,* 2001). The study course lasted ten days and covered the following topics:

- History and overview of radar meteorology and real-time flood forecasting
- Operating weather radar for real-time hydrological applications
- Properties of weather radar
- Rainfall forecasting techniques
- Flood forecasting
- Urban flood forecasting

3. UK Operating Agencies

3.1 Environment Agency

Training in weather radar is primarily aimed at flood warning and forecasting staff. All flood warning duty officers attend the “Introduction to Weather Radar” training course provided by the Met Office. Duty officers initially attend this course once, followed by a refresher some years after.

The Agency has a national programme of training which has a number of courses that are tailored to specific job roles and duty roles based around a set of “skills and competences” identified as being required by staff to carry out their roles. The Met Office “Introduction to Weather Radar” training course was set up independently from this programme as a response to the Easter 1998 Bye Report Actions.

There are plans to review the training requirements for flood forecasting and warning in 2005. At present there is a flood warning foundation course for new staff, which is separate to the “Introduction to Weather Radar” course.

3.2 Scottish Environment Protection Agency

Weather radar is used operational by SEPA’s hydrology staff for flood warning and forecasting. No national programme of training exists for flood warning and weather radar at present. However, in a review of operational requirements of weather radar for flood warning (SEPA, 2002) it was identified that there is a need for training in the operation and technical aspects of weather radar.

The National Flood Warning Development Team in SEPA has developed a programme for national training in flood warning. The training has been designed to meet a set of competences required for flood warning operation. This training programme as yet has not been implemented. However, the Met Office has provided training courses on “General Meteorology” and “Introduction to Weather Radar” to a number of hydrology staff. The intention is to run these courses annually to ensure all hydrology staff attain the basic level of knowledge in meteorology and weather radar.

3.3 Department of Agriculture and Rural Development, Northern Ireland (Rivers Agency)

Existing legislation in Northern Ireland (Drainage (Northern Ireland) Order, 1973) contains no specific provision relating to a flood warning function. Therefore at present there is no compelling requirement for the Rivers Agency to operate flood warning schemes. However, the Agency does attempt to pre-empt the onset of flooding through the receipt of Heavy Rainfall Warnings and National Severe Weather Warning Forecasts from the Met Office, interpretation of the Castor Bay radar and observation of real-time field gauging equipment.

A recent feasibility study into flood warning in Northern Ireland, commented that the Castor Bay radar is currently used as a qualitative indication of current and future rainfall; however, data could be more effectively integrated into everyday operations of the Rivers Agency, e.g. real-time display capability in all area offices of the agency, with staff trained in the interpretation of the radar information (Babtie Group, 2002).

3.4 Water Utilities

Water companies across the UK have limited access and use of weather radar. Some companies operate either MIST or ENVIROMET for operational purposes for urban drainage and water supply. There is also some use of radar data in modelling.

At present there is some training provision for the use of weather radar, although this varies across the water companies and may be provided internally – this level of training is one of Awareness Training of what radar rainfall products can be used for and accuracy levels.

Future training requirements depend on the take-up of radar across the water companies. There would appear to be a requirement for a basic level of training for users of systems such as Enviromet, particularly in the basics of weather forecasting and interpretation of radar data. If the companies develop their use further, there would also be a requirement for training in the use of radar data in modelling, calibration and accuracy of radars and the use of radar data in return period analysis.

3.5 States of Jersey

The States of Jersey’s operational interest in weather radar is for urban drainage. However, the main, and currently only operational user of weather radar in the States is the Met Office. The Met Office forecasters will be trained through the Met Office’s Remote Sensing training course. All will attend this course and a refresher once every 8 to 10 years.

Operational Use	Radar Access	Training	Frequency and Numbers	Future Training Plans
Environment Agency				
Flood warning and forecasting	HYRAD and Enviromet	Met Office 'Intro to Weather Radar'	All duty officers	Flood warning 'skills and competences'
Scottish Environment Protection Agency				
Flood warning and forecasting	HYRAD and Enviromet	Met Office 'Intro to Weather Radar'	12 duty officers per annum	-
DARDNI Rivers Agency				
No requirement for flood warning at present	-	-	-	None, but may be required if flood warning develops
Water Utilities				
Urban drainage and water supply	Enviromet	In-house	-	Basic radar training and advanced user may be required
States of Jersey				
Urban drainage and Met Forecasting	-	-	-	-

4. Comment

Training courses are clearly being delivered for the agencies that have an operational requirement for weather radar. This is usually at a basic level, i.e. introduction to weather radar for flood warning staff in the EA and SEPA. For agencies that do not have an operational requirement, there are as yet no requirements for training. However, it is clear that if the business requirement changes, i.e. flood warning in Northern Ireland or increased urban drainage modelling within the water utilities, then this will drive a need for training delivery.

Therefore there are two main areas that the IAC should consider ensuring that operating agencies are catered for in the future:

(1) That agencies developing into new business areas are catered for with regard to training. At a basic level this could mean that the Committee make available information about existing courses to the agencies developing into operational use of weather radar and that these courses meet their requirements.

(2) That the IAC consider ways of developing more advanced training courses for the hydrological use of weather radar, for flood forecasting, urban drainage and water supply modelling.

References

Babtie Group 2002. *Northern Ireland Fluvial Flood Warning Feasibility Study*. Report commissioned by DARDNI Rivers Agency.

Collier, C. G. 2001. *COST Action 75 – Advanced Weather Radar Systems 1993-97*. Final Report, European Commission, Research Directorate-General, Brussels.

Griffith, R. J., Cluckie, I. D., Austin, G. L. and Han, D. eds. 2001. *Radar Hydrology for Real Time Flood Forecasting*. Proceedings of an Advanced Study Course, University of Bristol, 24 June to 3 July 1998, EUR 1988, European Commission, Brussels.

SEPA 2002. *Operational Review of Weather Radar for Flood Warning – Consultation with SEPA Flood Warning Duty Officers*. National Flood Warning Development Team Report, SEPA.