Evaluation of Integrated Flood Forecasting Systems

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R&D Technical Report W17

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Statement of use
The purpose of this document is to increase the awareness of the different systems used for flood forecasting within the Environment Agency and former NRA Regions. It will provide useful comparison of the systems used and will be of use to Regional Flood Defence Managers and Flood Warning staff.

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EXECUTIVE SUMMARY

Following the state of the art review of NRA river flood forecasting in 1991, R&D Project 287 was established to evaluate the new integrated forecasting systems which were about to be commissioned in the former Yorkshire and Wessex regions of the NRA. Whilst the detailed performance of individual models would be examined by the developers of the systems, the main purpose of this project was to evaluate the overall effectiveness of the forecasting systems in operational conditions, comparing them with on-line forecasting procedures already operating in some other regions.

It is suggested in this report that objective evaluation of operational performance should be based on the extent to which the forecasting systems make it possible for reliable warnings to be issued with the required lead time. Traditionally, flood warnings for individual flood risk areas were issued when the river level at an associated reference point reached a specified warning level. This was satisfactory on some of the larger U.K. rivers where the reference points could be sufficiently far upstream, so that the time of travel of the flood wave from the reference point to the area at risk provided the required lead time. More generally, target lead times can only be achieved by basing warnings on <u>forecast</u> levels at reference points, and the time at which such forecasts are required depends on the location of the reference point relative to the area at risk. To provide a uniform standard of service target lead times for forecasts therefore need to be site-specific. A method of monitoring performance relative to site-specific forecast lead times, using data which should be routinely available, is detailed in this report.

The present position is that the new RFFS and WRIP systems are operating in Northumbria and Yorkshire region and in South Western region respectively, but the development/calibration of the models has, with a few exceptions, not yet reached the stage where warnings can be reliably based on the forecasts produced. The systems provide considerable help to duty officers by collecting, processing and displaying telemetry and radar data on a region-wide basis, but their operational performance as forecasting systems cannot yet be measured.

As it is now five years since this project was established, it has been decided to produce this report now, to draw attention to the urgent need to expedite the ongoing work in the relevant regions to improve the operational performance of the "new" systems, so that the potential benefits in terms of timely and reliable flood warnings are achieved. These systems need to be fully functional, and once proved, will probably need to be extended to additional areas to meet public expectations of advance warning of flooding. In view of the number of flood risk areas, a long term aim should be to make the forecasting and warning process as automatic as possible.

The report recommends that the proposed method of monitoring, based on site-specific forecast lead times, be tried out in one region to assess whether it would be a suitable way of evaluating the performance of the new systems when their development reaches an appropriate stage.

The integrated data collection and forecasting systems currently used in the NRA are briefly described in the main report with further regional details in the Appendices. Section 4 of the report discusses further work required in connection with the WRIP and RFFS systems and comments on the relevance of catchment response time and the value and limitations of real-time

updating.

KEY WORDS

Flood Forecasting, models, flood warning, flood risk, operational performance, rivers

1. INTRODUCTION

The 1991 review of river flood forecasting (NRA R&D Document No. 201/2/SW) was compiled at a particularly interesting time in the development of flood forecasting procedures. New forecasting systems were about to be commissioned in several NRA regions, with the objective of improving the service that could be given by flood warning duty officers in terms of geographical coverage and timeliness of warnings. In these systems, the processing of data collected by telemetry and by weather radar was to be integrated with mathematical modelling, to produce forecasts of river levels at reference points throughout the relevant regions.

Some computer-based forecasting procedures were already in operation, and whilst these were of considerable assistance to duty officers, reliable four-hours-ahead forecasts could be provided only for the middle and lower reaches of some of the larger rivers of England and Wales. The new systems were being designed to allow duty officers to monitor and initiate warnings for a large number of flood risk areas. It was hoped that improvements in the calibration of weather radar data, in quantitative rainfall forecasting and in real-time modelling would make it practicable to include many quick-response urban and upland catchments.

Whilst it is possible, where suitable computer facilities exist, to examine the potential performance of the various elements of the forecasting systems "off-line" using historic data, this project was established primarily to assess the actual performance of the complete systems in operation. The overall project objective was "to evaluate the integrated flood forecasting systems to be commissioned in Wessex and Yorkshire regions and those operating in Severn Trent and North West regions and provide recommendations for future development" and this was extended to include developments in Anglia and Thames regions. The detailed objectives were :

a) To carry out a detailed examination of integrated flood forecasting systems in use or being installed in each of the National Rivers Authority Regions.

b) To evaluate the performance of each of the systems in real time flood forecasting situations.

c) To assess the suitability of each of the systems for use by other regions and to make recommendations as to the methods which should be applied to allow systems to be transferred.

d) To produce a report setting out in detail:

   i. Structure and form of the models
   ii. Results of forecasting evaluation tests
   iii. Assessment of advantages and disadvantages of each model
   iv. Recommendations for general use within the NRA

The project started in 1991 and the first interim report (R&D Document No. 287/1/SW) was produced in May 1992. The report summarised the main features of the flood forecasting systems operating, or being introduced in the six regions mentioned above, and included some preliminary thoughts on aspects of performance to be reported. A short section on future development was included, as it was felt that this could help to identify the important features of current developments.

Unfortunately, commissioning of the new systems in the former Wessex and Yorkshire regions was delayed, and it is taking much longer than originally expected to calibrate them to the stage where the forecasts can be relied upon in operational conditions. Whilst the forecasts are of value to the duty officers in deciding whether warning levels are likely to be exceeded, most public warnings are still based on actual levels at reference points some distance upstream. Until warnings are more widely based on forecasts, objective performance data for the new systems cannot yet be collected, and in the absence of such data it is not possible to fulfil the original terms of reference. More important, from the point of view of the NRA and the public, is the fact that the potential benefit of these systems is not yet being achieved.

In the meantime, three spin-off reports have been produced for the Joint NRA/Meteorological Office Working Group on the development of the National Weather Radar Network. These were notes on:

* The Use of Weather Radar in NRA Regions, October 1994.
* NRA Telemetry Rain Gauge Networks, Rainfall Data sent to Met. Office in Machinable Form and Regions' views on a Radar Data Archive, December 1994.
* Weather Radar Benefits, March 1995.

The accuracy of radar-derived rainfall estimates is the subject of several current research projects, so it is not discussed in any detail in this report.

In view of the delays which have occurred, this report has been prepared with the aims of summarising the progress that has been made, commenting on some aspects of the forecasting systems in advance of performance measurement, and putting forward recommendations. Appendix A summarises the developments in NRA regions since the completion of the 1991 review, and Appendix B is an updated version of the equivalent appendix in the 1992 interim report.

2. NRA REGIONAL FLOOD FORECASTING SYSTEMS

2.1 General

The new flow forecasting systems commissioned by the former Wessex and Yorkshire regions were products of two separate, parallel research and development programmes. The Wessex "WRIP" system was developed by Salford University, and the Yorkshire "RFFS" system by the Institute of Hydrology (IH) and Logica. The WRIP system, and its associated STORM radar display package, are now available for use alongside other procedures, in South Western, Anglian and North West regions. As if to maintain the balance, the RFFS which is operational in Northumbria and Yorkshire is also being implemented in Thames region, whilst the HYRAD radar processing and display package developed originally by IH for Thames, is being adopted by Northumbria and Yorkshire region and by Southern region.

North West region continue to use the relatively simple models built into their Regional Telemetry Scheme (RTS) and Severn Trent region have progressively improved their Flow Forecasting System (FFS) which was developed largely in-house with assistance from external software suppliers.

Brief descriptions of these systems are given in the following Sections, and more details are available in the Appendices.

2.2 The WRIP System

WRIP - originally the Wessex Radar Information Project, but more recently interpreted as Weather Radar Information Processor - is a VAX or UNIX based system for real-time flow forecasting. A "sister" package MATH (Model Analytical Tool for Hydrology) is used in South Western region for off-line work using archived data. The current version of WRIP uses Physically Realisable Transfer Function (PRTF) models which are constrained to be stable and non-oscillatory. All such models in current use are of the lumped rainfall/run-off type for individual catchments. For hydrological flow routing within a dendritic river network, a model incorporating a cascade of linear reservoirs has been adapted for calibration using a "genetic" algorithm, which can cope with a large number of parameters. This model is being evaluated initially in the Bristol Avon catchment with seven sub-catchments providing inputs to the routing model. The basic structure of transfer function (TF) models has been described by Cluckie et al (1989) and by Moore (1993).

In these models the forecast flow at any time step is based on immediately preceding observed or forecast values of rainfall and flow. The time step is normally one hour, but this can be varied. Typically, forecast flow is based on the preceding three hourly flow values together with the last hour's rainfall. In some cases, up to four previous hourly rainfall amounts are also used; the number of hourly flow and rainfall readings included being determined individually for each catchment. In principle, rainfall values before the last hour are not used unless they add significant information to that already contained in the three most recent flow values. The catchment rainfall estimates are normally based on national radar network data, with telemetered raingauge information as an alternative. The system includes local forecasting of rainfall by automatic extrapolation of both the movement and changing intensity of precipitation. As a further alternative, the duty officer can select from a range of future rainfall profiles.

In real-time operation, simulated flows at successive time steps, based on observed, and subsequently forecast rainfall, are displayed as a forecast hydrograph. The duty officer can select "simulation" mode, and specify the time at which the simulation should start. In this mode, observed flow values are also plotted as a separate curve on the same display, and the duty officer can adjust the shape of the forecast hydrograph to conform more closely to that of the observed hydrograph. The first adjustment facility provided was a "delta factor" applied to the input rainfall, which was similar to a percentage run-off adjustment, but the current version of WRIP allows the shape of the hydrograph, the total volume of run-off and the catchment lag to be adjusted. An experienced duty officer, with detailed knowledge of the behaviour of the prototype catchments and models, can use these adjustment facilities to allow for differing antecedent catchment conditions or storm characteristics. As an event progresses, the same parameters can be notified to ensure the model simulations are in line with the latest observed flows.

South Western region believe that the performance of the models could be significantly improved, and the need for adjustment reduced, if one or more of the model parameters could be related to the catchment conditions at the start of the event. They have demonstrated that the models, calibrated for average catchment conditions, tend to over-estimate peak flows resulting from rainfall on a dry catchment and vice versa, so some form of soil moisture accounting may be required. Work is currently under way to identify those hydrological or hydrometeorological variables that might be utilised automatically to control the setting of the model parameters. One of the variables which will be considered is the observed flow, as used in the system described in Section 2.7.

In the alternative "forecast" mode of real-time operation the forecast starts from the last observed flow available at the time the request is made. This would probably be the preferred mode when using a well calibrated reliable model, but the simulation mode gives the duty officer a better appreciation of the way the model is performing at the present stage of development.

2.3 The RFFS System

The River Flow Forecasting System (RFFS) as described by Moore (1993) is a generic system for flood forecasting in simple or complex river networks. It incorporates an interface to the HYRAD radar processing and display system as well as providing facilities for telemetry data acquisition, forecast display, decision support, and dissemination of flood warning messages by fax. The system is modular, so that a variety of rainfall/run-off, routing and other models can be included, and models within a catchment can be chained to increase lead time. The system maintains a data-base of levels and flows at specified locations within the region, using observed data where available and using forecast values to infill any missing historic data and to extend the data-base into the future.

Whilst the RFFS runs intermittently - normally once a day, with additional runs when required during events - the modelling is continuous in the sense that following a forecast run, the "states" of the models are stored, and any subsequent run will start forecasting from the time the model states were last stored.

The types of models available in the RFFS, are described in detail in Moore (1993). The available models include algorithms for rainfall/run-off, channel flow routing, snowmelt, hydraulic modelling of tidal river reaches and error prediction. Other modules are designed to merge data from different sources, on a priority basis, to ensure that any data series required for forecasting is complete.

The standard rainfall/run-off model in the RFFS is the Probability Distributed Moisture (PDM) model, though other model types can be included, as in Thames region. The PDM model has been developed to allow representation of a broad range of hydrological responses whilst using as few parameters as possible. It is a conceptual model in which rainfall is apportioned to direct run-off and subsurface run-off using a probability-distributed soil moisture storage concept, which allows for variation in soil moisture across a catchment. The direct run-off is routed through surface storage, and the remaining rainfall enters soil storage where it is depleted by evaporation and groundwater recharge. The latter contributes to basin run-off after being routed through the groundwater storage.

The "KW" flow routing model available in the RFFS is a kinematic wave model, extended to provide for discharge-dependent wave speed and overflows into washlands. The "PACK" snowmelt model is based on sub-division of a snowpack into dry and wet stores, with a temperature-excess melt equation. Rate of release of water from the wet pack is assumed to be proportional to the wet pack storage up to a critical water capacity, and then at an enhanced rate, except that drainage is inhibited when the temperature falls below freezing point.

The RFFS includes facilities for real-time updating of forecasts by reference to observed values of river level or flow using state updating or error prediction. In state updating, the notional contents of the various stores are adjusted to give a forecast which agrees more closely with the latest observed values, whilst error prediction methods exploit the tendency for errors in forecasts to persist. In Northumbria and Yorkshire, state updating is used for the rainfall/run-off models and error prediction for the routing models.

Northumbria and Yorkshire Region have recently undertaken a programme of off-line testing of RFFS forecasts for selected river networks within the region. The conclusions of these reports indicate that the performance of many of the models is not yet satisfactory at the lead times investigated. Recommendations were made regarding the need to review the calibration of many of the models and, as part of this process, to calibrate or extend the calibrations of a number of river level stations.

2.4 Thames Region Systems

Thames region was faced with the particular problem of developing forecasting procedures which would enable flood warnings to be issued for the relatively small urban catchments in the London area. These catchments have a very rapid hydrological response and in many cases it was clear that, for target lead times to be achieved, warnings would have to be based on forecast rainfall. In view of the value of property at risk in these areas, the region took the lead, jointly with the

Institute of Hydrology, in the development of local rainfall data processing and forecasting. The duty officers now have access to a range of displays of areal rainfall estimates, based on radar or raingauges, or an optimised combination of these techniques, together with the local and national quantitative forecasts of areal rainfall. The national forecasts are now provided by the Met. Office Nimrod system which has replaced the FRONTIERS procedures.

The areal rainfall estimates, including the forecasts, for individual catchment areas are available as input to rainfall/run-off models, and the range of models has been increased with the adoption of the RFFS system. Three types of model are used as noted in Appendix A, and calibration is in progress. The GANDOLF system is being developed to improve the forecasting of thunderstorms, and to provide guidance on the use of rainfall forecasts. The forecasting system has been designed to cater for a wide range of catchments, from the quickly-responding small urban catchments in London to the large rural catchments of the Thames and its tributaries west of London.

R&D Note 225 describes an assessment by IH of the influence of using different forms of rainfall as input to rainfall/run-off models, together with an assessment of different types of models and updating methods. The subsequent Operational Guidance Note (R&D Note 387) made detailed recommendations regarding the implementation of the rainfall and flow forecasting procedures.

2.5 The North West RTS System

The relatively simple forecasting facilities built into North West region's regional telemetry scheme have now been operating for some twenty years and the display facilities do not compare with the more recent systems. They are included here because they illustrate some important features of forecasting systems. These features include:

* Being linked to a radio-based telemetry system they operate continuously and forecasts are automatically updated every 15-minutes.

* For some flood risk areas several independent forecasts, based on different sources of information, are available.

* For any particular risk area, these independent forecasts are plotted as separate forecast hydrographs.

* The duty officers plot and extrapolate the hydrographs of observed levels or flows, following the trends of the forecasts, subjectively giving more weight to those forecasts which are known from experience to be the more reliable. (See Figures 4.2 and 4.4 of IWEM, 1987)

* Flood warnings are based on the extrapolated hydrograph of observed levels or flows.

* For the flood risk areas included in the formally documented system, 2 to 4 hours' warning is generally achieved.

In addition to the RTS system, the North West region now have a version of the WRIP system with 14 rainfall/run-off models but, as noted in Appendix A, it has not yet been possible to examine the calibration or performance of these models in any detail.

2.6 The Severn Trent (FFS) System

The Severn Trent system was credited by Moore (1993) with being the first region-wide system in operation in the U.K., and with having a software design which was highly modular. The original system was described by Bailey and Dobson (1981) and progressive improvements have been described by Dobson and Davies (1990) and Dobson (1991). The current version is described in detail in the Wallingford Water Stage 2 River Soar report (1995). Being based on a series of conceptual models the Severn Trent FFS has similarities with the RFFS. The Wallingford Water report compares the two systems and makes recommendations for combining the best features of both. The present FFS is based on three types of model:

* A conceptual rainfall/run-off model, broadly similar in structure to those in the RFFS.

* An in-house river reach flow routing model, in which upstream flows and lateral inflows are lagged and attenuated, and allowance made for floodplain storage and flow.

* An error correction procedure, which will predict a future error pattern and apply this to the raw forecast to improve its accuracy for up to 48 hours ahead.

Catchment area rainfall estimates for the rainfall/run-off models are based on up to six raingauges for each catchment, with provision for radar-based estimates to be used in the future when radar calibration techniques are sufficiently advanced. The RECS regional emergency communications system collects 15-minute level data and time-of-tip raingauge data from outstations, but only hourly instantaneous levels and hourly total rainfalls are stored for use in forecasting. As in the RFFS the model "states" required to initialise a subsequent run are stored.

The calibrations of these models are being progressively reviewed, and current regional policy is to base flood warnings on forecasts, whenever these are considered to be sufficiently reliable, rather than wait for the warning level to be actually reached. To assist the duty officer in assessing the validity of current forecasts, the display for any forecasting point shows both the original forecast and the hydrograph as adjusted by the error correction procedure - the latter as an extension of the observed hydrograph. The ELFS computerised level to level correlation system is also used as a means of validating the FFS forecasts. Some 95% of warnings are now issued when the duty officer is confident that a warning level will be exceeded, without waiting for that level to be actually reached.

2.7 The Solway River Purification Board System

This system, outside the NRA area, is included because it has several notable features which are of general interest. It is a good example of necessity being the mother of invention, and it also illustrates the benefit of clear responsibility for project management in a small organisation.

The Board required a flood warning system for Dumfries, but did *not* have sufficient staff resources to set up a duty officer rota. The solution to this problem, developed jointly by in-house staff and the Centre for Research on Environmental Systems and Statistics (CRES) at Lancaster University, is a fully automatic system running on a personal computer. When triggered by an alarm from an outstation, the computer collects the last three days' hourly data from six river level stations and three raingauges. After quality control and infilling of any missing values, the models are run and when necessary flood warnings are issued directly to the police with a five-hour lead time. The system has been operating for almost five years, and has been shown to be reliable.

The system, described by Lees et al (1994), is based on interconnected transfer function (TF) models for sub-catchment rainfall/run-off and for flood routing. A feature of the rainfall/run-off modelling, which may be of interest to users of the WRIP system, is that the observed river flow is used as an indicator of catchment conditions: the effective rainfall estimate is based on the product of the observed rainfall and the river flow recorded "t" time steps earlier. ("t" can be zero or positive). During the first two years of operation, the first order rainfall/run-off TF model for the Cluden Water (247 km^2), which is based on two raingauges and incorporates a time delay of 3 hours, produced 3-hour lead time forecasts of peak levels with an average error of 93 mm, measured over the 9 highest events. If one event, in which the recorded precipitation was falling as snow (giving an over-estimate of 278 mm) is excluded, the average error becomes 70 mm.

The first order flood routing models include an adaptive gain parameter, which varies the steady state gain of the models. For the 5-hour ahead forecasts of river level at Dumfries, this automatic adjustment reduced the average error in peak level estimates for the nine events mentioned above, from 125 mm to 57 mm. Confidence limits are indicated on the forecast hydrograph displays.

3. EVALUATION OF PERFORMANCE

3.1 General

Before discussing the state of development and performance of rainfall and flow forecasting systems, the remarkable value of the existing on-line data collection and display systems must be acknowledged. The utility of the weather radar images is widely appreciated, but tends to be taken for granted, and on the larger U.K. rivers the display of river levels or flows in near real-time often makes it possible for flood warnings to be issued on the basis of the observed levels, or on subjective extrapolation having regard to rainfall and river level trends at upstream stations.

However, public perception of current technology is such that they expect to be given advance warning of flooding, wherever it occurs. The integrated forecasting systems were intended, by partially automating the forecasting process, to make it possible for duty officers to monitor, and initiate warnings for a large number of flood risk areas. Planning for comprehensive coverage meant that forecasting procedures had to be developed for rapidly responding upland and urban catchments, and for other technically complicated situations such as those involving tidal or variable backwater effects. Regional forecasting systems therefore need to offer a range of forecasting procedures which can be applied optimally to individual catchments, and any evaluation of performance needs to have regard to the relative difficulty of forecasting in each catchment.

Several regions have commented that performance is likely to be influenced more by the representativeness of the input data and the quality of calibration, than by the type of model used. If the NRA wished to compare the performance of different model types, for example TF and PDM rainfall/run-off models, the modular structure of the RFFS would allow such models to be set up in parallel for selected catchments, as suggested in R&D Note 387. That Note also suggested that an automated assessment procedure could be used to compare the model performance in detail.

This project is concerned with the overall performance of forecasting systems in actual operation. The project is relevant to those flood risk areas where, to achieve the required lead time, a warning has to be issued before the trigger level is reached at the reference point for the zone. This line of thought is developed further, after the following brief review of recent relevant reports.

3.2 FDERNLOS Measures

In 1993 the NRA's Flood Defence Emergency Response, National Levels of Service Group produced a matrix of nine possible measures for post-event appraisal of flood forecasting and warning performance. Three of these measures were concerned with the dissemination of warnings and these activities are outside the scope of this project.

The remaining six measures were:

* Proportion of flood risk locations flooded, for which forecasts were made.

* Proportion of flood risk locations where exceedance levels at a reference point were predicted to a defined level of accuracy.

* Proportion of forecasts made in target lead times defined for flood risk location.

* Proportion of warnings issued for flood risk locations for which flooding was forecast.

* Proportion of warnings followed by predicted event.

* Proportion of warnings issued with appropriate target lead time.

In the opinion of the present author, these measures can be simplified by defining the end of the forecasting process to be the time when a warning is issued. A perfect forecast is of no value if the duty officer does not have sufficient confidence in it to issue a warning.

3.3 IH Categorical Measures

In R&D Note 225, IH explained categorical measures of performance which are appropriate where the object of forecasting is to predict the exceedance of specified warning levels or flows. The suggested categories, which were used with specified lead-times and thresholds in the IH off-line study, were:

* Threshold exceeded during forecast <u>and</u> during event (ie. correct forecast).

* Threshold exceeded during forecast <u>but not</u> during event (false alarm).

* Threshold <u>not</u> exceeded in forecast, but <u>exceeded</u> during event (missed flood).

Three skill indices were derived from the numbers of forecasts/events falling into each of these categories. These were the Probability of Detection, the Correct Alarm Rate, and the Critical Success Index; the last of these, for example, being the number falling into the first category divided by the total number in all three categories.

3.4 The Krzysztofowicz ASCE Paper

In Krzysztofowicz (1994) the authors stated that the planning and design of a local flood warning system should include a reliability analysis. They suggested that the reliability of warnings could be quantified in terms of the "relative operating characteristic" - a relation between the probability of detection and the probability of false warning. From this, the "performance trade-off characteristic" - a relation between the expected number of detections and the expected number of false warnings per year - could be derived. The further trade-off between reliability and lead time was demonstrated.

The conceptualisation of the forecasting process into Monitor - Forecaster - Decider is interesting, and parallels NRA procedures. When any pre-defined set of conditions is observed, the monitor triggers operation of the forecasting system, the flood observing network is activated and a forecast of the flood crest is prepared. This forecast is supplied to the decision system - an emergency management organisation or a flood plain manager - who must then decide whether or not to issue a warning to the public. When the flood plain extends across a range of elevations, it is divided into elevation zones; a flood warning is issued for a zone. The performance of the monitoring, forecasting and deciding stages was examined using four binary variables, which indicated whether the system had been triggered, whether flooding had occurred anywhere, and, for each particular zone: whether a warning had been issued and whether the zone had flooded.

In the flood forecasting part of the forecasting/warning process, the NRA is mainly interested in the reliability of forecasts of levels or flows at reference points, representing flood risk zones, but this paper prompts the question as to whether the NRA would also wish to monitor the triggering of flood forecasting and warning procedures to see how often a trigger is followed by flooding, or whether any warning thresholds are exceeded without the system having been triggered.

3.5 The WMO - MOFFS System

In 1990 the World Meteorological Organisation proposed a point scoring method for describing and monitoring the performance of flood forecasting systems, known as MOFFS (Management Overview of Flood Forecasting Systems). This was based on subjective points scales and it was concluded in Marshall (1992b) that the format as a whole could not be recommended for use within the NRA. However, the concept of a minimum lead time for forecasts for each forecast site is potentially useful.

The MOFFS minimum lead time is the time needed between a forecast being issued and the quoted level or flow actually being reached at the reference point. It is the time needed to permit the necessary response, and can be zero if the location of the reference point is far enough upstream of the flooding site for the time of travel of the flood wave from the reference point to the flooding site to exceed the public warning time required.

3.6 Severn Trent Region Data

Severn Trent region provided records for periods during 1992/93 and 1993/94 showing the times when warnings had been issued, together with the corresponding times at which the relevant warning levels had been reached. These records illustrated a number of points regarding lead times:

* The established trigger points and levels had originally been chosen so that warnings based on the specified levels being actually reached would give reasonable warning of flooding. Many warnings were therefore issued close to the time when the warning level at the reference point was reached.

* The elapsed time, from the issue of the warning (at time T_1) to the time the relevant warning level was reached at the reference point (time T_2), has been calculated for each of the warnings issued in the November 1993 to January 1994 period. The results are shown in histogram form in Figure 3.

* On average, warnings were issued 2.5 hours before the warning level was reached at the reference point. If the average delay between the exceedance of a warning level and the onset of flooding was, say, 1.5 hours, the target of 4 hours warning would, on average, have been achieved.

* Over 70% of the warnings were issued before the warning level was actually reached at the reference point. Since 1993/94, with increasing reliance on the forecasting and validation procedures this proportion is understood to have increased to around 95%.

* In a few cases the travel time of the flood wave from the reference point to the area at risk is such that a warning issued several hours after the warning level has been reached can still give reasonable warning of flooding. This sometimes means that the transmission of warnings in the middle of the night can be avoided, and this explains the larger negative values in Fig. 3.

Consideration of these data led to the conclusion that the individual travel time from each reference point to the associated area at risk needs to be taken into account in determining the need for forecasting at that reference point and the target forecast lead time required. This is discussed further in the following Sections.

3.7 Target Lead Times

In Paper FD(93)48, Emergency Response Levels of Service, prepared by Lindsay Pickles for the Flood Defence Managers Group in 1993, the lead time for warnings was envisaged as being composed of three parts:

$$T_L = T_W + T_D + T_R$$

where

T_W = the time to issue a warning to the Police.

T_D = the time for the Police to disseminate the warning.

T_R = the time for recipients to respond to the warning.

It was suggested that whilst T_W might be 0.5 hr in all cases, appropriate values for T_D and T_R might be related to land use. If each of these varied between 0.5 and 2.0 hours, the paper noted that the required warning lead time T_L could vary between 1.5 and 4.5 hours. It is not clear why residents in land use band A were to be given 2 hours in which to respond to warnings, whilst those in band B were to be given 1 hour, and those in bands C, D and E only 0.5 hour.

In the subsequent paper FD(93)60, Borrows (1993), the target level of service is "to provide the public at risk with at least 2 hours advance warning" of flooding. Other reports have concluded that 4 hours' public warning is about the optimum, where this can be achieved.

The detailed arrangements and targets for flood warning are outside the scope of this project, but the lead time targets are fundamental to the planning, and the evaluation, of forecasting systems. Looking ahead to September 1996 when the Environment Agency will be disseminating forecasts direct, rather than via the police, it is assumed for this report that the Agency will specify the target time allowed for the dissemination of warnings: T_D, and the minimum time to be allowed for the public to respond: T_R.

It will also be possible to specify a target for T_W which is the time required to process the most recent input data and to decide whether to issue a warning. Data processing would include running models to update forecasts, where necessary, as discussed below.

The values of T_W, T_D and T_R could be standard throughout England and Wales, giving a fixed minimum value for T_L at all flood risk locations.
However, because input data and forecasts are updated at discrete time intervals rather than continuously, and the overall conditions justifying a warning could occur just after an update, the overall lead time for warnings needs to be:

$$T_L = T_W + T_D + T_R + T_I$$

where T_I is the interval between successive updates of the information or forecasts on which the warning is based, which could be typically 15 minutes or 1 hour.

3.8 Target Lead Times for Forecasts

Decisions to issue flood warnings are usually based on the exceedance, or forecast exceedance, of specified levels at reference points close to, or upstream of flood risk areas. Ideally, the reference points should be close to the areas at risk. This allows accurate relationships to be established between levels at the reference points and the extent of flooding in the adjacent areas.

The water level at each reference point needs to be available via telemetry for real-time use, and needs to be logged for use in the development of forecasting procedures and in the optimisation of warning trigger levels.

Many of the existing reference points are some distance upstream of the associated flood risk areas, either because an existing gauging station was adopted or the site was deliberately chosen so that the travel time of the flood wave from the site to the area at risk would provide several hours' lead time.

For this report, the objective of the flood forecasting process is taken to be the forecasting of levels or flows at the specified reference points. The derivation of relationships between levels at the reference points and the extent of flooding, together with the optimisation of the flood warning trigger levels, are taken to be flood warning matters.

Where there is a simple relationship between level or flow at an upstream reference point and the extent of flooding in the associated flood risk area, that reference point will continue to be the focus of the local forecasting procedures. Where such a relationship is found to be unreliable, consideration should be given to establishing a new reference point close to the area at risk, and developing forecasting procedures for levels at the new reference point. A similar recommendation would be made where warnings are based on several upstream data sources, such as flows in two or more tributaries, if there is currently no reference point adjacent to the flood risk area.

Subject to the above comments, the Environment Agency will wish to make the best use of existing installations so as to minimise overall costs and to build on accumulated experience. Inevitably therefore, if reasonably uniform lead times for warnings are to be provided, the travel time of the flood wave, from the reference point to the area at risk, needs to be taken into account. Across a region these travel times will vary from zero to several hours. The travel time from any particular reference point to its associated flood risk area will also vary from one flood to another, but a reasonable minimum value needs to be adopted for each site. If the minimum travel time from a particular reference point to the associated area at risk is T_T, forecasts of level or flow at the reference point will be needed, with a forecast lead time T_F where:

$$T_F = T_L - T_T$$

ie. a method of forecasting is needed which, using observed data up to any time t, will produce a forecast of the level or flow which will occur at the reference point at time $(t + T_F)$.

Summarising the above, the target lead times for forecasts of levels or flows at reference points need to be site specific because T_T will vary from site to site:

$$T_F = T_W + T_D + T_R + T_I - T_T$$

where:

T_W = the time required to process the most recent input data (including any modelling) and to decide whether to issue a warning.

T_D = the time allowed for the dissemination of warnings.

T_R = the time allowed for recipients to respond to warnings.

T_I = the time interval between updates of the information or forecasts on which warnings are based.

T_T = for an individual flood risk area, this is the travel time of a flood wave from the reference point to the area at risk (strictly, the minimum time between a warning level being reached at the reference point, and the onset of the related flooding).

If the calculated T_F is negative, no forecasting is needed as warnings can be based on observed levels or flows at the reference point. (It might be useful to note any negative values in procedural documentation if advantage was to be taken of any opportunities to avoid transmitting warnings at night.)

In practice, this overall concept would be straightforward to operate, since T_W, T_D and T_R could be specified nationally and T_I would be constant throughout any forecasting system, leaving only T_T to be determined for each flood risk area. A refinement would be to increase T_R at those reference points on larger rivers, where more lead time could be given without a significant decrease in reliability.

3.9 Monitoring Performance of Forecasting Systems

In the context of this project, it is suggested that the primary measure of the overall performance of a forecasting system should be the percentage of occasions for which a correct forecast, of the exceedance of a warning level, was issued with at least the specified lead time for the site.

Bearing in mind the earlier comment that even a perfect forecast is of no value if the duty officer does not have sufficient confidence in it to issue a warning, the individual forecasts to be included in the analysis should be those on which warnings were based.

In practice therefore, the records of warnings issued could be used as the basis for the analysis, along with the records of the times at which the warning levels were actually reached at the reference points. These records should be readily available. The target lead time for forecasts, defined above, includes a time T_W for data processing and decision making. If an individual warning is issued at time T_1 and the warning level at the reference point is reached at time T_2, the target lead time will have been achieved if:

$$T_2 - T_1 > T_F - T_W$$

To set up a performance monitoring system on this basis would initially require the following information for each flood risk area:

River
Reference Point
$T_F - T_W$ (hours)

Events could then be recorded in spreadsheet format, with the following being recorded for each event:

Reference Point (by reference number)
Warning level (by reference letter)
Warning issued, date and time
Warning level reached, date and time

Whilst the above details would be sufficient to indicate whether targets were being achieved, it may be appropriate to include some measure of the difficulty of forecasting at each reference point. There are at least two ways in which this could be done. The simpler would be to quote the $T_F : T_p$ ratio in the permanent details relating to each reference point. Generally, this ratio is a direct indicator of the difficulty of forecasting, as discussed in Section 4.3.

Alternatively, the forecast method on which each warning was based could be indicated in the records. For example, a numerical code could be used:

0. Warning based on actual level at reference point. No forecast required.

1. Forecast based on single upstream level or flow. Forecast based on correlation or routing.

2. As 1, but based on more than one upstream level or flow eg. main river and tributary.

3. As 1 or 2, but necessarily "chained" with one or more upstream models to give the required lead time.

4. Forecast based on a rainfall/run-off model and observed level or flow at reference point, possibly split into: 4R if radar data are used in estimating areal rainfall, or 4G if based solely on gauged rainfall.

5. As 4, but necessarily incorporating forecast rainfall to give the required lead time.

However, this list would probably not cover all situations, and in some cases warning decisions are based on subjective interpretation of the output from more than one forecasting method. The complications of this approach may therefore outweigh any benefit, and the simpler $T_F : T_p$ ratio may be preferred.

Analysis of records

If all warnings, and all occasions when warning levels were reached at reference points, were recorded, it would be possible automatically to identify:

- n_1 the number of correct forecasts issued with at least the target lead times,
- n_2 the number of correct forecasts issued late, ie. with less than the target lead times,
- n_3 the number of missed floods; and
- n_4 the number of false alarms.

These four numbers would describe performance succinctly, but could be further summarised, if required, in terms of a slight variation of the IH Critical Success Index (CSI) where:

$$CSI = n_1/(n_1 + n_2 + n_3 + n_4)$$

The further monitoring of the relationships between the exceedance of warning levels at reference points and the onset and extent of flooding, is more in the field of flood warning than forecasting, and as such is outside the scope of this project.

4. SUITABILITY OF SYSTEMS FOR USE BY OTHER REGIONS

4.1 General

When this project was approved, it was envisaged that the performance of the systems in real-time operation would be a major factor to be considered when drafting recommendations for further development. As already explained, the forecasts being generated by the WRIP and RFFS systems are not yet, with the exception of a few sites in Yorkshire, sufficiently reliable to be used as a basis for warnings, so the expected operational performance information is not yet available.

In view of the substantial investment in these systems, in both capital and staff time, it is recommended that adequate resources be made available to complete the commissioning and calibration of the WRIP and RFFS systems so that the potential benefits are achieved as soon as possible.

In the meantime, this Section includes comments on the various models and forecasting systems, based on the reports listed in Appendix C and discussions with regional staff.

4.2 Advantages and Disadvantages of Different Models

The relative advantages and disadvantages of the conceptual models used in the RFFS and Severn Trent systems, and the transfer function models used in the WRIP system, are not yet fully understood in terms of their impact on the reliability of real-time forecasting.

The main problem with the current rainfall/run-off models in the WRIP system seems to stem from the fact that forecasts are based entirely on rainfall and flow data collected over the last three or four hours (and coefficients determined from a number of calibration events). The basic method does not therefore take into account the state of the catchment, either at the time a forecast is being prepared, or at the times of the calibration events. Facilities are provided to vary the shape of the hydrograph, the total volume of run-off and the catchment lag, but procedures which would make appropriate adjustments to these parameters in real time have yet to be developed.

The problems with the conceptual rainfall/run-off and routing models in the RFFS system as tested in Yorkshire also make the forecasts unreliable at the present time as a basis for warnings. Internal NRA reports have noted this performance and recommended that many of the models be re-examined. The February 1995 flood event has provided useful data for this purpose.

The current problems have been highlighted in order to focus attention on the action required to obtain the maximum benefit from these systems, but these problems should be kept in perspective. Both systems represent a considerable achievement in the way they collect, process and display hydrologic information on a regional scale. The WRIP system has a good graphical user interface and the RFFS is a comprehensive generic system. Both systems have potential for application in other areas, as has already been demonstrated. Different types of models can be fitted into the modular RFFS structure so, for example, if it were shown that TF models performed better than the conceptual versions in certain applications, these could be accommodated. It is possible that the in-house testing referred to gives a pessimistic view because performance was examined at fixed lead times of six hours or more. If site-specific forecast lead times had been defined and used for the testing a rather better picture may have emerged. When evaluating the performance of the public warning procedures it is important to concentrate on what is needed at each reference point. However, it is noted that the RFFS forecasts are also used by duty officers, public relations and operations staff to plan rotas, press releases, meetings with local authorities, movement of plant etc. In these cases, forecasts are often requested with much greater lead times than those required for site specific public warnings.

In a report to Severn Trent region, Wallingford Water (1995) identified features of the existing Severn Trent system which could be integrated with RFFS systems to provide improved forecasting procedures for the River Soar catchment. This is a technically difficult catchment in so far as water levels along the main river are subject to control at a series of weirs with sluices which are operated during flood periods. The use of a hydrodynamic model, which could be accommodated in the RFFS structure, was recommended in these circumstances. The report also recommended that the Severn Trent rainfall/run-off and routing models should be made available for optional use within the RFFS so that the most appropriate models could be used in individual catchments and river reaches. Where a model was already working well, and staff had confidence in it, it should be incorporated in any new system. Severn Trent region have commissioned consultants to assist them in developing a five-year strategy for flood forecasting for the region in the light of the Wallingford Water report.

4.3 The Relevance of Catchment Response Time

The importance of the hydrological response time of individual catchments has recently been highlighted in R&D Note 433, referring to earlier work by Reed (1984). It was suggested that catchments could be divided into three broad categories, though it was noted that the boundaries between the three categories were not sharply defined :-

- For slowly responding catchments (T_p > 9 hours approx.) flood routing was the recommended forecasting approach.
- For quickly responding catchments (T_p < 3 hours approx.) rainfall/run-off modelling based on forecast rainfall would be needed.
- For intermediate catchments, rainfall/run-off modelling plus flood routing would be appropriate.

This approach can be further refined by considering the forecast lead time required. Clearly, to maximise the reliability of warnings, forecast lead times should be as short as possible. With reference to Section 3.7 above, if T_W, T_D and T_R are specified nationally, with values which will minimise the total lead time required, whilst allowing reasonable time for recipients to respond to warnings, site-specific forecast lead time targets, T_F can be calculated for each reference point as described in Section 3.8.

The ratio T_F : T_p is probably as important as the magnitude of T_p when considering alternative forecasting techniques. For example, if T_F is small compared with T_p the best forecast might be obtained by simple extrapolation of the observed hydrograph, irrespective of the value of T_p. Similarly, if T_F approaches T_p, forecasts would probably need to be based on forecast rainfall, whatever the value of T_p.

Generally, considering a range of catchments, as the ratio $T_F : T_p$ increases, the difficulty of forecasting also increases because the forecasts have to be produced at a relatively earlier stage in the event. At the higher ratios, forecasts have to be based on information from earlier in the event, perhaps using chained models, rainfall based models or ultimately procedures based on forecast rainfall. Also, updating routines work less well at high ratios because of the limited amount of observed data.

4.4 Recommendations for the WRIP and RFFS Systems

With regard to the current problems with the models in the WRIP system it may be possible to use the observed flow as an indicator of catchment conditions, as at Dumfries (Lees et al, 1994). Alternatively, some form of soil moisture accounting could be considered, but Professor Cluckie of Salford University who has been intimately involved in the development of TF models and their application in the WRIP system indicated, in a private communication, that he had reservations about soil moisture accounting models because of the degree of scatter around the logical relationships between catchment wetness and run-off coefficient. As WRIP rainfall/run-off models are already installed in the on-line systems in three regions, this problem needs to be resolved as expeditiously as possible. A dendritic river network version of WRIP, including TF routing models is being developed, and this should be evaluated as quickly as possible for comparison with the network structure of the RFFS.

With regard to the RFFS, Thames region have the best rainfall data in the U.K. as a result of their cooperative work with IH over many years, and they will be in the best position to evaluate the rainfall/run-off models within the RFFS. In Northumbria and Yorkshire the RFFS has been set up to cover a wide variety of catchments, and it is recommended that site-specific target forecast lead times, as described in Section 3.7 and 3.8, be determined for all the forecast reference points in Yorkshire. The forecasting procedures should then be reviewed, starting with the reference points having the lowest $T_F : T_p$ ratios.

Some sites may be found where $T_F = 0$ and warnings can be based on observed levels. For sites with small $T_F : T_p$ ratios, extrapolation of the observed hydrograph, or existing level correlations may be appropriate. The statement in R&D Note 433 that routing is preferred to correlation methods is not universally true. There are level correlations between stations which are not calibrated in terms of flow. Even where flows are available, if an existing correlation method gives sufficiently accurate forecasts, staff time should not be devoted to converting this to a routing model whilst there are more urgent needs elsewhere. The internal regional reports have identified a number of river level stations where flows would be beneficial and many others where ratings need to be extended to include higher flows. The concept of the RFFS is ambitious, with lead times up to 48 hours being mentioned, but for the immediate review the minimum forecast requirement at each reference point should be considered.

In view of the number of outstations which are now connected to the regional telemetry scheme in Northumbria and Yorkshire, it is recommended that the structure of the modelling upstream of each reference point be subjectively reviewed to ensure that the best use is being made of the hydrometric data available. This review should concentrate on the modelling immediately upstream of each reference point, including only those sources of information which are necessary to produce a forecast with the required lead time. Models further upstream may have to be examined in connection with other reference points, but in principle, upstream models which extend the lead time beyond T_F can have a lower priority.

At higher $T_F : T_p$ ratios, rainfall/run-off modelling will come into the picture, and the present practice in Yorkshire of basing estimates of catchment rainfall on a single raingauge should be reconsidered. For comparison, Severn Trent use up to six raingauges for each catchment, weighted according to altitude and distance from the catchment. Whilst Yorkshire region will shortly have the HYRAD radar data processing system, it would be advisable to ensure that the best use can be made of raingauge data as an alternative input for rainfall/run-off models.

4.5 The Value of Real-Time Updating

The impression is sometimes given that updating, by reference to observed levels or flows at the reference point for which forecasts are being made, will make up for any deficiencies in the basic model output. This is not the case. If the discrepancy between the forecast and observed values is large, or if it is not known whether the difference is in magnitude or in timing, real-time adjustment of the forecast can make the forecast worse. This is illustrated by Figures 1 and 2 in which the "forecast" hydrographs are forecast flows using historic raingauge rainfall values to produce simulated flows, without reference to observed flows, except at the start of the event.

* Simply reducing the volume of forecast run-off, ie. the ordinates of the forecast hydrograph could dramatically improve the forecast shown in Figure 1.

* During the early stages of the event shown in Figure 2 it would appear that a similar adjustment would be required - but this would have led to an increased error in the forecast flood peak.

* In real-time operation, during the early part of an event, it is often not clear whether a discrepancy between the observed and forecast hydrographs is due to an error in timing or in flow - or both.

Rungo et al (1991) described a pattern recognition approach, which was aimed at resolving this ambiguity. In their method, a forecast hydrograph is moved, both along the time axis and along the discharge axis until the best agreement between the forecast and observed curves is achieved. From the examples given in their paper it can be seen that this procedure might work satisfactorily where any magnitude error was consistently positive, or consistently negative, throughout an event, but it is difficult to see how it would cope with an event where, due to non-linearities, a magnitude error changes sign part way up the rising limb, as in Figure 2. The developers of the Severn Trent system appreciated these problems, Dobson and Davies (1990) when describing the development of their error correction (updating) model, stated :

"If the error pattern is relatively small and consistent, the model will predict a future error pattern, and apply this to the raw forecast to improve its accuracy for up to 48 hours ahead. If the pattern is complex, or the error is large, the model will attempt to improve for only a few hours ahead. This problem sometimes occurs in the earliest forecasts, when timing errors between observed and simulated flows are most likely to be apparent."

It is therefore vital that rainfall/run-off and routing models should be structured and calibrated to produce forecasts of known reliability, before updating procedures appropriate to the basic model performance are introduced. The following approach is suggested for consideration:

Concentrate first on optimising the sources of data to be used as input to the model, and then on developing the model to forecast the timing of the peak to within prescribed limits. Subsequent calibration can then concentrate on reducing magnitude errors, and when these have been reduced as far as reasonably practicable state updating or error prediction updating methods can be considered as a way of reducing the remaining pseudo-random errors.

The recommendation in R&D Note 433 that updating of forecast models should always be used needs treating with caution. It is probably correct in the longer term, but the performance of many models needs to be improved first. This is, in effect, acknowledged in Section 3.3.4 of the Note, which includes the statement that "While updating improved accuracy for short lead-times, most participants in the WMO study agreed that a good (representative) model is necessary to achieve consistently good forecasts at longer lead times" because at short lead times relative to the response time of the catchment, updating is really producing a forecast which is an extrapolation of the observed hydrograph.

4.6 Automation and Man-Machine Interfaces

All the present systems within the NRA are designed to assimilate information collected by telemetry and by weather radar, and display this information, together with forecasts, at the request of duty officers. While initial alerts are generated by outstations, and in some cases by regional computers, the onus is generally on the duty officers to drive the systems, requesting information and forecasts when these are needed. Duty officers have to keep track of developing situations and, using detailed flood warning procedural manuals, endeavour to ensure that warnings are issued at appropriate times. As the numbers of different types of data increase, and as more flood risk areas are included in schemes, the duty officers will find it increasingly difficult to find time to assess the situation and make the subjective quality control input on which schemes have hitherto relied.

The efficiency of the man-machine interface and the degree of automation are therefore of increasing importance. Severn Trent region stress the value of efficient dissemination of information and ease of use of systems. Their REMUS system makes hydrometric and radar data, together with forecasts, available to users throughout the region; requested information being stored locally for display as required.

With regard to the "new" systems, WRIP, with its X-window graphical interface, appears to be easier to use than the RFFS as at present used in Yorkshire. However, the WRIP system in South Western region already includes more than 20 separate catchments and this number will increase as coverage is extended to the many relatively small catchments throughout the region. It is envisaged that linked rainfall/run-off and routing models will be added for several of the larger rivers in the region. The Yorkshire RFFS system currently uses a command-line, menu based procedure which gives the duty officer detailed control of whether fresh data is to be collected, the forecasts to be generated, whether the state variables are to be updated as a result of a requested model run, whether the forecast produced is to be made available to colleagues in the areas who are currently responsible for issuing warnings, etc. It is understood that a Windows version of the RFFS is being developed. Subject to the above comments on current reliability, the Northumbria and Yorkshire RFFS is already producing data and forecasts for some 80 reference points, so whilst a single request can generate information for a large part of the region, the problem of assimilating that information continuously can be appreciated.

It was therefore suggested in the Interim Report for this project, in 1992, that if the best use is to be made of the duty officers' time and expertise, they need to be relieved of the need to drive the systems. In operational mode a more developed computer system could monitor conditions throughout the region, collect data and run forecasting models at intervals appropriate to the conditions, and keep the duty officer informed of any developing threat of flooding. When necessary the computer would recommend the transmission of a specific warning, and simultaneously make available the information which the duty officer would require to assess the validity of the recommendation. If approved, the warning would be automatically transmitted.

A comparison was made with avionics practice, in particular with the TCAS traffic and collision avoidance system which was directly analogous to the flood warning requirement. Both systems are concerned with relatively rare events to which attention needs to be drawn and appropriate action advised. The TCAS system was noted as an excellent example of complicated information being processed and monitored by computer, with clear audio and graphical output to the user conveying, in sequence, just the necessary amount of information, warnings and advised action.

Careful thought needs to be given to the presentation of information to duty officers in the next generation of forecasting systems. Having automated the process as far as possible, the decisions required from the duty officers would be identified and the displays designed to provide the required information as efficiently as possible. For example, if a subjective decision is needed on the basis of several independent forecasting procedures, the separate forecast hydrographs should be displayed simultaneously in one window with any back-up information such as upstream hydrographs or rainfall accumulations over the catchment in a related window. However, the possibility of complete automation of the procedures for some reference points should be borne in mind.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 In view of the investment already made, the operational performance of the WRIP and RFFS systems should be improved as quickly as possible, so that the potential benefits in terms of timely and reliable flood warnings are achieved.

5.2 The dendritic version of the WRIP system should be evaluated as quickly as possible, for comparison with the network procedures of the RFFS.

5.3 Target lead times should be established nationally, which will maximise the reliability of warnings whilst still giving recipients time to respond.

5.4 The implied site-specific forecast lead times could then be used as a basis for optimising forecasting procedures in all regions and for monitoring performance.

5.5 Whilst the review of the performance of the WRIP and RFFS systems is in progress, the performance monitoring procedure recommended in Section 3.9 could be tried out, as a pilot study, in Severn Trent region.

5.6 At a subsequent stage the results of such a study could form a basis for the evaluation of other systems.

5.7 The modular structure of the RFFS presents an opportunity to compare the performance of alternative models, such as the TF, PDM and Severn Trent rainfall/run-off models, which could be set up in parallel for one or more test catchments.

5.8 In advance of objective evaluation in real-time operation, there is a view that the representativeness of input data and calibration may be more important than the choice of model.

5.9 In the present state of development, if there are several forecasts available for a reference point these should all be presented to the duty officer for appraisal.

5.10 Updating should only be used to trim the output from well structured, well calibrated models.

5.11 To make the best use of duty officers' time and expertise, the forecasting process should be automated as far as practicable.

5.12 The possibility of full automation for some reference points, where forecasting models are sufficiently reliable, should be borne in mind.

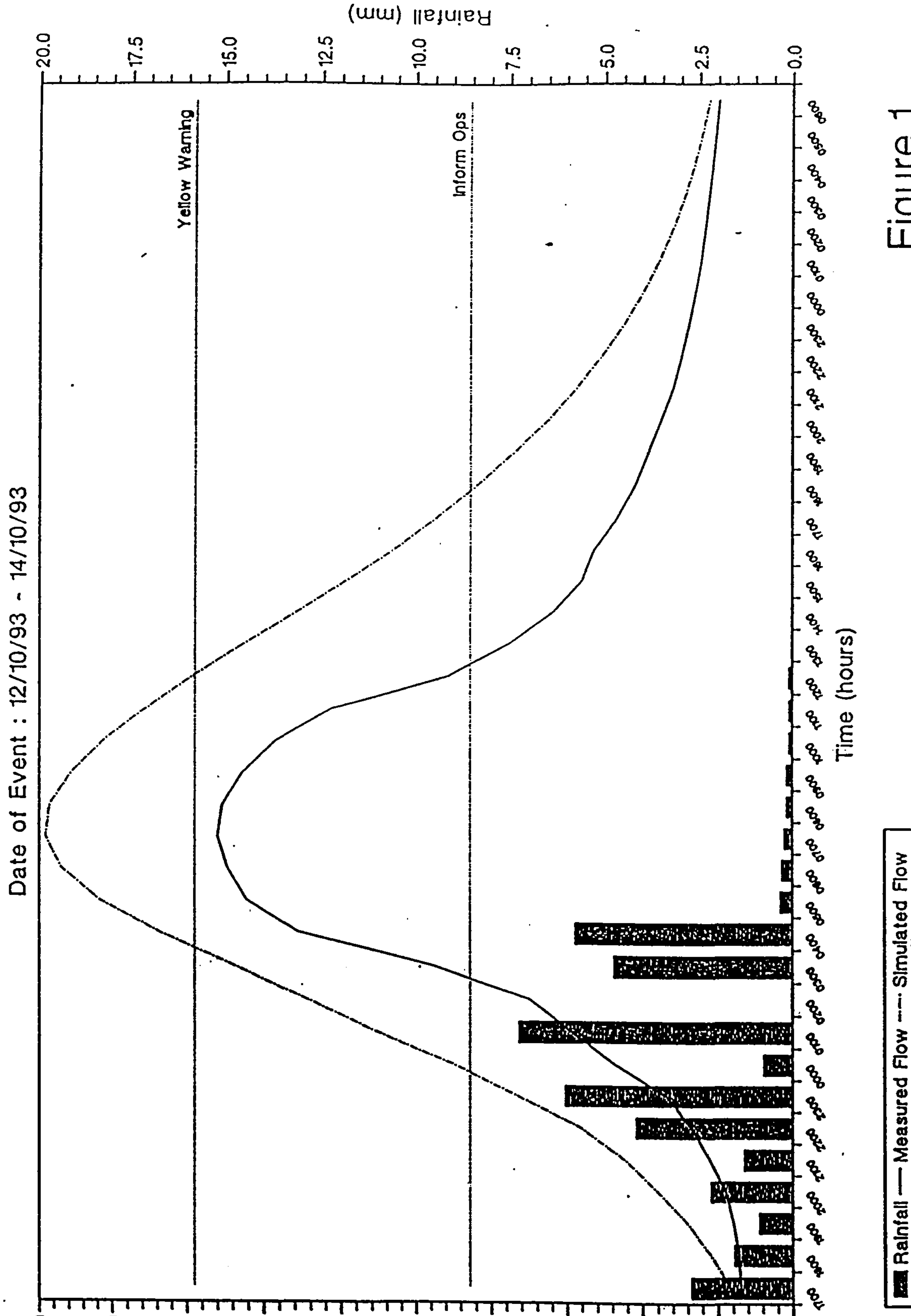
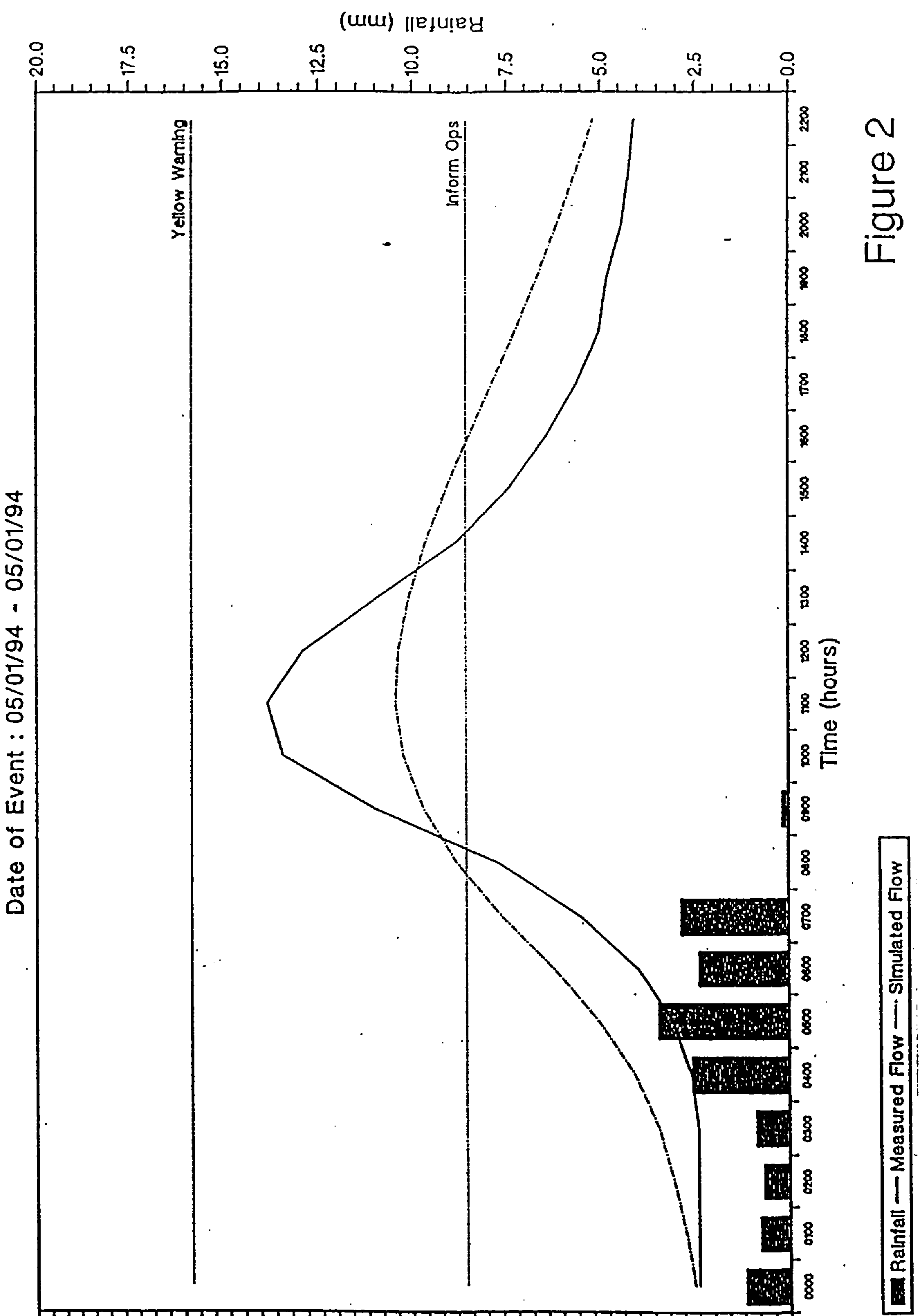

Date of Event : 12/10/93 - 14/10/93
Yellow Warning
Inform Ops
River Flow (m³/s)
Rainfall (mm)
Time (hours)
Rainfall — Measured Flow --- Simulated Flow

Figure 1



Date of Event : 05/01/94 - 05/01/94
Yellow Warning
Inform Ops
Time (hours)
River Flow (m³/s)
Rainfall (mm)
10.0 9.0 8.0 7.0 6.0 5.0 4.0 3.0 2.0 1.0 0.0
20.0 17.5 15.0 12.5 10.0 7.5 5.0 2.5 0.0
Rainfall — Measured Flow — Simulated Flow

Figure 2

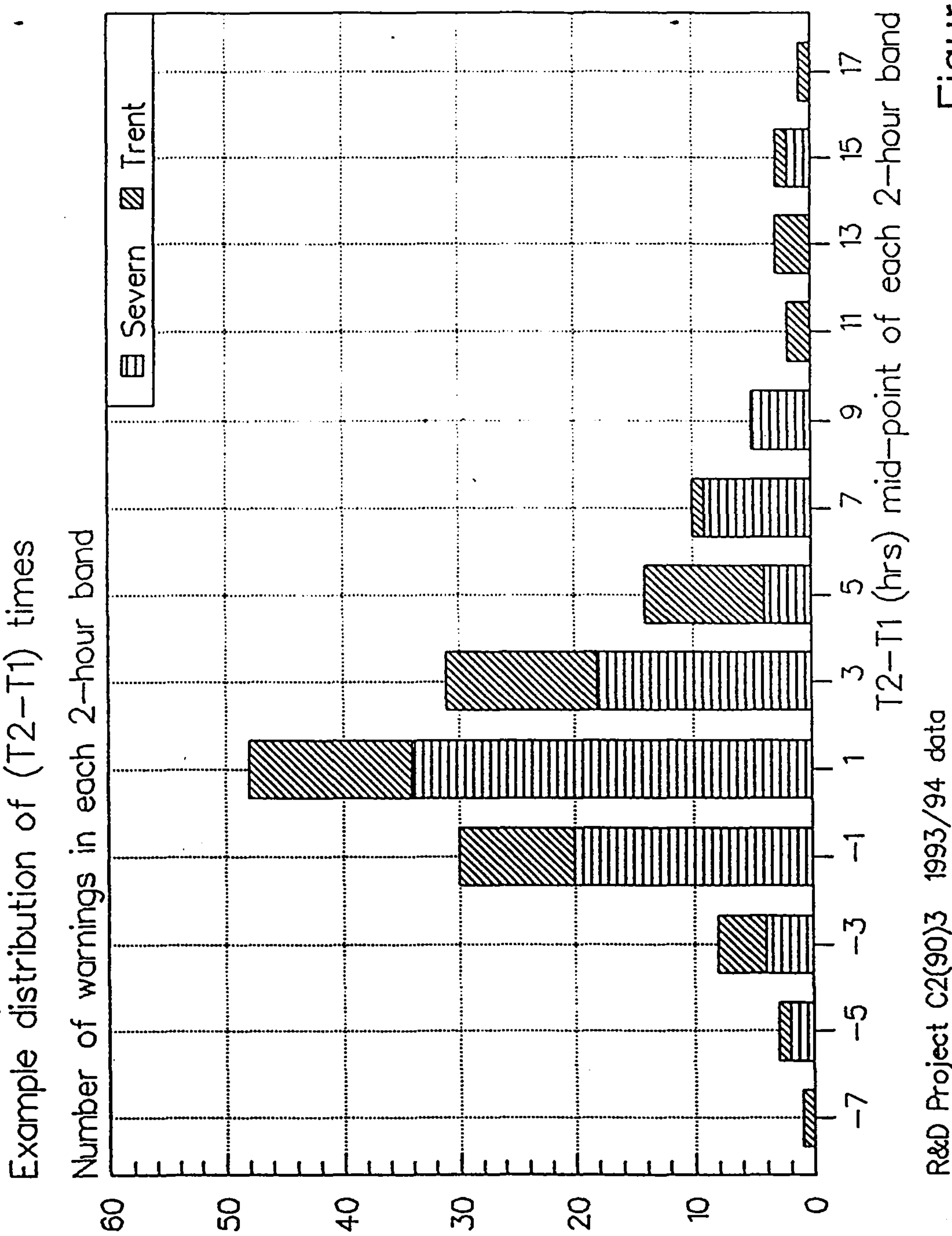

Example distribution of (T2−T1) times
Number of warnings in each 2-hour band
Severn
Trent
0
10
20
30
40
50
60
−7
−5
−3
−1
1
3
5
7
9
11
13
15
17
T2−T1 (hrs) mid-point of each 2-hour band
R&D Project C2(90)3 1993/94 data

Figure 3

APPENDIX A

Developments inNRA Regions (1990 - 1995)

1. Anglian

Anglian region have commissioned the first phase of a new telemetry system, and approval has been obtained for three further phases. In the first phase, the Logica telemetry system, operating on PDP computers, has been replaced by a Servelec SCOPE X system based on a Sun computer. Later phases will provide a new flow forecasting system, with approximately 200 new telemetry outstations and some 26 new gauging stations.

Prior to the commissioning of the new telemetry system, flow forecasting facilities had been provided on a VAX computer, and this system is now linked to the Sun computer. The facilities on the VAX include:

* RADGAP (Radar Gauge Adjustment Program) is a local calibration system, developed by Salford University, which uses surface fitting algorithms to combine national network radar information with raingauge measurements to give a more accurate representation of distributed rainfall. The results are output in 5 km grid format for display by other systems such as STORM.

* CORGI (Consolidation of Radar and Gauge Information) which converts the RADGAP output to STORM format and also produces sub-catchment totals for use in flow forecasting.

* STORM (System To Obtain Radar rainfall Measurements - also developed by Salford) generates radar images which can be viewed in a window on the telemetry terminals, via the Sun system. The following data streams are available:

    * national network information as received
    * national network information after local calibration
    * Nimrod "actuals"
    * single site Ingham Type 1 (5 km, 3 bit)

* Software has been developed which allows Nimrod forecasts to be received. (The automated Nimrod system has replaced the FRONTIERS procedures).

<u>Flow forecasting</u> Some 40 transfer function (rainfall/run-off) models are now available for use in the Anglian version of the WRIP system. They are run individually, on demand, by the hydrologists in the three Areas and the resulting forecast hydrographs can be made available to other users via the Vax computer.

The Sun computer collects rainfall and river level data from outstations every 24 hours (or every hour when high frequency scanning is initiated by a hydrologist). On the Vax computer, files containing the last 48 hours' hourly rainfall and river level data are updated every hour by the Sun. The Vax computer also stores the site and model parameters, but the forecasting models are run on the hydrologists' personal computers.

The procedure, which can be operated from any PC connected to the regional DECNET network, is that the user's PC first displays a list of sites (forecast points) available on the Vax. When the user selects a site, the relevant files are transferred to the PC which calculates and displays the forecast hydrograph together with the catchment rainfall on which it is based. The present models are all rainfall/run-off models using raingauge values or locally adjusted Network radar data as input, but the hydrologist can enter forecast rainfall and edit historic rainfall, for example to allow for snowmelt. A single key-stroke stores a forecast hydrograph on the Vax so that it can be displayed by other users, such as district office staff.

The forecast hydrographs are used to assist forecasters, and in a few cases confidence is sufficiently high for warnings to be based on the model output. In most cases however, flood warnings are still based on threshold flows or levels actually being exceeded. Flood warning performance monitoring, comparing warnings with events as proposed by the Emergency Response Levels of Service group, has recently been introduced in the region.

2. North West

Outstation data for flood forecasting continue to be collected mainly by the radio-based telemetry system with back-up PSTN links to key stations. ISO models run automatically every 15 minutes on the PDP telemetry computers, producing forecast levels in digital form. This telemetry system was designed over twenty years ago with limited processing facilities so, whilst observed data can be displayed graphically, forecasts have to be manually plotted.

The 14 TF rainfall/run-off models developed by Salford University for catchments in the North West are now available on a VAX computer which is linked to the real time data-base, so these models can be run on demand. These models run within the WRIP system originally developed for the former Wessex region. The X-Windows graphical user interface is an attractive feature of this system allowing, for example, the effect of different rainfall profiles to be seen very quickly (but such alternative forecasts can not, at present, be displayed simultaneously). The rainfall input to the TF models is normally the 5 km network data, with raingauge data as an alternative. The region also receives Nimrod forecasts, but these are not at present input to the models.

Whilst the TF models are available for real time use, there has not yet been any objective evaluation of their performance. This is primarily because there is no convenient method of running the models in simulation mode using historic data - only some eight days' data are stored within the WRIP system. No assessment has therefore been made of the possible need to improve the calibration of individual models. A method of off-line running is also required for training purposes, and this is included in a planned UNIX version of WRIP.

The overall aim of the NW region system is to provide two to four hours' warning of the exceedance of specified warning thresholds at river level stations close to each of the flood risk areas covered by the scheme. For each such station the duty officers plot the forecasts available from one or more models, and use these plots as a guide when extrapolating the observed hydrograph as the primary basis for warning decisions. Warnings are issued when the duty officer is confident that the appropriate threshold will be reached.

Prompted by the need to add over fifty new outstations, and the desirability of updating the telemetry computers, the region is currently inviting proposals for a new telemetry system.

3. Severn Trent

The Severn Trent data collection and flow forecasting system (FFS) which was developed jointly by in-house staff and software suppliers during the 1980's, has been further improved over the last five years. The telemetry system is PSTN based; 15-minute and event data being collected from on-site loggers. A Microvax 3100-95 computer at Solihull controls the telemetry and runs the forecasting models which are currently of three main types: conceptual rainfall/run-off models, hydrological channel flow routing models and an error prediction and forecast adjustment procedure. Hourly data are used throughout, and forecasts can be produced for up to about 200 locations.

Forecasting procedures are run under the control of the regional duty officer, but flood warnings are issued by duty officers in the four areas. They and other remote users can down-load data and forecasts on request, and display them locally as required, using the REMUS software. Communications have recently been improved by linking the FFS to the region's wide area / local area network, and by increasing the speed of PSTN communications to 14400 baud. There are now 110 remote users of the system including staff in all NRA functions. The REMUS software includes a facility to retrieve data direct from outstations if necessary, and a stand-by emergency level forecasting system (ELFS) based on level-to-level correlations, together with an emergency alarm handling system have recently been added.

Radar images are available to all users via REMUS, MicroRadar and MacroRadar, but the radar-based estimates of catchment rainfall are not yet considered sufficiently reliable to be used as input to the hydrological models. The region has taken a leading role in the Long Range Radar Calibration Study, and has also been closely involved in Lancaster University's development of an Adaptive Radar Calibration System.

Model calibration software, based on the Rosenbrock automatic optimisation procedure was introduced in 1992, since when the calibrations of some 40% of the catchment and reach models have been reviewed, with parameter improvements being made where possible. Since April 1994, it has been possible to run a version of the FFS off-line for development purposes, normally with the current real time data-base. Some 95% of warnings are now issued before the warning level is reached. These warning decisions are taken by the flood warning duty officers having regard to the FFS forecasts, the ELFS level forecasts and the duty officer's knowledge of the state and behaviour of the catchments.

In January 1995, the region received a report prepared by Wallingford Water (IH and HR) which describes the facilities provided by the present Severn Trent FFS, and compares them with an idealised design for flow forecasting in the River Soar catchment. The report contains a wealth of detailed information and makes recommendations for future development. Briefly, the report recommends retaining the best features of the Severn Trent system and integrating them with additional facilities available in the RFFS, developed by the Institute of Hydrology and Logica, originally for the former Yorkshire region. Consultants are currently assisting the region with the preparation of a five-year strategy for flood forecasting and warning throughout the region.

4. Southern

Southern region commissioned a regional telemetry and emergency control system (RECS) with good alarm handling facilities. The system, supplied by Data Sciences Ltd. is based on that developed for Severn Trent region and adapted to meet the requirements of Southern region. The system consists of Dynamic Logic and DTS outstations logging 15-minute data which are polled via the PSTN by a Vax computer at regional headquarters.

Alarms are displayed in the control room with a message advising the operator of the appropriate action, and in response the operator is required to enter a brief note of the action taken. When an alarm is received, automatic polling of other outstations can be triggered.

The Vax computer stores information from raingauges and river level stations together with Chenies 5 km radar data. Up to four days' data can be viewed on remote PCs using regional networks or modem links. Raingauge information can be displayed as hyetographs with associated river level hydrographs, or alternatively in a table, with the gauges listed in geographic order or ranked by the quantity of rain recorded over any specified period up to 96 hours. Status information relating to gates, pumping stations, etc. can also be viewed on the PC screens.

The transfer function model of the upper Medway catchment has been updated and linked to the telemetry system so that it can be operated on-line with graphical output to assist operation of the Leigh Barrier. An off-line ISO model referencing ground water level as well as river flow and rainfall, has been developed for the River Lavant at Chichester. Flood warnings are at present based on observed, rather than forecast levels.

5. South Western

South Western region operates a VAX based Servelec SCOPE 3 regional telemetry system which has the capacity to communicate with over 450 outstations. It provides basic data display mimics, on-line storage of the most recent 100 days' data and has a well developed alarm handling facility. The region operates a range of Seprol, DTS and Dynamic Logic outstations. Programs, developed in-house, control the real-time transfer of rainfall and river level data from SCOPE to WRIP.

The WRIP system, developed for the former Wessex region is operational, with some 23 transfer function rainfall/run-off models installed for testing in operational conditions. The system, developed by Salford University, uses national network radar data as the normal source of rainfall information. Lead times are extended by using local rainfall forecasts generated automatically by extrapolation of both the movement of rain areas and changes in rainfall intensity. The duty officer has the option of specifying alternative past and future rainfall profiles.

A Unix version of WRIP is currently being commissioned, and a dendritic river basin model of the Bristol Avon developed by Salford University as a module within WRIP, is being tested. At the present time, flood warnings are based on observed levels, but a considerable effort is being put into improving the performance of the models. Salford University are working on the automation of transfer function adjustment parameters, and the system originally developed for the former Wessex region is to be extended to cover the whole of the South West.

6. Thames

The following systems have been introduced in Thames region:

* Local radar calibration in which a surface fitting procedure is used to adjust the 2 km Chenies radar data to agree more closely with the readings of the telemetering rain gauges.

* Local rainfall forecasting, based on Chenies Type 2 radar data, extrapolates the movement of areas of rainfall to produce quantitative forecasts on a 2 km grid, up to 2 hours ahead.

These systems, which were developed by the Institute of Hydrology for Thames region, are now used routinely, along with the Meteorological Office Nimrod forecasts, which provide 5 km intensity and accumulation data out to six hours ahead. Accumulation data are used to generate sub-catchment totals which can be displayed in map format as well as being input to sub-catchment models.

A third rainfall forecasting system, GANDOLF, is being developed by the Met. Office and this system will concentrate on thunderstorm forecasting. The system will generate "thunderstorm alerts" and forecast rainfall data (instantaneous and accumulations) on a 2 km grid. The GANDOLF system will incorporate an expert system which will advise duty hydrologists on which rainfall forecasting system should be used for a given synoptic situation.

Thames region have purchased the Institute of Hydrology's River Flow Forecasting System (RFFS) and this is being operationally implemented at present. The system will allow rainfall/runoff models to be run automatically for all forecast points using the "best" data available at the time and real-time updating will be a feature. Three types of model will be available: the Isolated Event Model, the Thames Conceptual Model and the Probability Distributed Moisture Model. Thirty forecast points have been calibrated in the Region to date. The models will be run routinely every 15 minutes using forecast rainfall data (using advice from GANDOLF), radar data (raingauge adjusted using 99 gauges) and flow measurement for updating purposes.

An "Operational Guidance Note" R&D Note 387, produced by the Institute of Hydrology for Thames region, provides valuable discussion and guidance on the use of rainfall forecasts and models in flow forecasting.

At the present time, rainfall and flow forecasts are still viewed as giving guidance. Duty Officers are not confident enough with the forecast accuracy to base flood warnings solely on their predictions. Errors in the models themselves and inconsistency in the quality of radar data are the main concerns. However, some flood warnings are issued on the basis of measured rainfall, model output and the duty officer's knowledge of the catchment, before river levels reach alarm levels at critical locations. The issue of radar accuracy is being pursued with the Meteorological Office.

7. Northumbria and Yorkshire

The new Regional Telemetry System (RTS) supplied by Logica, and the Regional Flow Forecasting System (RFFS) developed by Logica and the Institute of Hydrology have been commissioned, and the RTS is now used for the routine collection of hydrometric data, as well as real-time forecasting. The IH HYRAD system for processing and displaying weather radar data has been introduced, and radar data are now available for use in RFFS models.

Forecasting models are run by regional flood duty officers, but flood warnings continue to be the responsibility of Area flood operations officers. They and other staff normally obtain historic and current data from the RTS using PC terminals or portable computers. The models are run automatically once every 24 hours following overnight polling of the outstations by the RTS. These runs produce forecasts for up to 48 hours ahead whilst model states (soil moisture etc.) are updated and stored for use in subsequent runs.

During an event, forecasting models are run by the Regional flood duty officer and the resulting hydrographs can be stored within the RFFS where they can be accessed by Area flood operations officers and other staff. Forecasting modules are linked in groups, so that when a forecast is requested for a particular point on the network, all modules relevant to that point are run with the objective of filling any gaps in observed data and extending the forecast as far into the future as the available information will allow. The information available for automatic use by the rainfall/run-off modules includes estimated future rainfall quantities for each of seven sub-regional areas input directly by the regional Met. Office (input as 6-hr totals for the next 36 hrs and 12 hr totals for a further 72 hrs.)

The Regional flood duty officer is given detailed control of the main steps in preparing a forecast. For example, having specified a forecast point, the duty officer instructs the system to get the necessary information from the RTS, (having first given a separate instruction to poll the relevant outstations if it is desired to use the most up-to-date data). The duty officer confirms the set of model states to be used and whether these states are to be updated as a result of the requested run. Having plotted the forecast a further decision is made as to whether to store it for general use and if so its run number and details are entered on the "notice board". Area officers access the forecast by reference to the run number.

Most of the planned stations are now connected to the RTS, and the RFFS currently generates forecasts for some 80 points. However, only about six of these are sufficiently reliable at present to be used as a basis for warnings. A seconded member of a Consultant's staff has been assisting the region with model testing, but a considerable amount of further work is needed to improve the modelling.

The region no longer uses the British Aerospace Dartcom satellite image display system mentioned in the 1992 Interim Report.

APPENDIX B

Main Features of On-Line Modelling and Forecasting Systems

Six regions currently operate on-line modelling and forecasting systems, the main features of which are summarised in this Appendix, which is an updated version of that included in the 1992 Interim Report.

Feature		Anglian	North West	Severn Trent
TELEMETRY:				
1.	Telemetry computer	Sun server	Dual PDP	Microvax 3100-95
2.	Telemetry software	Servelec SCOPE X	Plessey	Data Sciences
3.	Communications	PSTN	Radio	PSTN
4.	Outstations:			
	Type	Logica Micromedina Telegen 1150 Seprol	Plessey and Plessey emulation Telegen 1150 as back-up	Telegen 1050 for alarms Telegen 1150 loggers
	Periodic recording interval	Selectable, normally 15 minutes	15 minutes	5,15 or 60 minutes
	Event logging (rainfall)	No	No	Yes
5.	Routine scanning interval	Selectable, normally 24 hours	15 minutes	24 hours
6.	Parameters scanned	Rainfall, river level, gate positions, pumping stations, tidal levels and others including water quality	Rainfall, river level, gate positions, pumping stations, tidal levels, water quality	Rainfall, river level & flow, gate positions, climate and many others including water quality
7.	Alarms generated by: (see also Item 21)	Outstations via PSTN and telemetry computer	Outstations via PSTN and by PDP computer	Outstations via PSTN and Microvax computer
8.	Automatic computer response to an alarm	Alerts 24-hour control room staff and/or operational staff	Displays PDP alarms in forecasting centre/ control room Routine 15 minute cycle of polling outstations, deriving flows, running forecasts, checking any exceedance of thresholds Alarm added to displays	Relays alarm to duty officer by synthetic speech Polls outstations Checks any exceedance of thresholds Starts flow forecasting system Adds alarm to display in control room

Feature		Thames	South Western	N'bria & Yorks
TELEMETRY:				
1.	Telemetry computer	Vax/Argus	Vax	Vax
2.	Telemetry software	NRA/Ferranti	Servelec	Logica
3.	Communications	PSTN/Radio	PSTN	PSTN
4.	Outstations:			
	Type	Dynamic Logic D.T.S. Plessey TC6	Servelec, Telegen 1150 Dynamic Logic	Logica, Dynamic Logic Technolog (R. Tees)
	Periodic recording interval	Radio: continuous PSTN: selectable, normally 15 minutes	15 minutes	Selectable, normally 15 minutes
	Event logging (rainfall)	Yes	Yes	Yes
5.	Routine scanning interval	24 hours	24 hours	24 hours
6.	Parameters scanned	Rainfall, river level, river flow, gate positions and tidal levels	Rainfall, river level, gate positions and tidal levels	Rainfall, river level & flow, tidal levels, climate, pumps, control structures & water quality
7.	Alarms generated by: (see also Item 21)	Outstations via VAX and Argus computers	Outstations via PSTN	Outstations via PSTN and Vax computer
8.	Automatic computer response to an alarm	Relays alarm to duty officer via Alarm Forwarding Unit, mobile phones and Vodalert paging system Could initiate polling of outstations and model runs Adds alarm to displays in flood room	Alerts control room staff Adds alarm to display in control room	Relays alarm to duty officer and to any specified location on the network Increases rate of polling outstations Could initiate automatic model runs Adds alarm to display in control room

Feature		Anglian	North West	Severn Trent
9.	Updating of central data-base during events	On request or at intervals as defined by control room staff	Routine 15-minute scans continue, plus real-time update of remote data-base	Manual Automatic, at intervals preset by duty officer Automatic, following receipt of alarm
FORECASTING:				
10.	Forecasting computer(s)	Microvax & PCs	PDP and VAX	Microvax 3100-95
11.	Types of model and stage of development	TF models run on PCs linked to Vax	ISO models run continuously on PDP TF models being tested on Vax	Conceptual models in operational use
12.	Modules currently available	Rainfall/run-off (Salford TF models)	Rainfall/run-off:- ISO, TF Flow routing:- Regression, TF	Rainfall/run-off Snowmelt Flow routing Updating (Error correction)
13.	Source of rainfall data for rainfall/ run-off models	Raingauges or locally adjusted Network radar data	Raingauges, subcatchment radar data from Hameldon, and locally recalibrated radar subcatchments	Raingauges. Subcatchment radar data from Clee Hill and Ingham available as alternative input in future
14.	Provision for manual input of alternative rainfall/snowmelt estimates (hindcast period)	Yes	No	Yes, for snow-pack amounts only
15.	Basis of forecast rainfall if used in models	Manual input	Nimrod (future)	Manual input

Note: TF = Transfer Function
ISO = Inflow/storage/outflow

Feature		Thames	South Western	N'bria & Yorks
9.	Updating of central data-base during events	Automatic at 15 minute intervals	Manual Automatic, at intervals preset by duty officer	Manual Automatic at 1 hr or 15 min intervals following alarm
FORECASTING:				
10.	Forecasting computer(s)	Vax	Vax and Unix	Vax
11.	Types of model and stage of development	IH RFFS with IEM, PDM and TCM models being implemented	TF models being tested Dendritic TF being developed	A range of separate and chained models (mainly conceptual) available in RFFS
12.	Modules currently available	Rainfall/run-off	Rainfall/run-off Flow routing	Rainfall/run-off Snowmelt Flow routing Tidal reaches Control structures Washland storage Reservoirs Updating procedures
13.	Source of rainfall data for rainfall/ run-off models	Raingauges Subcatchment radar data from Chenies Locally recalibrated radar data	Network radar or raingauges on request	Raingauges, Radar as alternative using HYRAD
14.	Provision for manual input of alternative rainfall/snowmelt estimates (hindcast period)	Yes	Yes	Yes
15.	Basis of forecast rainfall if used in models	Nimrod accumulation forecasts (5 km grid) Local radar-based rainfall forecasts (2 km grid) GANDOLF system (2 km grid)	Local automatic WRIP forecast plus options:- 1. No more rain 2. Manual input 3. Nimrod (future) 4. Past average rain	Quantitative rainfall forecasts input by Met. Office to forecasting computer by Telex Optional manual input, quantity and selected profile

Feature		Anglian	North West	Severn Trent
16.	Rainfall forecasts within system	Met office warnings/ forecasts distributed to forecasters and operations staff by Fax Nimrod forecasts	5-day forecasts input directly by Met Office using electronic mail Nimrod data displayed, and will be available for input to models	Daily forecasts input directly to Bulletin Board on forecasting computer by commercial forecast office
17.	Principal displays available at all terminals			
	General reports:	Current alarms Outstation details and status	5-day forecast Current alarms Configuration details	Bulletin board Weather forecast Current alarms Daily summary log Sensor data lists Activity/alarm logs
	Rainfall:	STORM radar display (Network, Ingham, and locally adjusted data) Raingauge totals for standard periods in map format with hyetogaphs for individual gauges available Hyetographs, catchment rainfall on hydrograph displays (based on gauges or on locally calibrated radar data)	Hameldon and Network radar images including Nimrod actuals and forecasts Table of raingauge totals for standard selected periods up to 24 hours at all gauges Table comparing radar and raingauge totals Hyetographs of gauge or radar subcatchment on hydrograph displays	Clee Hill, Ingham and Network radar images and ranked sub-catchment totals Raingauge totals for period in map format with hyetographs for individual gauges selected by cursor Hyetographsofcatchment rainfall on hydrograph displays Selected terminals have access via dial-up Microradar to network radar Nimrod etc.
	Level/flow:	Observed and simulated hydrographs displayed simultaneously, the latter extending into the forecast period	Hydrographs of observed levels/flows Tables of historic and forecast levels	Observed and simulated hydrographs displayed simultaneously. Both extend into the forecast period (see text)

Feature		Thames	South Western	N'bria & Yorks
16.	Rainfall forecasts within system	5-day forecasts and heavy rainfall warnings received by Telex automatically onto Vax	By manual input	5-day Met Office forecasts received automatically by Telex ontoforecastingcomputer
		Nimrod, local radar based forecasts & GANDOLF under trial	WRIP radar forecast	
17.	Principal displays available at all terminals			
	General reports:	Weather forecast Heavy rainfall warnings Current alarms Flood warnings in force Daily summaries	Current alarms	Notice board (general information on system, forecasts prepared etc.) Weather forecast Current alarms
	Rainfall:	Chenies 5km, 2km and Network images and similar 2km display based on raingauges. Nimrod actuals, forecasts and accumulations for 5km grid and subcatchments. Locally calibrated 2km images and subcatchment totals. Local rainfall forecasts 2km & subcatchments	Network radar and similar map display based on raingauges Raingauge totals for selected period in map format with hyetograph for individual gauges selected by cursor Hyetographs of catchment rainfall on hydrograph displays	HYRAD display of Hameldon, Ingham and Network radar images As South Western Hyetographs of individual gauges on hydrograph displays
		Raingauge totals for standard periods in map format, showing alarm status by colour. Hyetographs of gauge or radar subcatchments on hydrograph displays		
	Level/flow:	Hydrographs of observed levels/flows Block diagram of current levels at all stations showing alarm status by colour	Hydrographs of observed levels/flows extended into forecast period	As South Western

Feature		Anglian	North West	Severn Trent
	Other displays/ reports available at all terminals:	User defined mimic diagrams which can include current values at outstations HELP mimics	Mimic diagrams with automatic updating of values	
18.	Warning thresholds indicated on forecast hydrograph displays?	Yes	No	Yes
19.	Additional displays available only in main forecasting offices	"COST" data	Archive data	
20.	Automatic re-run of active models as soon as new radar/telemetered information becomes available?	No	Yes	Yes
21.	Automatic alerting of duty officer to any actual or forecast exceedance of a warning threshold?	Actual:- Yes	Actual:- Yes Forecast:- Yes	Actual:- Yes Forecast:- Yes
22.	Remote user access to radar images, telemetry data-base and forecasts	Access to both radar and forecasting systems using Toshiba portables Access to telemetry data-base already available from PCs	Via Toshiba portables. STORM software for radar images. Tabulated telemetry data Back-up system using "Floodbuster" software gives direct access to Telegen loggers	Via REMUS system using PS2 or Toshiba portable computer, and Macroradar Requested data downloaded to local store for display as required
23.	Role of forecasting computer in generating warning messages	None	None	None
24.	Facilities for post-event analysis	Not formalised but performance in major events reviewed	Minimal	Events can be re-run, all data stored on archive

	Feature	Thames	South Western	N'bria & Yorks
	Other displays/ reports available at all terminals:-	Forecasting model display of observed and forecast rainfall and flow Mimic diagrams of river control structures Telex display for generation of warning messages		Mimic diagrams of river level & flow stations, climate stations, pumping stations and river control structures, giving current values and alarm status
18.	Warning thresholds indicated on forecast hydrograph displays?	Yes	Yes	Yes
19.	Additional displays available only in main forecasting offices	Network radar COST data	Network radar plus area zoom-in facility	-
20.	Automatic re-run of active models as soon as new radar/telemetered information becomes available?	Models reactivated manually Automation intended soon	Models reactivated on request	One run each night to update model states Groups of linked models re-run on request
21.	Automatic alerting of duty officer to any actual or forecast exceedance of a warning threshold?	Actual:- Yes Forecast:- Intended	Actual:- Yes	Actual:- Yes Forecast:- Intended
22.	Remote user access to radar images, telemetry data-base and forecasts	Terminals in duty officers' homes, Reading and Thames Barrier control rooms Area incident rooms	PCs in Area offices and duty officers' portable computers	Any terminal in Area offices and duty officers' portable computers
23.	Role of forecasting computer in generating warning messages	Warning messages stored in VAX. Sent automatically by Telex/ Fax when initiated by flood duty officer		Warning messages stored on computer sent automatically by fax or telex when initiated by duty officer
24.	Facilities for post-event analysis	Events can be re-run, all data stored on archive	Events can be re-run, all data stored on archive	Textual and graphical reporting facilities but archive not yet available

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