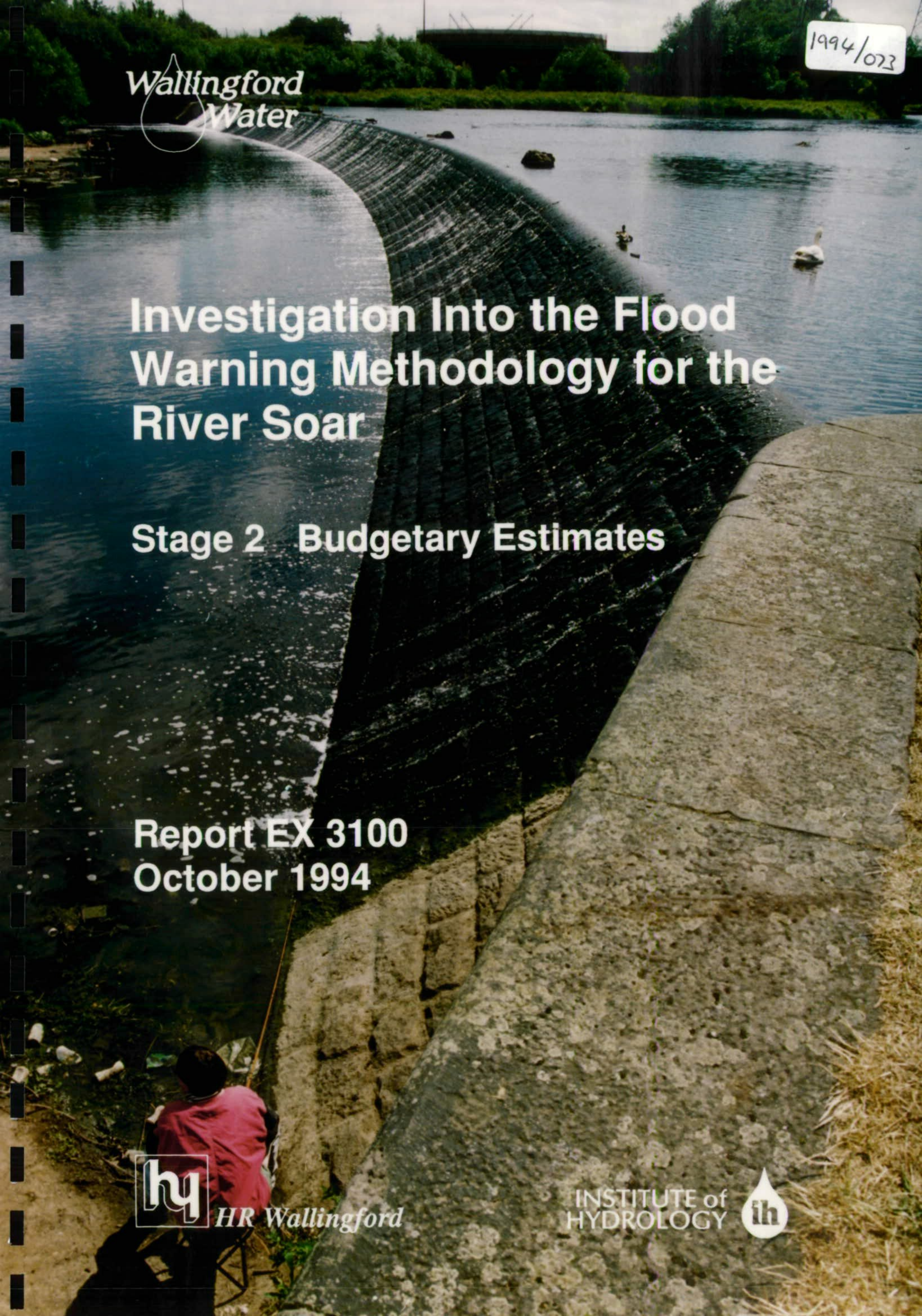

Wallingford Water

Investigation Into the Flood Warning Methodology for the River Soar

Stage 2 Budgetary Estimates

Report EX 3100
October 1994

HR Wallingford

INSTITUTE of HYDROLOGY

A FLOOD FORECASTING AND WARNING SYSTEM FOR THE RIVER SOAR

STAGE 2 REPORT

SUMMARY, RECOMMENDATIONS AND BUDGETARY COSTS

This report is prepared by Wallingford Water for the National Rivers Authority, Severn-Trent Region

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Executive Summary

Failure of the existing flood forecasting system in use for the Soar catchment, in the Trent basin, required a review of the situation. The Stage 1 report took a fresh approach to flood forecasting and warning for the Soar, not influenced by existing systems, by proposing a new hydrometric network and forecasting system under the idealised assumption that nothing exists. Recommendations were made for a notional implementation of the idealised system design, giving details of the proposed hydrometric network and the flood forecasting and warning system along with an outline implementation plan. The purpose of the Stage 2 study is to identify shortcomings of the existing network and system and to compare them with the idealised design proposed under Stage 1. Definitive recommendations for action follow as a result of this assessment and comparison.

The Stage 2 report is presented as two documents. The first is a technical document giving the detail of the Stage 2 study. This is the second document which provides a summary of the findings of Stage 2, a set of recommendations, the benefits of the proposed solution, an outline implementation plan and budgetary costs. The main recommendations derive from an examination of the potential sources of unreliability in the current flood warning system and are as follows:

- Improved measurement of catchment average rainfall by installing two new raingauges, utilising data from five further gauges within NRA Anglian Region, obtaining better resolution by using smaller buckets, replacing the low resolution Type 1 radar data with much higher resolution Type 2 and employing the improved radar calibration and forecasting facilities available through HYRAD, including access to Frontiers forecasts.

- Improved and extended measurement of river stage and flow by installing new gauging stations at Freemans Weir and the Eye at Brentingby, enhancing the performance of existing stations at Kegworth, Pillings Lock, Littlethorpe, Syston and Eye Kettleby and utilising the control gates for flow estimation via extended telemetry and a current metering programme.

- Better resolution of all monitored data by employing a 15 minute data storage time step giving more accurate flood forecasts.

- Improved soil moisture accounting by upgrading the Brooksby climate station, leading to better rainfall-runoff modelling.

- Greater flexibility for rainfall-runoff modelling by gaining access to additional algorithms such as the PDM model which offers real-time state updating.

- Greater flexibility for channel flow routing by gaining access to the KW model.

- More scientific representation of flow phenomena such as backwater influences, inundation of floodplains and the operation of control structures by implementing the ISIS hydrodynamic model.

- More efficient and effective calibration of the hydrological and hydraulic model parameters via user friendly, visual calibration and optimisation tools.

- Improved updating scheme by employing a simpler, more stable error predictor.

- Greater flexibility in forecast construction, with the system providing for extension to new catchments, models and forecast variables, such as water quality.

The Consultants believe that these recommendations will lead to a significant improvement in the reliability of the flood warning service for the River Soar Catchment and restore the confidence of the Flood Duty Officers in the system. The budgetary cost of the main set of recommendations is £410K. A further £129K covers options which include some costs for extension to the rest of the Severn-Trent Region.

Preface

This report has been prepared by Wallingford Water, a joint venture between the Institute of Hydrology (IH) and HR Wallingford Limited. The work has been undertaken by R. J. Moore under the project management of T. Parkinson, Wallingford Water. Additional support has come from V.A. Bell at IH on the hydrometric network assessment and from P. Hollingrake, HR, on field investigations and gauging method selection.

Particular thanks are due to Roy Ladhams, Trent Area Office, NRA-ST, for acting as NRA Project Manager and supporting the take-on of information and field investigations undertaken for this study. Other NRA members on the Project Steering Committee - Andy Johnson and Tim Harrison - are thanked for providing valuable guidance and further information, including the supply of digital data from the NRA-ST hydrometric data archive. Richard Cross is thanked for his help in understanding the forecasting software in use by NRA-ST. Les South and Simon Wills provided information on the control structures and river gauging network respectively. Jim Waters is thanked for thoughtful discussions on the hydrometric network.

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1. Introduction

This document provides a summary of the work undertaken as Stage 2 of a study concerning an investigation into the flood warning methodology appropriate for use within the Soar catchment which forms part of the Trent basin. The reader is referred to the main technical report for further details of the Stage 2 work. The study was carried out against a background of failure of the existing forecasting system to provide accurate and reliable warnings. Factors which may account for this poor performance are thought to range from the use of inappropriate models to inadequacies in the hydrometric network. Complications which are likely to affect modelling performance include a high degree of control to maintain navigation levels along the main Soar, the use of automatic gates to mitigate flooding and major areas of embanked washland. Significant backwater influences on the main channel also demand the use of special gauging methods.

The main technical report of the Stage 2 study assessed the existing hydrometric network to support flood forecasting, the models used and the nature of the system environment employed to construct forecasts and to make and disseminate flood warnings. This assessment was undertaken against the background of the idealised design proposed under the Stage 1 study. The Stage 1 study ensured a fresh approach was taken to the problem by ignoring the existence of systems currently in place for hydrometric measurement and flood forecasting. The final conclusions regarding an appropriate flood forecasting and warning system for implementation to the Soar catchment are presented in this executive report. These conclusions are presented first as a summary of the findings of the study and then as a set of recommendations for action. This executive report ends with a review of the benefits of the proposed solution and an outline plan for implementing the recommendations along with budgetary costs.

2. Summary

2.1 HYDROMETRIC NETWORK

(i) **Raingauge network**: A recommendation of the Stage 1 report was that the raingauge network should comprise between 8 and 10 tipping bucket raingauges (0.2 or 0.1 mm buckets) recording the time of tip. These should be configured on a regular lattice as a guiding principle, although issues of representativeness, ease of access and land ownership should influence the detailed local siting. The configuration should aim to ensure that at least one gauge is located within each of the major tributary catchments. In practice, the actual network in the immediate vicinity of the Soar comprises 7 gauges configured approximately on two east-west lines through the middle and southern part of the catchment. The gauges record time-of-tip, but employ a .5 mm bucket size.

It is recommended that two further gauges be installed, one located in the middle/upper Rothley Brook catchment at circa SK 480 070 for use in the Rothley catchment model and the other to the east of the Middle Soar, for estimating the ungauged lateral inflows entering along the right bank, located at circa SK 660 070. The buckets of the existing gauges should either be counterbalanced and recalibrated to record a tip for every 0.2 mm of rain, or new 0.1 mm buckets installed (the more expensive option).

Any further model calibration should investigate the value of records from the 5 raingauges along the eastern edge of the catchment, located in the NRA Anglian Region. If these prove useful then a telemetry connection to the Severn-Trent Region will be needed in order to make use of these stations in real-time. These gauges are likely to be useful for a local radar recalibration system for the Soar based on HYRAD.

(ii) **Radar network**: The Soar is poorly served by the UK radar network, with over half the catchment lying beyond a range of 76 km from the Clee Hill and Ingham radars. Nonetheless, radar will prove invaluable in a qualitative way in portraying moving storms as they approach the Soar. Results reported in a draft copy of the Long Range Calibration Study Final Report for the Leicester Laterals subcatchment suggest that radar estimates are of acceptable quantitative accuracy over the Soar. Through local calibration using HYRAD there is some prospect for improved rainfall estimation, although the height of the radar beam above the Soar means that low, shallow rain-bearing cloud will not be detected. It is recommended that the processing and display features of IH's HYRAD Windows 3.1 system be adopted for use with the Flood Forecasting System. This provides both calibrated and forecast rainfall fields and catchment averages with an interface to the Flood Forecasting System, as well as animated images of real-time radar data displays. The Met. Office Frontiers forecasts should be utilised to provide longer term rainfall forecasts, say from 2 to 6 hours ahead.

The Stage 1 report highlighted the benefit of the Type 2 radar data for use in modelling, providing data quantised at 208 intensity levels, and at 2 km resolution within a range of 76 km of the radar. In practice only Type 1 data from the Clee and Ingham radars are received, along with the Network product providing the broader national picture. Both provide intensities at only 7 levels plus zero and are at 5 km resolution. They are not suitable for regional processing, including local calibration, rainfall forecasting and calculation of catchment average rainfall. Whilst the advantages of Type 2 data are arguably not so strong for locations beyond 76 km, it is recommended that Type 1 data be replaced by Type 2 data for quantitative use as a strategy for the Severn-Trent Region. Existing investment in the MicroRadar system can be protected, through its use for qualitative display purposes in the many offices of the NRA Severn-Trent Region. However, in the longer term, migration to standardise on Type 2 data and higher quality displays should be borne in mind.

(iii) **River gauging network**: The nine stations proposed under the Stage 1 study are largely already supported by the existing network and the recommendations relate primarily to how existing sites can be improved. One exception is the recommendation for a gauging site in Leicester at Freemans Weir, to be equipped with an accurate level sensor and with the weir maintained rigorously in summer against weed growth. Such measures should achieve more sensitive flow measurement over this long weir. The other eight recommended sites are met by the following existing stations: the lower Soar at Kegworth, the middle Soar at Pillings Lock, the upper Soar at Littlethorpe, the Sence at South Wigston, the lower Wreake at Syston, the middle Wreake at Frisby, the Eye at Brentingby (meeting the upper Wreake near Melton Mowbray requirement) and the Rothley Brook at Rothley.

Since much of the Soar downstream of Leicester is under backwater influence it was considered likely that the multi-path ultrasonic gauging method would be an appropriate choice for the main Soar. The site recommended for the middle Soar near Loughborough corresponds well to the Pillings Lock gauging site, being located in a section of the river which is also the navigation canal. Gauging is by the multi-path cross-path ultrasonic method and therefore conforms with the recommendation. Silting of the lower sensors has occurred. It is recommended that the sensors be relocated and the cross-section re-surveyed. The implementation of sensors to measure flood plain flows, which otherwise bypass the station, has not proved successful. It is recommended that all aspects of the flood plain sensor installation be subject to review. Whether or not the sensors have ever been submerged is uncertain because of the use of a barrel memory, infrequently downloaded, and lack of telemetry access. Planned improvements to logging and remote access of the sensor values should help, and are supported. Diversion of the ditch adjacent to the towpath on the left bank is also planned and supported here. The review should expose the need, or not, of lowering the sensors, although this seems a likely prospect. Regular grass cutting, to a level below the sensor path, may be needed if this proves to be the case.

The Stage 1 report also recommended more use of the control structures, along with their associated level and gate position measurements, as another means of gauging. Inclusion of all gates (including Zouch and Eye Kettleby) in the hydrodynamic modelling of the Soar will achieve this objective, although a current metering programme would provide valuable support and validation to the modelling work. In practice the NRA have recently established provisional rating curves for Frisby and Zouch, based on levels downstream of their respective gates and flows from a current meter programme. Further work, supported by current metering and modelling, is recommended to estimate flows over the full flow range through these gates.

Some further investigation of the suitability of the station on the Eye at Brentingby is required. If found suitable the station should be upgraded, a current meter programme initiated to establish a rating and telemetry installed.

The following needs, or plans, for improvement to existing gauging stations have been identified in consultation with the NRA:

(a) Soar at Kegworth: Replacement of old ultrasonic cable in order to improve accuracy, especially at low flows.

(b) Soar at Zouch Sluice Gate: There is a requirement to interpret the gate angle sensor records in terms of angle in degrees, as intended in the original design.

(c) Soar at Littlethorpe: Extension of electromagnetic gauge insulating membrane up the right flood bank and raising of bank level by 0.5-1.0 m over a length of 50-70 m in order to extend the range of flow estimation by the gauge. Establish a rating curve above this based on a continuation of the existing current metering programme, with main channel metering from the bridge and floodplain metering across the bypass culverts. These measures will improve the station's performance at high flows, when underestimation occurs due to bypassing.

(d) Wreake at Syston: Silting up of the right side of the channel suggests that the present constructed section has been designed with too large a width. A physical model study of the section used by this electromagnetic gauge should be commissioned. It is probable that a two-stage channel form will prove appropriate. The gauging section should be engineered to the new design and the electromagnetic gauge recalibrated.

(e) Wreake at Frisby-on-Wreake: Recalibration and installation of timers controlling gate movements, which are possibly stuck on the maximum 30 minute delay (this is in hand).

(f) Wreake at Eye Kettleby: The gate position should be put on telemetry.

(g) Eye at Brentingby: Review suitability of station for upgrading, and if satisfactory install telemetry and initiate current meter programme.

(h) Scalford Brook at Melton Mowbray: Service upstream pressure transducer installation, which has been offline for some time.

(iv) **Weather station**: The Stage 1 report recommended that a single AWS installed in the Soar catchment monitoring the standard set of variables required to calculate Penman evaporation (wet and dry bulb air temperature, wind speed, net radiation) along with rainfall. Inclusion of wind direction and incoming solar radiation, whilst not essential for this application, would conform to standard practice. Data should be recorded at 15 minute intervals and telemetered to the forecasting computer, where they can be automatically processed to estimate daily PE values for input to rainfall-runoff models and used to support snowmelt forecasting at a finer time resolution. Whilst the Stage 1 study assumed no existing climate stations, it pointed out that in the event that a station exists, use should be made of it to capitalise on existing equipment and historical records where practical. This might imply addition of sensors rather than installation of a complete AWS.

In practice two climate stations exist in the catchment at two of the telemetry raingauge sites: Narborough and Brooksby (see Figure 2.2.1). The climate station at Brooksby, due for closure, would make an ideal site for enhancement to a full AWS. It currently records air temperature, wind run and rainfall on telemetry. It is recommended that this station be upgraded to include wet bulb temperature, net radiation, wind direction and incoming solar radiation on telemetry. The existing telemetry outstation has the capacity to support these additional sensors.

(v) **Soil moisture station**: A decision on the installation of a soil moisture station in the Soar catchment should be deferred pending the outcome of ongoing research at IH.

2.2 FLOOD FORECASTING AND WARNING SYSTEM

(i) **Hydrodynamic river model**: The Stage 1 report recommended that a hydrodynamic model, such as ISIS, should be used for the main Soar from the confluence with the River Trent to upstream of Aylestone Causeway (on the south west edge of Leicester) and for the River Wreake to Melton Mowbray, with the possible omission of the stretch from Ratcliffe to Frisby. Since the existing Flood Forecasting System does not employ a hydrodynamic model, making exclusive use of a conceptual hydrological channel flow routing model, the Stage 1 recommendation is reinforced here. One exception is that consideration be given to shortening the extent of the hydrodynamic model through Leicester, with Freemans Weir being used as the upstream boundary. The acceptability of this change depends particularly on the success in gauging Freemans Weir. The upstream boundary on the Wreake, in the vicinity of Melton Mowbray, should be taken as the station on the Eye at Brentingby, provided this proves a satisfactory flow gauging site.

It was anticipated in the Stage 1 report that the ONDA model configuration for the Soar, currently being undertaken by Halcrow, could be used to support an initial configuration of ISIS for real-time use. However, access to node maps of the model during Stage 2 has served to identify four areas where the model configuration will require extension. These are: from Birstall (the ONDA model upstream boundary) to Freemans Weir and the channels of the Kingston Brook, Black Brook and Quorn Brook where they cross the Soar floodplain. The three brooks need to be entered into the model on the edge of the floodplain and not directly into the main channel of the Soar.

(ii) **Hydrological channel flow routing model**: Stage 1 recommended that the convection diffusion equation, or an approximation to it, should be used for channel flow routing on reaches not significantly affected by backwater. The KW model was suggested as one choice in providing an appropriate approximation tailored for use in real-time. The NRA-ST's own DODO model is currently used as the reach model in the forecasting system for the Soar. This model falls into the class of model recommended. It is based on the Muskingum storage concept, which has been shown by Cunge to provide an approximation to the convection-diffusion equation. The way it handles floodplain flows has a stronger conceptual basis than the IH KW model, but the latter arguably has greater flexibility to accommodate a range of behaviours. This is achieved through the use of a variety of speed-discharge functions and threshold storage functions able to represent the transfer of channel flows to the floodplain. A detailed empirical intercomparison, using flood events for several reaches, would be needed to support any recommendation for change. Therefore, given the widespread use of the DODO model in both the Soar and elsewhere in the Severn-Trent Region, it is recommended that this model be supported by the proposed Flood Forecasting System. The implication of incorporating the DODO model into the RFFS is to recommend that it be coded as an RFFS Model Algorithm, capitalising on the RFFS's generic model algorithm interface to ease this task. Use of the RFFS has the added advantage of giving immediate access to the KW model to support any evaluation study. Indeed the two models may be configured alongside each other for operational trials if required.

(iii) **Rainfall-runoff catchment model**: Stage 1 recommended that a conceptual rainfall-runoff model based on continuous soil moisture accounting principles should be used to model the tributary catchments draining to the channel routing reaches. An appropriate choice was suggested to be the PDM model specifically tailored for real-time use and having considerable variety in the behaviours it is able to represent. For snowmelt conditions again a conceptual water equivalent accounting model was recommended. The PACK model was suggested as an appropriate choice at present pending the outcome of ongoing research sponsored by the NRA and MAFF.

In practice the catchment model used for modelling the Soar tributaries employs a conceptual model of the type recommended, both for rainfall-runoff and snowmelt. In this case the PDM has certain advantages in the way it represents soil moisture variability over the catchment, the use of a mathematical formulation which originates in continuous time, and the incorporation of inbuilt empirical state correction procedures for real-time updating. However, because of the widespread application of the Severn-Trent catchment model in the Soar and elsewhere across the region, there would be a need to perform a model intercomparison before recommending a change to existing practice. The recommendation is to develop a Model Algorithm form of the catchment model for use in the RFFS. Again the option to trial or use the PDM model, or other models, is provided in this integrated approach.

(iv) **Forecast updating**: In the Stage 1 report it was recommended that empirical state updating be used as the updating technique for the rainfall-runoff model and ARMA error prediction for the hydrological and hydrodynamic channel flow routing models. Some investigation of a newly developed state updating method for hydrological channel flow routing models was needed before this approach could be commented upon. In practice the method of updating used in the Soar model, for both reach and catchment components, is a form of error prediction. A careful analysis of the performance of the approach used suggests that it's two-phase form can lead to rather odd behaviours and is often not very helpful. A simpler approach is recommended based on ARMA error prediction, in which a constant parameter ARMA model fitted off-line can be guaranteed to produce a stable adjustment which asymptotes to the simulation forecast with increasing lead-time. If necessary, a special form of ARMA model based on an AR model with equal roots and allowing for errors in the observations could be used. In the absence of a state updating scheme for the catchment model the most straightforward implementation would make use of the ARMA error predictor for catchment, reach and hydrodynamic models.

(v) **Model Calibration Facility**: Stage 1 recommended that model calibration facilities should be incorporated in the supplied system and these should support both automatic optimisation procedures and visually interactive calibration aids. Facilities are available in the system in use to calibrate the reach and catchment models using the Rosenbrock automatic optimisation procedure. The recommended RFFS calibration facilities employ a Simplex method, but there is little to choose between this and the Rosenbrock method. More important is the visually interactive calibration aids now supported by the RFFS, which ease the task of estimating parameters of conceptual catchment models which invariably lack uniqueness and independence. This is seen as the major shortcoming in the calibration facilities in current use by NRA-ST. Other features that are lacking include: (a) pooled calibration across a set of events; (b) continuous soil moisture accounting between events for catchment models, through a switch to daily rainfall data, removing the need for event state initialisation sets; (c) long-term (many-season) optimisation of water balance parameters using a switch to a daily time interval and using daily observed flow values; (d) embedded optimisation of stage-discharge curves, useful for extending the range of existing relations or for establishing new ones; (d) embedded optimisation of ARMA error predictor parameters; and (e) assessment of updated model forecasts using fixed-origin variable lead-time plots, fixed lead-time variable time-origin plots and associated performance statistics. These are features available in the RFFS Calibration Facility. A further feature of value is the calibration of nested models. The most useful example of this is where rainfall-runoff catchment models of ungauged lateral inflows are nested within a reach model, with the parameters optimised with reference to the observed outflow from the modelled reach. A specification for the optimisation of general configurations of models has been prepared at IH, and coding is ongoing.

(vi) **Forecast construction**: Stage 1 recommended that the kernel to the forecasting system should be generic and configurable to new forecast requirements and new model algorithms. It should also employ state variables as a means of efficiently constructing seamless forecasts when forecasts are made at infrequent intervals during non-storm periods. It should also support the concept of subnetworks which allows only parts of the modelling system to be run in response to real needs. Such functionality is provided by the ICA within IH's RFFS system. The ST-FFS in use in the Soar catchment, and elsewhere in the Severn-Trent region, has some of these features but not all. The system is configurable to new forecast requirements but cannot readily accommodate new model algorithms through a generic model algorithm interface. This is particularly important with regard to the ease with which a hydrodynamic model might be accommodated within the existing system, which is judged to be quite difficult. The FFS is well designed in its use of state variables but does not support the subnetwork run concept, other than supporting a Trent model and a Severn model. The recommendation is therefore to adopt the RFFS ICA system, whilst capitalising on the telemetry functionality provided by RECS.

(vii) **System environment**: Stage 1 recommended that the forecast system environment should have a generic design configurable to new requirements. It should have interfaces to external systems, such as telemetry, weather radars and weather forecasts as well as a graphical user interface and reporting and dissemination facilities. Definitive recommendations on the shell environment and associated interfaces were deferred pending a review of RECS and REMUS under Stage 2. This has now been undertaken and the following recommendations can now be made. The RECS/FFS system should be retained to provide the telemetry interface to the RFFS system but the FFS component should be replaced by the RFFS ICA for forecast construction. RECS should be modified to accommodate 15 minute telemetry data.

REMUS is due to be revamped as a Windows 3.1 system in the NRA's work programme. The radar functionality of REMUS should be provided by HYRAD, a Windows 3.1 implementation. IH is also developing a Windows 3.1 (and Chicago) shell for RFFS, with an interface to HYRAD, and this is likely to meet most of NRA-ST's requirements for a shell environment. A useable system is scheduled for completion towards the end of 1995.

(viii) **Computing provision**: The type of flow forecasting system envisaged in the Stage 1 recommendations typically would run on a workstation, such as a Sun Sparc 2, VAX station 3100 or similar, although the system kernel proposed is largely machine independent. The workstation would function as a server to client PC's running on 486 processors or better. In practice the ST-FFS runs on a MicroVax II, although an upgrade to a VAX 3100/Model 95 is planned, which acts as a server to client PCs running REMUS. There is a clear advantage to NRA-ST in staying with Digital, through the support of existing VMS applications needed to meet operational responsibilities, particularly flood warning. The recommendations of Stage 2 support the upgrade to the processor and the need for more disk capacity, which is often more than two-thirds full.

3. Recommendations

3.1 HYDROMETRIC NETWORK

(i) **Raingauge network**:

(a) It is recommended that two further gauges be installed, one located in the middle/upper Rothley Brook catchment at circa SK 480 070 for use in the Rothley catchment model and the other to the east of the Middle Soar, for estimating the ungauged lateral inflows entering along the right bank, located at circa SK 660 070.

(b) The buckets of the existing gauges should either be counterbalanced and recalibrated to record a tip for every 0.2 mm of rain, or new 0.1 mm buckets installed (the more expensive option).

(c) Any further model calibration should investigate the value of records from the 5 raingauges along the eastern edge of the catchment, located in the NRA Anglian Region. If these prove useful then a telemetry connection to the Severn-Trent Region will be needed in order to make use of these stations in real-time. These gauges are likely to be useful for a local radar recalibration system for the Soar based on HYRAD.

(ii) **Radar network**:

(a) It is recommended that the processing and display features of IH's HYRAD Windows 3.1 system be adopted for use with the Flood Forecasting System. This provides both calibrated and forecast rainfall fields and catchment averages with an interface to the Flood Forecasting System, as well as animated images of real-time radar data displays.

(b) The Met. Office Frontiers forecasts should be utilised to provide longer term rainfall forecasts, say from 2 to 6 hours ahead, as a complement to the HYRAD forecasts.

(c) It is recommended that Type 1 weather radar data be replaced by Type 2 data for quantitative use as a strategy for the Severn-Trent Region. Existing investment in the MicroRadar system can be protected, through its use for qualitative display purposes in the many offices of the NRA Severn-Trent Region. However, in the longer term, migration to standardise on Type 2 data and higher quality displays should be borne in mind.

(iii) **River gauging network**:

(a) **Soar at Freemans weir**: It is recommended that a new gauging station be established in Leicester at Freemans Weir. The station should be equipped with an accurate level sensor and with the weir maintained rigorously in summer against weed growth so as to achieve more sensitive flow measurement over this long weir. The other eight recommended sites are met by the following existing stations: the lower Soar at Kegworth, the middle Soar at Pillings Lock, the upper Soar at Littlethorpe, the Sence at South Wigston, the lower Wreake at Syston, the middle Wreake at

Frisby, the Eye at Brentingby (meeting the upper Wreake near Melton Mowbray requirement) and the Rothley Brook at Rothley.

(b) **Soar at Pillings Lock**:

- It is recommended that the silted-up sensors on the left bank of the main channel be relocated and the cross-section re-surveyed.

- It is recommended that all aspects of the flood plain sensor installation be subject to review. Planned improvements to logging and remote access of the sensor values are supported. Diversion of the ditch adjacent to the towpath on the left bank is also planned and supported here. The review should expose the need, or not, for lowering the sensors, although this seems a likely prospect. Regular grass cutting, to a level below the sensor path, may be needed if this proves to be the case.

(c) **Frisby and Zouch gates**: Further work, supported by current metering and modelling, is recommended to estimate flows over the full flow range through these gates.

(d) **Soar at Kegworth**: Replacement of old ultrasonic cable in order to improve accuracy, especially at low flows.

(e) **Soar at Zouch Sluice Gate**: There is a requirement to interpret the gate angle sensor records in terms of angle in degrees, as intended in the original design.

(f) **Soar at Littlethorpe**: Extension of electromagnetic gauge insulating membrane up the right flood bank and raising of bank level by 0.5-1.0 m over a length of 50-70 m in order to extend the range of flow estimation by the gauge. Establish a rating curve above this based on a continuation of the existing current metering programme, with main channel metering from the bridge and floodplain metering across the bypass culverts. These measures will improve the station's performance at high flows, when underestimation occurs due to bypassing.

(g) **Wreake at Syston**: Commission a physical model study of the section used by this electromagnetic gauge, to include consideration of a two-stage channel form. Engineer the section to have the new design and recalibrate the em gauge.

(h) **Wreake at Frisby-on-Wreake**: Recalibration and installation of timers controlling gate movements, which are possibly stuck on the maximum 30 minute delay (this is in hand).

(i) **Wreake at Eye Kettleby**: The gate position should be put on telemetry.

(f) **Eye at Brentingby**: Review suitability of station for upgrading, and if satisfactory install telemetry and initiate current meter programme.

(g) **Scalford Brook at Melton Mowbray**: Service upstream pressure transducer installation, which has been offline for some time.

(iv) **Weather station**: The climate station at Brooksby currently records air temperature, wind run and rainfall on telemetry. It is recommended that this station be upgraded to include wet bulb temperature, net radiation, wind direction and incoming solar radiation on telemetry. The existing telemetry outstation has the capacity to support these additional sensors. Data should be recorded at 15 minute intervals and telemetered to the forecasting computer, where they can be automatically processed to estimate daily PE values for input to rainfall-runoff models and used to support snowmelt forecasting at a finer time resolution.

(v) **Soil moisture station**: A decision on the installation of a soil moisture station in the Soar catchment should be deferred pending the outcome of ongoing research at IH.

3.2 FLOOD FORECASTING AND WARNING SYSTEM

(i) **Hydrodynamic river model**: It is recommended that the ISIS hydrodynamic model, a new integrated version of the Salmon and Onda models, should be used for the main Soar from the confluence with the River Trent upstream to Leicester, probably at Freemans Weir, and for the River Wreake to Melton Mowbray, probably as far as the Eye at Brentingby, with the possible omission of the stretch from Ratcliffe to Frisby.

The ONDA model configuration for the Soar, currently being undertaken by Halcrow, should be used to support an initial configuration of ISIS for real-time use. Four areas where the model configuration will require extension are: from Birstall (the ONDA model upstream boundary) to Freemans Weir and the channels of the Kingston Brook, Black Brook and Quorn Brook where they cross the Soar floodplain. The three brooks need to be entered into the model on the edge of the floodplain and not directly into the main channel of the Soar.

(ii) **Hydrological channel flow routing model**:

(a) It is recommended that the existing DODO reach model be supported by the proposed Flood Forecasting System.

(b) The implication of incorporating the DODO model into the RFFS-ICA kernel is to recommend that it be coded as an RFFS Model Algorithm, capitalising on the RFFS's generic model algorithm interface to ease this task.

(c) It is recommended that a formal off-line evaluation of the performance of the DODO and RFFS-KW reach models be carried out, possibly as a joint investigation with the NRA.

(iii) **Rainfall-runoff catchment model**:

(a) It is recommended that a Model Algorithm form of the CRM (Catchment Runoff Model) is developed for use with the RFFS-ICA kernel software.

(b) It is recommended that a formal off-line evaluation of the performance of the CRM and RFFS-PDM rainfall-runoff models be carried out, possibly as a joint investigation with the NRA.

(iv) **Updating procedures**:

(a) It is recommended that the ERM method of error prediction be replaced by the ARMA error prediction approach. A constant parameter ARMA model fitted off-line can be guaranteed to produce a stable adjustment which asymptotes to the simulation forecast with increasing lead-time.

(b) If necessary, a special form of ARMA model based on an AR model with equal roots and allowing for errors in the observations could be used.

(c) It is recommended that, at least initially, a straightforward implementation is made where ARMA error predictors are used for catchment, reach and hydrodynamic models.

(d) An approach based on state updating may be considered at a later stage, initially through an off-line evaluation study.

(v) **Model Calibration Facilities:**

(a) The NRA-ST's Calibration Facilities lack the following important features which are present in the RFFS Calibration Facilities:

- visually interactive calibration aids which ease the task of estimating parameters of conceptual catchment models which invariably lack uniqueness and independence

- pooled calibration across a set of events

- continuous soil moisture accounting between events for catchment models, through a switch to daily rainfall data, removing the need for event state initialisation sets

- long-term (many-season) optimisation of water balance parameters using a switch to a daily time interval and using daily observed flow values

- embedded optimisation of stage-discharge curves, useful for extending the range of existing relations or for establishing new ones

- embedded optimisation of ARMA error predictor parameters

- assessment of updated model forecasts using fixed-origin variable lead-time plots, fixed lead-time variable time-origin plots and associated performance statistics.

It is recommended that a strategy be developed to provide some, or all, of this functionality. This might be achieved by either extending the present NRA facilities or adopting the RFFS Calibration Facilities and incorporating the DODO and CRM models within the RFFS calibration shell environment. An enhanced form of the latter, specified and undergoing coding at present, will provide for nesting of models. This is seen as particularly important for calibrating reach models with significant ungauged lateral inflows, allowing the parameters of rainfall-runoff models of the ungauged tributaries to be estimated along with those of the reach model.

(vi) **System environment**:

(a) **Forecast construction**: It is recommended that the RFFS Information Control Algorithm, or ICA, be used as the environment to construct forecasts in real-time, with an interface to the telemetry data provided by RECS.

(b) **Telemetry interface**: The RECS/FFS system should be retained to provide the telemetry interface to the RFFS system but the FFS component should be replaced by the RFFS ICA for forecast construction. RECS should be modified to accommodate 15 minute telemetry data.

(c) **Graphical User Interface**:

- The radar functionality of REMUS should be provided by HYRAD.

- IH is developing a Windows 3.1 (and Chicago) shell for RFFS, with an interface to HYRAD, and this is likely to meet most of NRA-ST's requirements for a shell environment. A useable system is scheduled for completion towards the end of 1995. It is recommended that the NRA consider adoption of this shell as a replacement for REMUS. This might be scheduled as a second phase system enhancement.

(d) **Computing provision**: The planned upgrade of the modelling computer to a VAX 3100/Model 95, together with an increase in disk capacity, is supported.

4. Benefits of the proposed solution

4.1 INTRODUCTION

The forecasting of flows and river levels in natural river networks is a complex task associated with many sources of uncertainty. This uncertainty arises from the natural variability in the forcing inputs to the system, primarily in the form of rainfall, and to a lesser extent climate forcing variables which affect evaporation loss to the catchment system. In addition to the natural variability of rainfall in space and time there is the uncertainty associated with the measurement of rainfall fields, either by raingauges or radar or a combination of both. In order to extend the lead time of flow and level forecasts the need arises to forecast rainfall fields: this is associated with even greater uncertainty, particularly as the lead time increases.

Within the river network, errors associated with the measurement of river level and flow provide another source of uncertainty, which is likely to be greatest during overbank flood conditions. Lastly, there is the uncertainty associated with modelling the complexity of the propagation of water through natural river systems. Such systems are characterised by complex networks of flow paths and storages, both underground and at the surface, including the concentrated flow paths we recognise as river channels. Paradoxically, when complexity is greatest, such as in the land phase of runoff production, an appropriate model representation is often relatively simple. For the case of catchment rainfall-runoff models, simple conceptual formulations which employ configurations of storage elements are the norm. However, whilst such models are appropriate for representing the complexity of runoff production at the catchment scale they can be an important source of uncertainty in flow forecasts. Where the pathway is better defined, principally in the river channel, a more detailed modelling of the process can often reduce uncertainty. This is particularly true when additional information are available in the form of land surveys and bed roughness estimates derived from field data. However, in simpler river channel situations the more complex hydrodynamic model formulation naturally reduces to simpler forms, such as those based on kinematic flow routing which can be represented by quite simple hydrological storage formulations. In such situations, and with accurate measurements of inflows to the river channel reach, uncertainty in flow forecasts can be least. Where the flow dynamics are more complex, such as where backwater from flood gate and navigation level controls exert an influence, then the greater complexity of a full hydrodynamic model becomes justified. In such situations the uncertainty in flow and level forecasts may not be great, provided the system is well defined in terms of survey data and measurements of lateral inflows and of river levels and settings at the controls.

Accuracy becomes a more complex issue still when the ability to update model forecasts with reference to observed flows and levels is considered. In general updating techniques can greatly reduce the uncertainty of forecasts for short lead times, but will be largely ineffective at longer lead times when the adequacy of the deterministic model formulation becomes paramount, along with the uncertainty of the possibly forecast input variables.

The above review of uncertainty in flood forecasting systems serves to highlight the considerable variability in uncertainty due to

- the natural variability in rainfall and other climatic forcing inputs

- the forecasting of model inputs, especially rainfall
- the sampling and measurement errors associated with rainfall along with river level and flow
- the modelling approximations employed, and
- the forecast updating schemes used.

Any proposal for improvement should address each of these sources of uncertainty, and this proposal has followed this route. However, it must be clear from the above review that forecast uncertainty is complex and highly variable in time, in space and in context. For this reason the benefits of proposed improvements to an existing forecasting system cannot generally be forwarded in a quantitative manner, such as proposal X will lead to a Y% reduction in forecast uncertainty at site Z, leading to C% reduction in flood damage costs at the set of sites R at risk.

The aim of the recommendations is to tighten up the existing system where uncertainty and error exist: in the hydrometric network and in the modelling system. However, the benefits go beyond reducing uncertainty of flood forecasts to providing a modelling environment that allows more to be done, notably in decision-support for flood warning and control, and which can evolve over time as new developments in modelling and measurements arise and as new requirements for forecasts emerge. Some of these benefits are identified in the following sections with reference to specific recommendations.

4.2 HYDROMETRIC NETWORK

River gauging stations

The main shortcoming in the existing hydrometric measurement network is the failure of some river gauging stations to measure flood flows, particularly when incursion on the flood plain occurs. This leads to volume errors in models downstream of the gauging station. A complicating factor is that models fitted using data which fail to accommodate flood plain flows can take on model parameter values which implicitly compensate for this fact. This leads to essentially equivalent models, which in some cases can provide adequate forecasts, but sometimes for the wrong reason. The source of uncertainty becomes progressively obscure as one progresses down the river system, as measurement errors mix with model errors, including those associated with model calibration to error-prone flow measurements as well as those associated with inadequacies in model formulation. As a consequence, the flood duty officer loses confidence in the forecasting system as it fails to provide a reliable tool to support flood warning. The proposed improvements to the river gauging stations aim to address the problem at source, which will mean that subsequent model calibration will be more robust and not a source of error propagation down the model river network. Forecast updating in real-time will be more assured of improving the accuracy of forecasts downstream if the measurements of flow used for updating are reliable.

Whilst the extent of the river gauging station network is broadly adequate the study has identified the need for one new station at Freemans Weir on the main Soar at Leicester. This is needed to provide the upper boundary condition to the proposed hydrodynamic model for the main Soar. A second station at Eye Brentingby on the River Eye, in the upper Wreake catchment, needs to be upgraded to provide an upstream boundary condition for the proposed hydrodynamic model encompassing the Eye Kettleby flood gate control. Other hydrometric improvements required, that relate to the hydrodynamic river models, concern the logging of gate movements which are essential if the effect of gate controls are to be properly forecast.

Rainfall measurement network

The proposals for enhancing the raingauge network are not radical, with only two additional gauges proposed to provide a more even coverage which will be of benefit for rainfall-runoff modelling. Of course little benefit will accrue from this enhancement during uniform rainfall over the Soar, but in other situations the benefits may be more significant. Greater resilience of forecasts from the rainfall-runoff model for Rothley Brook, and for the ungauged lateral inflows draining from the east into the middle Soar, will be the main benefit. These gauges when used for local radar rainfall calibration will also lead to improved accuracy in spatial rainfall estimates, at least on average, as indicated by IH's research over the Thames basin. The proposal to increase the resolution of the raingauges, from 0.5 mm to 0.2 or 0.1 mm, is justified in terms of improved radar calibration and of improved updated forecast accuracy from the use of a 15 minute model time step, and the consequential need for greater rainfall resolution when moving from the current one hour interval model time step. Improvement in forecast accuracy when a 15 minute time interval is employed for forecast updating of rainfall-runoff models has been demonstrated in IH's research over the Thames basin.

The use of both Frontiers and HYRAD systems for radar rainfall forecasting will bring benefits in terms of extending the lead time of forecasts. This will also make more feasible the forecasting for flood risk sites higher up the Soar and on its tributaries. A notable example is Rothley where flood warnings are not presently given on account of the short lag in catchment response to rainfall. It is important to exercise caution on the benefits of rainfall forecasts, on account of their relatively low accuracy. The justification for using both HYRAD and Frontiers forecasts is the demonstrated improved accuracy of the former for lead times up to two hours.

Weather station

The proposed upgrade to the Brooksby climate station to incorporate the full set of sensors of a standard automatic weather station has two main benefits. Penman evaporation (PE) estimates will be of benefit when used in the soil-moisture accounting component of the catchment runoff model. Whilst a simple sine curve approximation over the year is sometimes used, near-real time estimates are obviously a better reflection of evaporation demand. With telemetry and the ability to automate the PE calculation on the modelling computer, these data become immediately available for use in the forecasting system. The second benefit is to snowmelt modelling, where temperature and possibly wind speed and humidity are used.

4.3 FLOOD FORECASTING AND WARNING SYSTEM

Hydrodynamic river model

The major failing in the forecasting models currently used for the Soar is that the reach model cannot accommodate conditions of backwater and variable gate controls. As a consequence, the main benefit from improved modelling will be expected to arise in such conditions through the use of the ISIS hydrodynamic river model. This will include the main Soar downstream of Leicester and the Wreake where it is affected by backwater from the main Soar and from gate controls. It is also expected that improved modelling of flood plain flows will be a benefit of the hydrodynamic model approach.

The benefits of ISIS as an RFFS model algorithm will extend beyond its immediate use in the Soar catchment. In particular, extension of the forecasting system to other parts of the Severn-Trent region will demand adoption of a hydrodynamic modelling approach in the tidal reaches of both the Severn and the Trent. The RFFS in Yorkshire has demonstrated the viability of using a real-time hydrodynamic model for flow and level forecasting, through its application to the tidal Ouse and Derwent tidal barrier.

Incorporation of gate control algorithms as part of the hydrodynamic model will provide for the first time in the Soar an explicit representation of the effect of gate movements on river levels and flows. This will have the added benefit of allowing the model to be used as part of a decision support system for gate operation. The gate operator will be able to ask "What if?" questions on possible gate movement strategies and see the likely consequences before implementing a strategy for real. Greater confidence of gate operation and a reduction in flood risk are the expected benefits.

Hydrological reach and catchment models

A conservative recommendation to continue with the use of the DODO reach model and CRM rainfall-runoff model has clear benefits in protecting existing investment in the application of these models and in the understanding of them by NRA staff. Introducing new models to replace them can only be justified through a demonstration that there are benefits to be gained through improved accuracy. For this reason the recommendations include an off-line trial of these models with the KW and PDM models proposed in the Stage 1 Report.

A more important advantage of the RFFS-ICA forecasting environment proposed is that as advances in modelling are made, or preferences change, new models can be readily accommodated through the generic model algorithm interface. Indeed the RFFS allows for more than one type of model to be configured into the real-time system to make forecasts for the same point, if this flexibility is required.

A consequence of the generic model interface design is that model selection becomes a less critical issue, with the opportunity to periodically review the choice of models against the present state-of-the-art. The benefit is an extended life for the forecasting system.

Forecast updating

The form of error predictor used to incorporate current measurements of flow to form improved, updated forecasts is unsatisfactory. Its two phase form can lead to rather odd looking forecasts and in general is neither helpful nor easy to interpret. A simpler approach based on an ARMA error predictor is recommended. This can be guaranteed to provide a stable adjustment which asymptotes to the simulation forecast with increasing lead-time. A multivariate form of this predictor is available for use with the ISIS hydrodynamic model. The benefits are a simpler, easier to interpret scheme. Use of off-line optimisation to fit the ARMA error predictor parameters for each gauged reach or catchment should also ensure greater accuracy than that obtained with the present scheme, which employs fixed parameters at all sites. A special fitting scheme is available, if needed, to accommodate for situations where there are significant errors in the observations used for updating.

Model calibration facility

A number of useful features of the RFFS Calibration Facility have been identified previously. Perhaps the most important is the pooled calibration across several events. This avoids many individual calibrations for each event and a later, ad hoc inference of a compromise parameter set. The benefit is saving in staff time for model calibration and a better optimum parameter set. Interactive visualisation facilities for manual parameter estimation bring further benefits in this area. The ARMA error predictor models, referred to above, can be calibrated as an integral part of the hydrological model from which the errors derive. Facilities to display different types of forecast graphically - fixed-lead-time and fixed-origin - help to understand the model performance expected in real-time as well as supporting the model calibration process.

Forecast construction

The following summarise the main benefits of adopting the RFFS-ICA for managing forecast construction:

(i) A generic model algorithm interface which can accommodate an infinite variety of model types. This means that new models can replace old ones, without changes to the "inner code", as modelling advances are made or model preferences change. Use of a generic model algorithm interface means that quite radical extensions, for example to incorporate water quality algorithms, can be made with ease. In the case of the Soar forecasting requirement this feature is particularly important in easing the task of integrating the ISIS hydrodynamic model into the real-time forecasting environment.

(ii) Full resilience to missing data, allowing the model to function, albeit less accurately, even with the total absence of telemetry data.

(iii) The ability to run a network model for the whole network or selected parts of the network. Sub-networks can be dynamically definable during a run of the model if required, or can be pre-configured. The sub-network functionality is particularly appropriate where repeated runs on a particular part of the network are required to support "what if?" decision-support runs, such as in scheduling future flood control gate movements. With extension of the system to the tidal reaches of the Severn and Trent, a typical use of sub-network configuration would allow the non-tidal model to be run faster and more frequently to support flash flood forecasting on the fluvial river.

(iv) The ability to readily incorporate weather radar data into the system for use with catchment models, with a run-time switch to revert to raingauge data when radar data are judged to be more reliable (and vice versa). The switch might also be used as a "what if?" to judge the uncertainty of the flow forecast associated with the rainfall input.

(v) A re-run option which allows a model run previously enacted to be repeated with new options. This is used particularly for decision-support where the exact data used for one run must be used for the next, except that involved in the "what if?" option being considered. If this is not done, in real-time there is no guarantee that new data are not affecting the outcome rather than the option being investigated.

Other functions which are partly supported by the present FFS include:

(vi) The ability to reconfigure the system to incorporate new forecast points or telemetry sites for an existing system, or to a completely new river network, without expensive recoding. Network structure is data defined, allowing low cost modifications as well as using the same software to be used for subsequent implementations. Not needing to modify the program code, as well as having cost advantages, also makes new implementations less error prone.

(vii) The use of a state formulation to allow models to be initialised from a past set of state values, avoiding a long warm up for model initialisation. This means that the model can be run intermittently but yield a "seamless" result as if the model had been run continuously.

System environment

Existing investment in the RECS system for telemetry management is protected through the recommendation that this is retained to provide a telemetry interface to the RFFS. Whilst RECS currently receives 15 minute and event data these are consolidated to an hourly interval for database access. This needs to be modified so that database access to the 15 minute data is provided in order to meet the modelling requirement for data at this interval.

As a staged enhancement of the existing system it is proposed that initially an interface from the RFFS to the existing REMUS forecast display system be established. REMUS needs to be replaced by a system running under Windows 3.1, or better. The recommendation for Phase II is that it be replaced by the new RFFS shell GUI under development at IH and due for completion in 1996. This will be supported under Windows 3.1, or better. The benefits are a phased implementation and investment, and a state-of-the-art GUI.

Computing provision

The NRA's plan to purchase a VAX 3100/Model 95 (plus additional disk storage) provides an appropriate computer platform to support the new forecasting system. Staying with Digital has clear benefits given the importance of maintaining an operational flood forecasting and warning system throughout the development project time period.

Severn-Trent wide implementation

The recommendations envisage a Phase III project which will be a Systems Analysis Study to extend the new forecasting system to the entire Severn-Trent region, including the tidal reaches of the Trent and Severn. Thus the benefits of implementation on the Soar will be greatly extended, with the Soar really serving as a pilot development and implementation study for the region as a whole. The Systems Analysis study will review the requirements for flow forecasts in the region and propose a strategy for implementation including costs and time schedules. A subsequent implementation of this strategy will allow the full benefits of the developments made in the Soar to be realised throughout the Severn-Trent Region.

4.4 OVERVIEW OF BENEFITS

The requirements for flood warning identified in the Stage 1 report highlighted that the key areas needing warning were on the Lower Soar, downstream of the confluence with the Wreake, and on the middle and lower Wreake. These are the areas that have been designated as river reaches requiring a hydrodynamic approach to modelling, on account of variable backwater induced by navigation level and flood gate control. This approach represents a quite radical departure from the current use of a simple conceptual hydrological channel flow routing model in which the effect of backwater is not accommodated. The failure of such models, particularly in the vicinity of flood gates such as at Frisby on the Wreake, are evident from the assessment of forecasts for past events presented in Section 4 of the main Stage 2 Report. The reliability of forecasts have been so uncertain that flood duty officers have lost confidence in the use of the Flow Forecasting System and have tended to switch to monitoring the flood and its trend rather than rely on the forecasts. In this regard it is suggested that the benefits of a replacement system for the Soar be viewed as the full benefit of a forecasting system, implying that the benefit accrued from the existing forecasting system has zero value.

An examination of the sources of unreliability in the present flood warning system suggest that the following benefits will derive from the recommendations of this study:

(i) Improved measurement of catchment average rainfall by installing two new raingauges, utilising data from five further gauges within NRA Anglian Region, obtaining better resolution by using smaller buckets, replacing the low resolution Type 1 radar data with much higher resolution Type 2 and employing the improved radar calibration and forecasting facilities available through HYRAD, including access to Frontiers forecasts.

(ii) Improved and extended measurement of river stage and flow by installing new gauging stations at Freemans Weir and the Eye at Brentingby, enhancing the performance of existing stations at Kegworth, Pillings Lock, Littlethorpe, Syston and Eye Kettleby and utilising the control gates for flow estimation via extended telemetry and a current metering programme.

(iii) Better resolution of all monitored data by employing a 15 minute data storage time step giving more accurate flood forecasts.

(iv) Improved soil moisture accounting by upgrading the Brooksby climate station, leading to better rainfall-runoff modelling.

(v) Greater flexibility for rainfall-runoff modelling by gaining access to additional algorithms such as the PDM model which offers real-time state updating.

(vi) Greater flexibility for channel flow routing by gaining access to the KW model.

(vii) More scientific representation of flow phenomena such as backwater influences, inundation of floodplains and the operation of control structures by implementing the ISIS hydrodynamic model.

(viii) More efficient and effective calibration of the hydrological and hydraulic model parameters via user friendly, visual calibration and optimisation tools.

(ix) Improved updating scheme by employing a simpler, more stable error predictor.

(x) Greater flexibility in forecast construction, with the system providing for extension to new catchments, models and forecast variables, such as water quality.

The Consultants believe that these recommendations will lead to a significant improvement in the reliability of the flood warning service for the River Soar Catchment and restore the confidence of the Flood Duty Officers in the system.

5. Implementation plan

The following is a broad outline of the implementation plan:

Stage I: Hydrometric improvements and software development

(i) Improvements to the hydrometric network

(ii) Development and testing of ISIS Model Algorithm

(iii) Development and testing of reach and catchment Model Algorithms

(iv) Interface development from RECS to ICA and REMUS

Stage II: Soar implementation

(i) Data take-on for model calibration

(ii) Calibration of rainfall-runoff, hydrological channel flow routing and error predictor models to operate at a 15 minute time step.

(iii) Configuration of the ISIS hydrodynamic model to the Soar

(iv) Calibration and proving trials of the ISIS model

(v) Configuration of the RFFS ICA to the Soar catchment

(vi) Configuration of HYRAD to the Soar catchment

(vii) Development and implementation of RFFS shell to replace REMUS

(viii) Factory acceptance tests

(ix) Site acceptance tests

(x) Training

(xi) Maintenance and support

Stage III: Region-wide Implementation

(a) Systems Analysis Study
(b) Implementation

Stage I is expected to run over a 9 month period, Stage II a further 9 months and Stage III a further 12 months.

6. Budgetary costs

6.1 HYDROMETRIC NETWORK

6.1.1 Raingauge Network

6.1.1.1 Conversion of 7 raingauges from 0.5 to 0.2 (or 0.1) mm tips (NRA cost)

a) Counterweight plus recalibration option:
35×7 = £250

or

b) New bucket option
120×7 = £840

6.1.1.2 Addition of 2 raingauges on telemetry (NRA cost)
2×1000 = £2000

6.1.1.3 Telemetry link to 5 raingauges in Anglian Region

£8-10K (NRA cost)

6.1.2 Weather radar

6.1.2.1 IH HYRAD system

a) VAX kernel software licence £15K

b) PC GUI licence @ £1000 per PC : say × 5 £5K
£20K

6.1.2.2 Met. Office Frontiers rainfall forecasts

£17.6K (NRA cost)

6.1.2.3 Reception of Type 2 data from Clee Hill and Lincoln (no additional subscription cost from Met. Office)

Comms. costs for two radars £6K pa (NRA cost)

6.1.3 River gauging network

6.1.3.1 Level measurement, telemetry and weir cleaning at Freemans Weir
NRA work

a) Level measurement: Stilling well £2.5K (est.)
Recorder £150

b) Telemetry £1250

c) Weir cleaning £500 per annum

6.1.3.2 Frisby and Zouch gates: Current metering programme (say 12 gaugings per annum at each site) £2K per annum

6.1.3.3 Upgrading of Eye at Brentingby

a) Current meter gauging programme £1K per annum NRA cost (say 12 gauging per year)

b) Installation of telemetry £1250 NRA cost

c) Telemetry kiosk £2K NRA cost

6.1.3.4 Improvements of Pillings Lock

a) Relocation of silted-up sensors on left bank and resurvey of cross-section £3-4K (NRA cost)

b) Review of flood plain sensor installation No cost for review

c) Subject to b), relocation of flood plain sensors £5-6K (NRA cost)

6.1.3.5 Soar at Kegworth: replacement of old ultrasonic cable

6.1.3.6 Soar at Littlethorpe

a) extension of electromagnetic gauge insulting membrane up right bank £12K (NRA cost)

b) raising of bank level by 0.5-1.0 m over length of 50-70 m £5-7K (NRA cost)

6.1.3.7 Wreake at Syston :

a) Option 1: Physical model study (HR cost) £20K
Engineer new section and recalibrate em gauge £70K

b) Option 2: Install structure at Fisherman's weir £100K

6.1.3.8 Wreake at Frisby : Recalibration and installation of timers controlling gate movements (in hand)

6.1.3.9 Wreake at Eye Kettleby : Put gate position on telemetry
£3.5-4K

6.1.3.10 Scalford Brook at Melton Mowbray : Service upstream pressure transducer
Nil cost

6.1.4 Weather station

Addition of the following sensors at Brooksby:

(a)	wet bulb temperature (screen, thermometer)	£380 + £100
(b)	net radiometer	£480
(c)	wind direction (potentiometer input)	£340
(d)	incoming solar radiation	£940
(e)	installation cost	£500

(NRA costs)

6.2 FLOOD FORECASTING AND WARNING SYSTEM

6.2.1 ISIS hydrodynamic model

6.2.1.1 ISIS RFFS Model Algorithm development cost

HR cost: £40000

IH cost: 2 man months PSO £17160

6.2.2 DODO reach model RFFS model algorithm licence (IH cost)

£3800

6.2.3 Catchment Runoff Model (CRM) RFFS model algorithm licence (IH cost)

£3800

6.2.4 Model calibration

6.2.4.1 (a) ISIS model configuration and calibration

HR cost: £17000

2 week PSO IH cost: £4290

(b) Survey of four areas not in ONDA model

Cost: £20K (NRA cost)

Data required for the out-of-bank model in Leicester may be available from the recent aerial survey, which will reduce this cost.

6.2.4.2	DODO and KW reach model calibrations (2 reaches-Upper Soar and Middle Wreake)		
		1 week HSO	£1270
6.2.4.3	CRM and PDM catchment model calibrations (4 catchments)		
		2 weeks HSO	£2530
6.2.4.4	ARMA error predictors for all models		
		2 weeks HSO	£2530
6.2.4.5	Data management for above		
		4 weeks HSO	£5060
6.2.4.6	Report on off-line evaluation of KW/DODO and PDM/CRM models		
		2 weeks HSO	£2530
		1 week PSO	£2150

6.2.5 RFFS-ICA configuration files

1 week PSO £2150

6.2.6 Model calibration software

Option 1:

6.2.6.0 This is a no cost option assuming DODO and CRM calibration codes work at a 15 minute time-step

Option 2:

6.2.6.1	RFFS Calibration Shell DODO reach model licence	
		£3800
6.2.6.2	RFFS Calibration Shell CRM Catchment model licence	
		£3800
6.2.6.3	Integrated reach/catchment model calibration licence	
		£8580
6.2.6.4	ISIS Calibration Environment (optional: HR cost)	£12500

6.2.7 RFFS software licence

6.2.7.1 Includes: RFFS ICA, RFFS ICA Model Algorithms, Calibration Facility, TFN Package, Hydrometric utilities (Penman, Non-modular rating software)

Soar catchment	£10K

(Severn-Trent wide: £50K)

Annual maintenance and support licence: 10% of purchase price

Exclusion of the Calibration Facility, TFN Package and non-modular rating software would have no impact on the Soar licence cost, but the Severn-Trent wide licence would reduce to £35K.

6.2.7.2 ISIS maintenance and support (optional: HR cost)

£1500 per annum

6.2.8 RECS/RFFS telemetry data interface and database development, including 15 minute time-step data management

6 weeks SSO	£10260

This assumes work to be undertaken by IH. The merits of a joint IH/Data Sciences development need to be considered.

6.2.9 REMUS replacement by RFFS shell under WINDOWS 3.1

Licence	£30K
PC licence @ £1000 per PC: say x 10	£10K
	£40K

Replacement of the 90 Remus systems in use across the region would be discounted from £90K to £60K.

6.2.10 Region-wide implementation

a)	Systems Analysis Study	£25K
b)	Implementation	Subject to (a)

6.2.11 Project management

IH - Stage I cost:	£6440
IH - Stage II cost:	£6440

HR cost: covered by Wallingford Water Agreement

6.2.12 Modelling computer

VAX 3100/95 plus disk upgrade a planned NRA upgrade

6.2.13 Training

ISIS training (HR cost)		£1500
RFFS training (IH cost)		
	1 week PSO	£2150
	1 week HSO	£1270

The above are budgetary costs at Wallingford Water's 1994/95 rates and are subject to approval of its financial administration. Table 6.1 presents a summary of the costs, including options, together with a suggested scheduling of the project over three stages.

Table 6.1 Summary of Costs, Project Staging and Options

		Stage I	Stage II	Stage III	Options
6.1	**Hydrometric Network**				
6.1.1	Raingauge network	2,840			10,000
6.1.2	Weather radar		43,600		
6.1.3	River gauging network	133,650 (+3,500 pa)			
6.1.4	Automatic weather station	2,740			
	Sub-total 6.1	£139,230 (+£3,500 pa)	£43,600		£10,000
6.2	**Flood Forecasting and Warning System**				
6.2.1	ISIS Model Algorithm	57,160			
6.2.2	DODO Model Algorithm	3,800			
6.2.3	CRM Model Algorithm	3,800			
6.2.4	Model calibration		57,360		
6.2.5	ICA configuration		2,150		
6.2.6	New calibration software				28,680
6.2.7	RFFS software licence		10,000 (1,000 pa)		+40,000 (+5,500 pa)
6.2.8	RECS interface	10,260			
6.2.9	RFFS shell		40,000		+50,000
6.2.10	Region-wide Systems Study			25,000	
6.2.11	Project Management	6,440	6,440		
6.2.12	Training		4,920		
	Sub-total 6.2	£81,460	£120,870 (£1,000 pa)	£25,000	£118,680 (+£5,500 pa)
	Total	£220,690 (+£3,500 pa)	£164,470 (£1,000 pa)	£25,000	£128,680 (+£5,500 pa)

Grand Total £410,160 + £4,500 pa

Options total £128,680 + £5,500 pa