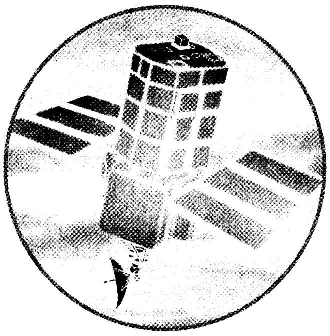
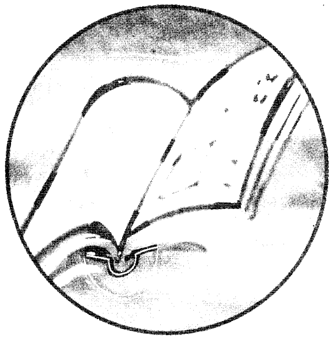
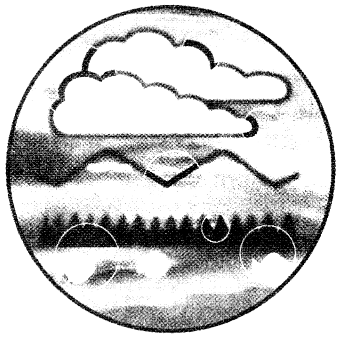
Economic Benefits of Flood Warning and Forecasting: Phase 1

July 1996 - January 1997

Research and Development

Technical Report
W53

ENVIRONMENT AGENCY

Economic Benefits of Flood Warning and Forecasting: Phase 1
July 1996 - January 1997

R&D Technical Report W53

Research Contractor:

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This R&D Technical Report contains an evaluation of methods which can be used for assessing the economic benefits of flood warning and flood forecasting. The Note also lists a series of case studies on which these methods could be tested, and a programme of work for doing so. The results of this research are intended, primarily, to give guidance to the Environment Agency on the conduct of Phase 2.

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Economic Benefits of Flood Warning and Flood Forecasting - Phase 1

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R&D Technical Report W53

FOREWORD

This report describes the work commissioned by the Environment Agency as part of its R&D programme for 1996/97. The Environment Agency's reference is R&D Contract W5C/001; Entec's reference is 32067. The research and report writing were completed by Mr Ken Taylor, Dr Pete Floyd and Mr John Ash, with assistance from Ms Meg Postle, Mr Matthew Hickman, Mr Paul Reaston, Miss Iona King and Miss Kirsty Butler. The consultants would like to extend their thanks to members of the Steering Group - Mr Peter Borrows, Mr Ian Pearse, Mr Mike Knowles, Mr Glen Watts, Miss Linda Aucott and Mr Seneka Jayasinghe - for their assistance. Thanks are also due to others in the Environment Agency who helped in providing information and assistance, namely: Mr Martin Whiting, Mr Chris Haggett, Mr Ken Barton, Mr Geoff Bayliss, Mr Roy Davey, Mr Tim Woods, Mr Peter Robinson, Mr Mick Whiley, Mr Mike Steen and Mr Richard Cross. A final thank you to Ms Jenny Lissaman and Dr Maxine Forshaw, Environment Agency R & D Coordinators, for their assistance.

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GLOSSARY

i. Abbreviations

AVM	Automatic Voice Messaging
CBA	Cost Benefit Analysis
CVM	Contingent Valuation Method
DoT	Department of Transport
the Agency	Environment Agency
Entec	Entec UK Ltd
FAS	Flood Alleviation Scheme
FFWRS	Flood Forecasting and Warning Response Systems
FTV	Flood Trauma Value
IoH	Institute of Hydrology
MAFF	Ministry of Agriculture, Fisheries and Food
MUFHRC	Middlesex University Flood Hazard Research Centre
NRA	National Rivers Authority
R&D	Research & Development
RPA	Risk & Policy Analysts Ltd
STWS	Storm Tide Warning Service
TBM	Trauma Benefit Method

ii. Definition of Terms

Benefits: The returns on the investment of a project; the gains or the avoided losses it produces.

<u>**Colour Coded Warnings**</u>

Amber Warning: Second level warning in a series of three, which indicates that flooding is likely in certain areas.

Red Warning: Highest level of warning in a series of three, and is an indication that serious flooding is probable in specified locations.

Yellow Warning: Lowest level warning in a series of three. It is a general alert or cautionary warning indicating that the catchment is in a state susceptible to flooding.

Cost-Benefit Analysis: A form of economic analysis in which losses and gains are converted into money values for comparison.

Economic Analysis: Aimed at evaluating all of the effects of a policy or project and valuing them in national resource terms. Takes place in a comparative framework.

False Warning: An occasion when a message delivered to those at risk of the likelihood of a flood event occurring is not followed by a flood, or that the person in receipt of the warning does not experience a flood.

Flood Event: An occasion when there is an overflowing or influx of water beyond its normal confines.

Flood Forecast: A prediction of the likelihood of a flood occurring.

Flood Warning: A message delivered to those at risk of the likelihood of a flood event occurring.

Intangible Benefit: Those goods and services for which there is no direct market price and an alternative method is required to assign a price.

Main River: A watercourse shown as such on a main river map. There are no statutory criteria (or non-statutory guidelines) for the designation of main rivers.

Major Incident: A catastrophic event of such seriousness that local emergency resources are deemed unlikely to be able to cope adequately, thus requiring the disaster plan to be invoked.

Tangible Benefit: Those goods and services for which a direct market price can be observed.

Unofficial Warning: An occasion where an individual who perceives himself or herself to be at risk from flooding comes to believe that a flood is imminent without a warning having been issued by public bodies such as the EA, the police or the local authority.

EXECUTIVE SUMMARY

1. Background

The Environment Agency (the Agency) has a duty to exercise general supervision over all matters relating to flood defence, including flood warning.

The Agency has set itself a target level of service of providing at least a two-hour warning of a flood event, with a long-term target of 80% accuracy of warnings given. Substantial improvements in technological support are likely to be needed if these targets are to be met in most situations.

Realising flood warning benefits requires that an accurate forecast can be made, and an effective warning issued and disseminated to the "customers". Data are drawn from a wide range of sources of varying degrees of accuracy and reliability, and used in flood forecasting models to generate a forecast showing the likely severity and time of onset of a flood. Using information on past events (empirical or theoretical) a decision is made whether or not to issue warnings, and of what level of severity. The Agency is now responsible for disseminating warnings; these go to a range of public authorities (local authority, police, etc), the media and the public (Automatic Voice Messaging (AVM) systems are now employed to speed this component). Figures 2.2 and 2.3 indicate the sequence of events which lead up to a warning being issued.

In order to realise benefits it is necessary that:

- the warning is accurate;
- the message is received and understood;
- the recipient is willing and capable of responding;
- the recipient responds effectively.

Figure 2.4 provides a diagrammatic representation of the pattern of possible responses and their effect on benefit realisation. Evidence is beginning to emerge from previous research, but also more comprehensively via the AVM reporting functions, that a high percentage of messages (c 95% in one case quoted) remain unacknowledged. Potential benefits from Agency-funded investment can also be eroded by false warnings and target recipients' reliance on unofficial warnings.

2. Objective

The Agency is required to demonstrate that the cost of defence schemes does not exceed the benefits derived therefrom. With regard to flood warning no methodologies are available to allow the benefits of flood warning to be comprehensively assessed. The purpose of this research is to review the current literature and recommend suitable techniques which could be applied to selected case studies throughout the country.

3. Results

Consequences of Flooding

Flood warning benefits are, in most cases, a secondary effect, in that that they represent a reduction in the scale of losses arising from a flood event. Therefore, there is merit in considering the nature and consequences of flooding, before considering how to assess the benefits achievable by giving a warning.

Types of Flood Event

Flooding can be divided into two types - tidal and fluvial. Heightened risk of tidal flooding can be more easily predicted because of the well understood correlation between tide levels and the gravitational forces exerted by the sun, earth and moon. However, the unpredictability of the meteorological conditions which might coincide with high tides (eg low pressure causing tidal surge, wind strength and direction which affect wave height, amplitude and direction) increase flood forecasting complexity. Some of these key variables are often not stable, and forecast accuracy can be low, particularly on the west and south coasts, where the Atlantic influence exaggerates instability.

In contrast, fluvial flooding is a direct result of rainfall or snowmelt in the river catchment. The extent, depth and timing of the flood is dependent on the intensity and duration of the rainfall, the catchment characteristics, the extent to which the ground is saturated and the land's relative porosity. Provision of accurate forecasts therefore relies on monitoring of both rainfall and river levels/flows; the former is particularly important in catchments where river levels respond rapidly to rain.

Effects of Flooding

A significant body of work has been undertaken, much of it by Middlesex University's Flood Hazard Research Centre (MUFHRC) to develop methods for the assessment of damages arising from flooding. These are described in detail in MUFHRC's "Blue, Red, and Yellow" Manuals. The losses sustained can be categorised into:

- damage to property fabric;
- damage to property contents;
- disruption to communications and infrastructure;
- damage to industry and commerce;
- effects on agriculture.

In addition to these so-called tangible effects, there are a number of other effects, collectively, if somewhat misleadingly, called intangibles, which are gaining increasing recognition and acceptance. These include effects on:

- human health (death, injuries, stress);
- the natural environment;
- recreation.

The size and nature of such damages, and the methods available to measure them, are significantly less widely and well understood than for tangible benefits.

Benefits of Flood Warning

A review of the scientific literature, mainly in the UK and USA,, has revealed a moderate amount of work aimed at assessing the tangible benefits of flood warning, but very little addressing the gains made in human and environmental terms (eg relief of stress, savings in lives) from flood warnings.

Another limitation is that the earlier research has tended to focus on benefits arising from a minimum warning of two hours, relative to no warning at all. The benefits of shorter warning lead times have not been explored to any significant degree. Therefore, a new methodology has been developed by drawing on previous work in this field where possible, and bridging shortfalls by novel combinations of, and extensions to, work from other fields. The method has been developed and tested successfully on three semi-hypothetical case studies.

In each of the case studies, tangible benefits have been calculated using standard methods described by MUFHRC and others. It is in the area of "intangibles" that new methods have evolved.

Death and Physical Injury

The Department of Transport (DoT 1996) has produced figures which purport to represent the monetary value of fatalities and injuries (the latter split into serious and slight), and these values are used in the methodology where similar impacts occur. Assumptions have been made about the frequency of type of injury by household and by flood event, in order to allow a flood damage value to be calculated. By varying the assumptions, the benefits of a warning can be reflected (i.e. by a reduction in the number of deaths and injuries).

Stress

It is proposed to develop a stress model that provides actual costings per person following (or indeed prior to) a flood event. The starting point for this model is the Social Readjustment Scale as used by Allee (1980). This scale defines stressful events in relation to other stressful events, and examples are given in Table 1.

Table 1 Examples of the Social Readjustment Scale

Life event	Mean value
Death of spouse	100
Divorce	73
Personal injury or illness	53
Marriage	50
Pregnancy	40
Death of a close friend	37
Change in responsibility at work	29
Change in living conditions	25
Change in residence	20
Change in schools	20
Change in recreation	19
Change in sleeping habits	16
Change in eating habits	15
Christmas	12

Although flooding may be responsible for some of the life events given in the table, it was hypothesised that flooding as a life event itself would rank about 25 on the scale. This does not mean that actually being flooded would be the same as a 'change in living conditions', but the relative impact upon an individual's life would be similar.

The next stage in the analysis is to calculate a flood trauma value (FTV) on a scale from 0 to 100, where 0 reflects 'no trauma' and 100 'maximum trauma'. It is this value which forms the basis for assigning an economic value to stress. The FTV is composed of four elements:

a demographic factor;
an urgency factor;
a panic factor; and
a 'hassle' (or nuisance/inconvenience) factor.

The sum of the four factors has a maximum value of 100. Within each factor group there is a maximum value, reflecting its relative importance in the analysis. The four factors can therefore move within a range of 0 to their maximum value. These are summarised in Table 2.

The demographic factor is considered the most important variable (and given twice the weight as the other factor groups) and is determined by the area flooded, i.e. it is constant throughout the analysis for a given area. The sub-components are placed on a sliding scale reflecting their weighting and importance for the particular area under consideration. When summed, the resultant figure out of a maximum score of 40 reflects the area's potential ability to minimise damages. Therefore, a score of 0 would indicate a high ability to cope and a score of 40 would indicate a very low ability to cope.

Urgency factors reflect the level of urgency prior to a flood event (such as when a warning is given) or during and after a flood event. The urgency factor is considered the rational reaction (as opposed to panic, see below) of a flood victim to the flooding event. The factor is further sub-divided into three areas, initial preparedness, "knowing what to do" and time left to flooding incident. Once summed, these give an urgency factor with a maximum score of 20, where 0 shows no level of urgency and 20 an extreme level of urgency.

Table 2 Summary of the Components of the Flood Trauma Value (FTV)

Component	Range	Maximum Total
Demographic	**(0 - 40)**	
- population reactivity	0 - 20	
- nature of housing	0 - 12	
- car ownership	0 - 8	**40**
Urgency	**(0 - 20)**	
- initial preparedness	0 - 5	
- "knowing what to do"	0 - 5	
- time left to flooding incident	0 - 10	**20**
Panic	**(0 - 20)**	
- reaction	0 - 3	
- severity of flood	0 - 7	
- level of preparedness	0 - 3	
- previous flood experience	0 - 7	**20**
Hassle	**(0 - 20)**	
- forced evacuation	0 - 6	
- length of time out of homes	0 - 6	
- lack of basic living necessities	0 - 4	
- extent of clean-up and problems associated with it	0 - 2	
- work missed	0 - 2	**20**
Total (Flood Trauma Value)	**0 - 100**	**100**

The panic factor highlights a totally irrational response to either a flooding event or the warning of a flooding event. The sub-components of this factor when summed give a panic factor with a maximum value of 20. A score of 0 would show no panic, while a score of 20 shows extreme panic.

The hassle factor reflects the level of inconvenience or nuisance that a flood warning/event can cause. The source for such a factor has its roots in Allee (op. cit.). It is dependent upon the severity of a particular flood event, and this value is therefore constant throughout an event. The sum of the sub-components have a maximum score of 20. A score of 0 shows that no hassle is attributable to the event (or a warning) and a score of 20 shows maximum hassle is attributed to an event/warning.

The next stage is to attribute a monetary value to the FTV. From Department of Transport figures, it is possible to determine average injury costs per person. Averaging the human costs (reflecting pain, grief and suffering) of a slight and serious injury gives a money value of £46,615. This is a cost per accident and requires a conversion into per person costs, considering that, on average there are 1.23 casualties per accident. This gives an average injury cost per person, when rounded, of £38,000.

To combine this value with the social readjustment scale, it is assumed that this figure is equal to a mean value of 53 ('personal injury or illness' in Table 2). Given that it is also assumed that a mean level of 25 is attributed to flooding, the maximum value, in monetary terms, of the FTV is calculated as 25/53 x £38,000, i.e. the maximum value of FTV (100) is equal to £18,000 per person. The value for a particular flood event is then a percentage reduction of this figure.

Decision Analysis

The final part of the analysis is to calculate the benefits for different levels of flood warning to annualised figures which takes into account the range of expected flood events, the reliability of forecasting and the adequacy of the dissemination of the flood warning and effectiveness of the response by individuals. This is proposed by the use of an event tree which would be the subject of detailed examination in the Phase 2 study in order to explore the significance of particular components in the chain from the occurrence of initial conditions through to flood forecast, the issue of flood warnings and the response to the warnings. An example of the generic event tree is shown in Figure 1.

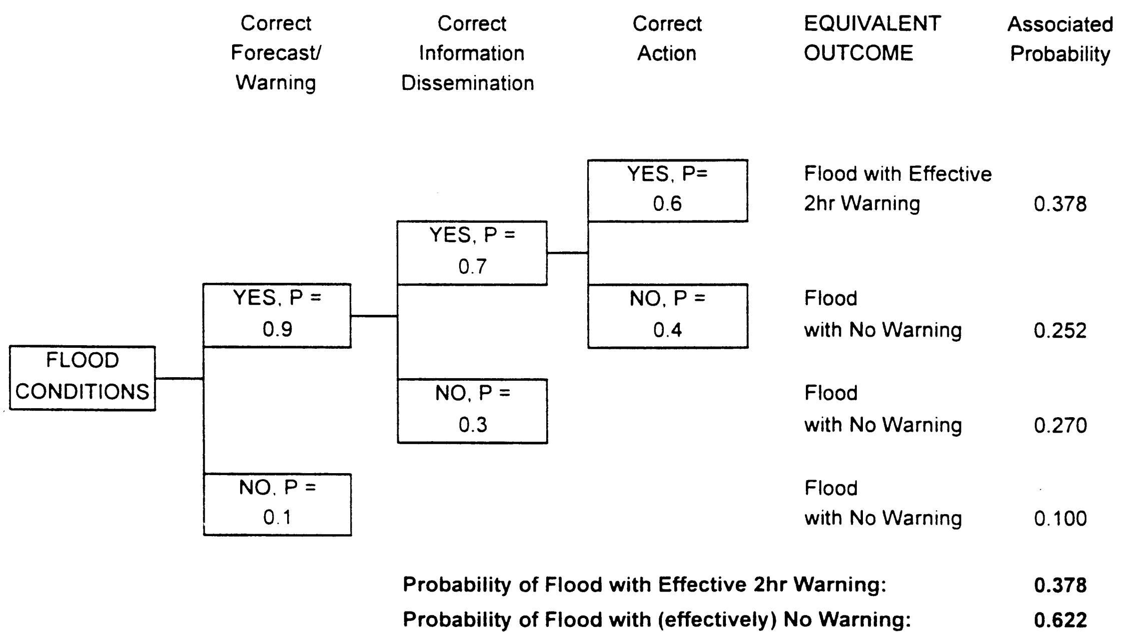


Figure 1 Event Tree for a 2 hour Warning

From the assumptions underlying Figure 1, some of the benefits of the two hour warning are lost due to failures in forecasting, inadequate dissemination of information and, perhaps, most importantly, in failing to respond. Based on the event tree, it can be seen that there is an estimated 38% chance of success in achieving a two hour warning (i.e. in 62% of the cases, the losses would be effectively the same as for a flood with no warning).

The decision analysis, together with the annualised costs of different scenarios for flood warning can then be used to explore the cost effectiveness of improving any of the components within the process from forecast to avertive action taken, and hence maximise the effectiveness and resources available.

4. Conclusions and Recommendations for Phase 2

Given the novel nature of the methodology described above, wider consultation is believed to be necessary before progressing to Phase 2. Assuming the methodology is found to be worthy of further development, Phase 2 of the research programme should be used for this purpose. Potential case study areas, one from each Agency Region, have been identified, which collectively represent a wide range of flood forecasting/warning situations. Recommendations of what scenarios could usefully be assessed using the new method have been put forward.

Conduct of the case studies should result in the acceptance of a new technique, or array of techniques, for assessing flood warning benefits (including short lead time and intangible benefits) and set(s) of standard data which can be used by flood defence engineers in future scheme appraisals. It may be appropriate to present both these elements in a manual, similar to those produced by MUFHRC.

5. Keywords

Flood Warning; Flood Forecasting; Economic Benefits; Stress Measurement; Decision Analysis.

1. INTRODUCTION

1.1 Contract Details

The Environment Agency (the Agency) supports a programme of Research and Development (R&D), the results of which are intended to assist the Agency in the fulfilment of its duties and responsibilities. In July 1996, the Agency awarded a contract to Entec UK Ltd (Entec), working in association with Risk & Policy Analysts Ltd (RPA), entitled Economic Benefit of Flood Warning and Flood Forecasting : Phase 1.

This project is the first phase of a two phase project and will *inter alia* set out recommendations for how the second phase should be undertaken. The project is intended to run from 1st August 1996 to 31st January 1997. A progress report was submitted in September 1996. In the Agency's hierarchy of reporting, this is a draft R&D Technical Report which presents the results of the research undertaken. Consequently, it is intended to focus on the key findings, conclusions and recommendations. The final report will be accompanied by an R&D Project Record; this will contain more detailed information.

Section 6 - Programme for Phase 2 - has been prepared as something of a "stand alone" document which can be used as a basis for the project specification for Phase 2.

1.2 Objectives

The Agency's responsibilities in relation to flood warning and flood forecasting are discussed in Section 2.3 below. In meeting its obligations, the Agency is able to install and operate Flood Forecasting and Warning Response Systems (FFWRS). The capital cost of setting up such systems can be offset by grant support from the Ministry of Agriculture, Fisheries and Food (MAFF) and Welsh Office Agriculture Department (WOAD). In order to qualify for grant support, and also in order to meet the general requirement for financial prudence within the Agency, it needs to be demonstrated that the benefits of the FFWRS exceed its cost. This is usually demonstrated using Cost Benefit Analysis (CBA).

MAFF rate the provision of FFWRS as top priority in their strategy for flood defence (MAFF 1993). CBA requires that the costs of providing such services have to be justified in a rigorous manner. However, techniques for calculating the benefits of FFWRS are not well developed. It is in this context that the research is being undertaken.

The objectives of the research are therefore:

1. To evaluate the tangible and intangible benefits associated with the provision of a flood forecasting and warning service in order to make sound decisions

when consideration is given to enhancing the service (applies to Phase 1 and Phase 2).

2. To confirm the approach and establish the methodology to be used in order to evaluate certain case studies involving flood warning (Phase 1 only).

The main objective has been to look at benefits arising from improved (either in accuracy or timeliness) warnings at site specific level. However, it should be noted that the results may be applicable for incremental improvements in data gathering or monitoring networks outwith the actual area likely to realise benefits.

The Project specification is included in the Project Record. It has been assumed that the research should only focus on benefits arising from flood forecasting and warning. However, other benefits might arise from, for example, using flow models to predict pollution dispersal or water resource availability; these potential benefits have not been considered.

Another important factor in exploiting flood warnings to realise economic benefits is the civic response (i.e. by the local authority). However, consideration of their roles and responsibilities was considered outside the scope of this research.

1.3 Methodology

The methodology for conducting the research was, in outline, as follows:

- an initial meeting of the Steering Group to clarify the methodology to be used;
- search of the academic literature, focusing on the UK and USA, and appraisal of the research identified;
- identification of benefit assessment frameworks;
- discussions with Anglian Region, Eastern Area flood operations staff to identify current flood forecasting and warning procedures;
- preliminary contact with representatives of each Region to identify a long list of potential case studies;
- a second project meeting to discuss progress;
- a series of mini-case studies were completed as a preliminary test of methods;
- a series of visits to Regions to discuss specific regional variances and widen coverage of ideas and research; and
- report preparation.

Details of the methods used, sources of data and results, will be included in the Project Record.

2. OVERVIEW OF FLOOD FORECASTING AND FLOOD WARNING IN ENGLAND AND WALES

2.1 Introduction

The purpose of this section is to set the context within which FFWRS operate in England and Wales. It is not intended to be definitive. It is included as an aid to understanding the chain of events which link forecasting to dissemination of a warning, and the responsibilities for its functioning. For a more detailed review of general legislation relating to flood defence, the reader is referred to Institution of Civil Engineers 1996 (ICE 1996).

2.2 Legal and Institutional Infrastructure

2.2.1 Relevant Legislation

Recent legislation of relevance to flood forecasting and warning includes:

1. **Environment Act 1995** - This Act provides for the setting up of the Environment Agency, and the transference of powers and duties from its predecessors, including the National Rivers Authority (NRA). The Act places a duty on the Agency to further conservation and enhance natural beauty. Section 39 places a general duty on the Agency to take into account the likely costs and benefits in exercising its powers where reasonable to do so.

2. **Water Resources Act 1991** - Definitions are given of the meaning of "flood defence", namely as "the drainage of land and the provision of flood warning systems". The Act extends the range of projects for which MAFF grant aid can be paid.

3. **Water Act 1989** - This Act provided for the establishment of the NRA and the transference of certain duties and powers previously vested in the Regional Water Authorities.

A series of Land Drainage Acts (1930, 1976, 1991 and 1994) have defined the extent of the responsibility of land drainage authorities. The 1976 Land Drainage Act (Section 32) give the regional water authorities powers in respect of flood warning systems. These powers enable the competent authority (now the Agency) to:

- provide and operate flood warning systems;
- provide, install and maintain apparatus required for the purposes of such systems; and
- carry out any other engineering or building operations so required.

As with flood defence, the powers are permissive in nature, as opposed to duties. However, both regulatory legislation and common law of negligence lay stress upon the obligation of organisations to establish and maintain safe systems in the conduct of their operations. Such organisations can be made liable both for failures in respect of any system they have adopted and failures of individual employees in carrying out what would otherwise have been a good system (Parker *et al* 1992a).

It should be noted, however, that little of this complex body of legislation has been tested in the courts.

2.2.2 Responsibilities

Responsibilities in relation to flood defence and flood warnings are discussed here only insofar as they apply to the Agency. A more detailed discussion of the current responsibilities of other organisations with interests in flood defence is given in ICE 1996.

The Agency has a duty to exercise a general supervision over all matters relating to flood defence (S.6(4) Environment Act 1995). Within its own corporate strategy documents, its declared aims include:

- to provide effective defence for people and property against flooding from rivers and the sea; and
- to provide adequate arrangements for flood forecasting, warning and responding to flood events (NRA 1996).

The main focus of the Agency's activities (and its predecessors) has been main rivers, and coastal defences over which it has responsibility.

Its responsibilities in relation to flooding from:

- sewers
- burst water pipes
- surcharging storm overflows
- non-main rivers
- dam bursts

are in some cases, less clearly defined. However, it is pertinent to note that a FFWRS designed to provide warnings in main rivers could, in many cases, be used to provide forecasts and warnings, by simple extension, to areas threatened by non-main rivers, for example. Consequently, additional benefits might accrue. Nevertheless, it is assumed that the Agency does not seek to provide flood forecasting and flood warning services for any of the circumstances listed above.

Until 1st September 1996, the Agency's role in flood forecasting and warning was, by general agreement amongst the interested authorities and by established practice, one of monitoring conditions, forecasting when the risk of flooding was high and issuing warnings to the police and local authorities. Wider dissemination of the warnings was undertaken in some Agency Regions and Areas but in general this was accepted as being a responsibility primarily of the police.

Since 1st September 1996, under a Ministerial directive the Agency has assumed the responsibility of dissemination of warnings to the general public. One exception to this is in Norfolk, where the public disseminating role is retained by the police. In response to these changing roles, the Agency has embarked on a leafleting campaign in areas at risk to raise people's awareness. It has also started a programme to develop Flood Warning Dissemination Plans for each Police Force Area within England and Wales. A plan developed in North Wales (Bullen Consultants 1996) is being used as a "model".

The Agency do not assume responsibility for people's action (or indeed inaction) upon receipt of a warning: the emphasis is on awareness and self-help.

Responsibilities for warning dissemination in the event of a "major incident" or a "peace time disaster" appear to be unclear. In such circumstances, the police are obliged to assume the lead role in coordinating resource deployment. However, it is reported that uncertainty exists over the effectiveness of warnings on the scale likely to be required, and by what means.

2.2.3 Target Levels of Service

In the context of providing a flood warning service to the general public (as opposed to other public sector organisations such as the police or the local authority) levels of service are typically defined in terms of warning lead time. This is the time between issuing of the warning and actual or expected onset of the flood. A distinction needs to be made here between the forecasted lead time (i.e. "flooding is expected to occur in x hours") and actual lead time (i.e. the time between issuing a warning and actual onset of the flood).

There is no legal requirement upon the Agency to achieve a specific lead time for warnings: therefore, any such targets are self-imposed. Nationally assumed targets are for a minimum of two hours lead time, with a longer period where possible in urbanised areas.

There appears, however, to be some divergence amongst Regions on how to apply the flood warning service where this lead time cannot be achieved. Two distinct practices appear to have evolved:

1. provide as early a warning as possible, even if less than two hours;
2. only offer to provide a service where the two hours lead time can be achieved.

Similarly, views differ on whether to issue warnings which are more than say 8 hours ahead of the expected onset of the event. Some Regions will issue general warnings via the media, but specific warnings to property-holders would only be issued closer to the event's expected onset.

Targets have also been defined in terms of warning accuracy. These define a long-term target of 80% of warnings issued to the public to be accurate.

There are several observations which are pertinent to make about such an approach to target setting:

1. The quantified targets (eg minimum of two hours) are essentially arbitrary. A two-hour warning is clearly better than only a five-minute warning, but is it "right" in an absolute sense? However, the warning does have some absolute grounding in that two hours appears to be a period sufficiently long for benefits to be accrued, and yet at the lower limits of what is technically feasible in many cases.

2. Setting such targets and publicising them to the public may be appropriate in public relations terms. However, it could lead to conflict with the over-arching demands of CBA - if the costs of providing such a service exceed the benefits to be derived, what course of action should be followed?

3. Once a flood warning service has been put in place, it may be difficult (on grounds of liability) to subsequently withdraw the service if, for whatever reason, such a move is contemplated.

It can be concluded from the above discussion that applying such a levels of service approach is not straightforward in practice.

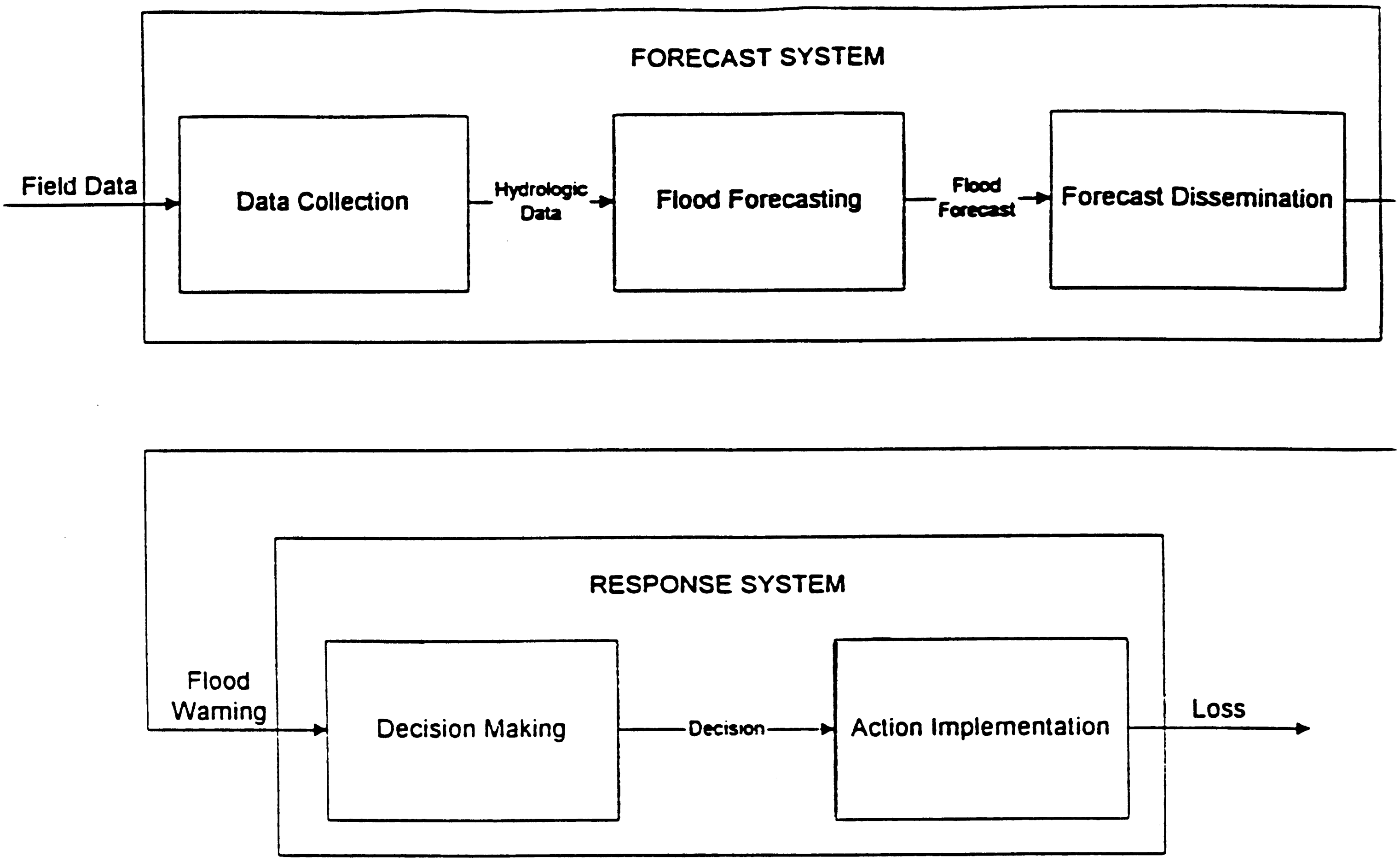
2.3 Operation of the Forecasting and Warning System

2.3.1 Introduction

Realising economic benefits from a flood warning depends on a sequence of activities being completed successfully. This sequence falls into two distinct parts - as described by Krzysztofowicz et al (1983c) - see Figure 2.1. Operation of these two systems in England and Wales is discussed briefly below.

2.3.2 Forecast System

This part of the Forecast-Response system is seen as that which falls within the Agency's direct control, starting with the collection of data and leading to the issuing of a warning. The forecast system has been represented diagrammatically in Figures 2.2 (for fluvial) and 2.3 (for tidal).



The model assumes that the decision maker begins to respond when they are sufficiently sure that a flood will reach their property. Their degree of certainty that this will happen is represented by a subjective probability, the value of which depends on their past experience with floods and losses and on the warning they receive.

Following a flood event, the decision maker learns from that experience and revise their subjective probability of a flood and loss toward an objective (historical) value, to an extent dependent on 'willingness to learn'.

Source: Krzysztofowicz (1983) - Ref 6

Figure 2.1 Flood Forecast-Response System

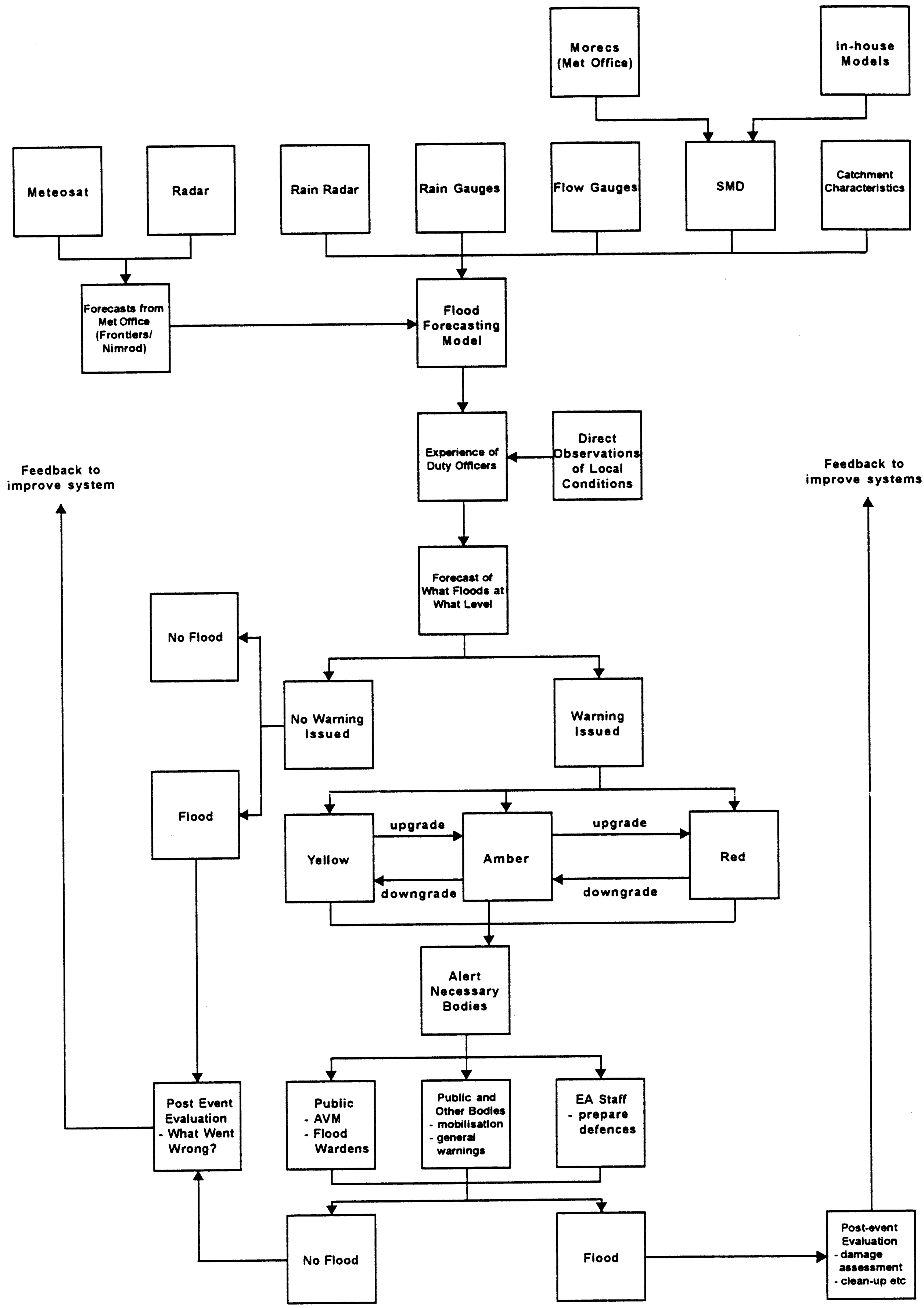


Figure 2.2 Fluvial Flood Forecasting Model

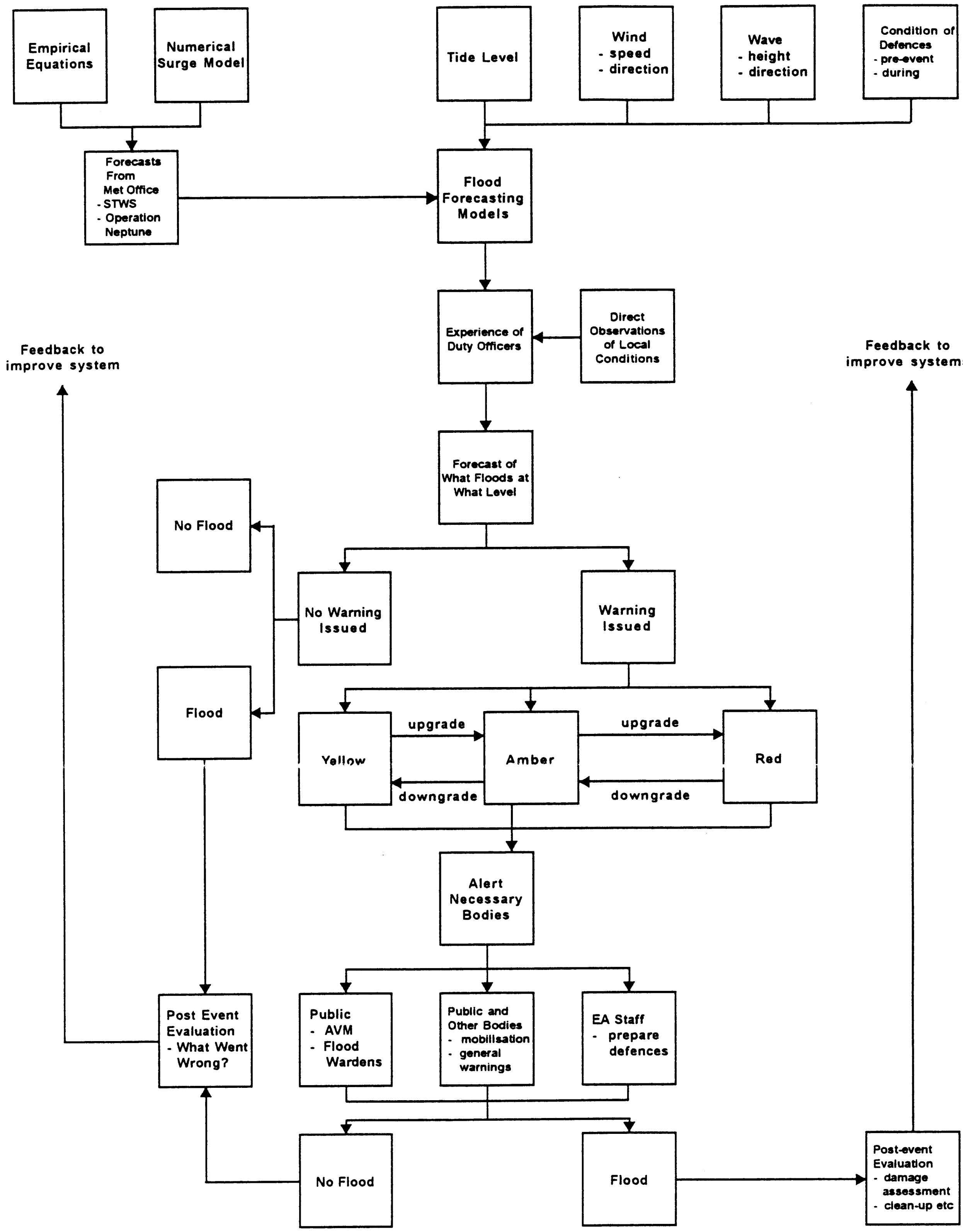


Figure 2.3 Tidal Flood Forecasting Model

Variations exist between regions in:

- the sources of data employed;
- priority given to different sources;
- type and sophistication of models used to generate forecasts;
- means of warning dissemination used; and
- extent of post-event evaluation carried out and feedback mechanisms used.

Despite these differences, the general structure described in the two figures appears robust.

During the course of the regional survey, interviewees were questioned about the various components of the two models, their confidence in the data derived and the overall accuracy of the forecasts. Notes of these meetings are included in the Project Record. However, the key points are consolidated and summarised below:

(a) Fluvial

- Met Office forecasts are generally accurate and a high level of confidence is attributed to them. However, accuracy of forecasts is better with frontal systems, qualitative forecasting and when expected to be dry.

- Rain/Weather Radar is considered to be accurate in qualitative terms (ie it shows clearly where and when rain is falling) but is poor in quantitative terms (ie in predicting how much rain is falling).

- Rain and Flow Gauges are, on the whole, sufficiently accurate except where flow gauges are by-passed at high flows or there is mechanical failure. Obviously, such high quality data can only be provided where gauges exist.

- The perceived importance of Soil Moisture Deficit varies across the Regions, and the Met. Office MORECS data are accepted as being sufficiently accurate for run-off modelling purposes.

- Knowledge of catchment characteristics, and the extent to which forecasting models take them into account, is highly variable within Regions, and tends to reflect the importance of the areas at risk within the catchment.

- Flood forecasting models typically rely on rainfall run-off functions to provide flow data which can be translated into levels.

- All Regions allow the local knowledge of flood duty officers to modify or interpret the forecasts, although the extent of their influence varies.

- Direct observations of local conditions is seen as a valuable adjunct to the model forecasts, but gathering of this information is not done systematically.

- Accuracy of forecasts in terms of occurrence of an event (ie that a flood will occur) is generally high (i.e. forecasts that a flood event will occur are correct in about 90% of cases) and are perceived as such by the public bodies directly involved. Forecasts to individual members of the public (ie that their property will be affected) are not as high (i.e. fewer than half the warnings issued to specific individual members of the public proved to be accurate).

- The flexibility of upgrading or downgrading warnings means that, in the large majority of cases, the correct colour code warning is given.

(b) Tidal

- It is more difficult to be accurate with tidal warnings than fluvial, particularly on the south and west coasts of Britain, because of the changeable nature of wind speed and direction (the Atlantic influence).

- It is difficult to forecast the exact direction and height of waves, and thus to make accurate predictions of the risk of overtopping.

- The Agency generally only monitors the condition of its own defences during periods of high risk.

In most Regions, the data used to make the forecast are processed centrally, but the decision to issue a warning is made locally (by the Area staff). In some cases the warnings are issued to flood wardens, who then relay the message to the public; in others the message is conveyed direct, using an Automatic Voice Messaging (AVM) system. Not all Regions use all the colour coding system in all cases, reflecting differences in historical flood warning classification systems and dissemination methods.

2.3.3 Response System

Delivery of a flood warning can result in the realisation of positive, negative or no benefits depending on the reaction to the warning. Figure 2.4 provides a diagrammatic representation of the range of reactions available and their influence on the nature of the benefits thus realised. The model assumes that a flood does actually occur.

A more complete discussion of the positive benefits is provided in Section 4 below. However, it is pertinent to consider here, in general terms, the responses envisaged.

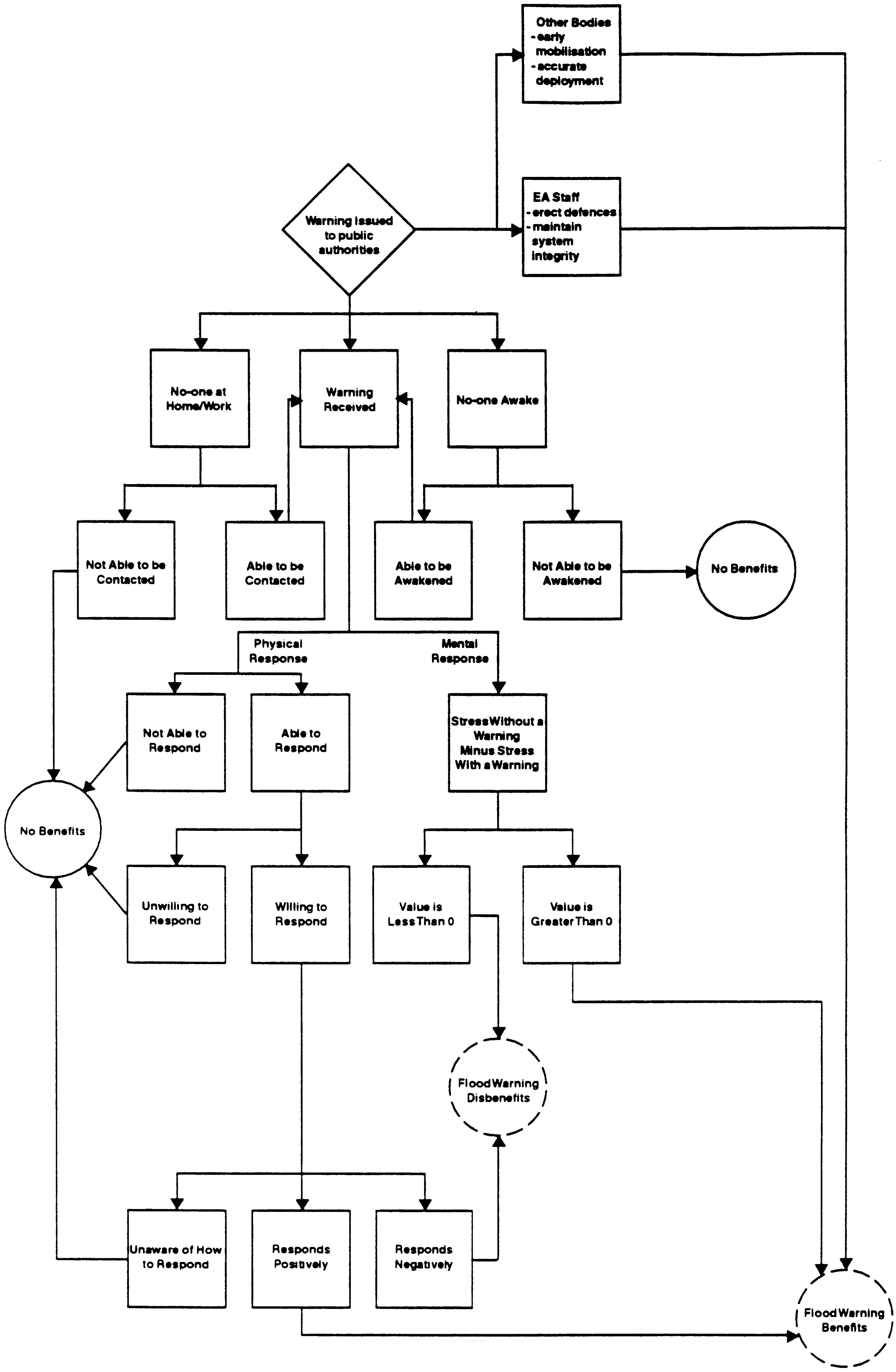


Figure 2.4 Response System and Benefit Realisation

An alert issued to operational staff within the Agency will allow them to activate certain types of flood defence schemes such as raising the Thames Barrier, closing flood gates or flooding washlands. Efforts can be made towards maintaining system integrity, for example ensuring culverts remain clear and monitoring the condition of flood embankments. Such activities if successfully completed, can realise benefits without requiring action from the public.

Warnings issued to other bodies may enable them to mobilise staff and equipment and help to ensure they are deployed where and when needed. Given sufficient time, staff from these organisations can reach the areas at risk and exert an influence on the potential flood victims which can increase the effectiveness of their response. This source of possible benefits reduces with lead time.

Research has shown (eg Hyde 1992) that in the past a high proportion of warnings are not received, although data are limited. The success rate may have changed radically since the Agency has taken over responsibility for warning the public direct. The AVM system now in use will allow much closer monitoring of performance. During the course of the regional survey, some performance data were obtained and are offered by way of an example. In the Agency's Southern Region, on 28th October 1996, the AVM system issued 260 warnings. Of these approximately:

- 5% were answered and acknowledged;
- 90% were answered but were not acknowledged; and
- 5% were not answered.

The 90% category comprises those:

- messages received onto an answerphone;
- received by individuals who do not possess a touch button telephone; and
- who received the message and failed to acknowledge (either because they did not understand the messages, did not know how to acknowledge or chose not to acknowledge).

If subsequent attempts at delivering a message are successful, benefits may still be realised, but the lead time is effectively reduced; otherwise, no benefits are realised.

Receipt of a warning will probably induce stress in the recipient. If the warning is accurate (ie a flood occurs) it is likely that the overall level of stress suffered will be less than if no warning is received at all. However, if the warning proves to be false, then any unnecessary stress caused may represent a disbenefit.

Realising economic benefits by way of a physical response to the warning is dependent on the recipient being:

- able to respond (ie not physically incapacitated);
- willing to respond (prepared to help him or herself); and
- aware of how to respond effectively and positively (Heijne et al, 1996).

Disturbingly, some Agency staff have reported a growing tendency for recipients to expect the authorities to provide the necessary input to effect a response. In some cases, the recipient's response has been to wilfully increase the extent of flood damage so that the subsequent insurance claim can be extended to belongings considered to be in need of replacement. In such circumstances, disbenefits will accrue. However, in the models used in Section 4 it has been assumed that all people act in good faith.

A number of other factors may need to be considered as part of the response system:

1. As noted above, if the warnings prove to be false, there are no opportunities for realising positive benefits.

2. The extent of the benefits derived from a warning issued by the Agency may be diluted by "unofficial warnings".

3. Flood Warning Benefits (tangible and intangible) may arise from positive management of the inundation of water meadows (referred to as warping in some parts of the country). These include increased fertility of the flooded land and duck shooting over the inundated areas.

4. There may be a potential to realise nature conservation benefits in areas managed mainly for that purpose as a result of a flood warning. However, these are likely to be limited because:

    - a flood is a natural event and ecosystems have evolved to survive such events; and
    - there is little man can do to intervene on behalf of nature conservation interests (the environment obviously cannot be packed up and taken upstairs!).

    Some nature conservation could be achieved through direction of flood waters to areas which would benefit from inundation and away from areas in which damage would be sustained (Neath 1996).

3. CONSEQUENCES OF FLOODING

3.1 Types of Flood Event

3.1.1 Introduction

The description of types of floods and their effects included in this section is provided in order to both set the context in which flood warnings will need to operate and to highlight the difference between the damages caused by flooding and the potential to reduce those damages by making forecasts and issuing warnings.

3.1.2 Tidal Flooding

Flooding caused by sea water can affect both low lying areas adjacent to the open coast and those within an estuary. The scale of the flooding will be dependent on a number of contributory factors of which the peak height of the tide level, the degree and direction of wave action and the duration of the event are the most significant.

Tidal Height

The levels to which a normal tide rises and falls vary in accordance with the gravitational forces between the earth, moon and sun and their centrifugal forces. The difference between high and low water, known as the tidal range, and the height to which the tide reaches also vary around the coast. However, due to the interactive forces following well understood scientific principles, it is possible to predict with some accuracy the height and time of all normal tides. These are published as tide tables by the Admiralty. Tides, including Spring tides, the highest predicted normal tides which occur twice a month, can therefore be forecast well in advance. Normal tides and the use of tide tables are well understood by those whose employment or leisure interest is in some way linked to the sea and is dependent on an understanding of the tide height changes. For example, the inhabitants of Holy Island off the coast of Northumberland have to allow for the tide when planning to cross the causeway from the mainland which is only passable at low tide.

The nature of normal tides is such that any activities carried out adjacent to the coast, e.g. agriculture or development, will not be within those areas subject to this type of regular flooding. They will be located either above this level or behind a defence and therefore given some degree of protection. However, the one area of uncertainty is the effect that global warming may have on the height of the tide in the future. This aspect of tidal height is considered outside the scope of this project.

Tidal Surges

The weather can also have an effect on the level that the sea can reach. Barometric pressure has the effect of raising or lowering mean sea level depending on the presence of low or high pressure systems. In addition, wind acting on the surface of the sea can lead to a building-up of water that again raises the level of the sea. The effects of the winds and pressure on sea level can be predicted, but only on a relatively short timescale and with varying degrees of accuracy. These predictions are carried out by the Meteorological Office's Storm Tide Warning Service (STWS) using weather forecast data to specifically forecast the time and level of tides around the coast of Britain. However, the timeliness and accuracy of these forecasts vary from West to East Coast with the more accurate predictions being made for the East Coast owing partly to the enclosed nature of the North Sea. This predicted height of the tide above the normal prediction is known as the Residual and the STWS does give a 36 hour prediction in addition to the 12 hour and 6 hour specific tidal alerts. The accuracy of the prediction depends on the initial forecast. If the weather pattern changes either more slowly or quickly than anticipated, then this can have an effect not only on the predicted height but also on the time the tide will peak at any specific location.

Wave Action

The other component that has to be taken into account in forecasting the severity of the tidal event is wave action. The two components of wave height and direction will have a direct effect on the coastline. Wave energy is dissipated as the wave breaks, with the capability to cause damage to natural defences such as beaches or sand dunes, or man-made defences such as sea walls. The prediction and forecasting of the scale of wave energy at the land/sea interface is not as well understood as tidal forecasting. This is partly due to changes in energy and direction as waves enter the shallower coastal zone.

Scale of Tidal Flood

The severity of the tidal flood is therefore the result of a number of contributory factors. If for instance a large tidal surge is coincident with a spring tide and the wind direction is on-shore with high wave energy, then undefended areas will be inundated and defences put at risk. Defences may also be overtopped and/or breached if the magnitude of the tidal event is greater than the design standard of the defence. The duration of the tidal event is also a factor in that a surge that is sustained for many hours together with significant wave action will severely test defences. If the defence is overtopped or breached it will give rise to larger areas being flooded and to greater depths by the physical amount of water that can be moved in the longer timescale. While it is possible with varying degrees of accuracy to predict the height of the tide and wave action, the degree to which any area will be flooded will be more difficult to estimate due to the uncertainties of the nature of breaching and/or overtopping of the defences, the physical characteristics of the flooded area and the potential duration of high water.

Estuaries

The forecasting of tidal levels within estuaries and tidal rivers is not as well advanced as that for the open coast and the effects of river flows also has to be taken into account. There is therefore greater uncertainty relating to the effects of tidal events and also the severity of flooding should defences be overtopped or breached, or undefended areas flooded. However, the longer timescale for high water to progress up an estuary may be of some benefit in giving timely warnings.

3.1.3 Fluvial Flooding

Flooding from rivers, fluvial flooding, is associated with the inundation of those areas bounding the river that are at a lower level than the level of the river in flood, or where defences protecting adjacent low-lying land have been overtopped and/or breached by the floodwater. The cause of flooding will be as a direct result of rainfall or snowmelt on the river catchment. The extent, depth and timing of flooding is dependent on the intensity and duration of rainfall, the catchment characteristics, (i.e. steepness), the extent to which the ground is saturated (soil moisture deficit) and the relative porosity of the land. e.g. large impervious areas will give shorter times for the flood to peak.

Rainfall

The measurement of rainfall is through the use of rain gauges linked to a telemetry system to give quantity and intensity. This is supplemented by the use of operational radar which allows for the areal distribution and movement of the rain to be observed and measured. This is particularly useful for flood warning as it can increase the lead time for the warning without having to wait for the rain to have fallen. There are drawbacks with the use of radar related to the accuracy with which rainfall can be predicted, but it is extremely useful in showing relative intensities, the movement of rain and the end of the rainfall event.

Snowmelt

Measurement of the amount of runoff due to snow melting is important as a significant proportion of upland winter precipitation falls as snow and in some years lowland catchments can also be seriously affected. Some of the most damaging historic fluvial flood events have had a snowmelt component, e.g. the 1947 floods which severely affected the River Trent, Cambridgeshire Ouse and Yorkshire Ouse. The information required is the volume and timing of the meltwater from the snow pack giving a catchment equivalent to rainfall. Such measurement has proved to be operationally difficult and subject to large errors.

Catchment Characteristics

The catchment characteristics will have an impact on the lead time available to give a warning and also on the duration of the flood once it has occurred. A steep catchment will give a shorter time to flooding from a given rainfall event than a flat catchment. This is especially evident in flood forecasting on the low lying rivers of East Anglia where 24 to 36 hours from rainfall event to flood peak at the tidal limit is not unusual. The saturation of the ground will have an effect on the time for the flood to peak in addition to the scale of the flood. A saturated catchment will not absorb any rainfall giving a faster and greater runoff than if the catchment were drier. This is also the case with a frozen catchment.

For many catchments, flood forecasting models have been developed which use catchment characteristics to give forecasts of flows, levels and times based on rainfall information and measured flows, or a combination of both. The more accurate models will be those for which there are historical flood data over a long period for model calibration.

Scale of Fluvial Flood

The depth and time for which any area is flooded is primarily dependent on the amount of precipitation either as rainfall or snowmelt. The intensity and duration will also be contributory factors and the physical characteristics of the catchment will dictate the area flooded. Many lowland rivers have well defined flood plains which are inundated on a regular basis with minimal harmful effect. Where development has taken place either for housing, industry or agriculture, defences may have been constructed to standards dictated by land use and economics to reduce flooding. There are, however, urban areas with no flood defences where flooding occurs regularly and the areas at risk increase with the severity of the event.

3.1.4 Breaching and Failure of Defences

The forecasting of floods, by salt water from the sea or fresh water from rivers can be implemented with varying degrees of accuracy depending on the various factors as mentioned above. The warning or forecasting of a failure of a defence, which can also lead to flooding, is much less reliable.

All defences are constructed to finite parameters with the standard of defence described in terms of the severity of event it has been designed to withstand, e.g. a 1 in 100 year event. This can be in terms of still water level, a predetermined wave action or a combination of the two. There is always the probability that the defence will fail as the design criteria are reached or exceeded. The prediction of failure will rest with those who have a detailed knowledge of the construction and condition of the defence and its likely performance given the forecast flood conditions. A breach can occur suddenly with little or no warning.

If the design standard of the defence is exceeded, water will overtop the defence leading to flooding. The effects of overtopping can be calculated with a knowledge of the relative heights of the top of the defence, the flood water level and the duration of the event. Thus, knowing the geography, the volume of water can be translated into the area and depth flooded. There is also the possibility that continued overtopping of a soft defence will eventually give rise to a breach as material is washed out from the back of the bank. This will again depend on the severity and duration of the event, and the construction and condition of the defence.

3.2 Tangible Effects

3.2.1 Introduction

The preceding section has explained, in some detail, the types and causes of flood events and those factors that are applicable to flood warnings as opposed to flood defence. This distinction is important as the objective of the project is the identification of benefits that will arise from FFWRS and the methodologies that can be used to assess them. The benefits are therefore the reduction in disbenefits as the result of a warning being received and, as in the case of flood defence schemes, can be tangible or intangible.

The techniques for assessing the tangible damages (ie disbenefits) of flooding are well researched. Three manuals (Penning-Rowsell et al 1977, Parker et al 1983, Penning-Rowsell et al, 1994) have been written by Middlesex University's Flood Hazard Research Centre (MUFHRC) which deal with the evaluation of damage caused by a flood event. The methodologies are in accordance with Government guidelines in that the costs of damage are evaluated in terms of national loss.

The assessment of tangible effects can be subdivided into direct and indirect effects. Direct effects are those relating to restoration to the condition preceding the flood. Indirect effects are those occurring as a consequence of the flooding such as disruption to traffic, loss of industrial production, etc. In quantifying the effects and costs of damage and comparing them with the reduced damage costs resulting from the construction of a physical defence to exclude or reduce flooding, a 'benefit' can be calculated from carrying out the flood defence works.

Assessing the difference to tangible losses made by flood warning can, to a large extent, use similar methods; however, the benefit is only accrued if certain actions are taken to reduce the effect of flooding (which is usually the relocation of moveable objects to a position of safety and minor works to reduce the severity of the flooding to one's property). Time to be able to respond effectively is, therefore, an important consideration. Typical tangible effects of flooding are discussed below, although it should be noted that for specific flood warning schemes a full assessment based on the specific location in conjunction with the standard data in the Middlesex Manuals (Blue, Red and Yellow), would be carried out.

3.2.2 Damage to Property Fabric

The effects of flood water on the fabric of a property include:

- damage to the fabric of the main building and outbuildings;
- electric light and power fittings (but not appliances);
- plumbing and heating installations; and
- boundary walls, gates and fences.

The type and construction of the property is a major factor in the assessment of the effects, as is the depth and duration of the flooding and, to some extent, the velocity. The effects of salt water are much more severe than 'fresh' water and this is reflected in the standard data in the 'Yellow Manual' for coastal flooding. The costs assigned to the tangible effects of the fabric are those to restore it to its pre-flood condition and include cleaning-up costs.

3.2.3 Damage to Property Contents

Damage to the contents of the property, refers to those items that can be moved and include:

- domestic appliances, heating equipment and electrical appliances;
- furniture and soft furnishings; and
- personal effects including books, clothes, ornaments, etc.

Within the context of flood warning the extent to which these items can be 'saved' will be dependent on the type of property, (e.g. a single storey dwelling has no easily accessible upper refuge), the time available and the physical ability to move the objects. The potential savings, to both inventory and fabric, by giving a warning has been assessed by Parker (1991) and is included in the 'Yellow Manual'.

3.2.4 Disruption to Communications/Infrastructure

Flooding may cause disruption to communications such as rail service and road traffic either as direct damage or as costs of disruption. The effects to both will be site specific with the most common form of disruption being to roads. Estimation of the disruption caused by the need for diversion of traffic can be calculated using the procedures as set out in the 'Red Manual'. It is interesting to note that any changes due to a flood warning being given will increase these disruption costs as it is likely that the road would be closed by the emergency services before it became flooded. The direct damage to road and rail, and to other infrastructure such as water, electricity, gas and telephone can be costed and it is unlikely that a warning would significantly reduce the effects.

3.2.5 Damage to Industry/Commerce

The effects of flood water on industrial and commercial premises is similar to that for property in that there will be damage to fabric and to inventory items. In general terms, any indirect losses, such as loss of production, will not be a national loss as the shortfall can often be made up from other sites in the country. The level of damage will be specific to that particular enterprise and be related to depth and duration. General information on the assessment of costs due to flooding is given in the 'Red Manual'. The reduction in damage, especially to inventory items, will be dependent on the size, manpower and equipment available to move stock and the availability of space for receiving the moved goods.

3.2.6 Effects on Agriculture

The effects of flooding on agriculture can be separated into damage to:

- breakdown of soil structure (particularly with salt water inundation);
- crops: arable or pasture;
- livestock;
- building fabric and clean-up costs;
- stored crops, feedstuffs and fertilisers;
- agricultural vehicles and moveable equipment; and
- fixed equipment.

The scale of the damages will again be dependent on the depth and duration of the flood and whether it is salt or fresh water. It will also be specific to the type of agricultural operation, i.e. arable, grazing or mixed, and would be influenced by the time of year, e.g. before or after harvest.

The methodology for identifying losses is well documented in the Middlesex 'Blue Manual' and in MAFF's Project Appraisal Guidance Notes (MAFF, 1993), with base information on agricultural costs being available in the Farm Management Pocket Book by John Nix and published annually.

The savings that can be achieved by issuing a warning relate only to those items that can be moved to a position above the flood. This includes all livestock if the warning time is adequate. In the 1953 floods, losses to livestock was recorded as 1,672 cattle, 9,242 sheep, 3,219 pigs, 52,942 poultry and 74 horses (MAFF, 1962).

3.2.7 Previous Models

A conceptual model for the actual damage avoided was proposed by CNS Scientific and Engineering Services (1991) and this was used by Heijne et al 1996 for the NRA, "The Assessment of the Costs and Benefits of Fluvial Flood Forecasting". The model used standard data for the estimation of potential damages avoided and converted this to flood damages avoided by the use of reduction factors related to reliability of the flood warning process, proportion and ability of residents responding.

3.3 Intangible Effects

3.3.1 Introduction

The assessment of intangible benefits of a flood, and the reduction in those disbenefits which can be achieved through an effective warning is under-researched, with little information available to attribute monetary values. The lack of research and an accepted methodology for the assessment of intangible benefits has led to an analysis focused on using the results of existing research and constructing a new methodology for the type of human cost which will result from a flood. An in-depth description of this methodology is presented in Section 4.

The intangible effects[1] of flooding are those for which costs cannot be directly attributed. There are no readily available market prices for them and opportunity costs can only be estimated through the use of specialist valuation techniques. The assessment of costs, or disbenefits affecting recreation or the natural environment as a result of a particular event can be assessed by the use of indirect methods such as the travel cost, dose response and hedonic pricing methods or through methods which rely on hypothetical markets such as the contingent valuation method (CVM). Work has been, and is being, carried out into the development of methodologies for use in assigning standard values for flood and coastal schemes arising from increased recreational value. The Middlesex Manuals and other published papers (e.g. Bateman and Turner, 1992), give examples of the methodology. This is not discussed further as its application to flood warning is limited.

Nevertheless, floods are recognised as impacting on the health of the individual flood victims and so the following sub-sections give general background into the intangible effects on humans, together with some effects on the natural environment.

3.3.2 Effects on Human Health

Death

Flooding can cause loss of life. The floods of 1953 led to the death of over 300 people in England and an even greater number in the Netherlands. The Mississippi floods of 1993 led to the loss of 47 lives and recent monsoon floods in central and southern Vietnam resulted in a death toll of some 120 people (Reuter, 1995). The floods in Bristol in 1968 caused one death by drowning. However, the probability of loss of life caused by floods in the UK is considered low (MAFF, 1993) in spite of over 2.4m inhabitants of England and Wales living within flood risk areas (Parker, 1992). The Ministry of Agriculture, Fisheries and Food suggests that if there is empirical evidence to allow robust probabilities of risk to life to be estimated, quantification by the use of values published by the Department of Transport as Highways Economic Note No 1, The Valuation of Road Accidents and Casualties

[1] The consultants wish to note their concern with the use of the catchall phrase 'intangible'. This implies that such effects could never be measured, i.e. it is an impossibility. The phrase 'environmental and human health effects' is more appropriate.

should be used as a basis for calculation. The fact that only a few deaths have been caused by UK tidal floods since 1953, could be due to the STWS set up after the 1953 floods and the active warning role taken by the Environment Agency (and predecessor bodies), the Police and Local Authorities and the improvement in communications, telephone, radio and television.

Injuries

There is very little recorded information on the number or severity of injuries caused by floods. However, by the very nature of the event, it is not unreasonable to assume that for all but the most minor events injuries could be experienced, either as a result of the flood, (e.g. tripping over unseen objects in the flood), or as a result of taking action to rescue inventory items, etc. It is suggested in this report that these injuries reduce with the length of warning as panic reactions are decreased/reduced. As for a life, the evaluation of the cost of an injury can be made by reference to the Department of Transport Economic Note No 1, which gives costs associated with serious and slight injuries covering both tangible and intangible costs.

Stress

There is evidence that the stress experienced as a result of a disaster event, (i.e. earthquake, major transport accident, flood, hurricane, etc.) does affect the mental and physical health of the victims. Research by Abrahams (1976) found that large numbers of people in all walks of life experienced major difficulties in their personal and family lives as a result of a flood. He found increases in both psychological and physical symptoms with greater increases for psychological symptoms.

The work of Bennet (1970) following the Bristol floods of 1968, when 300 houses, shops and other properties were flooded, made comparisons between people who had been flooded and people who had not been flooded with regard to surgery attendances, hospital referrals and admissions. One interesting observation was the increase in the mortality rates of the victims over the following 12 months. The most pronounced was among the age group of 45-54 where male deaths rose threefold and female deaths doubled; these mainly occurring in the three months following the flood. He also found increases within that group who had been flooded to a depth greater than four feet when compared with those who had been flooded to a lesser depth.

Bennet concluded that in all aspects studied, the health of the people flooded was worse during the 12 months after the floods than the health of those not flooded. In men, the change in health was statistically significant in all instances; for women, there was an increase of ill-health, but it did not reach a significant level. He also suggested that the increase in mortality probably meant that death can be hastened by the experience of having been flooded rather than somehow being caused by it.

Other work by Doizy (1991), Parker (1987), and Green et al (1985) have noted that warnings reduce the stress experienced during a flood, that a large percentage of victims of sea floods have been found to report health damage as a result of the flood they experienced, that the effects may last for many years, and that elderly flood victims experience a lower health status.

Studies on disaster stress, mainly in the United States, [Janerick (1981), Baum (1983), Adams & Adams (1984) and Phifer (1988)], show that disasters provoke increased stress for the victims and that this can have long lasting effects (chronic) in addition to any stress experienced in the short term (acute).

3.3.3 Effects on the Natural Environment

Flooding will affect, to varying degrees, those sites adjacent to rivers or the coast some of which have been given statutory designations due to their specific location and their aquatic inter-dependence. The natural interest of a site has often been as a result of flooding, and the timing of a flood may also be crucial. For example, a late spring flood on the Ouse Washes in Cambridgeshire can destroy the nests of the Black Tailed Godwits.

A classification of habitats was undertaken by Posford Duvivier (1995) in relation to the effects of flooding. This resulted in subjective statements of the type of damage that would result from a flood and gives guidance as to the degree of protection to be provided. This comparative approach can be of assistance to the decision maker when assessing a range of options but does not put a monetary value on the site.

The effect of flooding could be serious, especially if by prolonged salt water flooding on a fresh or brackish water site. There could also be long term effects to birds at the site, as a result of the disappearance of suitable nesting or feeding sites. However, this may only lead to a redistribution to other more favourable sites elsewhere. It is not feasible or possible to bodily remove flora or fauna either permanently or temporarily. The operation of sluices, to either evacuate water (to give additional storage), or to flood the area with fresh water in advance of a salt water flood (to give greater dilution), within the timescale of a warning would have a negligible effect (Pers Comm).

Within the context of this project, any actions taken as a result of a warning will have virtually no beneficial effect on the interest of the site and therefore no attempt has been made for an objective or subjective quantification.

Quantifiable damage from a flood event is restricted to damage to infrastructure such a walkways, hides, etc. and any equipment used in land management. The actions which can be taken following a flood warning will be restricted to movement of machinery and equipment.

3.3.4 Effects on Recreation

The recreational activities that can be affected by floods include informal pursuits such as walking and birdwatching and the more formal activities such as fishing and boating. The more usual occurrence of floods within the winter period will have only a minor effect on tourism or the holiday industry. The effects of any warning will be very small and may amount only to savings made on what would have been a wasted journey.

3.3.5 Previous Models

It appears from the literature search carried out, that the area of intangible costs and benefits in relation to human health as a result of flooding is under-researched. The work considered to be of most relevance to this project is that of Allee et al (1980) for the US Army Corps of Engineers who developed a procedure to measure the value of avoiding psychological impairment that might be caused by flooding. The procedure, termed the Trauma Benefit Method (TBM), used a survey of flood victims to create an index of flood-induced human impairment. The impairment index results were then monetised by applying a Veterans Administration schedule that related impairment to reduced earning potential in civilian occupation. In the event, the TBM was not adopted as a benefit measure technique within the review process; although, the reviewers did not dispute the potential for avoided psychological effects in flood control.

Discussions were also held with representatives of the insurance industry (Adams 1997). It appears that assessments of the value of stress are made mainly by reference to earlier court settlements in cases of a similar nature. Such an approach does not appear appropriate for use in assessing flood/flood warning benefits.

3.4 SUMMARY

3.4.1 Overview

The preceding sub-sections have indicated the effects that can be experienced from flooding and the way that they can be valued in economic terms. The development of cost-benefit methodologies in the past has generally been in relation to the justification of schemes designed to reduce the impact of flooding by the construction of a defence.

There has been little work on developing a parallel methodology for the benefits of providing a warning of a tidal or fluvial flood. The basis of the benefit to some extent follows the same methodology in respect of the avoidance of damages by taking some action, but for flood warning the variable of time within which to take this action also has to be taken into account.

It has been recognised by a number of researchers that the effects to human health following a flood or other natural disaster are significant, as discussed in Section 3.3.2. This has not generally been incorporated into a robust model for addition to the actual flood damages avoided by physically moving items above the flood level or reducing the effect by taking avertive action such as the use of sandbags, etc.

Consequently, effort has been focused on using the results of basic research in related fields to develop a methodology for the valuation of human health costs which result from a flood. This part of the methodology is described in Section 4.3 and 4.4.

3.4.2 Relevant Factors

The effectiveness of any flood warning depends on the:

- availability of accurate information on which to base a forecast;
- ability to predict the scale of the event;
- communication of a warning to those at risk; and
- capability of the respondent to take effective action.

The requirement of any flood warning system is primarily the safeguarding of lives and secondly providing the opportunity for those living and working within the flood risk areas to reduce tangible damages (by moving belongings or stock) and the stress impact of the flooding incident.

Section 4 develops an approach for quantifying the benefits of flood warning. This includes both the economic benefits of actions taken to reduce losses and an estimation of the reduction in human stress impact. The model is completed by assigning probabilities to the actions taken at each stage of the warning process to give a holistic approach.

4. BENEFITS OF FLOOD WARNING AND FORECASTING

4.1 Summary of Approach

4.1.1 Introduction

The modelling of the benefits accruing from flood warning and forecasting has been based on the addition of the tangible and intangible benefits. The evaluation of the tangible benefits has been based on previous research, mainly drawing on the work of MUFHRC. However, an extensive review of relevant literature failed to identify an acceptable methodology on which to model the intangible benefits in relation to human health. This has led to the development of a methodology that is based on an evaluation of flood trauma from stress research carried out in the US and costed by comparison with values used by the DoT in relation to accidents in the UK. This methodology was then successfully applied to three case study areas (as discussed in Section 4.4).

The application, by necessity, was limited to lead time data from previous research (i.e. 2, 4 and 8 hours relative to 0 hours). In any further testing (e.g. Phase 2), it is recommended that raw data are collected from appropriate sources to allow other lead times, especially between 0 and 2 hours, to be fully evaluated.

4.1.2 Outline of Model

To model the benefits of flood warning and forecasting, the approach adopted is divided into:

- a 'Benefits Model'; and
- Decision Analysis.

The framework for the benefits model is summarised in Table 4.1(a). The concepts underlying the model have considered the need for an easy to use tool which takes into account the different components of probable damages including both tangible and intangible elements. The benefit derived from a particular warning or forecasting system can be defined as the amount of total damages avoided, i.e. a reduction in dis-benefits caused by flooding as a result of a warning. Total damages are estimated under the assumption that the warning procedure functions perfectly and all individuals at risk **will** receive a warning. The validity of this assumption will then be tested via the decision analysis.

In order to determine the benefits of different lengths of warning, the model will be costed to reflect the following scenarios:

- no warning (the base case);
- 2 hour warning (the Agency's minimum national target);
- 4 hour warning; and
- 8 hour warning.

The benefit of a particular warning, when compared to the base case, is therefore the damage costs avoided by providing the flood warning. Methods for assessing the damage costs are explained in Sections 4.2 and 4.3. The completed model will then provide information on the damage reducing effects of flood warning.

The next stage of the analysis is to provide a framework to convert the calculated benefits for different levels of flood warning to annualised figures which account for the range of expected flood events, the reliability of flood forecasting, inadequate dissemination of flood warning and failures in responding to flood warnings. This is achieved through the use of event tree analysis, as discussed at the end of this section, which provides an approach to determine the range of potential outcomes given flood conditions and their associated probabilities of occurrence. This, in turn, provides a basis to quantify the benefits of flood warning in monetary terms.

4.1.3 Illustrative Case Studies

In order to test the underlying methodology of the benefits model, three Case Studies have been utilised. The Case Studies consist of areas with 'general' characteristics for different types of flooding event. The base case for the Case Studies is a 'no warning' scenario. The Case Studies are defined as:

- **Case Study 1**: coastal town, tidal flooding, 1 in 100 year event, flooding for less than 12 hours, salt water damage;
- **Case Study 2**: inland town, fluvial flooding, 1 in 10 year event; and
- **Case Study 3**: major coastal town, tidal flooding, flooding for more than 12 hours, 1 in 250 year event, event overtopping defence, possible breach.

Section 4.4 costs the individual components for the Case Studies given the warning scenarios and the results are summarised in Section 4.5.1 with the application of decision analysis presented in Section 4.5.2.

Table 4.1(a) Benefit Model Factors and Warning Times

	No Warning	2 hours	4 hours	8 hours
Extent of Property Flooded Damage to Fabric Damage to Fittings (Inventory)				
Agriculture/Livestock				
Road/Infrastructure				
Environment				
Human Effects - Stress - Physical				
TOTAL DAMAGE				

4.2 Tangible Effects

4.2.1 Property

Extensive research has been undertaken in the field of property damage as a result of flooding, most notably by MUFHRC (see Section 3.2). Not only does damage take the form of physical water damage, but in terms of business premises there could also be the additional cost of lost trade. The process for determining property damage costs takes the form of the following steps:

i. identify properties at risk/flooded;
ii. determine the floor levels (and hence depth of flooding);
iii. divide properties into residential and non-residential (retail, manufacturing, etc.); and
iv. using MUFHRC cost data[2], attribute damage to fixture and fittings, in some cases only total damage may be determined.

The nature of the make-up of these damages will be dependent on the area flooded or at risk from flooding. An area of heavy industrial usage will tend to have major damage costs due to the extent of stock/machinery lost.

These calculations are demonstrated via the use of the three Case Studies, i.e.:

- Case Study 1: only residential properties were flooded, depth of flooding and floor levels for residential properties were known. Data used were damage data for all residential properties, salt water flood duration less than 12 hours, total fabric damage and total inventory damage from the Yellow Manual;

- Case Study 2: a small number of residential properties were flooded at a single depth, data for fluvial flood damage were derived from the Blue Manual;

- Case Study 3: consisted of both residential and non-residential properties flooded at two depths. Residential depth/damage data were again derived from The Yellow Manual. Non-residential properties were divided into retail and manufacturing assuming a ratio of 5 retail premises to 1 manufacturing, depth/damage data were then derived from the Red Manual as generalised mean direct damage. The figures for retail and manufacturing were then summed to give the non-residential total direct damage.

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2 For residential properties The Yellow Manual depth/damage data have been used for salt water flooding and The Blue Manual for fluvial flooding. For non-residential properties The Red Manual generalised average depth/loss data have been used.

These Case Studies are considered to be representative of real life events occurring on the East Coast. Information regarding the events has been gathered during detailed consultation with Agency operations staff. Some modification of the information has been deemed necessary, such as extrapolating road damage costs for Case Study 3 and determining the number of livestock that would be killed for a given event, but the base scenario in all cases was a recorded historic event.

Depths of flooding for the Case Studies are summarised in Table 4.2(a).

Table 4.2(a) Depth of Flooding and Case Study Number

	Number of Properties	Depth of Flooding	Base Case Total Damage
Case Study 1	33 residential	4 x 1.5m 7 x 1.2m 8 x 0.9m 6 x 0.6m 4 x 0.3m 4 x 0.1m	£232,500
Case Study 2	8 residential	8 x 0.3m	£57,500
Case Study 3	230 residential 50 non-residential	160 residential x 0.6m 35 non-residential x 0.6m 70 residential x 1.2m 15 non-residential x 1.2m	£7.6m

4.2.2 Communications/Infrastructure

Damage to communications and infrastructure can severely disrupt a region affected by a flood. The term infrastructure refers to road, rail, electricity supplies, gas, telecommunications, water and sewerage networks. The present analysis breaks the stages down as follows:

- the number of roads/rail at risk/flooded;
- vehicles on the road at risk/damaged;
- physical damage to the road/rail infrastructure;
- 'inconvenience factor', such as increased journey time due to diversions;
- effect on telecommunications and utilities (gas, electricity, water, sewerage); and
- clean-up costs.

The source for data on damage to utilities would be MUFHRC (or by survey), although it has been assumed that none of the Case Studies are affected in this way. Actual data for the Case Studies for roads were obtained from those involved in the clean-up in the aftermath of a flood, with the exception of Case Study 3 (an extreme event scenario), where damage costs are extrapolated from the previous two Case

Studies. Although MUFHRC and the Department of Transport (DoT) do have monetary figures for diversion and inconvenience, these were considered not to play a major role in the costings. The damage estimates for the Case Studies are shown in Table 4.2(b).

The damages caused by flood waters to road or rail are assumed to be constant regardless of the length of warning. Longer warning times would have the advantage of closing the travel networks at an earlier stage and hence preventing vehicle damage in the flooded areas. It would be possible to, say, sandbag a road to prevent it from flooding but, the time and effort of such an operation could be best put to ensuring residents and/or livestock are moved to safety.

Table 4.2(b) Case Study Road Damage

	Damage Estimates
Case Study 1	Road surface damage: £7,000; clean-up costs: £1,000
Case Study 2	Road surface damage: £500
Case Study 3	Road surface damage: £10,000; clean-up costs: £20,000

4.2.3 Agriculture/Livestock

Flood warning and forecasting cannot prevent flooding to agricultural land, although it can give the farmer/landowner time to remove farm machinery, livestock and some stock . The components that factor into this analysis are:

- area of land at risk/flooded;
- type of land at risk flooded (grazing, crops, etc.);
- type of flooding, e.g. fresh or saltwater; and
- livestock at risk/injured/dead/lost.

Perhaps the most important factor economically from a flood warning and forecasting perspective is the loss of livestock. The removal of livestock (and farm machinery) will provide real savings. The main assumption for costing such animals is that the loss to the farmer is the market price of the animal lost (or replacement cost), as opposed to the gross margin on the animal (the profit obtained from the animal from purchase to sale) although, in practice, consequential losses can equal or even exceed the direct losses. There are several sources for developing replacements cost estimates; that used here is Nix (1996), and it is assumed that the cost of a cattle death is £550 and the cost of a sheep death is £40.

Timing of the event is also significant. For example, a freshwater flood of grassland lasting up to 4 days in winter will have no effect, especially when grazing livestock are housed. A flash flood of a field of cereals immediately pre-harvest would result in total loss of crop. However, in the interests of simplicity, timing has not been included as a factor in the analysis.

4.3 Intangible Effects

4.3.1 Human Effects

Stress

Stress induced by a disastrous occurrence (flood, fire etc.) can be related to health damaging effects such as reduced immune system response and increased susceptibility to certain illnesses. Measures for 'stress' in relation to a flooding incident have in the main been undertaken by the MUFHRC, although some of this work has been focused upon sewage flooding in homes, which is outside the remit of the present study.

Given the possible acute and chronic effects, as discussed in Section 3.3.2, the costs attributed to stress could be a major indicator in not only the area of flood warning and forecasting, but also in flood defence scheme justification. It is proposed, therefore, to adopt a stress model that results in actual costings per person following (or indeed prior to) a flood event. The starting point for this model is the Social Readjustment Scale (see Allee et al, 1980). This scale defines stressful events in relation to other stressful events, with the mean value of 100 being the maximum level of stress (being defined as 'death of spouse') decreasing to such events as 'divorce' (a mean value of 73) and 'Christmas' (a value of 12). Further examples are given in Table 4.3(a).

Although flooding may be responsible for some of the life events given in the table, it is believed that flooding as a life event itself would rank about 25 on the scale. This does not mean that actually being flooded would be the same as a 'change in living conditions', but the relative impact upon an individual's life would be similar. The value of 25 is chosen by comparing flooding event trauma with the relative events in the scale (assuming the scale is linear); for example flooding is not considered as serious as any form of death and it is considered more serious than changes in residence/schools/recreation. The value has also been confirmed from informal straw poll conducted with the audience attending a national meeting of the British Hydrological Society which suggests it is not unreasonable to place flooding at such a value in the scale. Clearly, this is not offered as a robust test of the value, but as corroboration of the figure proposed.

Table 4.3(a) Examples of the Social Readjustment Scale

Life Event	Mean Value
Death of spouse	100
Divorce	73
Personal injury or illness	53
Marriage	50
Pregnancy	40
Death of a close friend	37
Change in responsibility at work	29
Change in living conditions	25
Change in residence	20
Change in schools	20
Change in recreation	19
Change in sleeping habits	16
Change in eating habits	15
Christmas	12

The next stage in applying the stress model is to calculate a **flood trauma value** (FTV). This value will be on a scale from 0 to 100, where 0 reflects 'no trauma' and 100 'maximum trauma'. It is this value which forms the basis for assigning a monetary value to stress. The FTV is composed of four elements:

- a demographic factor;
- an urgency factor;
- a panic factor; and
- a 'hassle' (or nuisance/inconvenience) factor.

The sum of the four factors will give a maximum value of 100. Within each factor group there is a maximum value, reflecting its relative importance in the analysis. The four factors can therefore move within a range of 0 to the maximum value. For example, it is assumed here that the values will range from:

- demographic: 0 - 40;
- urgency: 0 - 20;
- panic: 0 - 20; and
- hassle: 0 - 20.

The **Demographic** factor is considered the most important variable (and implicitly given twice the weight as the other factor groups) and it is determined by the area flooded, i.e. it is a constant throughout the analysis for a given area. The demographics include such items as age, mobility, health and type of housing. This factor is further subdivided down into three areas:

- population reactivity;
- nature of housing; and
- car ownership.

Population reactivity reflects the ability of a population to react to the flooding incident, this includes such actions as ability to move valuables out of danger, the ability to secure one's property and the ability to evacuate effectively. For example, it is likely that a healthy, mobile adult would be able to secure the property and save inventory more efficiently than an elderly person with impaired mobility (although the factor of friends and family coming to aid may balance this difference out). The nature of housing is vital to the effects of a flood and different warning times. For example, a coastal town with a large number of bungalows, flats and chalets would be impacted greater than an area composed of housing with at least two floors (the upstairs floors being used to place valuables out of the flood's way). Car ownership not only reflects the ability to evacuate the area, but also may reflect the relative affluence of an area (although in some cases, such as Canvey Island, a sudden outflow of vehicles would cause additional problems due to restricted evacuation routes). These three factors are placed on a sliding scale reflecting their weighting and importance for the particular area under consideration. In this case, given a maximum value of 40, the scales are:

- population reactivity: 0 - 20 (where 0 would be most reactive [in terms of mobility, health, etc.] and 20 least able to react);
- nature of housing: 0 - 12 (where 0 reflects full ability to protect property and 12 poor ability, such as in bungalows and chalets); and
- car ownership: 0 - 8: (where 0 is maximum car ownership and 8 minimum car ownership).

When summed, the resultant figure out of a maximum score of 40 reflects the area's potential ability to minimise damages. Therefore, a score of 0 would indicate a high ability to cope and a score of 40 would indicate a very low ability to cope.

Urgency factors reflect the level of urgency prior to a flood event (such as when a warning is given) or during and after a flood event. The urgency factor is considered the rational reaction (as opposed to panic, see below) of a flood victim to the flooding event. The factor is further sub-divided into three areas:

- initial preparedness;
- "knowing what to do"; and
- time left to the flooding incident.

These sub-divisions are self explanatory and the sliding scales assigned to each are as follows:

- initial preparedness: 0 - 5 (where 0 represents most prepared and 5 least prepared at the outset, this may be reflected in any information that possible flood victims have been given by government agencies, most likely the Agency);

- "knowing what to do": 0 - 5 (where 0 shows that flood victims know exactly 'what to do' and 5 show a total lack of knowledge of how to respond); and

- time left to flooding incident: 0 - 10 (where 0 shows no time, i.e. a no warning scenario and 10 a large amount of response time, i.e. the 8-hour warning scenario or greater).

Once summed, these give an urgency factor with a maximum score of 20, where 0 shows no level of urgency and 20 an extreme level of urgency.

The **Panic** factor highlights a totally irrational response to either a flooding event or the warning of a forthcoming flooding event. The sub-components of this factor are:

- reaction;
- severity of flood;
- level of preparedness; and
- previous flood experience.

The initial reaction to either the flood or news of the flood is reflected in the first sub-component. Severity of the flood determines the extent of panic, and this may also be extended to 'expected severity of flood' which may bring in an element of false warning. The remaining components are self-explanatory. The sliding scales attributed to such factors are given below:

- reaction: 0 - 3 (where 0 shows that there is not, or expected to be, a panic reaction and 3 shows a severe panic reaction);

- severity of flood: 0 - 7 (where 0 is the equivalent to a 1 in 1 year flood and 7 greater than a 1 in 250 year flood). This component remains constant throughout a Case Study;

- level of preparedness: 0 - 3 (where 0 represents full preparedness and 3 no (or very little) preparedness); and

- previous flood experience: 0 - 7 (where 0 represents extensive flood experience and 7 no flood experience).

The sum of the above gives a panic factor with a maximum value of 20. A score of 0 would show no panic, while a score of 20 shows extreme panic.

The **Hassle** factor reflects the level of inconvenience or nuisance that a flood warning/event can cause. The source for such a factor has its roots in Allee (1980). The contributing components are:

- forced evacuation;
- length of time out of homes;
- lack of basic living necessities;
- extent of clean-up and problems associated with it; and
- work missed.

It can be seen that the hassle factor is dependent upon the severity of a particular flood event. and this value is therefore constant throughout a Case Study. The components are scored on the following sliding scale:

- forced evacuation: 0 - 6 (where 0 is equivalent to no evacuation and 6 to a full-scale evacuation);

- length of time out of homes: 0 - 6: (where 0 means no time out of the home and 6 means that there was a long time [say longer than a week] out of the home):

- lack of basic living necessities: 0 - 4 (0 means presence of satisfactory living necessities and 4 means definite absence of living necessities);

- extent of clean up and problems associated with it: 0 - 2 (where 0 means no [or very little] clean-up and 2 indicates an extensive clean-up operation); and

- work missed: 0 - 2: (where 0 means no work missed and 2 shows a reasonable amount of work missed).

The sum of these components would have a maximum score of 20. A score of 0 shows that no hassle is attributable to the event (or a warning) and a score of 20 shows maximum hassle is attributed to an event/warning.

A summary of all factors is shown in Table 4.3(b).

Table 4.3(b) Summary of the Components of the Flood Trauma Value (FTV)

Component	Range	Maximum Total
Demographic	**(0 - 40)**	
- population reactivity	0 - 20	
- nature of housing	0 - 12	
- car ownership	0 - 8	**40**
Urgency	**(0 - 20)**	
- initial preparedness	0 - 5	
- "knowing what to do"	0 - 5	
- time left to flooding incident	0 - 10	**20**
Panic	**(0 - 20)**	
- reaction	0 - 3	
- severity of flood	0 - 7	
- level of preparedness	0 - 3	
- previous flood experience	0 - 7	**20**
Hassle	**(0 - 20)**	
- forced evacuation	0 - 6	
- length of time out of homes	0 - 6	
- lack of basic living necessities	0 - 4	
- extent of clean-up and problems associated with it	0 - 2	
- work missed	0 - 2	**20**
Total (Flood Trauma Value)	**0 - 100**	**100**

The next stage is to attribute a money value to the FTV. From Department of Transport figures it is possible to determine average injury costs per person. Averaging the human costs of a slight and serious injury gives a money value of £46,615. This is a cost per accident and requires a conversion into per person costs, considering that, on average there are 1.23 casualties per accident (DoT, 1996). This gives an average injury cost per person, when rounded, of £38,000.

To combine this value with the social readjustment scale, it is assumed that this figure is equal to a mean value of 53 ('personal injury or illness' in Table 4.3(a)). Given that it is also assumed that a mean level of 25 is attributed to flooding, the maximum value, in monetary terms, of the FTV is equal to:

$$\frac{38000}{53} \times 25$$

i.e. the maximum value of FTV (100) is equal to £18,000 per person. The value particular for a flood event is then a percentage reduction of this figure, for example, if the total FTV is equal to 70, then the total flood trauma per person in monetary terms would be 70% of £18,000.

For each of the Case Studies, the FTV was calculated for the base case and three warning scenarios. The values attributed to the different scenarios are a result of internal discussions and the literature review, but it may also be possible to assign subjective phrases (as used in by MUFHRC in post flood stress research) to the sliding scales. This could then form an uniform approach for use in 'full scale' Case Studies (as suggested in Section 6).

Physical Injury (Including Death)

The costing of physical injury (including death) follows DoT 1996 figures for three classifications of injuries, namely:

- fatality;
- serious injury; and
- slight injury.

At this stage of the analysis, it is believed that these three classifications should be retained for simplicity's sake, although at a later stage it may be possible to develop a scale to reflect actual injury for use in post flood evaluation. The DoT's current average costs per casualty are given in Table 4.3(c).

Table 4.3(c) : Average Cost Per Casualty

	Cost (£)
Fatality	812,010
Serious Casualty	92,570
Slight Casualty	7,170

These costs reflect all the costs associated with a casualty, such as lost output, medical costs, emergency services, human costs (pain, grief and suffering) and insurance administration. In terms of flooding, it is believed that a number of 'panic injuries' may occur which would be 'slight' (1 panic injury would be equal to £7,000). Panic injuries would be dependent on severity of flood and warning time, for example a severe flooding event with no warning time would induce significantly more panic injuries than a 'small' flood with a long warning time of, say, 8 hours.

It is assumed therefore that, for any given number of properties (where 1.8 people live in each property), panic injuries in the base case would be around 10% of those affected. The effect of warning times on this figure will be discussed in Section 4.4 below.

4.3.2 Environment

Once a flood warning has been given, it may be possible to take steps to protect an environmentally sensitive site, where avertive measures could include sandbagging the area, attempting to move the animals themselves or even removing rare plants (although this is illegal under the Wildlife and Countryside Act). However, it is considered that in most cases such actions would not be carried out. Costs to physical property on such sites (such as repairing or replacing hides, repairing walkways, repairing visitor centres, and so on) would be constant regardless of warning time given. These repair costs for the Case Studies have been obtained via discussions with relevant bodies, such as the RSPB and Wildlife Trusts for a number of flooded reserves.

4.4 Lead Time Considerations

4.4.1 Property

Given that the base case damage to both residential and non-residential property is calculated using MUFHRC data, it would follow that data on the damage reducing effects of flood warnings would also come from this source. It is assumed that as warning time increases inventory damage is reduced. The Yellow Manual provides percentage reductions in inventory damage for given depths of flooding and different lengths of flood warning. Damage to the fabric of residential properties is assumed to reduce slightly as warning time increases and defences are installed, such as flood boards, sandbagging and so on. The exception to this rule of thumb is the impact of a severe event, as, given the magnitude of such an event, it is assumed that such damage would remain constant throughout warning times. The property damage for the Case Studies using MUFHRC data is shown in Table 4.4(a).

It should also be noted that mobilisation of public authority resources will incur a cost and these may be unnecessary costs if the warning proves to be false. These costs have not, however, been included in the estimates as it was agreed that costs of providing the FFWRS were to be excluded from the study.

Table 4.4(a) Property Damage and Warning Time for Case Studies

	No Warning	2 Hour Warning	4 Hour Warning	8 Hour Warning
Case Study 1				
No. of Properties Flooded	33	33	33	33
Damage to Fabric	£101,500	£101,500	£101,500	£101,500
Damage to Fittings	£131,000	£98,000	£85,000	£77,200
Case Study 2				
No. of Properties Flooded	8	8	8	8
Damage to Fabric	£36,000	£36,000	£21,100	£19,100
Damage to Fittings	£21,500	£15,100	£12,400	£10,800
Case Study 3				
No. of Residential Properties Flooded	230	230	230	230
Damage to Fabric	£700,000	£700,000	£700,000	£700,000
Damage to Fittings	£982.000	£740,000	£630,000	£580,000
No. of Non Residential Properties Flooded	50	50	50	50
Damage to Non Residential Properties	£5.9m	£5.6m (↓ %)	£5.3m (↓10%)	£5m (↓15%)

4.4.2 Communications/Infrastructure

An extension in lead time may allow the utilities to secure supplies. for example, through switching to another power grid. or shutting down supplies to prevent leakages/accidents. Such events would be covered in individual flood/disaster procedures. In terms of the road and rail network. although flood warning cannot prevent the road or rail from becoming flooded. it can ensure that vehicles and passengers are safely out of reach of the flood. A longer lead time in these cases will ensure transport networks at risk are shut down and arrangements are put into action to divert traffic elsewhere.

For the purpose of the Case Studies. it is assumed that **all** transport vehicles are moved from the flooded area given a warning of 2 hours or more. This cost is therefore eliminated by any length of warning. Physical damage to roads and clean-up costs for the three Case Studies are shown in Table 4.2(b).

4.4.3 Agriculture/Livestock

A lengthening of warning time will provide the farmer/landowner extra time to remove/secure such items as:

- livestock:
- farm machinery:
- stores (crops and inputs such as fertiliser and sprays): and
- farm buildings (both permanent and temporary).

For the purpose of the Case Studies, **Table 4.4(b)** shows the costs attributed to each scenario.

Table 4.4(b) Agricultural/Livestock Damages for the Case Studies

	No Warning	2 Hour Warning	4 Hour Warning	8 Hour Warning
Case Study 1	Livestock deaths: 4 cattle: £2,200 26 sheep: £1,040 125ha flooded	Livestock deaths: 2 cattle: £1,100 13 sheep: £520 125ha flooded	All cattle and sheep removed 125ha flooded	All cattle and sheep removed 125ha flooded
Case Study 2	1 cattle death: £550 100ha flooded	No livestock deaths 100ha flooded	No livestock deaths 100ha flooded	No livestock deaths 100ha flooded
Case Study 3	None	None	None	None

From Table 4.4(b) it can be seen that livestock deaths increase with severity of flood, for example, even given a warning of 2 hours, there are still livestock deaths in Case Study 1. It is also assumed for the Case Studies that no farm machinery is left in the floodplain.

4.4.4 Stress

At the outset of the study, it was hypothesised that the stress/warning time relationship may take the form shown in Figure 4.1. It should be noted that there is, as yet, no vertical scale on the diagram by which to measure stress, although an altered form of the FTV may be used. The total FTV for any given scenario would be equal to the area beneath the relevant curve (i.e. the integral of the curve would be equal to the total FTV). The FTV calculations for the Case Studies are shown in Tables 4.4(c) to 4.4(e).

It can be seen from the tables that a move from the base case scenario to a 2-hour warning gives a larger reduction in stress damages than a move from 2 to 4 to 8 hour warnings. This reinforces findings from the literature that the benefits from any warning are greater than the differences between lengths of warnings (and is consistent with what economic theory would predict in terms of diminishing returns at the margin). For example, the total stress damage from Case Study 3 in the base case is £5.5m and a move to a 2 hour warning reduces damages by £700,000. The next saving from 2 hours to 4 hours is £600,000 and the saving for a move from 4 hours to 8 hours is only £100,000. These findings are summarised in Table 4.4(f).

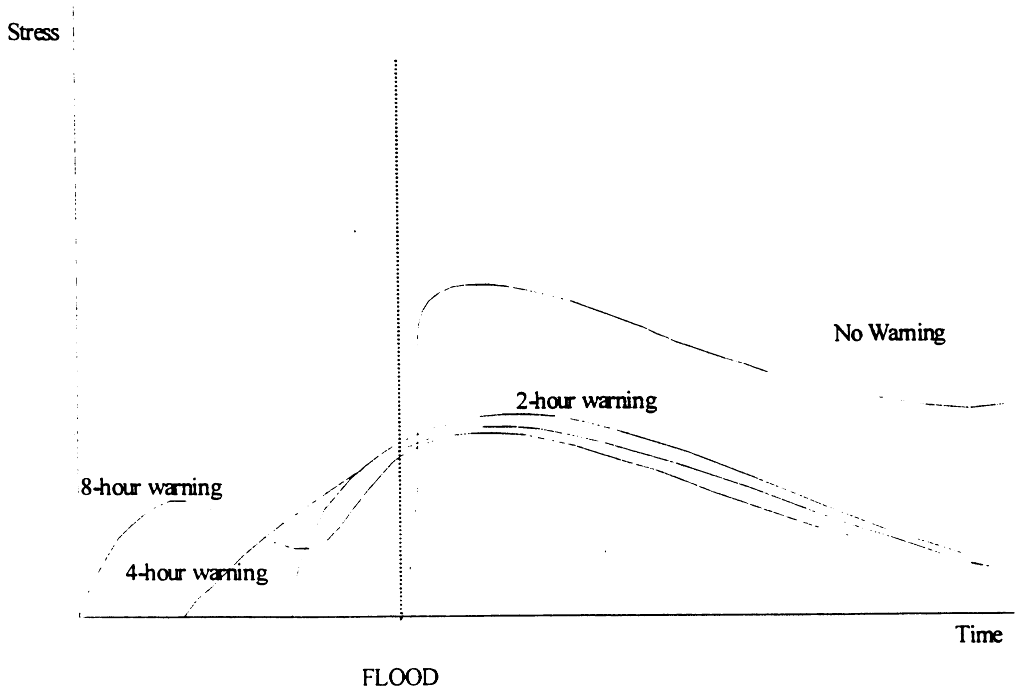


Figure 4. 1 Flood Warning Times and Stress Levels

Table 4.4(c) FTV for Case Study 1

	No Warning	2 Hour Warning	4 Hour Warning	8 Hour Warning
Demographic	21	21	21	21
Urgency	16	8	4	1
Panic	15	13	12	10
Hassle	17	17	17	17
Total FTV	69	59	54	49
£FTV per Person	£12.400	£10.600	£9,700	£8,800
Population Flooded £FTV*	£740,000	£630,000	£576,000	£523,000

*assuming 1.8 people per household

Table 4.4(d) FTV for Case Study 2

	No Warning	2 Hour Warning	4 Hour Warning	8 Hour Warning
Demographic	18	18	18	18
Urgency	17	8	4	1
Panic	11	9	7	6
Hassle	6	6	6	6
Total FTV	52	40	36	31
£FTV per Person	£9,300	£7,200	£6,500	£5,600
Population Flooded £FTV*	£134,000	£104,000	£94,000	£81,000

*assuming 1.8 people per household

Table 4.4(e) FTV for Case Study 3

	No Warning	2 Hour Warning	4 Hour Warning	8 Hour Warning
Demographic	20	20	20	20
Urgency	18	11	5	3
Panic	18	16	14	14
Hassle	18	18	18	18
Total FTV	74	65	57	55
£FTV per Person	£13,300	£11,700	£10,200	£9,900
Population (residential only) Flooded £FTV*	£5.5m	£4.8m	£4.2m	£4.1m

*assuming 1.8 people per household

Table 4.4(f) Comparison of Warning Times Stress Damage Reductions (i.e. Stress Marginal Benefits)

	No Warning to 2 Hours	2 Hours to 4 Hours	4 Hours to 8 Hours
Case Study 1	£110,000	£54,000	£53,000
Case Study 2	£30,000	£10,000	£13,000
Case Study 3	£700,000	£600,000	£100,000

4.4.5 Physical Injury

This category effectively has been separated into two 'injuries':

- death; and
- panic injuries.

Physical injuries are directly related to the severity of the event. Any deaths will substantially increase the costs of a flooding event. It is assumed that even the smallest lead time will aid in saving lives. As highlighted in Section 4.3.1 panic injuries are costed at £7,000 per injury. It is assumed that panic injuries will decrease as warning time increases, simply due to the presumed reduction in panic (as highlighted in the panic variable of the FTV). The costings for the Case Studies are shown in Table 4.4(g):

Table 4.4(g) Physical Injuries and Warning Time for the Case Studies

	No Warning	2 Hour Warning	4 Hour Warning	8 Hour Warning
Case Study 1	1 death:£812,000 Panic injuries: £21,000	0 deaths Panic injuries: £14,000	0 deaths Panic injuries:£7,000	0 deaths 0 panic injuries
Case Study 2	0 deaths Panic injuries: £7,000	0 deaths 0 panic injuries	0 deaths 0 panic injuries	0 deaths 0 panic injuries
Case Study 3	3 deaths: £2.4m Panic injuries: £280,000	0 deaths Panic injuries: £140,000	0 deaths Panic injuries: £70,000	0 deaths Panic injuries: £7,000

4.4.6 Environment

As previously noted, it is believed that any length of warning time would have very little effect upon any sites with environmental value. For this reason, any costs incurred on environmental sites as a result of flooding, such as clean-up costs, will remain throughout the model. The costs attributed to such damage are summarised in Table 4.4(h).

Table 4.4(h) Environmental Costs and Warning Time for the Case Studies

	Costs	Additional Information
Case Study 1	£25,000 repair costs	200 ha of bird reserve flooded; no breeding bitterns post flood; avocet numbers down
Case Study 2	No sites	No sites
Case Study 3	No sites	None

4.5 Framework for Evaluation of the Benefits of Flood Warning and Forecasting

4.5.1 Benefit Model

A summary of the total damage costs for all scenarios and Case Studies is presented in Table 4.5(a). Table 4.5(b) shows the reduction in total damages (reduction in dis-benefit) as one moves from one scenario to the next (i.e. no warning to a 2 hour warning; a 2 hour warning to a 4 hour warning; and a 4 hour warning to a 8 hour warning). The completed total damage tables for the three Case Studies, using the methodology described above, can be seen in Tables 4.5(c) to 4.5(e).

Table 4.5(a) Comparison of Total Damage, Warning Times and Case Studies

	No Warning	2 Hour Warning	4 Hour Warning	8 Hour Warning
Case Study 1	£1.8m	£880,000	£800,000	£735,000
Case Study 2	£193,000	£156,000	£128,000	£111,000
Case Study 3	£15.8m	£12m	£10.9m	£10.4m

Table 4.5(b) Marginal Benefit of Warning Scenarios

	No Warning	2 Hour Warning	4 Hour Warning	8 Hour Warning
Case Study 1	n/a	£920,000	£80,000	£65,000
Case Study 2	n/a	£37,000	£28,000	£17,000
Case Study 3	n/a	£3.8m	£1.1m	£500,000

From the total damage figures, three sectors stand out as benefiting from a flood warning:

- property damages (including residential and non-residential);
- stress impacts; and
- physical injuries (including death).

Table 4.5(c): Benefit Model for Case Study 1

	No Warning	2 hours	4 hours	8 hours
Extent of Property Flooded	33 residential	33 residential	33 residential	33 residential
Damage to Fabric	£101,500	£101,500	£101,500	£101,500
Damage to Fittings (Inventory)	£131,000	£98,000	£85,000	£77,200
Agriculture/Livestock	Livestock deaths: 4 cattle: £2,200 26 sheep: £1,040 125ha flooded	Livestock deaths: 2 cattle: £1,100 13 sheep: £520 125ha flooded	No livestock deaths 125ha flooded	No livestock deaths 125ha flooded
Road/Infrastructure	Road surface damage: £7,000 Clean-up costs: £1,000	Road surface damage: £7,000 Clean-up costs: £1,000	Road surface damage: £7,000 Clean-up costs: £1,000	Road surface damage: £7,000 Clean-up costs: £1,000
Environment	£25,000	£25,000	£25,000	£25,000
Human Effects Stress	£740,000	£630,000	£576,000	£523,000
Physical	1 death:£812,000 Panic injuries: £21,000	No deaths Panic injuries: £14,000	No deaths Panic injuries:£7,000	No deaths No panic injuries
TOTAL DAMAGE	£1.8m	£880,000	£800,000	£735,000

Table 4.5(d): Benefit Model for Case Study 2

	No Warning	2 hours	4 hours	8 hours
Extent of Property Flooded	8	8	8	8
Damage to Fabric	£36,000	£36,000	£21,100	£19,100
Damage to Fittings (Inventory)	£21,500	£15,100	£12,400	£10,800
Agriculture/Livestock	1 cattle death: £550 100ha flooded	No livestock deaths 100ha flooded	No livestock deaths 100ha flooded	No livestock deaths 100ha flooded
Road/Infrastructure	Road surface damage: £500	Road surface damage: £500	Road surface damage: £500	Road surface damage: £500
Environment	No sites	No sites	No sites	No sites
Human Effects				
Stress	£134,000	£104,000	£94,000	£81,000
Physical	No deaths Panic injuries: £7,000	No deaths No panic injuries	No deaths No panic injuries	No deaths No panic injuries
TOTAL DAMAGE	£193,000	£156,000	£128,000	£111,000

Table 4.5(e): Benefit Model for Case Study 3

	No Warning	2 hours	4 hours	8 hours
Number of Residential Properties Flooded	230	230	230	230
Damage to Fabric	£700,000	£700,000	£700,000	£700,000
Damage to Fittings	£982,000	£740,000	£630,000	£580,000
Number of Non Residential Properties Flooded	50	50	50	50
Damage to Non Residential Properties	£5.9m	£5.6m	£5.3m	£5m
Agriculture/Livestock	None	None	None	None
Road/Infrastructure	Road surface damage: £10,000 Clean-up costs: £20,000	Road surface damage: £10,000 Clean-up costs: £20,000	Road surface damage: £10,000 Clean-up costs: £20,000	Road surface damage: £10,000 Clean-up costs: £20,000
Environment	None	None	None	None
Human Effects				
Stress	£5.5m	£4.8m	£4.2m	£4.1m
Physical	3 deaths: £2.4m Panic injuries: £280,000	No deaths Panic injuries: £140,000	No deaths Panic injuries: £70,000	No deaths Panic injuries: £7,000
TOTAL DAMAGE	£15.8m	£12m	£10.9m	£10.4m

The prevention of death yields the single greatest reduction in total damages, supporting the argument that 'any warning is better than none', assuming that there are no panic deaths and that the warning functions perfectly with those warned being fully aware of how to react (although factors in the FTV will reflect any ability or inability to react to such a warning).

4.5.2 Decision Analysis

Overview

As indicated in Section 4.1, the next stage of the analysis is to provide a framework to convert the calculated benefits for different levels of flood warning to annualised figures which account for the range of expected flood events, the reliability of flood forecasting, inadequate dissemination of flood warning and failures in responding to flood warnings.

This requires three steps:

- the generation of annualised losses through flooding;
- the development of a generic 'event tree' to predict the range of possible outcomes in the event of flood conditions; and
- the application of probabilities in order to determine the benefits of flood warning in monetary terms.

Loss-Probability Curves

In evaluating the benefits of flood protection schemes, it is standard practice to develop a relationship between different levels of flooding and the associated damage costs (and an example is shown in Figure 4.2).

Such relationships may be represented as:

$$L = a/(x + b)$$

where
L = losses (£k)
x = exceedance probability (= inverse of return period)
a, b = area specific constants (and note $b \ll 1$)

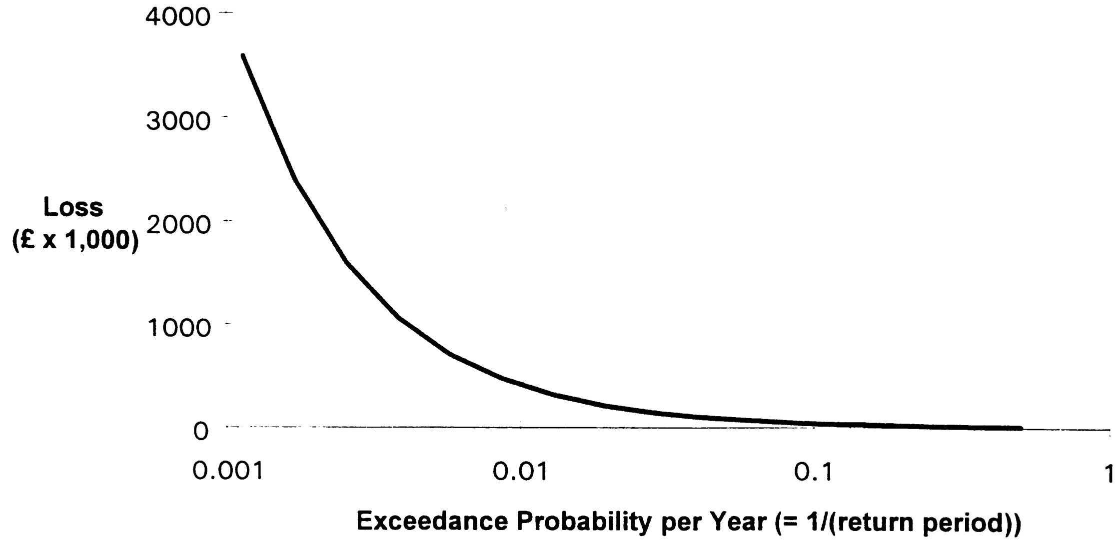


Figure 4.2 Typical Loss-Probability Relationship

The use of such an expression then provides a basis on which to determine the long term average annual loss from flooding through integration. In other words, the expected annual flooding loss will be the sum of the range of possible flood events from small but high probability events to severe but low probability events. In this analysis, consideration is given to the range of return periods from 1 in 1 to 1 in 1000 year events[3]. Mathematically, this appears as follows:

$$\text{Expected Annual Loss} = \int_{x=0.001}^{x=1} L\,dx$$

$$= \left[a \ln (x + b)\right]_{x=0.001}^{x=1}$$

$$= a\left[\{\ln(1+b)\} - \{\ln(0.001+b)\}\right]$$

3 In broad terms, it would be expected that a 1 in 1000 year event represents the upper bound of those events for which flood warning systems would be designed. In other words, for more severe events, it is very unlikely that 'systems' will be in place to ensure that all those affected can take appropriate action. However, an event of such magnitutde is unlikely to develop rapidly, except at a very localised level; therefore, time is likely to be available for warnings to be issued and disseminated, and suitable advice proferred.

Application to Case Studies

This above expression now needs to be combined with the damage cost estimates described in Section 4.4 above. This has been done for each of the Case Studies and the corresponding expected annual losses are shown in Table 4.5(f). In the absence of data on the variation of damage costs by severity of flood event, it was assumed that, as a first approximation, b=0.

Table 4.5(f) Expected Annual Losses - Case Studies

Parameter	Case Study 1	Case Study 2	Case Study 3
Return Period	1 in 100	1 in 10	1 in 250
Exceedance Probability (x)	0.01	0.1	0.004
Total Losses (L) in £ from Tables 4.5(c-e)	1.8m	193,000	15.8m
Value of 'a' (=Lx)	18,000	19,300	63,200
Expected Annual Loss (£)	124,000	133,000	437,000

As discussed above, the losses reduce with increasing 'warning time' as illustrated in **Table 4.5(g)**.

Table 4.5(g) Variation of Loss with Warning Time

Parameter	Case Study 1	Case Study 2	Case Study 3
No Warning	100%	100%	100%
2 Hour Warning	49%	81%	76%
4 Hour Warning	44%	66%	69%
8 Hour Warning	41%	58%	66%

Event Tree

The results of the work so far have provided:

- a description of flood forecasting/warning systems in general (Section 2);
- a detailed look at particular flood events (Section 4); and
- a means to evaluate flooding losses on an annual basis (above).

The next step of the analysis is to combine these into a methodology to enable one to evaluate the benefits of flood warning systems through the use of an event tree. As discussed in Section 2, the 'system' may be broken into the following stages:

1) The generation of information which leads to a flood forecast and the issue of a flood warning. Based on the discussions with the Agency Regions, it would appear that there is a general consensus that there is a high degree of reliability in correct forecasting, perhaps of the order of a 90%. In the event trees, it has been assumed that each of these "successes" has also been issued to comply with the national target of providing a two-hour warning.

2) Given a forecast, the next stage is to alert the relevant parties who need to take action (i.e. information dissemination) to ensure that full use is made of the 'warning time'. Although open to debate, it would appear that a preliminary estimate of 70% could be justified.

3) The last stage in the process is the need for those alerted to take appropriate action. Given the recent changes in responsibility for ensuring that the correct action is taken, the Agency (in general) has limited data on the actual effectiveness of flood warnings (i.e. did people take the appropriate preventative actions). However, even at this stage, it is noticeable that several regions expressed concern at the effectiveness of communications with those who might be at risk (for example, unacknowledged receipt of warnings by fax and answering machines). For the purposes of this analysis, it will be assumed that a 60% penetration will be achieved.

The probabilities of different outcomes can then be determined using an event tree. It is important to note that this provides a method for deriving an overall 'correction factor' and as such, it makes no difference mathematically, at least, whether a figure of 90% means 90% of occasions with 100% effectiveness or 100% of occasions with 90% effectiveness.

The event tree is shown in Figure 4.3. This provides a preliminary basis on which to evaluate the benefits of flood warning. As discussed later, it is envisaged that this will be refined during Phase 2 of the Study.

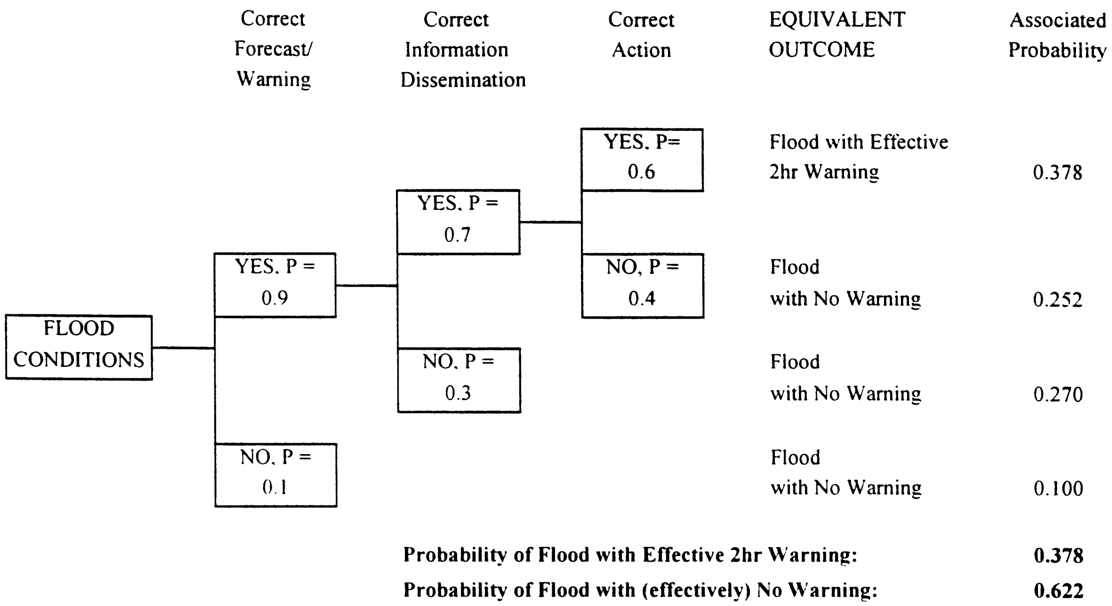


Figure 4.3 Event Tree "Normal" Flood Warning

Evaluation of Benefits

With no flood forecasting/warning systems, the expected annual flooding losses for the three case studies would be £124,000, £133,000 and £437,000 respectively (see Table 4.5(f)).

If all floods were correctly forecasted and everyone responded correctly to the associated warnings, the losses would be 49%, 81% and 76% of these values (from Table 4.5(g)). It needs to be recognised that even if recipients do nothing to save their tangible possessions, it is likely that they will suffer less intangible losses (e.g. they may be less likely to drown).

However, in reality, some benefits of the 2 hour warning are lost due to failures in forecasting, inadequate dissemination of information and, perhaps most importantly, in failing to respond correctly. Based on the event tree (Figure 4.3), it can be seen that there is an estimated 38% chance of success in achieving a 2 hour warning (i.e. in 62% of cases, the losses would be effectively the same as for a flood with 'no warning'). The benefits of the flood warning systems (in terms of losses avoided) can then be calculated as shown in Table 4.5(h).

Table 4.5(h) Benefits of Flood Warning by Case Study

Parameter	Case Study 1	Case Study 2	Case Study 3
A. Expected Annual Loss (£) with No Warning	124,000	133,000	437,000
B. % Loss with 2hr Warning	49%	81%	76%
C. Expected Annual Loss (£) with 2hr Warning (100% reliability)	61,000	108,000	332,000
D. Expected Annual Loss (£) with 2hr Warning (38% reliability)	100,000	123,000	397,000
E. Annual Benefits (£) =A - D	24,000	10,000	40,000

The Way Forward

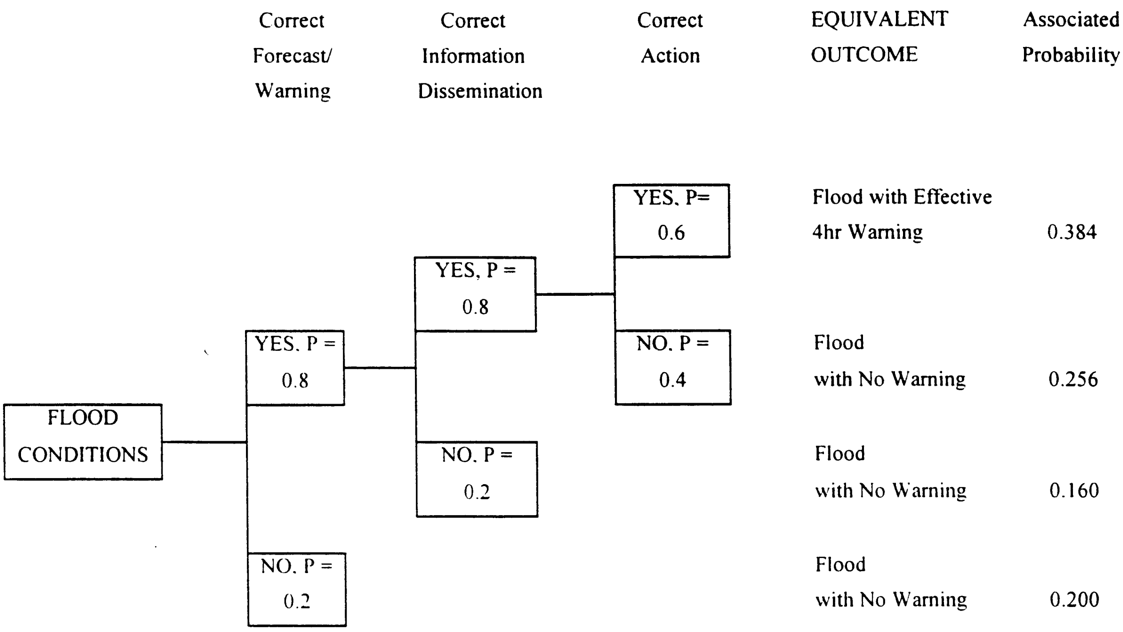
Given the results of Table 4.5(h), it can be seen that there are many opportunities to explore 'what if...?' type questions. By way of example, the following possibilities were examined:

a) increasing the warning time to 4 hours; and
b) improving the probability of correct response to a warning.

For the first option, it was considered that there would be an increased probability of correct information dissemination due to the longer time period involved. It could also be argued that the likelihood of corrective action being taken increases with lead time, but this has not been accounted for in the revisions. For the purposes of this analysis, the corresponding probability entry on the event tree was increased from 70% to 80%. However, with 4 hour 'lead time', there would be increased uncertainty in the initial flood forecast and as a result this probability entry was reduced from 90% to 80%. The revised event tree is shown in Figure 4.4, from which it can be seen that the overall probability of 'success' remains at 38%. The corresponding benefits are calculated as for the 2 hour warning as shown in Table 4.5(i).

Table 4.5(i) Benefits of 4hr Flood Warning by Case Study

Parameter	Study 1	Study 2	Study 3
A. Expected Annual Loss (£) with No Warning	124,000	133,000	437,000
B. % Loss with 4hr Warning	44%	66%	69%
C. Expected Annual Loss (£) with 4hr Warning (100% reliability)	55,000	88,000	302,000
D. Expected Annual Loss (£) with 4hr Warning (38% reliability)	97,000	116,000	385,000
E. Annual Benefits (£) =A - D	27,000	17,000	52,000
F. Marginal Benefit of 4 hr Warning Over 2hr warning (£/year)	3,000	8,000	12,000

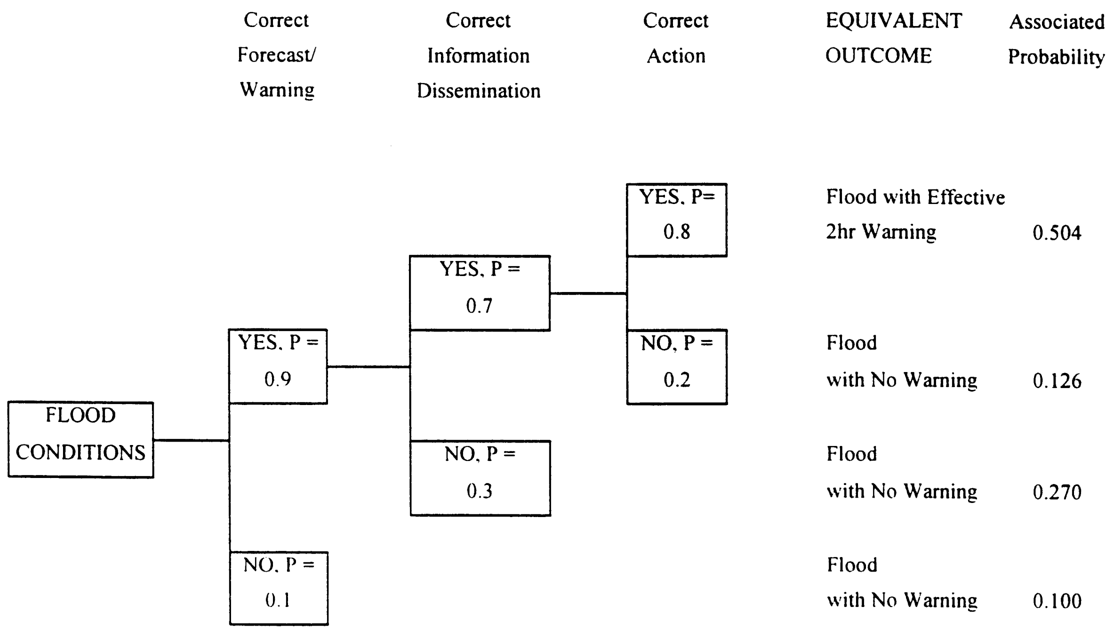


Probability of Flood with Effective 4hr Warning:	**0.384**
Probability of Flood with (effectively) No Warning:	**0.616**

Figure 4.4 Event Tree - "Enhanced" Flood Warning (Opt 1)

In other words, if the costs associated with increasing the warning time from 2 hours to 4 hours were £10,000 per year for each Case Study, the improvement would only be 'cost-effective' (i.e. benefits exceed costs) in relation to Case Study 3.

For the second case, it was assumed that consideration was being given to improving the response to those issued with a 2 hour warning. For illustrative purposes, it has been assumed that this would result in the probability entry for 'correct action' to increase from 60% to 80%. The associated event tree is shown in Figure 4.5 and the calculation of the benefits is summarised in Table 4.5(j).



Probability of Flood with Effective 2hr Warning: 0.504
Probability of Flood with (effectively) No Warning: 0.496

Figure 4.5 Event Tree - "Enhanced" Flood Warning (Opt 2)

Table 4.5(j) Benefits of Improved Response by Case Study

Parameter	Case Study 1	Case Study 2	Case Study 3
A. Expected Annual Loss (£) with No Warning	124,000	133,000	437,000
B. % Loss with 2hr Warning	49%	81%	76%
C. Expected Annual Loss (£) with 2hr Warning (100% reliability)	61,000	108,000	332,000
D. Expected Annual Loss (£) with 2hr Warning (50% reliability)	92,000	120,000	384,000
E. Annual Benefits (£) =A - D	32,000	13,000	53,000
F. Marginal Benefit of Improving Correct Action from 60% to 80% (£/year)	8,000	3,000	13,000

Interestingly, the levels of marginal benefit associated with increasing the probability of correct response are very similar to those associated with increasing the warning time from 2 hours to 4 hours. As before, if the costs associated with ensuring an improved response rate were £10,000 per year for each Case Study, the improvement would only be 'cost-effective' (i.e. benefits exceed costs) in relation to Case Study 3.

4.5.3 Discussion

As can be seen from the above analysis, there is considerable room for refinement during Phase 2 of the Study provided that sufficient data are available.

In particular, it can be seen that a pre-requisite for the Phase 2 analysis will be sufficient data to estimate the flood damages associated not only with various levels of flood warning but also with different levels of flood severity.

In relation to flood warnings, the Case Studies presented above considered the damages associated with no warning, 2, 4 and 8 hour warnings. The results indicate the greatest marginal benefits are associated with moving from no warning to a 2 hour warning. For Phase 2, there may be merit in focusing attention on shorter warning times - perhaps 30 minutes, 2 and 4 hours.

In relation to flood severities, it is considered that damage costs will have to be estimated for 3 levels of flooding (say, 1 in 3, 1 in 30 and 1 in 300 year events) in order to provide a degree of justification for the values of 'a' and 'b' used in the loss-probability expression.

Furthermore, it is envisaged that detailed examination of the Phase 2 case studies will enable the event tree to be expanded in order to explore the significance of particular components in the chain from the occurrence of initial conditions through to flood forecasts and the issue of flood warnings and the response to such warnings. By way of example, following the issue of a flood warning, it may be necessary to distinguish amongst:

- those people who receive the warning and respond correctly;
- those who receive the warning but fail to respond correctly; and
- those who do not receive a warning.

This will require modification of the 'generic' event tree which currently does not distinguish between the latter two cases, even though the levels of associated stress will differ.

Another issue which is not adequately accounted for in the 'generic' event tree is the issue of 'false warnings'. However, it is likely that this will be of secondary importance for two main reasons:

- in most regions, the issue of 'false warnings' for fluvial flooding is fairly rare; and
- although 'stress' may account for a large part of the total costs associated with flooding, much of this is 'post-flood' stress (see Figure 4.1).

The other factors also excluded from the event tree because they are considered to offer low benefits/disbenefits in relation to the difficulty of their measurement are:

- effect of "unofficial" warnings;
- environmental benefits/disbenefits;
- improved deployment of emergency staff;
- disbenefits arising from wilful damage (which can be caused with or without a warning).

4.5.4 Conclusion

The methodology described above contains many novel components which have been developed to fill a contentious methodological blank in the project appraisal map. Easy acceptance cannot be assumed. It is concluded that some wider consultation and, if necessary, initial refinement of the methodology should be conducted. Initial response from the project reviewer (Prof. R Krysztofowitcz) seems to endorse the overall approach, but proposes further development in several key areas.

The main purposes of this initial refinement stage are to:

- ensure that the logic being used is fundamentally sound and acceptable in principle;
- identify areas of weakness in terms of data availability; and
- gain some acceptance of the proposed approach.

Areas which are in need of further consideration include:

- frequency and distribution of flood events and their effect on annualised benefit estimates;
- increasing the sophistication of the loss probability curves used;
- accounting for false warnings and mobilisation costs;
- allowing for the effect of a range of warning lead times around the target/design time.

It is also considered necessary to explore ways of extending the event/decision tree by inclusion of factors relating to effectiveness of response. The extension can be done theoretically as part of the initial refinement process, or as something to be explored during the course of the Case Studies.

The proposed methodology should be reviewed critically and its various components assessed in terms of their robustness (ie the validity of the assumptions used and the quality of the data used to develop the key parameters). This should be accomplished as a desk exercise, but including consultation with leading practitioners in the field. It may also be appropriate at this stage to consult MAFF and obtain an indication of their reaction and attitude towards the proposed approach.

5. CASE STUDIES

5.1 Introduction

The Project Specification requires that a number of case studies be identified and up to eight suitable ones be selected for evaluation of the recommended assessment methodology in Phase 2. Collectively, these studies should represent a range of flood warning circumstances, with the emphasis being on short lead times.

During the course of the research, a number of criteria for selection have been identified and discussed. These selection criteria are presented in 5.2 below.

Also, discussions have been held with representatives in each of the Regions in order to identify initially a long list of possible case studies; these were then narrowed to a shortlist of one per region. Brief details of the circumstances obtaining at each site were also discussed, and are related below.

5.2 Selection Criteria

5.2.1 Overview

A number of criteria can be used to identify potential case studies; these are:

- a geographical spread across England and Wales;
- coastal and fluvial;
- natural events (ie overtopping) and "artificial" (eg breach or blockages);
- short and long lead time situations;
- recent and old events;
- different types of forecasting/warning scenarios; and
- data available.

A brief commentary of what are perceived to be the major factors is given below.

5.2.2 Geographical Spread

The Agency's jurisdiction covers England and Wales and thus embraces a very diverse range of hydrological, climatic, topographic and ground conditions. The Institute of Hydrology (IoH) Flood Risk Map of England and Wales (Institute of Hydrology 1996) shows that risk of flooding exists at many points around the coastline and along lengths of main river throughout the country. Consequently, it is proposed to select one case study per Region in order to ensure adequate representation across the country.

5.2.3 Coastal and Fluvial

Flooding from the sea is significantly different in character from river flooding. It is easy to predict astronomical high tides, although difficult to forecast whether these will coincide with meteorological events which might together conspire to cause flooding. In contrast, fluvial flooding is generated by a combination of meteorological and ground conditions. It is essential therefore to have both types of flood represented.

A further complication is, however, that coastal flooding on the west coast is much harder to forecast (and therefore provide a warning for) than on the east coast, due to the unpredictability of the Atlantic Ocean. In contrast, coastal flooding on the east coast can be more easily forecast because of the slow and predictable build up of water levels as the high tide moves southwards along the coastline. Therefore, examples of both east and west coast flood forecasting/warning scenarios are needed.

5.2.4 Natural and "Artificial" Events

A natural flood event is defined as a flood whose cause is due to exceedance of the carrying capacity or overtopping of defences. In contrast, an "artificial" event is one in which the flood is caused by a failure of man-made defences or structures (eg through a breach or blockage). The former is inherently easier to forecast than the latter.

Data on this aspect of flood warning and forecasts may be sparse. However, these two types of events can be styled as long lead time and short lead time events respectively. It may therefore be unnecessary to consider these independently; the focus is on flood warning and forecasting, and not flood causes.

5.2.5 Length and Predictability of Lead Time

Lead time is clearly a key factor and the Project Specification suggests an emphasis on short lead time situations. The length of lead time will be a function of both the nature and location of the flood risk area, and the type of hydrological event (eg thunderstorm, frontal system) to which they might be subjected.

5.2.6 Length of Time Since Last Event

Although recent events might provide reasonable data on tangible costs, it is likely that the "older" events will provide for better sources of data on intangible effects such as chronic health effects. In some cases, the event may be hypothetical, that is providing against an eventuality which has not yet occurred. An example of this may be flooding of say Thamesmead if the flood embankments along the Thames Estuary were overtopped or breached.

5.2.7 Different Types of Flood Forecasting and Warning Scenarios

In order to test the proposed economic benefit assessment methodologies, a range of different propositions are required. Examples include:

- moving from a two-hour warning to a four-hour warning
- assessing the cost:effectiveness of proposed methods where the extent and number of beneficiaries is small or well spread.

5.2.8 Data Availability

It is anticipated that, in order to carry out the assessments, various types of data will be needed. These include data on:

- hydrology and hydraulics;
- demography;
- effects of past events: and
- performance of previous flood warning/forecasting systems.

Whilst there are benefits in identifying case studies where all or some of such data exist, there is merit in also including cases where data are sparse and/or expensive to collect.

5.3 Selected Case Studies

5.3.1 Long List

A long list of possible candidates was identified by a series of telephone discussions with an individual in each Region. This long list is included in Table 5.3. This was subsequently reduced to eight during the regional survey and further adjustments made after discussion with locally-based staff.

5.3.2 Anglian Region

(a) Site Selected

The site selected from the Anglian Region is a section of the north Norfolk coast between Holme-Next-The-Sea and Sheringham.

(b) Local Circumstances

The site selected is a low lying area of coastal plain which is exposed to flooding from the sea. There is no risk from fluvial flooding. The area at risk is extensive, and includes the villages of Salthouse, Cley and Brancaster, areas of salt marsh and a golf course. The number of properties within the area is of the order of 4-500.

Table 5.3 Long List of Case Study Candidates

Region	Nomination	Comment/Description
Anglian	1. Norfolk Coast/R Bure 2. Eastwood Brook 3. Waveney	East coast flood, plus fluvial. V. short lead time, highly urbanised. Long-lead time, fluvial.
Midland	1. Soar Valley 2. Shrewsbury/R Severn 3. Nottingham/R Trent	FAS not justified, FFWRS being considered. FAS not justified. FFWRS in place. Large area at risk, last flooded in 1947.
North East	1. Upper Calder 2. February 1995	Recent application to MAFF for grant towards equipment to improve FFWRS. Region-wide event with post event research.
North West	1. Appleby/R Eden 2. Wildboarclough 3. Regional Telemetry	Benefits from warning, last flooded in Feb 1995. Non-main river, very short lead time event in 1988. Recently got approval for grant on new telemetry (ie cost benefit analysis completed).
Southern	1. Chichester/R Lavant 2. East Cowes	Surprise event in 1993/94. Tidal situation; small scale; amenity interests.
South West	1. Polperro 2. Buckleigh/R Exe 3. Weymouth	Limited warning system (sirens) in place. Regular flooding, small scale. Likely to be "unofficial" forecasting system. Small scale, urban situation. Complex hydrology.
Thames	1. Cripsey Brook/R Roding 2. Mimshall Brook 3. Maidenhead 4. Silk Stream	Rural area and villages, short lead time. Urbanised catchment, short lead time, FFWRS being installed. Well-researched, long lead time. Highly urbanised, short lead time, recent event which caused major disruption.
Wales	1. Towyn 2. S E Valleys	West coast event with lots of data. Short lead time events, mainly rural areas.

The more urbanised areas benefit from protection afforded by tidal defences, but the marshes and other undeveloped areas rely on shingle banks. Effective standards are considered to be between 1 in 100 and 1 in 5 years for developed and undeveloped areas respectively.

A flood event occurred in January 1996 which resulted in areas of land being flooded and roads being under water for some time. Flood warnings were issued.

High tides and surges are relatively easy to predict on the east coast and generally a four hour warning can be given, but risks of flooding through overtopping and damage to soft defences remains high and difficult to forecast with sufficient confidence to give an adequate lead time.

(c) Scenario to be Assessed

The situation to be assessed is - what are the benefits of improving forecasts of wave height (and thus risk of overtopping and damage) in terms of more accurate warnings.

(d) Justification for Choice

This proposed study offers some interesting features. These include:

- a live and recent event of some magnitude;
- an example of an east coast flood;
- a situation where warnings with a reasonable lead time can be achieved already but extra accuracy could be gained if wave height forecasts were better.

5.3.3 Midlands Region

(a) Sites Selected

Following discussions with the Area-based staff, it is proposed that a rural example is taken. Therefore, the site selected is a reach of the River Severn in the Welsh Hills between Llandinam and Glandulais.

(b) Local Circumstances

The catchment upstream of the selected reach is mountain and moorland with a high annual rainfall. During periods of low or zero soil moisture deficit, run-off can be rapid, leading to peaky hydrographs and rapid onset of flooding.

Flood events occur regularly - 8 to 10 times per year, mainly over the winter. The area affected is relatively small - about 2km^2 and is all farmland. Virtually all the land is grassland for conservation and grazing for sheep.

Although there is a telemetry point upstream of the target catchment, which can give warnings of rising levels, the lead time is limited to at best about one hour. Flood warnings are issued via AVM to flood wardens who then contact affected farmers direct.

(c) Scenario to be Assessed

The question to be addressed is - to what extent would benefits be increased by an improvement in lead times.

(d) Justification for Choice

This case study has been selected because:

- it is typical of a large number of situations encountered in rural parts of the country, particularly in uplands;
- an investigation may help explore the limits of what is cost:beneficial in small areas with low damages but frequent occurrences;
- there are likely to be "unofficial" warning systems operating alongside the Agency's.

5.3.4 North East Region

(a) Site Selected

The site selected in the North East Region is the Upper Calder catchment.

(b) Local Circumstances

The upper reaches of the Calder drain areas of moorland which receive high levels of precipitation, often in the form of snow. The valleys though which the Calder and its tributaries run are steep and deeply incised. This means that, during periods of snowmelt or heavy rain onto sodden or frozen ground, flash flooding can occur.

The catchment has a number of telemetry points including three rain gauges, and one flow recorder. Despite this coverage, warnings of onset of flooding have virtually a zero lead time. The warnings which can be given are effected through sirens located in the key places at risk - Todmorden, Hebden and Mytholmroyd. Property at risk includes a wide range of commercial and industrial premises, plus houses.

(c) Scenario to be Assessed

North East Region has already undertaken an evaluation of the existing flood warning circumstances and are about to move towards a phase 2. This will assess the feasibility of a better FFWRS, which will allow them to offer a two-hour warning and put forward design specifications. This feasibility study will form the basis of an application for grant aid from MAFF. The case study can be used to compare the methodology used in the feasibility study with that described in Section 4.

(d) Justification for Choice

The selection of the Upper Calder provides a good example of:

- a situation for which the benefit assessment methodology is specifically designed;
- short lead time flooding warning problem;
- mix of properties at risk.

5.3.5 North West Region

(a) Site Selected

The River Eden at Appleby, Cumbria, is nominated as the North West Region's case study.

(b) Local Circumstances

Upstream of Appleby, the catchment is mainly moorland and hills, with a capacity to slow run-off when not saturated. The area, however, experiences high precipitation and during periods of snowmelt or low/non-existent soil moisture deficits, run-off can be fairly rapid. A hydrological model of the catchment is available.

Flood warnings are issued by the Agency to the inhabitants of Appleby when necessary, with a reasonable (2 to 4 hour) lead time. A siren system is in place to alert people to the likelihood of flooding.

The most recent serious events in Appleby occurred in January and February 1995. These were considered to be a 1 in 25/30 and 1 in 15 year events respectively. The area at risk is well defined and about 80 properties were affected in the larger event, including a good mixture of residential and small-scale commercial properties.

A FAS has since been constructed but protects the left bank only. Its operation is predicated on the erection of temporary flood gates at times of expected high flows, but there is a residual risk of overtopping. Local resistance to a proposed scheme meant that the right bank remains unprotected. The flood forecast and warning system is therefore still maintained.

(c) Scenario to be Assessed

It could be argued that, with the FAS in place on the left bank and a scheme for the right bank rejected, that it is not cost:effective to continue to operate a FFWRS. An assessment could therefore be made of the disbenefits likely to occur if the current flood warning service was to be withdrawn, relative to the benefits from continued operation.

(d) Justification for Choice

The Appleby flood risk area is of interest because:

- it is an example of a situation where flood warning benefits will accrue without public intervention;
- it will address the issue of disbenefits of withdrawal of a service (even if this is hypothetical);
- it is clearly an area in which levels of local awareness of flooding are high but one in which the construction of a FAS may have caused people to assume that flooding will not recur;
- of variable lead times.

5.3.6 Southern Region

(a) Site Selected

The proposed case study location is Cowes, on the Isle of Wight.

(b) Local Circumstances

The outlet of the River Medina divides the two communities of Cowes (on the left, west bank) and East Cowes (on the right bank). The frontage is separated from mainland Britain by The Solent. Tidal patterns are complex because of the interaction between conditions in the Channel and the Solent, storm surges, and wind directions.

Properties on both banks of the Medina are at risk of flooding, but of differing character. East Cowes experiences surface water flooding when drains back-up during high tides. The impact of these floods is limited to flooding of roads, the curtilages of commercial property and some houses.

More is at risk in Cowes itself, the High Street being vulnerable at certain combinations of tides, surges and wind direction. The last significant event was in 1989. The properties affected are mainly retail outlets which are typically left vacant at night. It is an affluent area, commonly frequented by residents and tourists alike.

Tidal flood forecasts for the area are based on conditions observed in, and modelled for, the Channel. These ignore the effect of the Solent and warnings are issued with a low level of confidence. Therefore, the Agency does not issue Yellow warnings, only Amber and Red. Consequently, the proposed solution for Cowes is the construction of a Flood Defence scheme. This has been approved and construction will start within the next year or two.

(c) Scenario to be Assessed

The Agency Southern Region will need to decide what level of flood warning service should be provided to the two communities when the flood defence scheme is complete.

(d) Justification for Choice

This example provides a tidal situation where forecasting is difficult and therefore confidence is low. Its inclusion allows the methods used for assessing benefits of flood defence schemes and FFWRS to be applied in parallel and the results to be used for informing strategic decision-making.

The technology for improving the forecasts has not been considered but it may proffer benefits to a larger area than just Cowes. Such an example will allow the issue of benefit area to be considered.

5.3.7 South West Region

(a) Site Selected

The area selected for study is Weymouth.

(b) Local Circumstances

The catchment of the River Wey has some unusual characteristics, comprising areas of both clay and chalk. This creates a complex surface and sub-surface hydrology, with floods arising from resurgence of ground water through artesian wells. The mechanisms at work within the catchment are not well understood, making flood forecasting and issuing of warnings difficult to effect accurately.

Flooding last occurred in 1994 and substantial damage was caused to residential property (some 50 houses) and through disruption of road traffic. Following the flood, a FAS was considered but was found to be unjustifiable on cost:benefit grounds. Consequently, South West Region would like to introduce and operate a flood warning system.

A limited system is already in operation, but depends on data from a rain gauge at the top of the catchment and a flow gauge about halfway down. The flow gauge is, however, soon by-passed during high flows and, as suggested above, some of the main flows contributing to floods occur below ground.

Outline plans to assess the benefits of operating a warning system were drawn up but never undertaken because of the perception that the cost of assessment may be disproportionately high relative to the scale of benefits to be realised.

(c) Scenario to be Assessed

The proposition to be assessed is what benefits would be realised if the Agency were to introduce a FFWRS which enabled a flood warning to be issued two to four hours ahead of the event.

(d) Justification for Choice

The Weymouth example encapsulates many of the circumstances commonly encountered when considering a FFWRS:

- complex catchment characteristics means that accurate forecasting in sufficient time to be of value is difficult;
- the cost of assessing benefits, unless "standard" data can be used, is likely to be high relative to scheme benefits.

This case study would also provide an opportunity to gather data relating to long-term intangible effects of flooding, from which benefits of flood warning could be derived.

5.3.8 Thames Region

(a) Site Selected

The area proposed for study is the floodplain of the Silk Stream, a tributary of the River Brent in north London.

(b) Local Circumstances

The catchment concerned is relatively small but highly urbanised; it incorporates parts of Hendon, Edgware and Stanmore. The urban nature of the catchment means that run-off is extremely rapid and so property is vulnerable to flooding following heavy rain, particularly thunderstorms. Warning lead times are therefore very short, despite good coverage of rain and flow gauges.

In September 1992, one such event caused substantial flooding. Effects of the flood were severe, and included:

- loss of electricity supply to, and flooding of, a major hospital (causing closure of the cardiac unit);
- disruption to traffic on several major arterial roads (North Circular, Edgware High Street);
- damage to residential and other properties.

The high density of developments along, and concentration of service conduits along and across, the floodplain corridor prohibit construction of defences. However, benefits of issuing a warning (even if only of one hour) could be substantial. It should be accepted, however, that the technology to make such a forecast possible may not yet exist.

(c) Scenario to be Considered

A theoretical economic benefit (because it may not yet be possible to realise it) of a one hour flood warning should be assessed against the current situation of, in effect, no warning.

(d) Justification for Choice

The Silk Stream is particularly interesting because of the:

- very short warning lead times;
- nature of the properties at risk (and indirect threats to human life and health);
- opportunity this provides for assessed benefits to be used as a yardstick to determine what technical development costs can be justified.

5.3.9 Welsh Region

(a) Site Selected

The suggested site is Towyn, on the North Wales Coast.

(b) Local Circumstances

The major tidal flood of 26th February 1990 has been reported extensively elsewhere and it would not be possible to do full justice to the event in this report. One of the key factors identified in these reports has been the trauma which victims faced during and after the event (Welsh Consumer Council, 1992). This significantly influences current flood warning practice.

The Towyn incident arose from a breach of a sea embankment during a period of high tide and a storm surge (although not an extreme event in either case). In most cases the defences are adequate to prevent inundation in such circumstances. However, the forecasting system, and the regular inspection of defences by Agency staff which precedes an anticipated event, cannot identify where and when a breach might occur.

The sensitivity of local attitudes to flood risk means that warnings are issued whenever there is a heightened risk of breaching. This leads to frequent "false warnings" which ultimately may erode public confidence in the warning system, and cause undue stress in individuals traumatised by the 1990 flood.

(c) Scenario to be Assessed

An assessment could be made of the economic disbenefit of false warnings.

(d) Justification of Choice

Towyn is nominated because:

- it provides an example of a west coast flood risk area;
- much data have been accumulated about the 1990 event, including a lot of information on intangible aspects;
- it provides an opportunity to consider the disbenefits of false warnings.

5.4 Summary

A summary table (Table 5.4) demonstrates the range of different conditions covered by the proposed case studies.

Table 5.4: Summary of Case Studies and Range of Features

Region	Location	Coastal E = East W = West	Fluvial	Natural (N) or Artificial (A)	Lead Time[1]	Date of Key Event	Data Availability[2]	Scenario
Anglian	Norfolk	E		N	L	Jan 1996	M	Marginal benefits of improving accuracy of forecast.
Midlands	Glandulais		√	N	S	Annually	S	Benefit of improving lead time in rural, frequently flooded area.
North East	Upper Calder		√	N	M	Not known	M	Application for grant aid for FFWRS being prepared.
North West	Appleby		√	N	M	Feb 1995	M	Disbenefits of service withdrawal.
Southern	East Cowes	E		N	M	1989	S	Aid to strategic decision-making.
South West	Weymouth		√	N	S	1994	S	Assessing benefits to small communities.
Thames	Silk Stream		√	N	S	Sept 1992	G	Benefits of Improving warning lead time to one hour.
Wales	Towyn	W		A	S	Feb 1990	G	Disbenefits of false warning.

[1] S = Short (under 2 hours)
M = Medium (2-4 Hours)
L = Long (4 hours plus)

[2] G = Good
S = Sparse
M = Mixed

6. PROGRAMME FOR PHASE 2

6.1 Strategic Approach to the Conduct of Phase 2

The main conclusion to be drawn from Section 4 above is that delivery of flood warnings can offer substantial tangible and intangible economic benefits. Research has shown that, in broad terms, the service costs about £4m (regional survey) to operate but could be capable of delivering up to £15m in tangible benefits from fluvial flooding alone (Heijne et al 1996). However, the techniques for quantifying these benefits are not well-developed.

Assessment of the benefits of flood alleviation is, in contrast, quite well developed. The Blue, Red and Yellow manuals collectively provide both a range of benefit assessment methods which the user can select as appropriate to the circumstances under consideration, and sets of standard data which can be used as appropriate. The techniques recommended therein have become the industry norms, and in effect have to be followed in order to satisfy MAFF in grant aid applications (MAFF 1993a).

If flood forecasting and warning scheme benefits are to be afforded the same recognition and acceptance as those for flood alleviation, then it appears logical to adopt a strategy which will lead to the production of a similar manual of assessment techniques. Whether all of this should be within Phase 2, or whether the work should be divided into say Phase 2 (case studies) and Phase 3 (preparation of a manual of techniques) is a subject for internal debate within the Agency.

A further consideration is MAFF's role. Obviously, it would be appropriate to enlist their support (as possible co-funders of the research) and commitment to the development. This would be done with a view, ultimately, to gaining their acceptance of the techniques as valid for evaluating FFWRS benefits.

The stance taken in describing the programme for Phase 2 is that this strategic course will be followed. Bearing in mind the scale of the tasks, the proposed approach and methodology is given in outline only. The programme thus becomes more of an "operational requirement" document than a specification. A final section is included which gives options for how the work might be progressed in a contractual sense. The section is written so as to allow it to be treated as a stand alone document; this means that there is a (small) element of repetition of material presented earlier.

This research should also draw on information obtained by the Agency elsewhere; for example a project has recently been let to collect baseline data on public awareness of flood risks amongst the general public and inhabitants of flood plains. Data will also be collected from flood victims immediately post-event. Both sets of data will be valuable additions to the data needed to operate a cost effective methodology for assessing benefits of flood forecasting and warning.

6.2 Introduction

The Environment Agency (the Agency) is a major environmental protection agency charged with safeguarding and improving the natural environment. The Agency's main responsibilities include the protection of life and property from flooding. The Agency has a national research and development programme, aimed at improving the effectiveness and efficiency of the Agency's services. It is co-ordinated by Head Office with individual projects managed from the Regions.

6.3 Background

As part of its general duty to protect life and property from flooding, the Agency aims to provide adequate arrangements for flood forecasting, warning and responding to flood events. Consequently, in seeking to realise this aim, it will install and operate Flood Forecasting and Warning Systems. However, it is required by government to demonstrate that the costs of its activities are economically justified. For capital investment this is usually demonstrated through Cost Benefit Analysis.

Techniques for assessing the economic benefits of flood forecasting and warning are not well-developed. Three areas in particular are poorly understood:

- in situations where the flood warning lead times are short;
- the manner in which people react when warned of a flood, and what factors determine the effectiveness of their reaction; and
- the intangible benefits derived in terms of reduced human impact (alleviation of stress, reduced medical treatment costs) from a flood warning being received.

The Agency has therefore identified the need for further research and development in this area generally and the two areas noted above in particular.

An initial phase has been undertaken with a view to:

- identifying what methods have been used to assess benefits of flood warning and forecasting;
- assessing their suitability for use by the Agency; and
- identifying a series of case studies which can be used to test the recommended methods.

The second phase of the work, to which this section relates, will be to undertake the case studies using the recommended methods and report on the outcome.

6.4 Objectives

6.4.1 General Objective

The general objective for the project is to evaluate the tangible and intangible benefits associated with the provision of a flood forecasting and warning service, in order to enable the Agency to make sound decisions when consideration is given to modifying the service.

6.4.2 Specific Objectives

These are to:

- identify the geographical boundaries to the nominated case studies;
- characterise and define the scenario to be tested within each case;
- agree a detailed methodology with the Agency's Project Manager for undertaking an assessment of economic benefits of the new scenario relative to a defined baseline;
- undertake the assessments;
- prepare a critique of the assessment methods used;
- prepare a report which can serve as a guide to assessment methods and, where appropriate, contains standardised benefit data.

6.5 Methodology

6.5.1 Introduction

The methodology which has arisen out of Phase 1 has been developed in response to a perceived shortfall in available methodologies, particularly in respect of intangible benefits. It has only been tested to a very limited extent on three semi-hypothetical case studies during the course of this project. It should, prior to initiation of Phase 2, have been subjected to wider exposure, critical review and refinement. Assuming the method has been found to be sufficiently robust, the refined methodology could be more fully tested by seeking to apply it to some or all of the selected case studies.

6.5.2 Stage 1 - Conduct of the Case Studies

The conduct of the case studies will provide an opportunity to both collect data on the effects (both tangible and intangible) of issuing flood warnings and to test the methodology in real situations. However, the way in which the method is to be applied should be allowed to vary in relation to the unique circumstances obtaining at each location. It will therefore be necessary to define a detailed methodology for each separate case. An outline methodology is proposed for each of the 8 cases, but it is proposed that this be developed further in the proposals which come forward from potential contractors.

It is assumed that, as this is a theoretical (though hopefully producing results which will have some value in practice) exercise it is acceptable to assess scenarios which are not technically achievable at present. The analysis can be a CBA in reverse ie an assessment of benefits which indicates how much the Agency could afford to spend on improving its forecasting and warning systems.

The methodologies for conducting the case studies should not necessarily be constrained by the scale of the situation being assessed. However, researchers should take care to note the degree of effort involved in each case and propose ways in which the assessment can be conducted in a manner which will generate assessment costs proportionate to the likely scale of benefits.

The values attributed in the proposed model to the different scenarios (in the three Phase 1 Case Studies) are a result of internal discussions and a literature review, but it may be possible to assign subjective phrases (as used in earlier work by MUFHRC in post flood stress research) to the sliding scales. This would then form a unified approach for use in the full scale case studies described below. It would also be appropriate to include, where possible, questions to actual and potential flood victims of what they would consider to be the maximum lead time for a warning, and what benefits would accrue from warning in excess of, say, 8 hours.

Anglian Region

It will be necessary to establish a baseline position in terms of both tidal flood risk and area affected (including the land use within this area and information on the population). The Area staff would be required to provide detailed information on current predictions and their accuracy through examination of past records and discussions with operations staff. Discussions with hydrologists should establish the improvements in forecasting which are possible (even if only theoretically) and the consequent improvements in flood warnings (both in terms of accuracy and lead time) which could be achieved. The benefits assessment model can then be run on the enhanced flood warning values. It is considered unlikely that a detailed site or public survey will be needed.

Midlands Region

This case study should be conducted with minimum effort, ie as a desk exercise. Details of flood frequency, extent of area affected and the typical land use should be derived from discussions with local Agency staff. It will be necessary to gain information on what activities farmers would undertake given a two hour warning as distinct from virtually no warning (or at best say 30 minutes). This could be achieved by a telephone survey of farmers in the area, using a simple structured questionnaire.

North East Region

Timing of this case study should ideally follow on from the assessment to be done by North East Region in order to justify enhancements to the Flood Warning service in the area. It should be assumed that this work will provide an accurate reflection of the benefits insofar as tangible benefits are concerned. The case study should therefore focus on extending the work to include intangible benefits. Therefore, consideration should be given to undertaking analyses based on demographic data and public surveys in order to provide information which can be 'fed' into the assessment model. The scope of the questioning will depend to some extent on the number of people affected and the history of the flooding problem (time since last event, degree of impact etc).

North West Region

This case study provides an opportunity to bolster the knowledge about how businesses respond when issued with a warning, and so provision should be made for a personal interview survey of managers of businesses which were affected by flooding. It may also be possible to extend this to include some members of the general public in order to assess the extent to which complacency about flooding may have set in after construction of the FAS. During the course of the survey, information on what is at risk in the protected area (and, in the case of the right bank, unprotected area) should be obtained so that a detailed assessment can be made of both tangible and intangible effects of the warning.

Southern Region

Data should be obtained on the evaluations done to justify the Flood Defence Scheme; it is anticipated that this will contain information on the benefit area and the property and human components within it. The area in question may extend beyond the limits of Cowes/East Cowes and include other communities around the Solent. There is no recent history of flooding here, so a personal interview survey is likely to be limited in value in generating data on flood warning benefits, except in a hypothetical sense or if long-term residents can be identified and interviewed. Discussions with local staff should be conducted to characterise the current situation and provide some assessment of the accuracy of flood warning at different lead times. A current situation and possible future situation could then be synthesised for benefit evaluation using the model.

South West Region

This is another case where the area at risk is possibly too small to justify major expenditure on assessing the benefits of flood warning. However, the advantage of research is that it allows expenditure which is disproportionate to the direct results, because the results can be extrapolated to similar situations elsewhere. Consequently, a public survey should be contemplated which would seek to obtain information about:

- long-term intangible effects of flooding on victims;
- how people might react if threatened by further floods, distinguishing between those with experience of floods (long-term residents) and those without (new residents);
- comparisons with the likely out-turn with short and long lead times.

Thames Region

The Thames Region's case study offers some unique features in having a recent event of significant scale with major adverse effects. The opportunity should be taken of gathering data of interest to both flood defence justification and flood warnings. Given that virtually no warning was given to some victims and limited warnings to others, it provides opportunities to explore the relative merits of short lead time warnings (ie 30 minutes versus 2 hours). Therefore, a detailed assessment of those effects should be undertaken using site surveys and comprehensive questioning of those affected, particularly in the hospital. Data should be obtained on how people reacted and how they would have reacted given a longer warning.

Welsh Region

This case study will need to be conducted sensitively. A preliminary to any field work should be a review of the data already obtained from flood victims about the 1990 event. Data about the frequency with which warnings have been issued since should be obtained and compared with actual events in order to identify the occurrence of 'false warnings'. Research should then be conducted amongst the public authorities involved and a sample of those affected by the 1990 event. The research should be oriented towards validating the relative weighting of factors assumed in the proposed assessment model and the changes which a warning might bring about: in addition attitudes to 'false warnings' and their affect on those previously traumatised by the major flood could be sought.

6.5.3 Stage 2 - Reporting of the Results

The results of the case study should be reported in full on a case-by-case basis, and including a critical appraisal of the proposed methodology, its cost-effectiveness as a tool in a variety of situations and identification of any improvements which might be implemented.

6.5.4 Stage 3 -Production of a Manual of Techniques and Associated Database

The case studies should provide the basis for the production of a manual of Flood Warning Appraisal Techniques. They, together with data from the market research exercise referred to at the end of Section 6.1, will also provide a set of standard data of potential value to future users of the assessment techniques. It is recommended, therefore, that this knowledge is incorporated within a manual along similar lines as the three MUFHRC Manuals.

6.6 Timescale

The programme of work outlined above is substantial and sufficient time should be allowed for its completion and contemplation of the results at each stage. The following timetable is envisaged:

Stage 1 - Conduct of the Case Studies	12 months
Stage 2 - Reporting of the Results	2 months
Stage 3 - Production of a Manual	7 months

In total, this is a 21 month timetable, but the elapsed time may be extended to a significant degree by consultation, refinement and procurement mechanisms.

6.7 Project Management

6.7.1 Contractual Arrangements

It is assumed that the work will be let by competitive tender in stages using the normal Agency procurement procedure. It would be appropriate to consider combining Stages 1 and 2 into one contract, whereas Stage 3 could be let as a separate contract; this may be especially pertinent if MAFF support and funding is sought.

Stage 1 described above represents a significant amount of work and consideration could be given to dividing the work into two research contracts let to different contractors but running in parallel. This has certain advantages such as the ability to test the methodology across a wider spectrum of users, and to reduce risks associated with 'putting all your eggs in one basket'. It does also incur disadvantages such as complexity of project management, duplication of effort and potential rivalry between contractors. It may be appropriate to present contractors with the options and judge the most feasible approach on the basis of tenders received.

6.7.2 Internal Agency Arrangements

The proposed research is far reaching in its consequences and complex in its implementation. It is proposed that the following project management structure be adopted:

Project Director	Senior Manager with overall management responsibility for direction and completion of the research
Project Manager	Middle level staff member with a day-to-day management role
Steering Group	Mix of hydrologists, flood warning and flood operations staff to assist the director in guiding the research
Area Contacts	Individuals with knowledge of, and responsibility for, flood defence in the case study areas

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