RIBAMOD

River Basin Modelling, Management and Flood Mitigation

Final Report

Prepared by

P G Samuels

Project Co-ordinator

EC contract number ENV4-CT96-0263
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Contract

The RIBAMOD Concerted Action was funded by the European Commission (EC) Directorate General for Science, Research and Development (DG XII) under the Hydrological Risks component of the Environment and Climate Programme in the European Union Fourth Framework Programme. The parties to the contract were the European Commission and HR Wallingford and the EC Contract Number was ENV4-CT-96-0263. The project coordinator was Dr P G Samuels of HR Wallingford and the EC Scientific Officer in charge was Dr R Casale from May 1996 to June 1998 and Dr P Balabanis thereafter. The contract commenced on 1 May 1996 and finished on 31 October 1998. The HR Wallingford project numbers for the work were RRS0155 and RRS0156.

The RIBAMOD Steering Group consisted of representatives from the project partners

- HR Wallingford
- Danish Hydraulic Institute
- Delft Hydraulics
- National Technical University of Athens
- Potsdam Institute for Climate Impact Research
- University of Padua

In addition the Environment Agency provided additional support for the activities of HR Wallingford as project coordinator from the National R&D programme on flood defence. The Environment Agency project number was W5A (96) 08. The Agency representative was initially D Pettifer, who was replaced by B Empson during 1997. Dr P G Samuels was the HR project officer for the Agency contract and the HR project number was RRS0205.

The publication of this report does not imply any endorsement by the European Commission or the Environment Agency of the conclusions and recommendations in the report.

Prepared by ....

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(Title)

Approved by ....

(name)

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(Title)

Date..

Summary

RIBAMOD

River Basin Modelling, Management and Flood Mitigation

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The RIBAMOD Concerted Action was funded from the Fourth Framework Programme by the European Commission and lasted from May 1996 to October 1998. Five Expert Meetings and Workshops were held during the course of the Concerted Action. This final report presents the conclusions and recommendations of the Concerted Action, expanding upon the headline conclusions published in a separate project brochure. The Concerted Action covered the following topics:

- model structure and decision support
- current policy and practice
- integrated systems for real time flood forecasting and warning
- impact of climate change on flooding
- sustainable river management
- the exceptional flood on the river Oder in Summer 1997

Although the events covered different topics the discussion often turned on similar key issues these included

- the recognition that flood mitigation requires cross-disciplinary working from several professional groups
- that flooding problems have considerable social dimensions and engineering solutions are not always appropriate or possible
- the uncertainty which climate and other environmental change is bringing into flood management
- the need to use risk assessment in flood management

During the Concerted Action the outline of holistic flood management emerged as a sequence of
<u>Pre-flood activities which include:</u>

- flood risk management for all causes of flooding and disaster contingency planning,
- construction of physical flood defence infrastructure and implementation of forecasting and warning systems,
- land-use planning and management within the whole catchment,
- discouragement of inappropriate development within the flood plains, and
- public communication and education of flood risk and actions to take in a flood emergency.

<u>Operational flood management which can be considered as a sequence of four activities:</u>

- *detection* of the likelihood of a flood forming (hydro-meteorology),
- *forecasting* of future river flow conditions from the hydro-meteorological observations,
- *warning* issued to the appropriate authorities and the public on the extent, severity and timing of the flood, and
- *response* by the public and the authorities.

<u>Depending upon the severity of the event, the post-flood activities may include:</u>

- *relief* for the immediate needs of those affected by the disaster,
- *reconstruction* of damaged buildings, infrastructure and flood defences,
- *recovery and regeneration* of the environment and the economic activities in the flooded area, and
- *review* of the flood management activities to improve the process and planning for future events in the area affected and more generally, elsewhere.

Each of the conclusions is linked into the discussion and the papers presented at the Concerted Action events and they are presented under the themes of

- River Basin Modelling
- River Basin Management
- Flood Mitigation

Following the presentation of the conclusions, there is a summary of future challenges for research, development and practice. Appendix 1 gives summary administrative information for the Concerted Action. The proceedings of each of the RIBAMOD events are published by the European Commission and the contents for each volume is given in Appendix 2

Contents

1. INTRODUCTION – WHAT IS RIBAMOD

At the close of the Second RIBAMOD Workshop, Professor Jim Dooge, reminded the participants of the purpose and importance of the Concerted Action (Dooge & Samuels, 1998)

"In the midst of all the exciting technical and scientific issues raised during the workshop, it is important for us not to lose sight of why the European Commission has funded the RIBAMOD Concerted Action. These workshops and expert meetings have been sponsored because we, in the scientific community, have been set the task of responding to a real social problem which affects the quality of life of many European citizens. Indeed flooding from all causes is the most significant natural disaster world-wide with over 200,000 human lives being lost in floods in the decade between 1986 and 1995 (Munch Re, 1997) and over 10,000 in 1997 (Munich Re, 1998). Each one of these deaths has been a tragedy for the family involved. More than this, those who survive the flood may suffer prolonged health problems or face financial ruin through the loss of home, possessions and livelihood."

1.1 A brief international perspective on flooding

In recent years much attention in the European and International media has been given to floods. For example, in France 42 people died in 1992 during the flash flooding in Vaison-la-Romaine, basin wide floods caused widespread disruption and losses in the Rhine and Meuse basins in 1992, 1993 and 1995, and exceptional flooding struck the Po in 1994. In 1997 severe flooding occurred in several parts of Europe, both as localised flash floods and as basin-wide floods on major river systems causing loss of life, distress and disruption. The year started with flash flooding in Athens in mid January and then in July exceptional rainfall in the Czech Republic and Poland caused catastrophic flooding on the Oder river killing over 100 people and laying waste to vast areas of the countryside. Again, in early November, flash floods occurred, this time in Spain and Portugal with over 20 people losing their lives. Internationally in the 1990's, severe flooding has devastated the Mississippi basin, and thousands of lives have been lost directly or indirectly from flooding in many countries including Bangladesh, China, Guatemala, Honduras, Somalia and South Africa. Internationally, floods pose the most one of the most widely distributed natural risks to life, whereas other natural hazards such as avalanche, landslide, earthquake and vulcanism are more regional in their distribution.

Most nations have institutional and physical infrastructure to combat floods and their effects, and in many cases these have a long history. For example, in the middle Loire valley some major flood embankments are over 200 years old and the courses of the Rivers Rhine and Danube were substantially straightened before 1900 providing improved navigation and flood control. In Hungary, there is documentary evidence of flood defence works as early as the 13th Century and in the UK flood defence legislation can be traced back to 1531. However, with increasing social and economic development bringing pressure on land use within the flood plains of rivers, the potential for flood damage is increasing on many rivers. Added to this is a popular conception that flooding is increasing in frequency and severity, possibly induced by changes in the Earth's climate. It is against this background that the RIBAMOD Concerted Action took place.

Following concern expressed by several EU member states, the Directorate General of Science, Research and Development of the European Commission (DG XII) organised an expert workshop in May 1995 to discuss the state-of-the-art and research needs in the area of river flood management. As a consequence, DG XII funded the RIBAMOD Concerted Action as a part of the Fourth Framework Research programme, co-ordinated by HR Wallingford with a steering group drawn from six countries. RIBAMOD is an acronym for <u>Ri</u>ver <u>Ba</u>sin <u>Mod</u>elling, Management and Flood Mitigation.

The Concerted Action focused on flooding within the framework of integrated river management. Participants in the Concerted Action have come from most member states of the EU as well as the USA, Paraguay, Switzerland, Poland and the Czech republic. There are several different types of flooding and it is important to take account of their characteristics in developing mitigation and alleviation measures. Flooding may be:

1. localised or distributed
2. fast response or slowly developing
3. generated by precipitation (both rainfall and snowmelt),
4. caused by the failure of a structure (dam, embankment, control gate etc) or
5. from marine conditions.

The RIBAMOD Concerted Action considered flooding in the first three of the above categories (although in some cases high river flows will bring about the failure of structures and exceptionally high floods can overflow river embankments). In addition, severe meteorological conditions may trigger instabilities in the land surface generating debris flows, particularly in mountainous areas. The catastrophe in Sarno (Italy) in May 1998 is a recent and tragic example of the power of mudflows. Other EC research initiatives cover land instabilities and RIBAMOD did not consider these in detail. However, the review by Casale & Samuels (1998), completed as a part of the RIBAMOD Concerted Action, did include EC projects on debris flows, and thus some research needs in this area are identified in Section 5 below.

1.2 The Objectives

The Concerted Action had five main functions:-

- to identify difficulties arising from past management practices,
- to identify the state-of-the-art in its area,
- to identify best practice,
- to take an overview of current EU research projects in the area, and
- to identify research needs.

It was also expected that other benefits would ensue from the RIBAMOD Concerted Action including:

- establishing an informal network of researchers and practitioners, and
- transfer of information, results and experience between existing research programmes and practitioners.

It was intended that RIBAMOD would

- facilitate understanding of technical and policy issues in flood management,
- examine how advanced modelling should support planning, design, operation and maintenance of flood defence systems and
- identify methods and procedures for sustainable development, management and use of the river and its catchment.

These objectives were met through experts from many disciplines, from researchers to flood managers, meeting and sharing knowledge and experience during the RIBAMOD events.

1.3 The RIBAMOD events

The Concerted Action comprised five events, the first four of which were planned at the outset of the project. The final expert meeting was organised in response to the exceptional flooding in the Oder River valley in the Czech Republic, Poland and Germany during the summer of 1997.

Event	Location	Date	Topic
Expert Meeting 1	Horshølm, Denmark	10-11 October 1996	Forecasting and Modelling – Model structure and decision support
Workshop 1	Delft, The Netherlands	13-14 February 1997	Current Policy and Practice
Expert Meeting 2	Monselice, Italy	26-27 June 1997	Forecasting and Modelling – Real time warning and risk mitigation
Workshop 2	Wallingford, UK	26-27 February 1998	Sustainable Use of River Catchments, and, Climate Change
Expert Meeting 3	Potsdam, Germany	18 May 1998	The Oder Flood of Summer 1997

1.4 The outputs of the Concerted Action

The principal outputs of the Concerted Action are the collected papers from each of the events, printed by the EC as proceedings.

1. Bronstert A, Ghazi A, Hladny J, Kundzewicz Z & Menzel L, (1999), The Odra / Oder Flood in Summer1997, *Proceedings of the RIBAMOD European Expert Meeting in Potsdam, 18 May 1998*, Report 48, Potsdam Institute for Climate Impact Research, (also to be published by the EC, DG XII)

2. Casale R, Havnø K & Samuels P (Eds), 1997, RIBAMOD River basin modelling management and flood mitigation Concerted Action, *Proceedings of the first expert meeting on Model Structure and Decision Support*, EUR 17456 EN, ISBN 92-827-9562-4

3. Casale R, Pedroli G B & Samuels P (Eds), 1998, RIBAMOD River basin modelling management and flood mitigation Concerted Action, *Proceedings of the first workshop on Current Policy and Practice*, EUR 18019 EN, ISBN 92-828-2002-5

4. Casale R, Borga M, Baltas E & Samuels P (Eds), 1999, RIBAMOD River basin modelling management and flood mitigation Concerted Action, *Proceedings of the Workshop and Second Expert Meeting on Integrated Systems for Real Time Flood forecasting and Warning*, (to appear)

5. Casale R, Samuels P & Bronstert A (Eds), 1999, RIBAMOD River basin modelling management and flood mitigation Concerted Action, *Proceedings of the Second Workshop on Impact of Climate Change on flooding and Sustainable River Management*, (to appear).

Six newsletters were issued in the course of RIBAMOD to disseminate the outline of the results of the Concerted Action widely, these were distributed by mail and through the project Internet site on the Co-ordinator's server with the URL http://www.hrwallingford.co.uk/projects/RIBAMOD

Newsletter Issue	Date	Subject
1	June 1996	Announcing RIBAMOD and its objectives
2	November 1996	Report of Expert Meeting 1
3	June 1997	Report of Workshop 1
4	October 1997	Report of Expert Meeting 2
5	May 1998	Report of Workshop 1
6	November 1998	Report of Expert Meeting 3

In addition a review was undertaken with the EC of the advances made in selected research projects,

Casale R & Samuels P (1998), Hydrological Risks - analysis of recent results from EC research and technological development actions, European Commission, Directorate General of Science, Research and Development, BRUSSELS

At the time of preparation of this final report a paper is planned for submission by the Partners for publication in an appropriate refereed journal.

1.5 Layout of this report

The body of this final report covers the main conclusions of RIBAMOD developed by the RIBAMOD Steering Group. The conclusions are identified in **bold type** in 'boxes' in the following sections, they also are given in summary form in a separate brochure available from DG XII, the Co-ordinator and the members of the RIBAMOD steering group.

The conclusions are presented in the same order as in the Brochure and are grouped under the three themes of the RIBAMOD title:

- River Basin Modelling (Section 2)
- River Basin Management (Section 3)
- Flood Mitigation (Section 4)

Section 5 of this final report presents some challenges to guide further research, development and future practice.

Appendix 1 contains a summary of the contractual and administrative arrangements of the RIBAMOD project.

Appendix 2 lists the paper titles and authors for each of the events.

2. RIVER BASIN MODELLING

2.1 Types of model

River basin modelling in one form or another featured in all of the RIBAMOD events. Deterministic simulation is a principal method of analysis for meteorological forecasting, real-time hydrological modelling and flow simulation in rivers. Expert Meetings 1 and 2 covered modelling issues in some detail, and the proceedings of these events provide a good snap-shot of the current techniques in use both in practice and as research tools.

There are three main uses of simulation models and these were all illustrated in the papers presented at the RIBAMOD events:

- Modelling for real-time forecasting
- Modelling for basin planning and regulation
- Modelling for design and analysis of flood defence and river engineering works

These application areas have distinct characteristics and scales (temporal and spatial). The influence of "Scale" on model choice and parameterisation arose in several of the RIBAMOD events and the paper by Bruen (1997b) at the Second Expert Meeting gives an overview of the issues involved. River basin management in Europe involves actions and policies covering a wide range of spatial and temporal scales and an important conclusion of the Concerted Action is that:

There is no universal model applicable in all circumstances, but the model is tied to the study objectives

This conclusion is identified in the Second Expert Meeting for the specific context of real-time flood forecasting (Issue 31 in the Appendix to Kundzewicz & Samuels (1997)). However, the conclusion may be drawn more broadly for the whole of the area of activity of RIBAMOD.

The process models of principal concern for flood mitigation are

- Meteorological modelling for real-time forecasting
- Climate modelling with appropriate downscaling to generate information at the basin-scale
- Simulation of the processes transforming precipitation into river flow for forecasting or impact assessments
- Simulation of flows in rivers and their associated flood plains.

The papers presented during the Concerted Action provide an overview of current modelling techniques including the state of the art in some areas. This is especially the case for flood forecasting, which has been the subject of much recent EC funded research (Casale & Samuels, 1998). The simulation models used in the examples cited in the RIBAMOD events include those listed below. The references given for the models are to papers presented at the RIBAMOD events which illustrate the use of a particular model rather than the source reference to the model formulation by its originator.

<u>Meteorological and Climate Processes</u>

Modelling atmospheric processes requires substantial resources and the most advanced computational technology and so is mainly undertaken by specialist centres. For weather forecasting these include the Deutscher Wetter Dienst (DWD), the European Centre for Mid-range Weather Forecasting (ECMWF) and the UK Meteorological Office (UKMO). Long term climate modelling in the EU is carried out by two main centres of expertise, which are the Hadley Centre (part of the UKMO) and the Max Planck Institute for Meteorology in Hamburg (Germany). The information on synoptic-scale weather forecasts and regional climate scenarios and some of the process models used by participants in the RIBAMOD events came mainly from these organisations.

One area of current development is the use of information from limited area meteorological models (LAMs) for practical forecasting in real-time. Specific examples of LAMs in the RIBAMOD proceedings are:

ALADIN (see Salek, 1998)
DALAM (see Gozzini *et al*, 1997)
HIRLAM, (see Bruen, 1997a)

<u>Hydrological Processes</u>

Hydrological process models are used to transform precipitation into stream flow (or run-off) or to estimate representative flood discharges for the design and assessment of flood defence works. These models are based upon several conceptualisations of the hydrological processes within the river basin. Some models are event-based, producing hypothetical flood hydrographs suitable for design whereas others provide a continuous simulation of the river flows. The models discussed in the RIBAMOD events are representative of those in current practice internationally but certainly do not include all possibilities. No attempt was made within the Concerted Action to catalogue the domain of application or reliability of the models mentioned in RIBAMOD because the funding for the Concerted Action was directed at stimulating participation in the events rather than undertaking specific research tasks. The hydrological models illustrated in the RIBAMOD proceedings include:

AGREGEE from CEMAGREF, (see Gendreau & Gillard, 1997)
ARNO from University of Bologna (see Todini *et al*, 1997)
BROOK, (see Bronstert *et al*, 1998)
CLS from University of Bologna (see Bruen, 1997a)
HBV from Swedish Meteorological and Hydrological Institute (see Bergström, 1996)
LISFLOOD from the EC Joint Research Centre, (see De Roo, 1998)
MIKE-SHE from Danish Hydraulic Institute (see Refsgaard & Havnø, 1996)
PDM, from the Institute of Hydrology (see Moore & Jones, 1996)
PINE, (see Killingtveit *et al*, 1998)
RHINEFLOW (see Middlekoop *et al*, 1998)
SHETRAN from the University of Newcastle upon Tyne, (see Kilsby *et al*, 1998)
SINBAD, (see Killingtveit *et al*, 1998)
TOPMODEL from the University of Lancaster, (see Borga & Frank, 1997)

<u>River Flow Simulation</u>

There is less diversity in approach to the hydrodynamic representation of river flows than there is to representation of the surface hydrological processes. Most of the models listed below are based upon the St. Venant Equations (SVE) representing one-dimensional flow, except PAB which uses a further approximation to the SVE, and CVFE and WAQUA which are two-dimensional models. The river hydrodynamic models mention in RIBAMOD include:

CVFE, from University of Bologna (see Catelli *et al*, 1998)
DWOPER from the US National Weather Service (see Moore & Jones, 1996)
ISIS from HR Wallingford and Halcrow (see Sas *et al*, 1997)
MIKE11 from the Danish Hydraulic Institute (see Refsgaard & Havnø, 1996)
PAB, from University of Bologna (see Catelli *et al*, 1998)
SOBEK from Delft Hydraulics (see Parmet 1997)
WAQUA from Delft Hydraulics (see Klijn *et al*, 1998)
ZWENDL (see Duel *et al*, 1998)

Thus there is a diversity of commercial and academic modelling software for specific components of the hydrological cycle, which has been illustrated well within the RIBAMOD events. This partly reflects the relative maturity of the science of hydrological modelling (at least for the land surface components of the hydrological cycle), indeed there are some national "standard" methods for approach to some aspects for modelling to support flood mitigation. However in recognition of the duplication of hydrological simulation models, one of the recommendations from the First Expert Meeting was that a priority area for research was on rainfall-runoff models to produce better but fewer models (Cunge & Samuels, 1996).

The next advances in the science of river basin modelling are likely to come from coupling together of process models to examine interactions in the hydrological and related natural systems. In accordance with the European principle of subsidiarity, this coupling should also respect, where scientifically appropriate, different preferences and practice of individual institutions and authorities for use of standard software for the representation and simulation of particular processes.

2.2 Integrated Catchment Modelling

Currently advances in the practice of modelling are coming from the exploitation of modern Telematics technologies (it is in recognition of this that DG XIII has established the RIPARIUS Concerted Action). These new technologies will enhance the human-computer interaction (HCI) methods available to the practitioner. This will alter the interface between the "user", the simulation model, its data and results and rules describing the broader social economic and political context of environment in which decisions on river basin management are made.

Integrated Catchment Modelling (ICM) has been recognised as an important area for research and development in the coming years. For example, research in ICM was recommended by the recent EC Task Force on Environment-Water (European Commission, 1998) and catchment-scale modelling in certain sectors has formed part of the work programme for the Fourth Framework Programme (FPIV). The need for integrated catchment models is also implied by the General Conclusions of the First Workshop (Casale et al, 1988, p384) reported from the closing comments of Professor Cluckie.

- "*The main focus in flood management research should be on basin-wide integrated solutions…*
- *Developments in information technology and informatics present huge potential for the floods community…*"

These trends and scientific needs lead to the next conclusion of RIBAMOD.

There is need to develop integrated catchment modelling, based on an "open system" philosophy to combine existing process models, tailored to the local needs and preferences.

The need for integrated modelling is also implicit to support the conclusions in Sections 3 and 4 below on sustainable river management and a holistic approach to flood defence. In the past the provision of flood defences has been somewhat piecemeal with lack of feedback between impacts of catchment-scale land-use changes, specific river engineering projects and human use of the flood plains.

In the RIBAMOD meetings some ICM approaches were described for flood forecasting including the following systems:

DHYMAS from the from University of Padova (see Fattorelli *et al*, 1997)
EFFORTS from the University of Bologna (see Todini *et al*, 1997)
RFFS-ICA from the Institute of Hydrology (see Moore & Jones, 1996)
MISTERE from LHF (see Cunge & Samuels, 1996)

There are differences in the above approaches on the degree of integration which is sought between the models of the various processes, and this affects the closeness of the coupling that can be achieved. Cunge & Samuels (1996) note that the RFFS-ICA identifies model components as the fundamental building blocks of the ICM and this will enable coupling of processes, if needed, at the time-step level of the calculations. Coarser grained coupling is achieved through the construction of an ICM using a common database to archive the data and results of individual process models and this is the type architecture adopted by the MISTERE model management system. In this latter approach, coupling can only be achieved sequentially along the modelling process chain at the temporal resolution at which the model results are transferred between the different process modelling "tools".

An important feature of the concept of the "Open System" is that its architecture and communication are public so that the contents of the integrated modelling system are not restricted to the simulation models from a particular supplier. Integration of a variety of process modelling tools for river basin management within an open system could be achieved by the adoption of standard protocols for model information exchange within a shell which supports common tasks and data for categories of models. The potential scientific and application benefits of this approach are being explored and demonstrated within the EUROTAS project. This was one of three new projects on hydrological risks announced as part of FPIV at the RIBAMOD Second Expert Meeting (see Newsletter No 4).

A further development from integration of process model is the incorporation in an ICM of a decision support system (DSS) to assist the user of the models in achieving their goals effectively and reaching appropriate conclusions and courses of action. Refsgaard & Havnø (1996) give examples of DSS in hydrological and river system modelling. They identify the need to incorporate into the DSS broader information than has been traditionally the case for hydrological modelling, including environmental, economic and socio-political information. DSS is an active area of development and application of technology in the Telematics sector, growing out of research on artificial intelligence (AI) and Intelligent Knowledge Based Systems (IKBS) in the 1980's. In the specific context of flood forecasting, Catelli *et al* (1998) describe the FLOODSS decision support for inundation risk evaluation and emergency management which has been developed within the EC funded project DESIREE using the results of the EFFORTS research (Todini *et al*, 1997)

The development of DSS should ameliorate some potential difficulties in model application which were identified by Cunge & Samuels (1996) in the conclusions to the First Expert Meeting. These difficulties include:

- lack of appreciation of the range of uncertainty in the model results
- the temptation to believe every number that a computer produces
- illusory visualisation of model results (smoothing or removing "unwanted" features)
- the possibility of using models outside their range of definition
- unsatisfactory calibration of the model

2.3 Developments of simulation modelling

Although the science of free-surface hydraulics and, perhaps to a lesser degree, of hydrology is mature, the First RIBAMOD Expert Meeting identified that additional knowledge and understanding is required in some specific areas. These areas for process research are listed in greater detail below to support the conclusion:

Some development is needed of process models, particularly impact assessment of different environmental scenarios

In the Conclusions of the First Expert Meeting (Cunge & Samuels, 1996), the following development needs are identified:

- sediment transport in "real" river cases
- cohesive sediment transport,
- long term river morphology (plan form and section shape)
- interaction of pollutant with sediments, and
- flow simulation in steep and mountainous rivers
- computational methods adapted to the long time-scale of morphological processes

In the Second Expert Meeting the following development needs were identified (Kundzewicz & Samuels, 1997):

- design of the hydro-meteorological data network with sufficient redundancy to achieve the required accuracy and the security of information for forecasting in the most severe conditions,
- improved now-casting procedures based upon more realistic process descriptions of atmospheric physics,
- integration of data of different type, accuracy and source to determine the state of the atmosphere, of the river catchment and of the flood defence system,
- transfer of data and information at various scales in forming the link between different models (meteorological, hydrological, hydraulic),
- a better understanding and quantification of the uncertainty in the forecasting process, and
- the development of probabilistic forecasts rather than specific values (e.g. maximum water level).

In addition issue 30 Appendix 1 of (Kundzewicz & Samuels, 1997) restates the need identified by Borrows (1997) of

- how should the forecasting model account for the antecedent state of the catchment

The importance of the need to account for the antecedent conditions is linked to the triggering of debris or mudflows and this is one of the research needs identified in the review paper of Casale & Samuels (1998) which are also incorporated into Section 5 below. The tragedy in Sarno (Italy) in early 1998 underlined the urgent need for such understanding.

One theme at the Second Workshop was the impact of climate change on flooding. Dooge & Samuels (1998) discuss the needs for model development in the following terms.

> "Research is needed on the coupling between hydrological and meteorological models on the response of vegetation cover to changes in climate and on the consequent changes in evapo-transpiration and runoff. Research is also needed to determine the most appropriate means of downscaling general circulation model (GCM) scenarios for use in flood risk assessments. Key factors to account for are:
>
> - errors and uncertainties in the GCM results,
> - different meteorological mechanisms which generate precipitation and how these vary with the climate, and
> - how to change precipitation to match new totals from the GCM by the changing either number of wet days or the intensity of precipitation or both."

The paper by Bronstert *et al* (1998), which was presented at the Second Workshop, describes the need for research to improve understanding of the response of land surface cover and vegetation to climate change and the consequent influence on the catchment hydrology. Specific issues where model development is needed include

- water retention by land-cover,
- processes which influence infiltration through the soil , and
- the dominant runoff generation processes in severe storms.

2.4 The need for inter-disciplinarity

The participants at all the RIBAMOD events came form a variety of technical and professional backgrounds. The events thus provided a valuable opportunity for the participants to extend and consolidate their network of contacts in the general field of flood modelling and river management. Many of the technical presentations and subsequent discussions illustrated the complexity of the interactions between the scientific understanding of the processes involved in flood generation, river management and the economic, social and political context within which river management and flood mitigation takes place. This cross-fertilisation of ideas, technologies and practice is seen as a strength of the RIBAMOD activities, but the need for such interdisciplinary communication did not end with the completion of the Concerted Action.

One of the general conclusions of Workshop 1 (Casale *et al*, 1998 p384) was that

> "*Inter-disciplinarity is crucial to solve the complex problems of flood forecasting and protection …*"

In their paper to the Second Expert Meeting, Obled and Datin (1997) observed that:

> *"However, one must wonder why there exist so few effectively operated warning systems and speculate about the gap between tools developed for research and those actually implemented."*

Hence an important conclusion of the Concerted Action is that:

Better communication is needed between professional communities so that full benefit can be derived from their individual scientific advances.

From the discussions at the RIBAMOD events, specific areas can be identified where better communication is needed.

- between meteorologists and hydrologists to improve flood forecasting
- between climate modellers and the hydrologists in generating information from general circulation models of climate scenarios appropriate to river basin-scale climate change impact assessment,
- between the developers of engineering models and researchers in informatics in optimising the use of Telematics technologies to support decisions in river flood forecasting and river basin management
- between engineers, planners and ecologists for the design of flood defences, and
- between the research community and operational agencies in the implementation of research advances to the benefit of the citizen.

3. RIVER BASIN MANAGEMENT

3.1 Sustainable management of rivers and their basins

Rivers and their adjacent flood plain corridors fulfil a variety of functions both as parts of the natural ecosystem and for a variety of human uses, these include

- conveyance of catchment runoff and sediment from source to sea
- habitat for diverse flora and fauna
- water resource (potable supply, agriculture and industry)
- effluent disposal (point source and diffuse)
- hydropower
- navigation route
- fishing
- leisure and amenity

Thus rivers are a fundamental part of the natural, social and economic systems in every country and feature prominently in policies for land management. There is also increasing public interest and pressure for sensitive management of rivers and their corridors in many European countries.

The principle of Sustainable Development has received international acceptance and commitment as a fundamental policy aim for national governments and supra-national institutions, particularly since the 1992 Earth Summit at Rio (Unite Nations, 1993). The classic definition of sustainability was formulated in the Bruntland (1987) report as development which "*…meets the needs of the present without compromising the ability of future generations to meet their own needs.*" However, the working out of this principle in practice presents considerable challenges in that the impacts of development have to be assessed in a holistic manner with long time-horizons. In terms of river basin management, at its broadest scale, it may encompass

- scenarios for social, legal and political institutions
- spatial planning of land use, agriculture and industry
- scenarios for the future climate and associated impacts and adaptations
- scenarios for future demography, resource demands, trade, societal expectations etc.

There is need to promote understanding of concepts relating to sustainable development both with the general public and with the professional community. The pathway for sustainable development and management of flood plains must be achievable (technically, economically, socially and politically). It will require a broad view of the interventions in the river catchment rather than local single-issue design or management. Traditionally planning has been restricted to a select few politicians and professionals but future planning will have to be open with an informed public. There is a different philosophical basis for the provision of structural and non-structural flood defence. Historically man has sought to tame the flood through the construction of embankments and reservoirs to provide security for occupants of the flood plains. However, non-structural measures, such as flood plain zoning, development control, infiltration standards for new development and flood warning, recognise that flooding will still occur as part of the natural processes within the river basin. Difficult choices may arise in the management and protection of existing development and infrastructure on the river flood plain where this conflicts with the policy of sustainable flood plain management.

Issues relating to the management and mitigation of floods are, of course, a sub-set of the issues in river basin management. The sustainable management of rivers was one of the main subjects for the Second RIBAMOD workshop (Casale, Samuels & Bronstert, 1999). In his keynote contribution Galloway (1998) presented the thesis that sustainable development will occur, but his judgement was that there would be substantial challenges for the water resources community to achieve this. He identified the following challenges

- lack of public understanding of the issues

- rigidity in application administrative units which cut across river basin boundaries
- bureaucracy
- new players in the water sector – e.g. NGOs
- bias in project procedures which favour structural solutions
- lack of interdisciplinary approach
- appropriate use of new technologies

In his contribution to RIBAMOD, Galloway produced an action agenda which is encapsulated in the following conclusion:

The involvement of the public, politicians and professionals is essential in working out the sustainable development and management of river basins – the professional community must become involved in the public debate

Galloway drew his conclusions partly from his report for the US Government into the Great Mississippi flood of 1993. Some of these themes occur again in the contribution of Handmer (1997) to the First Workshop, reporting on the EC funded EUROFLOOD project. He identified that flood hazard and its management is linked in a variety of ways to sustainable development including public participation in decisions, maintaining the integrity of the ecosystem and preserving biodiversity. In addition, Handmer concluded that currently public participation is weakly developed in many countries.

In his discussion of "Towards sustainable development of water resources", Kundzewicz (1998) identifies that the approach of living with floods seems more sustainable than the historic approach of combating floods. He concludes that flood protection by catchment management, accommodating flood in flood plains and polders, flood proof construction and insurance measures deserve careful consideration. These are mostly non-structural approaches to the provision of flood defence and are taken up in a conclusion of RIBAMOD discussed in Section 4.1 below.

Some of the practical issues involved in achieving sustainable management of rivers are identified in the contributions of Borrows *et al* (1998) and de Smidt & van Westen (1997). Borrows *et al* discuss practices for the sustainable maintenance of rivers and they identify:

- the need for an integrated approach with other catchment management practices,
- for careful timing of maintenance operations,
- for training of those involved in river maintenance and
- the use of more environmentally sensitive forms of river engineering and bank protection.

De Smidt and van Westen describe guidance in the Netherlands of incorporating Landscape, Nature and Cultural Heritage (LNC-values) into the decision process. The national policy is to preserve the LNC-values as far as is consistent with the provision of public safety from flooding. Mapping the LNC interests and values is a prerequisite to making informed decisions on flood protection at the national, regional and local scales.

3.2 Flood Risk Management

The exposure of a community or enterprise in a particular area to flood risk is a combination of two factors, the probability of flood <u>hazard</u> in the area and the <u>vulnerability</u> of the area to undesirable consequences and economic loss should flooding occur (see for example Gendreau & Gilard, 1997). Thus mitigation of flood risk can be accomplished through managing either or both of the hazard and vulnerability, broadly speaking flood hazard may be reduced through structural measures which alter the frequency of flood levels in an area. The vulnerability of a community to flood loss can be mitigated though changing or regulating land use, through flood warning and effective emergency response. These issues are covered in more detail in Section 4.1 below. However, the ultimate goal of sustainable development will require that a holistic view be taken of the management of flood risk. Thus all potential means of flood mitigation should be examined, seeking those which are technically feasible, economically and environmentally sound and sustainable. Building upon the conclusions of the working groups at the First Workshop on Flood Risks and Integrated Flood Protection (Casale *et al* 1998, pp382-3) the following general conclusion has been drawn:

There is need for a catchment view of flood risk management, fully integrated with environmental effects, rather than a collection of unconnected, individual measures

The Belgian experience reported by Muys (1997) gives an illustration of a methodology which addresses flood protection as an integrated process over entire river basins. Many of the conclusions of the Belgian specialists accord with those of the reviews of the Mississippi and Rhine floods by Galloway (1995) and the International Commission for the Protection of the Rhine (1995).

No flood defence structure can be engineered for absolute security, there are potential failures from inadequate design, construction techniques and materials, unknown foundation conditions; failures can occur in operation for example though the breakdown of power supplies or the blockage of the structure with debris. The older the structure, the greater is likely to be the uncertainty in its performance under stress. Thus the hazard of flooding is more than the hydro-meteorological conditions which exceed the expected capacity of the defence, failure of the line of defence below the design standard needs to be considered. Although the main focus of RIBAMOD was flash and lowland flooding of inland rivers, one issue raised during the First Expert Meeting (Cunge & Samuels, 1996) was the fact that flooding poses similar threats and causes damage from whatever source. Hence a conclusion of RIBAMOD is as follows:

Flood risks should be evaluated from all potential hazard sources

There are other possible sources of flooding of area not directly related to a high river flow. These include:

- surface flooding in urban areas from blocked or inadequate storm sewers
- congestion of drainage systems behind major embankments which cannot evacuate by gravity
- flooding from storm surge and waves in the tidal reaches of a river
- catastrophic failure of a dam

The best means of managing the risk will depend upon the source of the flooding hazard but there will be several factors in common. A fundamental need is to map the areas of hazard together with land use to indicate the extent and severity of the risk.

3.3 The Challenge of Environmental and Climate Change

The IPCC (1996) Second Assessment Report concludes that there is evince for a discernible human influence on the climate. This change in the climate will have many impacts on the hydrological cycle directly through changing patterns and types of precipitation and indirectly through changes in land cover, land use and the soil moisture budget. In addition human adaptation to the changing climate may produce increased vulnerability to flood hazards, thereby increasing flood risk.

Current assessments of the impact of climate change on flooding are far from certain since flooding and the natural hazard it poses arise from a complex interaction of physical, biological and human factors. These compound the uncertainties which are inherent in the choice and modelling of future climate scenarios. Although the rise in mean sea level will bring a widespread increase coastal flood risk, the effect of climate change on river flood risks is likely to show significant regional and seasonal variation. The studies to date of climate impact on flood risk have greater uncertainty than flood frequency estimates for the current climate, see for example Saelthum *et al*, (1998) and also Beven & Blazkova (1998) who present a framework for estimating the uncertainty.

Analyses of historic and reconstructed flood records in major river basins have indicated linkage between major (natural) climate variation and the occurrence of severe floods. In a study of the flood history on the River Rhine from about 1000 AD, Krahe (1998) noted different types of flood occur depending upon the prevailing climatic conditions with an increase in flood intensity in the second half of the 20th Century due to a higher number of warmer, precipitation rich winters. However, Bergström & Lindström (1998) found no significant evidence for climate impact on flood frequency in Sweden.

In the conclusions to the Second Workshop, Dooge & Samuels (1998) discuss the effects and uncertainties of environmental changes on flooding in the following terms.

> *"Many traditional methods of design flood estimation are limited by an implicit assumption on the stationarity of the climate and catchment response (over the period of hydrological record). However there will be influences in this record from changes in land-use and land cover (form natural or anthropogenic causes) and from changes in the climate. Important questions are:*
>
> - *distinguishing natural variability and trends from anthropogenic changes,*
> - *should "safety factors" be introduced to account for our imperfect knowledge, and*
> - *what are the design objectives for any proposed intervention in the river system.*
>
> *The meteorological driving forces which will influence flood risk include precipitation (type, intensity, volume, seasonality, etc), temperature and wind-speed. The potential impacts of climate change on flooding are complex with variations regionally and seasonally and other climate-induced changes (apart from floods) in flow regimes will also have important consequences in river basins (e.g. the security of yield of surface water resource and hydropower systems). This implies that it is unlikely that a single universal impact model or methodology will be appropriate. The most appropriate type of hydrological model for climate impact assessment will depend upon the catchment and process scales and the impacts under investigation. Initial model investigations indicate that flood risks may be enhanced by changes in climate in several locations in Europe, whereas in other areas the flood risk may be reduced. The future variability of river flow may increase which will impact upon the frequency distribution of flood flows."*

In order to assess the adaptations needed for mitigation of any increased flood risk and the time-scales for decision, it is necessary to examine patterns of flooding under future climate scenarios. Hence, following the discussion from Dooge & Samuels (1998) quoted in Section 2.3 and above, a conclusion of the Concerted Action is as follows.

The need is increasing to understand the effects of environmental change on flood risk

Several examples of impact assessment for flooding were presented during the RIBAMOD events, with differing results. Burlando *et al* (1996) reported increases in flood peaks of up to 10% for a basin in Italy, Reynard & Crooks (1998) considered both climate and land-use changes for two basins in England with changes of up to 20%. In a study of a complex alpine basin, Burlando (1998) demonstrated marked seasonal changes in runoff, particularly in the spring. Bronstert et al (1998) demonstrate seasonality in the estimated climate impact on flooding in a basin in Germany. However, their assessment of land cover change was that it played only a minor rôle in winter flood frequency and they speculated on a greater influence on vegetation on summer flooding.

Clearly much remains to be understood on the linkage between climate and flooding and sound scientific research is needed to identify and attribute any impacts on climate change on flood risk.

3.4 Trans-border Rivers

Several major European rivers cross or form national boundaries, for example the Rhine and its tributaries, the Danube, the Meuse, the Elbe and the Oder. Thus flood management in these rivers has the additional complexity of requiring international co-ordination and co-operation. This has led to the formation of international commissions to cover many issues including flooding on the Danube, Meuse and Rhine. Muys (1997) illustrates the decision processes in the Meuse River, drawing in recommendations from the Rhine Commission and US practice from Galloway (1995). The papers from the Expert Meeting on the Oder floods (Bronstert *et al*, 1998) describe the influence of the failure of embankments in the upper reaches of the river in reducing the potential flood discharge and flood levels in the lower reaches. The issues in managing trans-border rivers are not restricted to the major rivers given as examples above, and a conclusion of RIBAMOD is that:

The special status of trans-border rivers must be recognised so that their management is undertaken as a whole rather than within administrative boundaries.

As a part of the discussions of the Oder floods, Nawalany (1998), set out a series of fifteen potential conflicts which can arise in flood management in trans-border rivers, together with suggested means of resolution. The solutions are based upon negotiation between the stakeholders, planning flood defence measures taking account of effects outside a single country and the provision and sharing of flood warning information. The EURAQUA network has also considered the international dimensions to flood management as reported by Lüllwitz (1997), here he indicates the different scales appropriate for decision making for various water resources issues, with flood defence and river basin management extending from local to international scale.

The discussions at the First Workshop identified a critical need for improved operational management of flooding as being for digital real-time information on the meteorological conditions over the river catchment and its hydrological response. European standardisation of data exchange and forecasting approaches could deliver real benefit in improving flood warnings; this could be developed by undertaking selected pilot studies.

Particular trans-national issues on flood management which arose on the RIBAMOD events include:

- hydro-meteorological networks for flood forecasting
- trans-border compilation of radar images for flood forecasting
- sharing flood forecast information between states
- river engineering and flood plain management
- operation of flood storage systems

4. FLOOD MITIGATION

4.1 A Holistic Approach

There was a recognition from amongst the RIBAMOD participants that flood mitigation depends upon much more than just the technical area of river basin modelling, its application to flood forecasting and its use in the planning and design of flood defences. The review by Kundzewicz (1997) of the impact of the 1997 flood on the Oder River in Poland, the Czech Republic and Germany, and the subsequent discussion at the Second Expert Meeting, crystallised the concept of a holistic approach to flood management (Kundzewicz and Samuels, 1997). The conclusion of the Concerted Action is that:

There is a need for a holistic approach to flood management (pre-flood planning, operational flood management and post-flood response).

The outline of holistic flood management was given in the fourth RIBAMOD newsletter and recurred in the Expert Meeting on the Oder floods. The mitigation of flood damage and loss does not only depend upon the actions during floods but is a combination of pre-flood preparedness, operational flood management and post-flood reconstruction and review. It comprises the following elements.

<u>Pre-flood activities which include:</u>

- *flood risk management* for all causes of flooding
- *disaster contingency planning* to establish evacuation routes, critical decision thresholds, public service and infrastructure requirements for emergency operations etc.
- *construction of flood defence infrastructure,* both physical defences and implementation of forecasting and warning systems,
- *maintenance of flood defence infrastructure*
- *land-use planning and management* within the whole catchment,
- *discouragement of inappropriate development* within the flood plains, and
- *public communication and education* of flood risk and actions to take in a flood emergency.

<u>Operational flood management which can be considered as a sequence of four activities:</u>

- *detection* of the likelihood of a flood forming (hydro-meteorology),
- *forecasting* of future river flow conditions from the hydro-meteorological observations,
- *warning* issued to the appropriate authorities and the public on the extent, severity and timing of the flood, and
- *response* to the emergency by the public and the authorities.

<u>The post-flood activities may include (depending upon the severity of the event):</u>

- *relief* for the immediate needs of those affected by the disaster,
- *reconstruction* of damaged buildings, infrastructure and flood defences,
- *recovery and regeneration* of the environment and the economic activities in the flooded area, and
- *review* of the flood management activities to improve the process and planning for future events in the area affected and more generally, elsewhere.

Thus the mitigation of flood risks needs to be approached in practice on several fronts, with appropriate institutional arrangements made to deliver the agreed standard of service to the community at risk. These institutional arrangements differ within the EU according to national legislation and public tolerance of flood risks and some of the differences in approach were evident in the papers and discussions, particularly at the First Workshop. (For examples of different approaches, see the papers by Empson & Chapman (1996), Jorissen (1997), Klaassen & Cappendijk (1997), Gendreau & Gillard (1997) and Holst (1997)).

To deliver this holistic flood management in practice will require the collaboration of professionals in several disciplines. In many countries these professionals are engaged predominately in the Public Sector, since river basin regulation and management is usually the function of national or local government departments, agencies and authorities. This holistic management will require multidisciplinary working, as identified in Section 2.4 above, and in particular the Concerted Action concluded the following.

There is a need for multidisciplinary working between meteorologists and hydrologists to improve flood forecasting and between engineers, planners and ecologists for the design of flood defences.

The collaboration between meteorologists and operational hydrologists should go further than the issues of modelling identified in Section 2.4. This need is exemplified by the independent post-flood review of the Easter 1998 floods in the UK (Bye & Horner, 1998). This review (pp31-32) documents the loss of impact when the precipitation forecasts where communicated from the Meteorological Office to the flood hydrologists in the Environment Agency. The discussion of trans-boundary rivers (section 3.4) identifies the need for data exchange across frontiers, on actual and forecast flows, precipitation forecasts, radar imagery etc.

A major aspect of flood mitigation has been traditionally the provision structural flood defences (embankments, storage reservoirs, relief channels etc). These can have substantial impact on the riverine environment and ecology and the trend of national legislation and Community directives has been to require detailed impact assessments and environmental statements to support the promotion of the project. This requirement drives the need for multidisciplinary working on the design of the flood defences, an example of this in practice is the implementation of the new flood works on the lower River Thames and its tributaries, see Gardiner (1998).

However, many major structural flood defence projects have been completed, particularly on lowland rivers and the recognition that future flood defence must be sustainable will influence the choice of measures implemented to further mitigate flood risk. It can be argued that a cycle of raising flood embankments and allowing unrestricted increase in vulnerability to potential flood damage on the flood plain is not sustainable. Hence the conclusions of the review group on Integrated Flood Protection at the First RIBAMOD Workshop can be summarised as:

The prominence of non-structural measures for flood defence will increase as part of the sustainable management of rivers.

Non-structural measures mainly control the “vulnerability” component of flood risk, they include:

- spatial planning policy with a presumption against development or encroachment of economic activities onto flood plains
- building regulations to control the additional runoff from any green-field development in the catchment outside the flood plain
- regulation of increases in vulnerability to flooding and of flood plain use
- provision of effective warning systems with emergency response plans
- insurance against flood losses
- public education in flood risk and encouragement of personal measures to reduce flood losses

4.2 River Restoration

Restoration of previously engineered and regulated rivers has been undertaken in many countries and such projects can form part of a sustainable development plan for the river basin. The objectives of river restoration are normally to create a wider diversity of eco-systems and improve biodiversity, by bringing the river into a closer contact with its flood plain (see for example Bettess & Fisher, 1998). The visual amenity of the watercourse may be improved and its natural function for flood storage and conveyance regained. River restoration was a theme for the Second Workshop (Casale *et al*, 1999) and a conclusion of the Concerted Action is that:

The restoration of flood plains to their natural function should be encouraged (where socially and politically acceptable)

Gardiner (1998) argues that river restoration must be integrated into a comprehensive set of measures for the conservation of land for the restoration to be of lasting value and sustainable. A fundamental question is that, since rivers are dynamic systems (of varying rates of morphological activity), to what historic state should a river be restored. However, it must be recognised that not all the historic interventions in a natural river are reversible, the ecological clock cannot be put back with the river channel. Engineering intervention in a natural or artificial river has a broad and complex range of interacting impacts and these must be considered before restoration is undertaken. The morphodynamics of the river system are important in determining the plan-form, size and gradient of the channel and flood plain system. The sediments, water quality and aquatic ecology are all closely inter-linked and this needs to be represented in any simulation modelling. The objectives of the restoration in recreation of particular habitats and ecotones need to be defined with their consequent physical characteristics. From this a design for the restoration can be developed by collaboration between ecologists, geomorphologists and hydrologists. The paper by Olesen & Havnø (1998) illustrates the complexity of the interactions which need to be simulated when a major restoration scheme is being designed. Bettess and Fisher (1998) conclude that currently available simulation models are insufficient for capturing all the complexities of river flows required in a restoration project and three-dimensional modelling may be required. The linkage between hydrodynamic and ecological assessments was identified in the First Expert Meeting as a research need (Cunge & Samuels, 1996)

The habitats on the restored river will evolve in time with the natural succession of species but the original biodiversity of the site may not be regained. Indeed a management regime may need to be instituted to maintain a desirable mix of species and to achieve an acceptable balance of functions. Much remains to be learned from monitoring pilot schemes and monitoring programmes are in progress on both the Skjern river restoration in Denmark (Olesen & Havnø, 1998) and the UK schemes described by Bettess & Fisher (1998). Although restoration of rivers may be desirable in terms of encouragement of biodiversity, such interventions may be contentious to some riparian landowners if it has an adverse impact on their use of the land. Hence public participation in the decisions on whether (and how) to restore a river is needed to ensure that the actions are socially acceptable and thus sustainable.

4.3 Project Appraisal

Project appraisal is the process which guides decisions on the selection and implementation of flood defence measures. Over recent decades the appraisal process has become more sophisticated with the need to include environmental statements on the potential impact of any major engineering works. Appraisal procedures are subject to national legislation and priorities with different emphases on safety standards, indicative standards of protection according to flood plain use and type of flooding, cost-benefit analysis, social and environmental factors. The first Worksop included discussion of the decision process, with illustrations of current approaches and developments in several Member States. Understandably, the severe flooding in several countries in the 1990's has prompted a review of the national investment in flood defence infrastructure. For example, Jorissen (1997) describes the safety policy for the Dutch flood defences and de Smidt & van Westen (1997) describe the incorporation of "non-use" values (LNC-values, see Section 3.1 above) into the decision on flood defence projects. Muys (1997) describes the Belgian "round-table" expert discussions on flooding which followed the Meuse floods of 1993 and 1995. One of the objectives was the promotion of environmentally sound strategies to minimise flood damage and a recommendation was

> "*all significant infrastructure works should be integrated into a strategic plan for the whole basin and should be preceded by an impact study including hydraulic and sedimentological effects, environmental impact, and cost effectiveness; communication with the public before and after reaching any decision is essential*".

In his discussion of the EUROFLOOD project, Handmer (1997) covers some difficulties with common economic analysis as applied to decisions on flood protection. He identified that contingent valuation methods are being increasingly used for non-market items but CV has strict limits and cannot be used for abstract items with little "use value". Whilst cost-benefit analysis remains a useful and informative tool, the conclusion of the working groups on Flood Risks and Integrated Flood Protection each identified a need to broaden standard cost-benefit analysis. Hence a Conclusion of the RIBAMOD Concerted Action is as follows.

There is a need to broaden economic evaluations to include "intangible" costs and benefits to assess the non-engineering aspects of flood defence activities within a common methodology for the assessment of flood damages.

4.4 Risk Assessment and Communication

The topic of risk assessment was a recurring theme being raised either in the presentations or discussion at all of the RIBAMOD events. For example, the conclusions of the first Expert Meeting (Cunge & Samuels, 1996) included the following observation:

> *"Holistic risk assessment can provide a framework for decisions and investment in flood defence activities. Several aspects of flood risk were raised including the appropriate form of design flood assessment, the delineation of areas at risk, the process and likelihood of dyke failure, the communication of risk to the public and special procedures for high hazard sites within flood risk areas. There are differences in the perception and acceptability of flood risk within the EU and there appears to be no accepted terminology for risk."*

The two components of risk – hazard and vulnerability - have been discussed in Section 3.2 above. In the past, flood defence practice has commonly been to design against a specific event either of historical significance (e.g. a recent "disaster") or of a particular assessed frequency of occurrence. The assumption being that the flood defence system will perform satisfactorily for all events up to the design standard. However, there is a small but finite probability that the defence may fail for a lesser event through say unknown weakness in an embankment or blockage of a structure leading to a greater hazard than that associated with the probability of the design event.

Thus a conclusion of the RIBAMOD Concerted Action is that

Risk should form the framework for managing and communicating the effects of flooding to river managers and the public.

There are several aspects of this conclusion.

The methodology for designing flood defences may need to change from the concept of a specified hydrological event to a more broadly based set of events assessed within a probabilistic framework such as that described by Plate (1997). The framework can incorporate many factors which may be difficult to analyse from the concept of a simple design event including:

- the effects of flooding caused by more than one forcing function,
- increases in the probability of failure of an embankment through ageing
- multiple lines and methods of defence and flood proofing.

The papers by Jorissen (1997) and Plate (1998) describe how risk concepts can be applied to the design and management of flood defences. Plate (1998) divides risk management into risk assessment and risk mitigation. In risk assessment both the flood hazard (or probability) and vulnerability (or consequence) are evaluated through methods similar to those of Gendreau and Gillard (1997). Risk mitigation is achieved through altering either or both of the hazard and vulnerability, through risk reduction prior to a flood and emergency response during and after a flood. The two basic components of risk reduction are prevention and preparedness. Thus Plate's description of the risk management procedure ties in closely with the principles of the holistic management of floods as described n section 4.1 above (see also Kundzewicz & Samuels, 1997).

Jorissen (1997) sets the provision of flood defence and safety in the Netherlands within two cycles of review for

- strategic provision of flood defence using risk assessment to determine whether the current provision is sufficient and identify new protection measures
- operational review of the standard of safety offered by the current state of defences to determine maintenance and repair needs.

The strategic review has a time scale of between 15 and 50 years whereas the maintenance review cycle has a shorter time scale of around 5 years.

The design and implementation of structural flood defences is undertaken by specialists and professional engineers. However, since no defence measure is absolutely secure it is necessary to provide public communication of the residual level of risk, the likelihood of flooding in any particular storm or season and the actions to take to reduce personal loss and damage. Traditionally, the severity of a flood has been described by he use of the concept of *return period*, but there are several reasons why this is not particularly helpful of communicating risk to the public at large, for example

- it gives no measure of the likelihood of flooding in any year, or in a given number of years
- it takes no account of non-stationarity in the hydro-meteorological forcing
- it may obscure the random nature of flooding and thus
- it may engender a false sense of security

In preference, the severity of a flood should be measured through the annual probability of occurrence and also the use of the human lifetime might provide a more understandable basis of comparison.

At the Second Expert Meeting the issue of uncertainty in forecasting was discussed and it was considered that flood forecasts (flow and level) should be expressed in a probabilistic way with uncertainty bands rather than as specific values. This will broaden the choices available to individuals, however, an issue remains on the effects on behaviour of issuing false-negative warnings (i.e. a flood warning given when no flooding occurs).

4.5 Societal Factors

Flooding is essentially a human problem. The occasional inundation of flood plains is a natural process – a part of the function of the river as the drainage route for excess runoff. Flooding becomes a problem when it conflicts with the human use of the flood plain for settlement, agriculture, industry, communication etc. As it has become possible to engineer defences against floods so the tolerance of the natural process has been diminished to the point which, in some countries, flooding on any wide scale becomes a catastrophe. Unexpected flooding produces many undesirable impacts on society:

- individual and commercial <u>damage</u> with consequent financial losses
- economic and infrastructure <u>disruption</u>

- distress to individuals which may last many months or years after the event.

In one sense, the "problem" of flooding could be argued to be a measure of the success of engineering flood defences. Although in some cases returning flood plain to its natural function by removing those at risk (e.g. in the US see Galloway (1998)) is part of the sustainable management of the land, this is not an option in many situations.

Thus in planning the provision of flood prevention measures, it is essential that social expectations and institutions are developed which are compatible with the residual risk. This was confirmed by the EUROFLOOD project, Handmer (1997), who comments that the project team saw:

> "*flooding as a problem of people and their institutions rather than simply a matter of too much water: a social problem rather than an engineering problem*".

Hence a Conclusion of the RIBAMOD Concerted Action is as follows:

It is necessary to incorporate the "human" factors in flood defence planning – how information is presented to achieve the desired effects of action.

In a review of flood warning carried out in the EUROFLOOD project, Penning-Rowsell & Tunstall (1997) identified a substantial variation in the method and contents of flood warnings issued in the UK, France, Germany and the Netherlands with regional differences in some countries. Given the economic and social importance of flood defence in the Netherlands it is not surprising that they found that the Dutch practice was generally the best. Pelleymounter (1997) describes research in the UK which demonstrated that the weakest "link" in the chain of forecasting > warning > response was the dissemination of effective flood warnings from the forecasters to the public at risk. Hence the UK Environment Agency addressed as a matter of priority the means of dissemination of warnings when the Agency took over the lead rôle in issuing flood warnings to the public. Pelleymounter identifies the following factors which influence the effectiveness of flood warnings when they are issued:

- Awareness of a warning - is the warning received before flooding occurs
- Availability to respond - can the property owner reach the property to take action
- Able to respond - is the owner physically capable of mitigating flood damage
- Effectively respond - does the owner know what to do and acts effectively?

Thus the institution of a flood forecasting system must be accompanied by
- local warning dissemination plans,
- identification of the areas at risk (even for low levels of risk),
- building public awareness of the extent of flood risk, the type of flood warning and actions to take if warnings are issued
- means of issuing general broadcast warnings and specific alert warnings to identified communities

The immediate priority after a flood is to provide relief to those who have been affected. A severe flood may have disrupted transport and communication links and essential services such as water supply, sewerage and health care. Communities may need to be self-reliant for many hours or days until external assistance is possible. Many issues arise including:
- mobilisation of civil and military rescue services
- search and rescue of survivors and the burial of the victims
- the provision of shelter, safe drinking water and food
- securing damaged buildings
- restoration of essential services and communication
- prevention of disease
- prevention of looting

5. CHALLENGES FOR RESEARCH, DEVELOPMENT AND FUTURE PRACTICE

It is clear from the discussions in Section 2, 3 and 4 above that many issues remain to be addressed in the area of flood risk reduction and alleviation. Two of the objectives of RIBAMOD were to take an overview of current EU research in its area and to identify research needs. To meet these objectives, the Co-ordinators of relevant projects (in progress and recently completed) presented their research findings during the Concerted Action events and also a review of Fourth Framework Programme projects was undertaken by members of the RIBAMOD Steering Group, see Casale & Samuels (1998). This review was cast somewhat more broadly than the specific topics of the five RIBAMOD events and the challenges and the research priorities laid out below are taken from that review, with additional points added from the RIBAMOD events.

Key areas for future research and development include

- the need to continue to improve the coupling of meteorological and hydrological forecasting for improved flood warning,
- the need for monitoring river and catchment conditions
- the need for improved estimation of flood discharge conditions over a variety of catchment sizes,
- the need for integrated approaches to flood management over whole river catchments and
- the need for integrated catchment models to examine issues of long-term environmental change.

These areas are further elaborated below using the headings of the review by Casale & Samuels (1998) rather than of the project brochure. However, all the issues in the brochure are included here.

5.1 Meteorological and hydrological forecasting

Advanced radar systems can differentiate rain from clutter, hail, and bright-band echoes, and can detect significant attenuation. They thus clearly provide better qualitative rainfall monitoring, but a full description of their quantitative capability has yet to be obtained. Forecasting of rainfall from current radar analysis needs further research taking account of atmospheric physics and the immediate past storm conditions. For example, can wind information from Doppler radar measurements improve the advection of convective storms and thus provide improved rainfall forecasting in severe storms? Further research should improve the precipitation forecasts in the context of flood forecasting

- from limited area meteorological models using information from the radar and of the conventional precipitation gauge network.
- from the use of satellite imagery to produce quantitative precipitation forecasts.

Research is needed to determine whether it is the hydrostatic assumption or the parameterisations which limit the quality of hydrostatic meteorological forecast models at high (< 10 km) grid resolutions. The performance of non-hydrostatic meso-scale models should be investigated. Study of precipitation patterns and internal structures is required for use in filtering forecast precipitation fields.

Improved understanding is needed of how errors in radar rainfall measurement affect the prediction of river flows and further research is needed on the optimisation of hydro-meteorological networks for the explicit purpose of flood forecasting. This is coupled to the need to improve the understanding of the rôle of soil moisture in runoff forecasting, its integration into hydrological modelling and the associated effects of scale.

5.2 Monitoring river and catchment conditions

Unfortunately, in some countries the extent and availability of hydro-meteorological data for research is affected by the commercialisation of the agencies involved and the focussing of effort on monitoring to ensure compliance with water related directives. There is need to identify the true value of long term monitoring of climate and streamflow for assessing potential environmental change and to identify the best means of access to this data to the research community and institutions involved in long-term planning.

Research is needed on the optimisation of measurement networks for flood forecasting and warning purposes, linked with other hydro-meteorological measurement networks. A particular issue is to maintain security and adequacy of information during the extreme meteorological conditions which can lead to severe flooding.

In the context of debris flow prediction, the monitoring of catchment and streambeds is clearly inadequate and insufficient. The installation of meteorological stations and various devices aimed at monitoring initiation areas and recording debris flow events is needed. Increased financial support by operating agencies as well as research funders is necessary and would be essential for practical applications.

5.3 Improved estimation of flood discharge

For the planning and design of flood defences it is necessary to assess the "design" river flow conditions according to the level of residual risk that is acceptable to the community. Hydrological models, in general, tend to be focussed on water resources investigations where the overall water balance is of primary concern and calibrations tend to produce models which compromise in accuracy between the low and the high flows. Flood risk research needs to concentrate on the appropriate modelling approach in cases where accurate estimation of the flood peak is paramount both in the planning and design context and also for flood forecasting when good forecasts are available of precipitation.

It is important to take account of non-stationarity of past data series and the possibility of future environmental change. The most appropriate estimation methods need to be established for different basin scales, climatic type and severity of event. In particular, the relative merits and applicability of continuous simulation, flow-duration-frequency (Qdf) and unit hydrograph approaches need research. For the investigation of the effects of climate change on flood risk, a key research issue is the generation of precipitation fields at the appropriate spatial and temporal scale from the results of GCM simulations of future climate scenarios.

5.4 Integrated approaches to flood management

The overall objective of flood management is to minimise losses within a river basin over time subject to constraints, such as society's attitude to risk, level of expenditure, etc. Thus a holistic view should be taken of flood management with distinct activities of:

- Pre-flood preparedness
- Operational flood management
- Post-flood response

The key actions in this area lie mainly in the development and dissemination of best operational practice (as begun in the RIBAMOD Concerted Action). In all flood defence activities it is essential to consider the impact of interventions on the flood risk in the river system as a whole and not just at the location of a particular project. This should be facilitated by the implementation of integrated catchment modelling and management information systems as these become available.

5.5 Integrated catchment models

There are many models available which are used in the overall assessment and management of flood risk. However, these mostly only tackle specific issues and there is a need to combine or couple models together to provide decision makers with tools which address the practical management of river systems. A particular challenge is the linking of models of water movement and riverine ecology. It is important that any framework produced should be built as an "open system" which will not be tied to specific proprietary software packages for particular tasks.

In addition to the integration of existing process models, research is needed on the interactions between different natural processes (e.g. sediment, vegetation, flow resistance, discharge time series, climate and water quality) and the complexity and level of integration of these interactions in an overall catchment simulation. Integrated catchment simulations may also address issues of other areas of the water sector apart from flood risk. Transformations between different scales of resolution can present difficulties, requiring aggregation or disaggregation of data, model parameters and model results. The appropriate representation of the hydro-meteorological system may itself change with the scale of the river catchment.

In some areas, improvements in process modelling are needed to meet the needs of the potential user. These include:

- the parameterisation of land cover and vegetation in hydrological models and its relation to climate,
- sediment transport in "real" river cases,
- cohesive sediment transport,
- long term river morphology (plan form and section shape),
- processes triggering debris flows,
- interaction of pollutant with sediments, and
- flow simulation in steep and mountainous rivers.

In addition to these improvements in process modelling it is necessary to understand further the uncertainties inherent in the modelling and how the uncertainty should be expressed to the users of the model and its results.

The use of integrated catchment models also raises issues on the management of complex modelling tools, their data and results to deliver information for non-specialists. This leads to the need for decision support and expert advice to be available within the modelling systems. Other advances in Telematics (e.g. integration of remotely sensed data into models, Genetic Algorithms, Artificial Neural Networks and Expert Systems) may find application in river basin modelling, river management and flood mitigation.

6. NEXT STEPS

Although the RIBAMOD Concerted Action has been completed, research into river basin modelling and the mitigation of flood risks continues through national research programmes and through European Research initiatives under the Framework Programmes. In particular, the research projects EUROTAS, FLOODAWARE, FRAMEWORK, HYDROMET, MEFFE, RAPHAEL and TELFLOOD and the Concerted Action CADAM have been funded under the hydrological risks component of the Environment and Climate programme of DG XII. The RIPARIUS Concerted Action began work in late 1998 funded by DG XIII to examine the exploitation of new Telematics technologies in the practical problem of the mitigation of flood risks.

The Fifth Framework programme is also expected to call for research in the area of natural and technological hazards which may provide opportunity of advancing knowledge and understanding in some of the areas described in this final report. Naturally research funded at the European level must tackle issues which have a definite European dimension and strive to make progress in solving problems of concern to the citizen. Clearly flooding is one such issue of public concern; a single, unexpected flood can have a devastating and lasting influence on anyone unfortunate enough to experience it, in whatever country they live.

7. ACKNOWLEDGEMENTS

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Dr E Baltas (National Technical University of Athens),
Dr M Borga (University of Padova),
Dr A Bronstert (Potsdam Institute of Climate Impact Research PIK),
Dr R Casale and Dr P Balabanis (DGXII),
K Havnø (Danish Hydraulic Institute),
K Heynert, R Moll and G B M Pedroli (all representing Delft Hydraulics)
Dr P G Samuels (HR Wallingford).

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Appendices

Appendix 1

Final administrative report of the RIBAMOD Concerted Action

Appendix 1 Final administrative report of the RIBAMOD Concerted Action

(River Basin Modelling, Management and Flood Mitigation)

funded by the European Commission
Directorate General of Science, Research and Development.
Contract Number ENV4-CT96-0263

The contract between the EC and HR Wallingford for the RIBAMOD Concerted Action was signed in April 1996 and the contract commenced on 1 May 1996. The duration of the Concerted Action was extended, within the same limits of funding, to 30 months by letters from the Commission. This final report to DGXII covers whole of the contract from May 1996 to October 1998.

To fulfil its objectives, the Concerted Action initially was committed to organising four events within its area of interest, two Expert Meetings and two Workshops. During the summer of 1997, a devastating flood occurred on the River Oder, and it was agreed that the Concerted Action should organise an additional Expert Meeting to consider the lessons to be learned from this event; this meeting took place on 19 May 1998 at Potsdam (Germany). In mid-1998 DG XIII commissioned the RIPARIUS Concerted Action to focus on the applications of Telematics in the mitigation of flood risk. RIPARIUS is co-ordinated by the Institute of Hydrology (also located in Wallingford, UK), and there has been exchange of information between RIBAMOD and the steering committee of RIPARIUS to ensure that the two Concerted Actions are complementary in their activities.

The Partners held eight steering group meetings. Five of these steering group meetings have been held with the Concerted Action events, but the other three steering group meetings were held outside the main RIBAMOD events. Dr R Casale from DG XII has assisted with planning the project at the steering group meetings. The Co-ordinator produced notes of each of the Steering Group meetings which have been circulated to all Partners and Dr Casale of the EC. The total project expenditure during the contract was 189268 ECU as shown on the annual Cost Statement which have accompanied the two annual reports and this final report. The original budget for the RIBAMOD Concerted Action was 191,000 ECU.

Appendix 2

List of Papers in the RIBAMOD Proceedings

Appendix 2 List of Papers in the RIBAMOD Proceedings

<u>EXPERT MEETING 1</u> – Horshølm, Denmark – 10-11 October 1996
"Forecasting and Modelling – Model Structure and Decision Support"

INTRODUCTION
Casale R, Havnø K and Samuels P

Impact of climate change on hydrological modelling and flood risk assessment
Burlando P, Mancini M and Rosso R

Modelling snowmelt induced by flooding
Bergström S

Linking hydrological and hydrodynamic forecast models and their data
Moore R J and Jones D A

Link between hydraulic and ecological models
Malmgren-Hansen A

New developments in modelling, framework for decision support
Refsgaard J C and Havnø K

Flood management in the Netherlands, recent developments and research needs
Janssen J P F M and Jorissen R E

Forecast systems for large rivers – The River Rhine Catchment
Wilke K

The overall reliability of flood defences
Empson B and Chapman J

Flood risk management support system
Gendreau N and Gilard O

Future modelling needs : Discussion and workshop conclusions
Cunge J A and Samuels P G

Workshop 1 – Delft, The Netherlands – 13-14 February 1997

"Current Policy and Practice"

INTRODUCTION
Casale R, Pedroli G and Samuels P

Flood hazard research within the European Commission 1987 to 1996
Moore R J

Understanding recent large river flooding (for example the Rhine Floods)
Engel H

Understanding flash flood experiences
Marcuello C

Probabilistic design for flood protection structures
Plate E J

Safety, risk and flood protection
Jorissen R E

Quality assessment of the meteorological forecasts for localised flash floods
Quiby J C and Schubiger F

Interdisciplinary recommendations towards integrated flood protection
Muys B

EUROflood. Abandoning "flood defence"?
Handmer J

Forecasting floods in urban areas downstream of steep catchments (TELFLOOD)
Bruen M

The development of active on-line hydrological and meteorological models to minimise the impact of flooding (HYDROMET)
Cluckie I D

Flooding risks in mountain areas (FRIMAR)
Klaassen G J

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"Forecasting and Modelling – Real Time Warning and Risk Mitigation"

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Destructive flood in Poland: Odra, Summer 1997
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Use of radar-rainfall estimated for flood simulation in mountainous basin
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Rainfall information requirements for Mediterranean flood operational forecasts
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Operational hydrometeorological input for real-time flood forecasting in Germany
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"Sustainable Use of River Catchments, and, Climate Change

Possible consequences of climate change on river basin management
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Beven K and Blazkova S

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de Roo A P J

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Bettess R

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