Comprehensive Flood Risk Management

Research for policy and practice

Editors
Frans Klijn
Timo Schweckendiek

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COMPREHENSIVE FLOOD RISK MANAGEMENT

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Foreword

Comprehensive Flood Risk Management is gaining ground in Europe and elsewhere, thanks to developments in science and policy, and devastating flood events every now and then. The scientific concepts, approaches and methods of flood risk analysis and management were shared and discussed among researchers and practitioners during the successful First European Conference on Flood Risk Management (FLOOD*risk*2008) in Oxford. This event marked the finalisation of the largest-ever European research project on flood risk management, FLOOD*site*. Shortly before, the European Commission issued the "Directive on the assessment and management of flood risks" (2007/60/EC), which triggered substantial activity in the EU member states. Recent flood events, for example in Pakistan (2010), Europe (2010 France, Romania and Ukraine), Japan (the 2011 tsunami), Thailand (2011), the USA (2011 Mississippi River), and Australia (2011 and 2012), once again stress the societal relevance of sound flood risk management, and ensure that we do not lose vigilance.

This makes 2012 a timely moment to share new insights and experiences from all over Europe and beyond, and to jointly set the course for new research and approaches in flood risk management.

Comprehensive flood risk management encompasses:

- preventive flood risk management, disaster management and recovery; in the fields of
- science, policy and practice; and thus actions such as
- analysis, assessment, and management planning; requiring involvement of
- natural sciences, social sciences, and arts/ethics; as well as their applied counterparts
- civil engineering, governance, and architecture and design.

Preventive flood risk management, disaster management and recovery are successive stages in an ongoing process of assessing flood risks, reducing them to an acceptable level against acceptable societal costs, then voluntarily bearing the remaining risk deliberately and consciously. This places comprehensive flood risk management at the centre of a continuously evolving societal consideration and debate about sustainable development and the place and role of flood risk management in that process. It is now commonly acknowledged that flood risk management is not a goal in itself but, instead, is an indispensable means to enable living safely and gaining benefits in environments that have much to offer in terms of prosperity and attractiveness, but not without risk. A delicate balance indeed.

Flood risk management puts the *risk* of flooding central, instead of the *hazard*. The notion that 'without people, there is no risk' requires not only an engineering approach to flood protection and flood control, but also a planner's approach to spatial development, to ensure that people and property are located outside hazardous areas or can cope with floods. This calls for further integration of water management and spatial planning. This obviously requires both a natural scientist's view on flood hazards and a social scientist's view on society's vulnerability. The natural scientist should look at coastal floods, river floods, pluvial floods, flash floods and tsunamis alike, but also at the development of flood hazard due to climate change. The social scientist should add focus on demographic developments and economic growth as key determinants of social vulnerability, but also on how cultural and technological developments may affect the people's coping capacity. And of course, we need the engineer's inventiveness, the designer's creativity and due knowledge about governance.

Finally, comprehensive flood risk management not only involves research and development, but—more importantly—also practical application and governance. FLOOD*risk*2008 already focused on research and practice, but the gap between these still remained large. Therefore, FLOOD*risk*2012 has as its adage: closing the gap between science, policy and practice. In this context, several recent developments are promising and deserve special mentioning.

In Europe, the issuing of the EU Floods Directive in November 2007 has given a huge impetus to the development and implementation of flood risk management in practice. This directive has been transposed into national legislation, and all member states have begun implementing the various required steps of preliminary risk assessment (2011), flood hazard and risk mapping (2013) and risk management planning (2015). This called for dedicated data collection, investigations and research, from which we can now learn a lot: about the actual questions which require an answer, about how to do deal with practical problems (e.g. of a lack of data when drafting flood hazard maps), and about the various approaches to making flood risk management plans in different member states. These practical questions have not only stirred up the responsible authorities, but also encouraged researchers and scientists to dedicate attention to flood risk management issues.

Simultaneously, dedicated European research within Framework Programmes 6 and 7 addressed relevant flood risk management issues, building on the foundations laid by FLOODsite. The research includes projects aimed at improving analysis methods (e.g. CONHAZ on cost estimates of hazards), with an emphasis on the influence of climate change (such as WATCH and ENSEMBLES), with a focus on certain flood types (e.g. IMPRINTS on flash floods, THESEUS on coastal flooding), on specific environments (e.g. CORFU, FloodProbe and SMARTeST on urban areas), on monitoring and warning (e.g. HYDRATE for flash floods and UrbanFlood for failing flood defences), on preventive policy (KULTURisk), on people's coping capacity (CapHazNet), and more. The majority of these projects present their latest findings at FLOODrisk2012. But also ERA-NET CRUE activities (e.g. EXCIMAP on hazard mapping), various Interreg IV projects (FLOOD-WISE) and several national research programmes (FloodControl2015, XtremRisK, Knowledge for Climate) have interesting new ideas and results to offer.

Rotterdam, FLOOD*risk*2012's venue, is among the world's leading seaports, and is the gateway to the hinterland of western Europe. With half the European inland shipping fleet and about 100,000 border crossings per year, the Rhine River is of utmost economic significance. However, there is a substantial flood hazard where this second largest European river meets the North Sea.

In this context, it is worth mentioning that more than 55% of the Netherlands is flood-prone, constituted of river floodplain, coastal plain, or land reclamation. And it subject to subsidence. This makes the country very dependent on reliable embankments, and vulnerable to climate change. The national authorities are dedicated to doing justice to their claim that the Netherlands is the best-protected delta in the world and to anticipating the consequences of climate change. To this end, a Delta Programme for the 21st century is being drafted, which stimulates the co-operation between science, applied research, policy and practice. This programme, for the first time in the Netherlands, drafts a comprehensive flood risk management strategy for the future that is not simply a response to an (immanent) flood disaster having occurred. This may explain the interest of the authorities in FLOOD*risk*2012.

On behalf of the Local Organising Committee, we express thanks to all those who helped make FLOOD*risk*2012 a success. Special thanks are due to the Scientific Committee for their efforts to review all contributions to this volume of abstracts, as well as the full papers on the enclosed CD.

Finally, on behalf on the Organising Committee, we welcome you to the conference and wish you many fruitful interactions and exchanges of ideas.

Frans Klijn & Timo Schweckendiek

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Keynote presentation

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Where next in flood risk management? A personal view on research needs and directions

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ABSTRACT: Over the past three decades or more, much research and development effort and resource has been devoted in national and international programmes to reduce the impact of floods and flooding. The way in which this research has been commissioned and organised has changed over the decades in response to the evolution of policy from the technical focus of flood defence to the multidisciplinary character of flood risk management. This paper begins with a look back at some illustrative programmes and approaches (drawn from the UK and the EC) before moving onto a personal view of the drivers of future flood risk and its management and the priorities for generation of further knowledge and understanding. After identifying the importance to R&D of the availability of and access to reliable data, I discuss research needs in support of three general areas: firstly on long-term planning and options assessment, secondly on management of flood emergencies and thirdly on exploring adaptation and resilience to floods. Finally, it is essential that, whatever research is done in the future, there is a clear plan and commitment for the research outcomes to be brought into practice.

1 INTRODUCTION

Over the past three decades or more, much research and development effort and resource has been devoted in national and international programmes to reduce the impact of floods and flooding. Research has been undertaken in many contexts—basic research for PhD theses, Government support to national institutes, strategic national programmes of applied research and development, and international programmes such as the Framework Programmes funded by the European Union.

The OECD "Frascati Manual" (Organisation for Economic Co-operation and Development 1993) provides an internationally accepted categorisation of research and development activities which I shall use in this paper. The following definitions come from the Second Chapter of the Frascati Manual.

"*Research and experimental development (R & D) comprise creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications.*

R&D is a term covering three activities: basic research, applied research, and experimental development

– ***Basic research*** *is experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundation of phenomena and observable facts, without any particular application or use in view.*
– ***Applied research*** *is also original investigation undertaken to acquire new knowledge. It is, however, directed primarily towards a specific practical aim or objective.*
– ***Experimental development*** *is systematic work, drawing on existing knowledge gained from research, and/or practical experience, that is directed to producing new materials, products or devices, to installing new processes, systems and services, or to improving substantially those already produced or installed.*"

In terms of flood risk management, research and development has supported a policy change from flood protection and flood defence to the broader objective of flood risk management (Klijn et al. 2008b). Flood risk is an evaluation of the combination of the probability of flooding and the adverse consequences that ensues. Thus the concept of risk is entirely a human construct through the values (monetary or not) we place upon the consequences of flooding. It is now widely recognised that absolute protection from flooding cannot be achieved and the societal goal is for the management of flood risks at an "acceptable" level. Flood risk management therefore has the character of a "wicked problem" (Rittel & Webber 1973) in that flood risk is part of a broader environmental and social system, there are many potential solutions with no "true" or "false" answers and different stakeholders have differing (and potentially conflicting) views of the problem.

In the past much research addressed specific technical issues such as the assessment of the capacity of a flood channel, construction of computational hydrodynamic models, radar hydrology or economic consequences of floods. Such projects generate knowledge for design of defences, forecasting software, estimation of flood damage etc. Research and development on flood risk management however is broader; it may combine aspects of physical and social sciences depending upon what part of and interactions in the overall risk system are being investigated.

This paper presents a personal reflection on the processes and content of research and development on flooding issues and is based primarily upon my own experience of research funded in the UK and by the European Commission (EC).

2 WHERE HAVE WE BEEN?

2.1 *Illustrative programmes and approaches*

2.1.1 *Flood research in the UK*

Within this section, few distinctions are made between the arrangements in the different countries (England, Scotland, Wales and Northern Ireland) although over the past decade administrative arrangements have changed with devolution of powers in the UK away from central government in London.

Historically the policy responsibility for floods lay with the former Ministry of Agriculture Fisheries and Food (MAFF) which maintained a commissioned programme of *applied research* which was informed by periodic reviews. Nationally eminent researchers led these reviews, with the most recent being those of Peter Ackers (Ministry of Agriculture Fisheries and Food, 1992) and Professor Edmund Penning-Rowsell (Ministry of Agriculture, Fisheries and Food 1999; Penning-Rowsell 2005). Over the past decade the research programme of MAFF, now reorganised into the Department for Environment, Food and Rural Affairs (Defra), has been integrated with that of the Environment Agency into a single Joint Programme managed by the Environment Agency. An outcome of the first of Penning-Rowsell's reports was a significant change in research organisation from disciplinary topics (rivers, coasts, meteorology, etc) into broader multi-disciplinary themes (policy, modelling, assets, risk, forecasting). The Environment Agency maintains a web portal to the results of this applied research and development programme.

In parallel with this Government-funded applied R&D, the UK research Councils have funded *basic research* on flooding processes through both "responsive" mode grants originating from a researcher and as part of a managed or directed programme. The research on the Flood Channel Facility (FCF) set up by the Science and Engineering Research Council (SERC) in 1986 and continued by the Engineering and Physical Sciences Research Council (EPSRC) (Knight & Sellin 1987) was undertaken as a series of responsive mode grants. The FCF research led to fundamental measurements of turbulence and understanding of capacity of natural channels (Shiono & Knight 1991) which through supplementary development funded by the Environment Agency has now entered into engineering practice (Mc Gahey et al. 2008, Knight et al. 2010).

In 2004 the EPSRC let the contract for a large managed programme (Pender, 2006) to the Flood Risk Management Research Consortium (FRMRC) which received a second round of funding in 2008. This managed programme included both basic and applied research with some of the research activities supporting directly the work of the Environment Agency and other funders. Over 20 academic institutions collaborated on the FRMRC research and, in contrast to the FCF research, the work of the FRMRC has moved more rapidly into practice.

2.1.2 *The EC Framework Programmes*

The EC Framework Programmes have supported research on hydrological risks and flooding since the 1980's. Much of the research commissioned in the collaborative projects falls in the Frascati categories of *applied research* or *experimental development*; 100 past and active projects were identified in 2003 in a project on the water resources technology and management course at the University of Birmingham (Ashton et al. 2003)[1]. These projects had been commissioned up to the Fifth Framework Programme (FP5). Since then, many more R&D projects have been commissioned in FP6 and FP7 between 2004 and 2012; the results of some of these are presented at the current conference FLOODrisk 2012. In FP7, the European Research Council (ERC) makes grants to support individual researchers to pursue their frontier research (see, for example, FloodChange[2]). This is in contrast to collaborative projects under the "cooperative funding" approach in FP6 and FP7 where large international project teams are assembled such as for the FP6 Integrated Project FLOODsite[3].

2.1.3 *The CRUE ERA-NET*

The EC Sixth Framework Programme (FP6) introduced the new "instrument" of an ERA-NET whose purpose was to support the structuring of a broader collaborative European Research Area with each network directed at a specific area of interest to Member States. Rather than funding research directly, the EC grant covered the additional costs of establishing the network of national research funders and establishing a mechanism for identifying, commissioning and reviewing research projects and programmes of interest to several or all the Member States participating in the ERA-NET. The CRUE network on flooding involved 12 EU Member States; it produced a database of recent research programmes and projects in the countries involved in the network, prepared a common research vision, and commissioned two rounds of research projects. The project website[4] provides public access to all the outputs.

2.1.4 *Ad-hoc international co-operation*

In addition to generic R&D programmes, international collaboration takes place on specific issues of common interest. An important current collaboration for flood risk management is the production of the International Levee Handbook (ILH) by an international team from France, USA, UK, Ireland, the Netherlands and Germany.

In September 2008, organisations from these six countries expressed a desire in principle to participate in an international project in order to learn from one another's experiences and to share the effort to produce good practice guidance as the ILH. There were several drivers for the collaboration including the US National Committee on Levee Safety which was established by Congress in response to Hurricane Katrina, the European Floods Directive (EC, 2007), various policy developments in the countries involved and the knowledge from research.

When completed, the ILH will be a compendium of good practice, offering comprehensive guidance on the design, construction, maintenance and improvement of levees as well as describing the international state of the art on these matters. It is planned that the ILH will

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1. available at http://www.actif-ec.net/library/review_EU_flood_projects.pdf
2. http://www.hydro.tuwien.ac.at/forschung/erc-advanced-grant-2012–2017
3. see www.floodsite.net
4. http://www.crue-eranet.net/

offer a decision support framework covering specific challenges during the life cycle of levees for competent engineers, rather than being a prescriptive decision making code of practice.

Further information on the ILH is included in the papers presented during the special conference session at FLOODrisk 2012 on the handbook, including the overview (Simm et al. 2012).

2.2 *Identification of research needs and programmes*

Much of the expenditure on flood risk management activities comes ultimately from taxation through national and local government sources. Hence in most countries there is public funding of relevant research to ensure that the expenditure on all flood risk management remains effective. The character of the research however will reflect the priorities of the funder, with basic research commissioned from research councils and more applied or site-specific research commissioned by the relevant executive agency (e.g. National Environment Agency, River Basin Authority, Government policy department, etc). Within EU, the European Commission prepares a Framework Programme for Research and Innovation (the Eighth Framework Programme starts in 2013) which addresses topics of pan-European concern (as opposed to those localised to one Member State).

The starting point is often the identification of some overarching needs, which form the backdrop for the formulation of more detailed programmes and projects. For example in the UK the research councils have identified a theme of "Living with Environmental Change" as being essential for the future. Flooding research fits within this as potentially flood risks will be influenced by changes to the climate and the land surface. In 2011, the NERC launched an extensive consultation on research needs to prepare a research programme. The UK Flood and Coastal Erosion Risk Management Research Strategy was published in January 2012[5]. The strategy identifies priority research topics in three themes: Understanding Risk, Managing Probability and Managing Consequences of flooding. A Steering Group oversees the implementation of the strategy; it will review progress and will update the strategy as appropriate.

In England and Wales DEFRA and the Environment Agency have a joint research programme on flooding and coastal risk management; the current (2009) programme is described in the Programme Definition document available on the Environment Agency website[6].

The research needs are identified primarily in consultation with the Environment Agency's flood risk management staff but refined with the assistance of Theme Advisory Groups (TAG), which include some external experts to give advice. The overall programme is moderated by a Joint Programme Board which again has external membership. The work commissioned is exclusively applied research and experimental development and covers topics of short and medium term need within DEFRA and the Environment Agency to improve their effectiveness. The research projects are managed within broad themes of Strategy and Policy Development, Modelling and Risk, Sustainable Asset Management, and Incident Management and Community Engagement.

The content of the EC Framework Programmes is developed within the Research Directorate of the European Commission with extensive consultation involving the other EC Directorates, the scientific community, and the national representatives of the Member States. The research programmes are developed at several levels starting with a broad definition of the whole framework programme's objectives covering research in all sectors. The programme is segmented by type of action and thematic content, with more detailed definition of specific topics for funding provided through competitive calls. The content of the detailed research is ratified before its publication and to be successful research projects address the topic of the call. Several research projects on urban, river and coastal flooding have been funded in different areas of the Seventh Framework Programme.

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5. http://www.lwec.org.uk/activities/uk-first-flood-research-strategy
6. http://evidence.environment-agency.gov.uk/FCERM/Libraries/FCERM_Documents/200911_PDD_Refresh_v3_FINAL.sflb.ashx)

The CRUE research agenda was produced through discussions within the Network members and an invited workshop. The research agenda is part of the overall CRUE Vision 2015, which is to "*provide a coordinated and comprehensive transnational evidence base on FRM (flood risk management) issues to underpin the work of key national and European policy-makers*". The research agenda document is published on the CRUE website (see above); it identifies five strategic research areas:

1. Developing resilience and adapting to increasing flood risks: climate change and new developments;
2. Risk assessment and mapping;
3. Implementing trans-national strategies on flood event management and recovery;
4. Meeting the multifunctional demands on flood prevention and protection and their sustainable management; and
5. Addressing public knowledge of flood risk and enhancing awareness, perception and communications.

The projects commissioned in two research calls have now been completed. The first led to seven projects within the theme of "*Risk assessment and risk management: Effectiveness and efficiency of non-structural flood risk management measures*"; the second call led to seven projects on "*Flood resilient communities—managing the consequences of flooding*". There is much in the CRUE research Agenda that remains to be tackled.

2.3 *Reflection*

Although the summary above is illustrative rather than comprehensive, some tentative common threads are evident.

Historically, research projects often addressed specific technical issues relating to flood defence leading to the development of new models, methods and datasets which could be applied in the design and assessment of flood defence measures.

For more than two decades large research programmes on flood risk management have been developed through a process of consultation with the stakeholders—researchers, policy makers, executive agencies, operation authorities, etc. The focus of these programmes has been on applied research and experimental development. In addition, basic and applied academic research has continued with funding predominantly in national projects but more recently internationally through the ERC.

Much research is now commissioned through large multidisciplinary programmes at the national and the European level. These programmes usually contain several separate projects but sometimes they commission a "super" project which then internally has major themes. In the case of the EC Framework Research flood research forms a component of larger priorities such as natural hazards, information technology application or security.

Although the applied research and experimental development is directed at solving complex problems arising in practice, the transfer of the research outcomes through to implementation and uptake into flood risk management practice is often not included within the scope of the research. This leads to an extended time from research advance to the benefits being fully realised. However, the CRUE Research Agenda did recognise explicitly the need for an implementation plan for utilising the knowledge. This issue is part of the broader current debate on the Science Policy Interface (Quevauviller 2011) and is not addressed further in the remainder of this paper.

3 WHERE SHOULD WE GO?

3.1 *The big issues*

The Foresight Future Flooding project examined the drivers of future flood risk for the UK though a combination of quantitative methods and expert elicitation (Office of Science and

Technology 2004). However, the analysis of the drivers highlights issues of broader application even though the balance between the factors will vary from one country to another. The highest rated drivers of future risk across all the linked climate and socio-economic scenarios included:

- Social impacts
- Infrastructure impacts
- Relative sea level rise
- Surges
- Precipitation
- Waves
- Coastal and river morphology

The report also identified those drivers with the greatest uncertainty as being particular candidates for further research (see Office of Science and Technology 2004, Appendix D of Volume 2).

Although changes in the hydro-meteorological factors were identified as of importance, social impacts were the highest or near highest rated influence in all scenarios considered. This should not be unexpected as flood risk management has strong human dimensions through the evaluation of flood damages, perception of and reaction to risk, policy for, and organisation of flood risk management measures. The expert elicitation component of the original Foresight project has since been updated.

The methodology has also been applied elsewhere, for example, to the Taihu basin in China (Harvey et al. 2009). In the different social, physical and economic conditions of that basin a different set of factors was identified as being the most important for driving future flood risk.

In my view, the backdrop internationally to the future evolution of flood risks and their management is dominated by the influence of:

- Climate change, extremes in precipitation and storms, and sea level rise;
- Population growth and density and the evolution of demographic distribution;
- Landscape-scale changes in land-use both for inland and the coastal zone including;
  - Location and growth of megacities;
  - Increased habitation on marginal land;
  - Value and distribution of assets in the land that is exposed to flood hazards;
  - Changing public attitudes to flooding and their resilience to flooding;
  - Ageing flood defence assets and the legacy of under-investment in maintenance and renewal;
- Cascading impacts, for example:
  - Destabilisation of soils causing mud and debris flows,
  - Threats to other critical infrastructure such as power, water supply, sanitation and food distribution networks,
  - Internationally significant manufacturing and commercial centres.

In addition flood risk management practice needs to respond to organisational and governance issues such as:

- Changes in legislation and in Europe the interaction of the Floods Directive with others including the Water Framework Directive;
- The need for greater public involvement in flood risk management planning;
- Constrained public finances in many countries;
- Response to international programmes such as the UN International Strategy for Disaster Reduction (UNISDR)[7] and the Hyogo Framework for Action (HFA).

7. For UNISDR and HFA see http://www.unisdr.org/

3.2 *The complexity of decision making*

The interaction of all these factors confirms that flood risk management is a "wicked problem". It has been recognised that flood risk management requires the use of a "portfolio" of measures rather than a single solution (Office of Science and Technology 2004, Samuels et al. 2006). These measures will include the traditional approaches of providing defences, increasing flow capacity and providing flood warnings during an event. However, more is needed. In Article 7, the Floods Directive (EC, 2007) requires that flood risk management plans should consider many aspects.

"Flood risk management plans shall take into account relevant aspects such as costs and benefits, flood extent and flood conveyance routes and areas which have the potential to retain flood water, such as natural floodplains, the environmental objectives of Article 4 of Directive 2000/60/EC, soil and water management, spatial planning, land use, nature conservation, navigation and port infrastructure.

Flood risk management plans shall address all aspects of flood risk management focusing on prevention, protection, preparedness, including flood forecasts and early warning systems and taking into account the characteristics of the particular river basin or sub-basin. Flood risk management plans may also include the promotion of sustainable land use practices, improvement of water retention as well as the controlled flooding of certain areas in the case of a flood event."

Economic and social development (physical, governance, institutional, social, etc) has become so complex that the occurrence of an extreme produces a shock to the ambient state leading to unforeseen and problematic consequences and impacts. Thus we arrive at a key challenge: how to make robust decisions given the uncertainty in future conditions? Moreover, past solutions may not be appropriate. Land exposed to flood hazard may need to be abandoned or settlements moved and land-use changed; life in urban areas might be designed to storm water flowing in "blue routes" above ground rather than below, and existing buildings and infrastructure may need adaptation.

Decisions taken now have inter-generational consequences and sustainability requires us to seek out a no-regrets route to meeting our needs without compromising the ability of future generations to meet their needs. One method under research for addressing this is that of "real options" (Woodward et al. 2011).

3.3 *A personal view on R&D priorities*

3.3.1 *Preamble*

In all flood risk management research programmes there is some form of categorisation to facilitate the identification of individual projects which meet the overall needs of the funders or the end-user of the research outcomes. For example, the UK Flood and Coastal Erosion Risk Management Research Strategy contains three broad areas (See Section 2.2 above) which respond to the business needs in particular of the Environment Agency.

My own set of research needs as discussed below uses the flood risk management cycle (Samuels et al. 2008, see figure 1), and I have coupled this with the need for adaptation to climate change. The general areas are:

- Improving our ability to make long-term plans and explore options for flood risk management;
- Support the response to, and the management of, flood emergencies;
- Support the adaptation of society to inevitable long-term changes in flood risk.

I hope these general areas are sufficiently generic to encapsulate the actions needed for flood risk management whatever the social and economic factors are in different countries; however, I would first like to identify the importance of data in supporting this R&D.

3.3.2 *Data*

Access to reliable data is the foundation for advancing understanding in flood risk management. This applies to all aspects of the research including the hydro-meteorology of floods and the socio-economic assessment of the consequence of flooding.

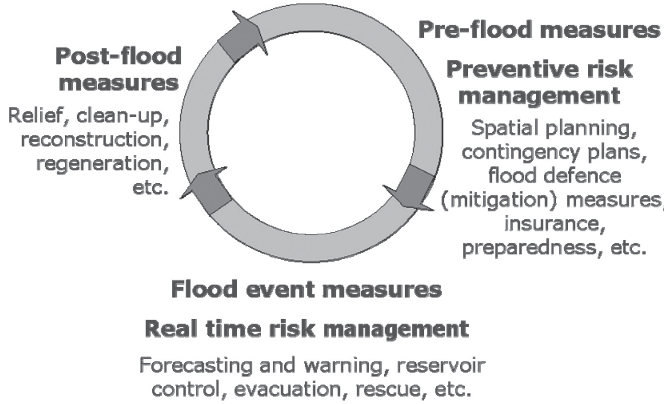

Figure 1. The risk management cycle.

As we move into a future where the assumption of stationarity in climatic conditions no longer can be made, long-term datasets are crucial for understanding and quantifying the effects of past change in climate and catchment conditions. The need for improved data was the focus of a workshop convened in January 2011 by the ACQWA project at the request of the EC Research and Innovation Directorate (Beniston et al. 2012).

Institutional, organisational and access issues for flood risk management R&D arising in currently held data and that being collected include:

– Recognising the long-term value of records as opposed to immediate value for example for legislative compliance or facility operation;
– Digitisation and accessibility to historic meteorological records;
– Measurement of river flows in extreme events;
– Precipitation measurement in remote areas;
– Consistent aggregation of datasets for physical parameters and the economic and social impacts of floods.

In addition new and emerging technologies may change the way in which data is collected and provide opportunities for new types of data to be available for analysis.

3.3.3 *Long-term planning and option assessment*

Research on extreme floods needs to be set in a multi-hazard framework for several risk sources, which may be coincidental, conjoint or cascading, taking a "whole systems" approach to the physical, environmental, ecological and social systems, and their interdependencies and interconnectivities.

A difficulty with public involvement in long-term planning is that the typical time-scale between the occurrence of major floods and the devastation caused may be two or more generations and thus the impacts lie outside the scope of life-time memory of much of society. Moreover, natural processes that are responses to these extremes (for example morphological adjustment of rivers) may undergo step changes in response to an extreme, upsetting the apparent benign appearance of a static equilibrium to which the public has become accustomed.

An additional complication is that policy development accounts for climate change over multi-generational timescales but investment decisions cover generational (decadal) timescales. Thus scenarios are needed to explore the potential flood hazards and risks over a timescale of say 100 years, with information at the decadal timescale suitable for investment appraisal.

Scenario-based analysis of strategic flood risk management alternatives has already been researched in FLOODsite with examples from the Netherlands and the UK (Klijn et al. 2008). However, there remains considerable uncertainty with generating hydro-meteorological scenarios at the catchment scale from climate modelling output and in terms of coastal surge and wave conditions. Hence I see this as an important area for future research requiring collaboration between the meteorological community involved in climate simulation, flood hydrologists and oceanographers.

Practical advice on decadal scale information is now beginning to be provided for decision-making. For example, in England and Wales, the Environment Agency has prepared advice for use in making spatial planning decisions (Environment Agency 2011). The advice derives from the national UKCP09 climate projections[8] and provides the range of allowances to use for climate impact on rainfall and mean sea level, with regional variations, decadal values and an estimate of range of the potential change. However, UKCP09 does not provide a full understanding of changes to extreme, convective rainfall at the scales needed to manage surface water flooding.

The need is urgent to improve understanding and reduce uncertainty for estimates of decadal timescale changes to floods and their impacts. This includes climate projections for short-duration extreme rainfall which are particularly relevant in risk management of impacts of extreme floods on society. In addition information is needed on the potential for change of the likelihood of sequences and combination of events. For the next decade or two greater use might also be made of past records in generating estimates of changes in flood hazards. Again the research will require collaboration between the meteorological community involved in climate simulation, flood hydrologists and oceanographers.

Better understanding is needed on the degree to which changes in the intensity of extremes can be attributed to natural variability or to anthropogenic influence on climate. Current research suggests that climatic signal in the trend in hydrological response may be discernable from natural variability within one or two decades.

In addition to climate scenarios, long term planning requires consistent scenarios for other environmental, social and economic factors. These scenarios will, of course, vary nationally allowing for different population projections, economic growth and macro-scale international governance.

Cost-benefit assessment is used widely in making decisions on flood risk management measures. This requires an assessment of the damages avoided by implementing the measures. In the first round of CRUE projects it was identified that the level of uncertainty in damage and risk estimates is about 45%, hence, more research is necessary to provide statistically sound foundation of damage functions and risk estimates. Research is needed on the appropriateness of traditional cost-benefit methods for the appraisal of certain non-structural flood risk measures such as spatial planning, regulation of land use, and the availability and take-up of flood insurance.

3.3.4 *Management of flood emergencies*

Over the past three decades research on radar hydrology and numerical weather prediction has led to substantial improvement in the reliability and the lead-time available from operational flood forecasting systems. Such systems are an essential component of warning of flood emergencies. The EC FP5 project EFFS has led directly to the European Flood Alert System EFAS, which now provides basin-scale probabilistic flood alerts over the whole of Europe for up to 10 days ahead (Thielen et al. 2009).

There remains much useful R&D to be done in the forecasting of river and coastal flooding. Improved flash-flood forecasting will come from the integration of high resolution numerical weather prediction with weather radar. It is still difficult to provide effective warning of short lead-time, rapid-onset flooding in urban areas and research should concentrate on developing the ability to warn at say a 12-hour time horizon combined with an estimate of uncertainty. Such improved precipitation forecasts will need to be coupled with detailed topographic models of the flow through the urban area to provide warning of so-called pluvial flooding.

8. See http://ukclimateprojections.defra.gov.uk/

Further research emphasis is needed on supporting the operational activities of the civil protection agencies during a flood emergency. Loss-of-life and evacuation models for emergency management have the potential to inform civil contingency planning and flood event management; this would assist a wider assessment of emergency plans as recommended by the ERA-NET CRUE project FIMFRAME. Likewise a better understanding and representation is needed of the inter-linkages between the flooding system and the socio-economic system that benefits from the flood defences. In particular, attention needs to be directed at potential failures of critical infrastructure that is exposed to flood hazard and the cascade of consequences so that civil contingency planning can explore the full extent of an emergency.

Another area where research is needed is in real-time detection of changes in the state of the flood defence system during an event and automatically integrating this information into flood forecasts. System changes could include failure of defence infrastructure (banks, sluices, pumps, etc) and blockage of structures by debris. Accessing real-time information on system states will assist in developing real-time risk information taking account of the changed probability of flooding and the consequences of inundation. Other papers at FLOODrisk 2012 cover the FP7 project UrbanFlood, which is making progress on this issue through integrating signals from sensors embedded in embankments into an early warning system.

3.3.5 *Exploring adaptation and resilience to floods*

Extreme floods are, by definition, experienced infrequently and thus the question arises to what extent should there be an attempt to control the extreme and to what degree physical and social infrastructure should be adaptable and designed as resilient to extreme conditions.

In any country, the appropriate mixture of measures and adaptations will depend upon the financial resources available for flood risk management and the resilience of the society to living with floods. Where resilience is poor, or the magnitude of extreme floods increases, flood emergencies may be transformed into disasters when serious disruption of the functioning of the community exceeds the ability of the society affected to cope using its own resources.

Although in many countries the move from flood defence to flood risk management has been made in the policy domain, the consequences of this change in approach still has to work through to individuals and businesses in the communities at risk. The policy implies the need for greater public and stakeholder involvement in managing the flood risks experienced and becoming individually and collectively more resilient. I see that this leads to three main questions each of which comprises further questions.

1. What is resilience and what influences it?
   - How do we characterise resilience to flooding, what indicators are appropriate to assess the effectiveness of actions to increase resilience?
   - What impact will demographic changes (e.g. age, population density, occupancy rates, ethnicity, mobility etc.) have on preparedness for floods, coping with an emergency and long-term recovery?
   - What are the consequences of this "privatisation" of risks for social vulnerability and the ability of individuals and communities to accept and cope with flood risk?
2. How do we best communicate on flood risk and involve stakeholders in flood risk management?
   - How do we make flood risk management become a real part of citizen's lives and for businesses, not just for policy-makers and professionals?
   - What are the best means of communicating different types of flood risk information for pre-flood planning or during an emergency? (How can citizens be concerned about floods if they have no experience in their area?)
   - Should we communicate emphasising the concept "danger" or that of "safety" from floods and how does risk perception change with citizen's age?

3 How will this change in approach work?
   - How do we encourage people at risk from flooding to undertake private precautionary measures?

– How best can we ensure that individuals and businesses respond appropriately to flood warnings?
– What influence will any greater expectation or reliance on individual risk management have on civil contingency planning?

An important issue in all countries and communities affected by flooding is the health impacts of flooding. Flood water can carry and spread pollutants and pathogens whose influence can last for many months after the flood has receded. Improvements in knowledge and means of mitigation of the negative effects of flooding on health will lead to faster recovery from flooding and thus improve resilience.

In accepting that some flooding will occur, the question arises on how the communities and businesses affected can be best supported to recover from the consequences of inundation. Comparatively little research has been done on flood recovery; further R&D could be done on social factors to facilitate recovery and possibly also on means of restoring physical damage.

4 CONCLUDING REMARKS

In the most simple terms flood risk management is about keeping flood water away from people or people away from flood water. This requires risk management measures and actions both before a flood and during a flood emergency. Nevertheless, it is unrealistic to expect that flood risks can be eliminated and so future flood risk management must include a degree of adaption of society to living with the flood hazard.

Past research on flood risk management has brought real advances in knowledge and understanding which have been taken up into practice and have shaped changes in policy. However, looking to the future indicates that flood risks are set to increase driven by changes in climate, population, demographics and patterns of land use and settlement. Our management of floods and flood risks must respond to these pressures in a sustainable way which does not prejudice the ability of future generations to meet their own needs; again this points to adaptation as a key strategy.

In this paper I have suggested some areas for research and development which I consider could improve our ability to understand, manage and adapt to flood risks. Others will want to add their own priorities for R&D and we must always be prepared to exploit technological development elsewhere in improving flood risk management. Whatever research is done it is crucial that there is a clear plan and commitment for the research outcomes to be brought into practice. As many flood risk management measures are undertaken by the state, this will require the flood management agencies to plan to integrate the research findings into their own policies and implement them in practice.

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Technical presentations

Flood hazard analysis

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A probabilistic approach to dam breach modeling

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Flood hazards that would be created by breached dams need to be evaluated to select spillway design floods and to prepare emergency action plans. Values of parameters used in empirical breach-formation models along with their uncertainties can be estimated from relations developed based on data collected from historic failures. The uncertainties of the breach parameter estimates can be large, as can their effects on planning actions developed to minimize flood hazards. Sensitivity analyses on breach parameters have shown that the computed peak flow from a dam breach can vary by as much as 100% or more. A deterministic approach, the traditional method for dam breach analyses, leaves the investigator little choice but to select breach parameters from the conservative side of the uncertainty range, sometimes leading to widely exaggerated peak discharges and flood inundation maps.

In an effort to better communicate the consequences of a dam failure, a different approach-a probabilistic approach-to dam breach modeling is offered. Instead of selecting conservative values for breach parameters, the uncertainty range is quantified by defining a probability distribution for each uncertain breach parameter. Through an automated Monte Carlo analysis, the uncertain parameters are randomly sampled from the defined distribution and plugged into an existing dam breach model. This process is repeated 10,000 times to arrive at a peak flow value that represents the 90% conditional non-exceedance probability (CNP) for a given dam failure. The breach outflow hydrograph that produces this peak flow can then be routed through the rest of the hydraulic model to produce 90% CNP water surface elevations and a resulting 90% CNP flood inundation map for dam failure. In practice, any percent CNP can be selected (does not have to be 90%) and only needs to be specified by the governing agency.

It is anticipated that this alternative approach to dam breach modeling will provide the public with more meaningful information specific to the consequences of the failure of a dam. Engineers and emergency planners will be able to take advantage of the communication benefits of a risk-based analysis by incorporating these results into cost-benefit analyses, loss of life estimates, and system-wide long term studies. It is also demonstrated that this type of analysis can be conducted in an "overnight" simulation (i.e. a simulation that can be initiated at the end of the work day, left to run overnight, with the results ready first thing in the morning) with a high degree of confidence.

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Methodology for risk assessment of flash flood events due to climate and land use changes: Application to the Llobregat basin

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Keywords: flash floods; global change; climate change; land-use changes; risk; hazard; vulnerability; Llobregat basin; IMPRINTS

The IMPRINTS project, framed in the EC 7th Framework Programme, has the main objective of contributing to the reduction of loss of lives and economic damage through the improvement of preparedness and operational risk management of flash floods and debris flow events. Global change is expected to increase the stress on the entire water cycle and extreme events are likely to increase due to climate change. That is why in the frame of this project, impacts of future changes are analyzed.

The results of the project have been tested in the Llobregat river basin, in the Northeastern part of Spain. Its source is in the Pyrenees, and due to the rough orography of the region and the reduced size of most of the sub-basins, the hydrologic response time of these watersheds are around a few hours. The basin presents the typical Mediterranean climate where one third of the average annual precipitation can fall in less than 48h. This is the reason why flash floods occur during convective storms.

An assessment of future flash flood risk has been undertaken in this basin. It is widely agreed that natural risks are the product of hazard and its consequences. Within this approach, risk is a function of hazard, exposure and vulnerability.

Regarding future hazard, transformation of current hazard maps has been undertaken taking into account future climate scenarios. In this case, the scenarios developed by the SMC, regionalised over Catalonia have been used.

Exposure is represented by the assets that are present at each location. Urban land-use changes have been simulated using the MOLAND cellular automata model implemented in the JRC. In order to obtain vulnerability, a monetary value has to be assigned to each land-use type, which has been done by using a classification based on the total economic value of exposed assets for each land-use class. The information on vulnerability has been derived from the JRC database of flood-damage functions.

The overlay of the different datasets previously mentioned enables to obtain risk maps. This must be done for each cell, by multiplying the weights assigned to different levels of hazard and vulnerability.

As a result, risk maps for the current situation and future scenarios have been obtained. IPCC SRES A2 and B1 scenarios have been used when simulating both, climate and land-use changes. For the several scenarios implemented (i.e. the four combinations of A2 and B1 scenarios for climate and land-use changes), a general increase of the flood risk for the future situations has been obtained. This increase is specially marked for the A2—A2 future scenario.

By representing the differences between the future and current risk maps, an identification of the areas presenting the higher increases has been done. It has been identified that these hot spots are normally accompanied by urban growth in the flood plains. On the other hand, the effects of climate lead to an increase of risk basin-wide.

Although throughout the whole methodology a number of uncertainties have been identified, the results can be used as a first step to localize the areas where more emphasis should be given when implementing adaptation measures.

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Regional flood frequency analysis in Slovakia: Which pooling approach suits better?

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1 INTRODUCTION

In Slovakia, estimation of flood quantiles and return periods for hydrological design has long been based purely on traditional at-site approach to a flood frequency analysis. The development of statistical tools for modeling probabilities of flood occurrence in a regional context has just started in the 1990s. These models followed concepts to regional flood frequency analysis based on fixed regions; later the Hosking & Wallis's (HW; 1997) theory was adopted and modified. Nevertheless, it turned out to be that delineating homogeneous regions using these approaches is not a straightforward task, mostly due to the complex orography of the country. For this reason, adoption of a pooling approach that makes use of 'flexible regions' seemed a promising alternative to overcome the difficulties imposed by the altitudinal variability of Slovakia.

2 DATA AND METHODS

In the paper, based on the annual peak discharges from 174 small and mid-sized catchments (10 to 340 km^2) from Slovakia, three approaches to a flood frequency analysis are intercompared. Besides the traditional at-site frequency modeling, two concepts of a regional frequency analysis are examined, i.e. a conventional regionalization approach based on the HW methodology, and a pooling approach based on the region-of-influence (ROI) method (Burn, 1990).

In the HW approach, homogeneous pooling groups with a fixed composition are identified on the basis of various combinations of about 20 site characteristics, using the k-means clustering method along with the Euclidean distance metrics. The homogeneity of the proposed clusters (pooling groups) is verified using Hosking's H_1 homogeneity measure.

On the other hand, in the ROI approach, unique pooling groups of similar sites are constructed for each site under study. The similarity of sites is defined on the basis of different combinations of selected site attributes that also proved applicability in a cluster analysis for the HW approach. The homogeneity of the proposed pooling groups is evaluated by the homogeneity test by Lu & Stedinger (1992). A further significant difference of the ROI pooling method in comparison with the HW approach is the fact that the target size of the ROI pooling groups is adjusted to the target return period T of the estimated flood quantiles. The actual size of the pooling groups is found on the basis of an automated iterative procedure (Gaál & Kyselý, 2009).

In each frequency model, the generalized extreme value (GEV) distribution with an L-moment based parameter estimation is applied to assess flood quantiles. In both regional approaches, the index-flood concept (Dalrymple, 1960) is adopted. The inter-comparison of different frequency models is evaluated by means of the root mean square error (RMSE) and the bias from Monte Carlo simulations (Gaál & Kyselý, 2009).

3 RESULTS

In general, there is no regional frequency model with an ultimate performance for all the return periods considered (10, 20, 50, 100 and 200 years). For small return periods, the ROI pooling schemes perform better. This is likely due to the fact that the size of pooling groups is tailored to the target return period, while the quantile estimation within the fixed HW regions may be skewed by redundant information. For larger return periods, the benefits and the drawbacks of the HW and ROI approaches are outweighed. The HW methodology shows a somewhat better performance than the ROI pooling schemes, mostly in terms of the average values of the bias and RMSE; however the spread statistics are more favorable for the ROI methodology (i.e. they show narrower boxes and whiskers).

It can also be concluded that the regional methods clearly outperform the at-site estimation for all return periods. The performance of the at-site models is only comparable with the regional frequency models while the return period of the quantiles is comparable with the sample size.

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Statistical assessment of storm surge scenarios within integrated risk analyses—results of the XtremRisK project

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Keywords: North Sea, storm surges, waves, risk analyses, joint probabilities

Within the joint research project XtremRisK the source-pathway-receptor concept (SPR Concept) is used to perform integrated risk analyses for two investigation areas in the German North Sea; Sylt Island as an open coastline and a famous tourist destination as well as the city of Hamburg as the only German megacity in an estuary. The SPR Concept consists of storm surge analyses (risk sources), dike/dune breach scenarios including the calculation of failure probabilities of the flood defence structures (risk pathways) and the quantification of potential losses in the hinterland (risk receptors). Hence, the knowledge of the characteristics of possible storm surges is essential and the calculation of exceedance probabilities represents a crucial step within risk analyses.

This paper summarises the key findings of the XtremRisK subproject (SP) 1b, which aims at calculating the exceedance probabilities of different storm surge scenarios. The latter are the outcome of SP1a and the estimated exceedance probabilities P_e are subsequently considered for the analyses in SP2 (i.e. calculating failure probabilities of the existing flood defence structures).

First, a methodology has been developed to stochastically simulate a very large number of synthetic storm surge scenarios (total water levels). The resulting data set is used as a basis for bivariate statistical storm surge analyses, where the highest storm surge water levels S and the storm surge intensities F (i.e. the area between the observed storms surge water levels and the German ordnance datum NN) are taken into account. Archimedean Copula functions are applied, as they represent flexible joint distributions, are able to handle mixed marginal distributions and account for the structure of dependence overlooking the margins. For the west side of Sylt Island, the wave conditions also play an important role and need to be considered in addition to the two storm surge parameters within the statistical assessment. This requires the application of a trivariate Copula approach, where the significant wave heights represent the wave conditions. The runoff of the Elbe River influences the storm surge water levels in Hamburg and therefore the runoff Q has to be taken into account in addition to the parameters S and F for this investigation area.

The results from statistically analysing 4 different storm surge scenarios for Sylt Island and 5 scenarios for Hamburg (provided by SP1a of the XtremRisK project) are presented in the paper. The key uncertainties in both subprojects (1a and 1b) are quantified and considered within the statistical analyses. Although the number of scenarios used to calculate the risk curves is relatively small, the range of possible storm surges is almost fully covered. Moderate storm surge events (with relatively large exceedance probabilities) are considered as well as very extreme events with very small exceedance probabilities. Some of the storm surges consist of very high water levels, while the intensity is small and for some scenarios the intensities are large, while the water levels are comparable low. Hence, reliable input data for the succeeding computational steps within the integrated risk analyses are provided.