

**AN ANNOTATED BIBLIOGRAPHY OF  
FLOOD RELATED CBA AND MCA  
LITERATURE**

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# Introduction

## Structure of the bibliography

In this bibliography each reference is annotated by means of an abstract which explains the content of the reference. The references are organised in the alphabetical order of the surname of the first author within discrete sections which structure the bibliography. These sections group together references addressing similar areas of benefit or impact as well as grouping together those reference which address a general overview and theory. Where a reference covers more than one area of impact, a judgement has been about the predominant content so that the reference has been allocated to the grouping which represents this predominance. Users may need to consult one or more sections of the bibliography.

This focus of this bibliography is flood-related Cost-benefit analysis (CBA) and Multi-criteria analysis (MCA). However, it includes a few selected general texts and papers on these methods which will help the user contextualise flood-related CBA and MCA applications. To aid users these CBA and MCA methods are first summarised below. Because financial analysis and cost-effectiveness analysis may also be used to evaluate project options, the basic differences between these methods and CBA and MCA are also briefly explained but literature relating to cost-effectiveness analysis is not specifically contained in this bibliography.

## Cost-benefit analysis (CBA)

CBA is the traditional method for organising information to aid decisions about the allocation of resources: most usually public or government investment resources. Its power as an analytical tool rests in two main features. Firstly, costs and benefits are expressed as far as possible in monetary terms so that they are directly comparable with one another. Secondly, costs and benefits are valued in terms of the claims they make on and the gains they provide to the community as a whole, so the perspective is a 'global' one rather than that of any particular individual or interest group. CBA requires a holistic analysis of all benefits and costs involved in order to assess a risk reducing activity in comparison to its net benefit. A distinguishing feature of this approach is that it may result in recommendations to implement different safety standards for different risk situations, depending on the specific risk and the costs involved to reduce it. The major and often criticised shortcoming of this approach concerns the fact that all benefits and costs are quantified in monetary terms and aggregated to a single number without the possibility of giving some risks a larger weight.

CBA is often attributed to the work the late 19<sup>th</sup> century economist Alfred Marshall, but the first use of CBA in the world was made in the flood risk management sector in the United States in compliance with the United States Flood Control Act of 1936. This Act specified that participation of the United States Federal Government in projects to control flooding on major rivers would be justifiable if the benefits to whomsoever they accrue are in excess of the estimated costs. Thereafter, authorities developed procedures to measure these benefits and costs. CBA is now widely used across sectors and countries and the methodology has been much refined.

The major strength of CBA that it is based on well-understood theoretical foundations, derived from more than a century of research in welfare economics. This gives CBA a high degree of internal consistency. Because all cost-benefit studies share a common methodology, lessons learned in one project appraisal can be transferred to other studies, allowing the accumulation of expertise.

## **Multi-criteria analysis (MCA)**

MCA is similar to CBA regarding the overall aim of undertaking a holistic analysis in order to identify and, if possible, quantify all benefits and costs of risk-reducing activities. Relative to CBA, the main merit of MCA is that it provides an explicit method of taking account of project impacts that are not easily given monetary values (often called 'intangibles' in CBA). However, MCA presents the opportunity of measuring the consequences of an activity in terms of different units while leaving the final weighting of criteria to the decision-makers or to a stakeholder group. Mathematical algorithms are then used to determine the most favourable risk reducing activity in the context of different risk perceptions, risk attitudes and preferences of decision makers and stakeholders. The results are then passed back and discussed within the political process in order to support the finding of the most appropriate risk-reducing activities.

The disciplinary origins of MCA or Multiple Criteria Decision-Making (MCDM) are in decision-making theory, operational research and management science. MCA had its origins in the 1960s in the application of linear programming to management and industry. Goal programming since has become a mainstay of management science and operations research.

## **Differences between CBA (i.e. economic analysis) and financial analysis**

Financial and economic analyses are similar. Both estimate the net-benefits of a project investment based on the difference between the with-project and the without-project situations. The basic difference between them is that the financial analysis compares benefits and costs to the enterprise or to the organisation, whereas economic analysis compares the benefits and costs to the whole economy.

CBA is concerned with the true value a project holds for the society as a whole. It subsumes all members of society, and measures the project's positive and negative impacts. In addition, economic analysis also cover costs and benefits of goods and services that are not sold in the market and therefore have no market price. There are two more significant differences between financial and economic analysis. While financial analysis uses market prices to check the balance of investment and the sustainability of a project, economic analysis uses economic prices that are converted from the market price by excluding tax, profit, subsidy, etc. Financial and economic analyses also differ in their treatment of external effects (benefits and costs), such as favourable effects on health. Economic analysis attempts to value such externalities in order to reflect the true cost and value to the society. The inclusion of externalities raises difficult questions of their identification and measurement in terms of money.

However, economic and financial analysis are also complementary. For a project to be economically viable, it must be financially sustainable. If a project is not financially sustainable, there will be no adequate funds to properly operate, maintain and replace assets. It has sometimes been suggested that financial viability should not be made a concern because as long as a project is economically sound, it can be supported through government subsidies.

## **Cost-effectiveness analysis.**

Cost-effectiveness analysis is an assessment of the costs of alternative options which all achieve the same objective. Where there are alternative options to achieve a specific objective, but where the objective itself cannot be valued, cost-effectiveness analysis may be used to assess the least-cost

way of achieving the objective. Cost-effectiveness analysis should include non-cash opportunity costs, such as the use of assets owned by the spending body, which would otherwise be put to some other use. It may also include external costs, if these are relatively straightforward to value in monetary terms – such as travel costs of commuters. It may possibly include shadow prices for some marketed inputs.

## **The relationship between flood damages/losses and benefits of flood risk management.**

Some of the literature contained in this bibliography focuses upon the impacts of flooding - whether these be damage to property and infrastructure or harm to human beings, including the ill-health effects of floods and loss of life in floods. The potential benefits of flood risk management are the equivalent to the avoidance of these losses and so benefits are estimated by assessing damages and losses potentially avoided.

## **Scope and limitations of the bibliography.**

Inevitably this bibliography is selective and there are therefore limitations in this regard. The literature searched and included is that in the English language only and the user should be aware that there is also a bias towards UK and European material which reflects the author's background.

## **Cost-benefit analysis**

### **General overview and theory**

**Commonwealth of Australia (2006) Introduction to Cost-Benefit Analysis and Alternative Evaluation Methodologies, Financial Management Reference Material No. 5, January, Department of Finance and Administration Financial Management Group, Canberra ISBN 1 921182 00 8 (print) ISBN 1 921182 02 4 (online)**

Managers in Australian Government agencies are often called on to evaluate programmes and projects to ensure that they represent an efficient and effective use of public money. Cost-benefit analysis (CBA) is a method of quantitative economic analysis that is widely used to evaluate existing and proposed projects, programmes and policies, and which can inform decision-making. Introduction to Cost-Benefit Analysis and Alternative Evaluation Methodologies (hereafter the Introduction to CBA) introduces CBA in a non-technical way and outlines the basic steps for its use.

The Introduction to CBA also discusses two alternative quantitative methods for evaluating proposals that have broad relevance to Australian Government agencies: financial evaluation and cost-effectiveness analysis. However, the Introduction to CBA focuses mainly on CBA. Three case studies are also provided. They are a cost-benefit analysis of an infrastructure proposal; a financial evaluation of a property project; and a cost-effectiveness analysis of a health programme.

The Introduction to CBA also includes a short technical section. Readers seeking a more technical account of these methods should refer to published texts on this matter, including Handbook of Cost-Benefit Analysis (hereafter the Handbook of CBA) published by the Department of Finance and Administration (2006).

**Commonwealth of Australia (2006) Handbook of Cost-Benefit Analysis, Financial Management Reference Material No. 6, Canberra ISBN (Print) 19 21182 01 6 ISBN (On-line) 19 21182 03 2**

The Handbook of Cost-Benefit Analysis provides guidance in the use of cost-benefit analysis for evaluation and decision-making. It is aimed at enhancing capacities and fostering good practices in

the use of cost-benefit analysis. The Handbook also covers two alternative methodologies – financial evaluation and cost-effectiveness analysis – for the evaluation of projects and programmes. The target audience of this Handbook is Australian Government agencies. It is intended for use by those officers involved in appraising and evaluating projects and programmes that carry major resources implications. However, it should be noted that other evaluation methodologies, which are not covered in the Handbook, are available and may be used by agencies. In any case, agencies should outline and justify the evaluation methodology chosen. Agencies are responsible for conducting and presenting (normally through written reports) their own evaluations. The Handbook is intended to be a resource document and guide for officers undertaking a cost-benefit analysis of a project or programme. It aims to explain concepts clearly and, in this way, does not assume any prior knowledge of economics. However, readers with a background or particular interest in economic principles are likely to relate to the material more readily than others. The Handbook includes a useful section on the criticisms and limitations of Cost-Benefit Analysis.

**Dobes, L. (2008) A century of Australian cost-benefit analysis: lessons from the past and the present, Working papers in cost-benefit analysis, Office of Best Practice Regulation, Department of Finance and Deregulation and ANU, WP 2008-01, Canberra <https://www.dpmc.gov.au/deregulation/obpr/docs/Working-paper-1-Leo-Dobes.rtf>, accessed 18/11/14**

A wide-ranging paper beginning with the origins of cost-benefit analysis in the USA with Benjamin Franklin and the much later 1936 Flood Control Act. The paper discusses the US experience with cost-benefit analysis and although Australia never institutionalised CBA in the way the US did, Australia can be proud of its heritage of early economic analysis. The author examines the costs and benefits that were attributed in Australia to rail gauge unification – a key area to which CBA was applied – and draws some lessons from history. The current use of CBA in Australia is discussed next focusing upon the large infrastructure projects promoted by Auslink (i.e. transportation projects) which introduces some interesting distributional issues. The relevance of CBA in the health and defence sectors are discussed next before the author makes the case for a renaissance of CBA and puts forward an argument for greater use of CBA but in ways which reduces the cost of such analyses. Ways of encouraging greater use are discussed.

**Green, C. H. (2003) A Handbook of Water Economics, John Wiley, Chichester (ISBN: 978-0-471-98571-6)**

The Handbook of Water Economics is presented in three sections: theory, methods and applications, providing the latest information in the growing area of water economics and the environment, covering the theory and issues relating to resource management techniques, policy formulation, implementation and evaluation in the water sector.

- \* Includes strong theory section which links to real world examples in the applications section
- \* Methods section includes coverage of methods of economic evaluation, use of economic instruments and cost-benefit analysis
- \* Applications section includes case studies on flooding and coastal zone management

Essential reading for those studying environmental economics modules in Departments of Environmental Management, Geography and Engineering, researchers in hydrology as well as professionals and policy makers in water companies, water authorities, NGO's and government agencies.

**HM Treasury (2012) The Green Book: Appraisal and Evaluation in Central Government, HM Treasury, London**

The UK Government's guidance in public investment appraisal including benefit-costs analysis. The 'Green Book' sets the standards by which central government departments, such as Defra, are required to adopt in assessing the benefits and costs of investments. This guidance applies to the full range of public investment appraisal and not just cost-benefit analysis applied to flood risk management, but it contains highly pertinent guidance for practitioners in flood risk management.

**Johansson, P. O. (1987) The economic theory and measurement of environmental benefits, Cambridge University Press, Cambridge**

This book is an advanced text in welfare economics and its application to environmental economics. It provides, in the first chapters, a comprehensive survey of developments in the theory of measurement of welfare, and then applies this theory to environmental economics. The first part derives consumer surplus measures to be used in a timeless world, and the second part looks at international issues.

**Navas, F., Malvarez, A., Corroero, R. and Pereira de Silva, C. (2014) FLOOD-CBA Project: Stocktaking on Flood Risk Management and Cost-Benefit Analysis, Seminario FLOOD CBA Lisboa, 21 January 2014 accessed at [http://www.floodcba.eu/main/wp-content/uploads/TASK\\_B-Actions-and-Results.pdf](http://www.floodcba.eu/main/wp-content/uploads/TASK_B-Actions-and-Results.pdf) on 1.11.14**

This is a PowerPoint presentation document from the FLOOD-CBA project. One of the FLOOD-CBA project goals is to ensure the involvement and engagement of stakeholders dealing with Cost-Benefit Analysis (CBA) for flood risk management in different economic environments within the EU, and to collect and facilitate the exchange of information among them. The peer-to-peer stakeholder network within this project is described as are the legal and other underpinnings relating to CBA in a number of EU member states. How CBA is employed and where it is employed in described as an output from a peer consultation process.

**Richard, P., Layard, G., Layard, R. and Glaister, S Eds (1994) Cost-Benefit Analysis, 2<sup>nd</sup> Edition, Press Syndicate of the University of Cambridge, Cambridge, ISBN 0521 46128 6**

This second edition covers all the main problems that arise in a typical cost-benefit exercise. It is entirely up to date, reflecting the most recent research in the area. Part One covers the main theoretical issues affecting cost-benefit analysis. Part Two considers the problem of ascribing a monetary value to things. The third part covers six separate case studies drawn from real-life examples. The book begins with an extended elementary introduction written by the editors.

## **Flood damages**

**Admiraal, J. (2011) Flood damage to port industry, MSc. Thesis, Faculteit der Aard – en Levenswetenschappen, Vrije Universiteit, Amsterdam**

Sea ports will experience many consequences of climate change; most of all rising water levels. However, no accepted method exists to assess flood damage to port industry. This study aims to illustrate a methodology to assess flood damage by climate change to port industry and infrastructure. A useful survey is made of known flood damage models from around the world and their characteristics. A comprehensive overview is made of the most recent estimations of the replacement value of port industry and infrastructure, and of the most detailed knowledge available about damage curves, which illustrate the direct economic damage to structures per inundation depth. From these surveys, a synthetic flood damage methodology is set up and applied to the port of Rotterdam, the largest port of Europe. Using pre-made climate change scenarios developed specifically for the port of Rotterdam, the vulnerability of the port to climate change is investigated.

The case study concludes that the unembanked areas of port of Rotterdam are very vulnerable to rising costs of flood events due to climate change. In comparison with the current situation (2010), the possible total costs of a flood event in 2050 range from approximately half as much to more than 6 times as much in cost. For 2100, the costs can be up to 14 times as high in comparison to 2010. The adaptation measure lockable/open` does not provide a substantial relief in damage costs.

**Boettle, M., Rybski, D. and Kropp, J.P. (2013) How changing sea level extremes and protection measures alter coastal flood damages, *Water Resources Research*, Vol 49 (3), 1199-1210**

Estimations due to the stochastic nature of extreme events are studied. Starting with the probability distribution of extreme flood levels, we calculate the distribution of implied damages in a specific regions employing stage-damage functions. Universal relations of the expected damages and their standard deviation, which demonstrate the importance of the shape of the damage function, are provided. How flood protection reduces the damages leading to a more complex picture is calculated, where the extreme value behaviour plays a fundamental role.

**Blanco, A . and Schanze, J. (2013) Conceptual and methodological frameworks for large scale and high resolution analysis of the physical flood vulnerability of buildings, In Klijn, F. and Schweckendiek, T. (eds), *Comprehensive Flood Risk Management*, 591-598, Taylor and Francis Group, London, ISBN 978-0-415-62144-1**

The impacts of floods on buildings in urban areas are increasing due to i.e. the intensification of extreme weather events, unplanned or uncontrolled settlements and rising vulnerability of assets. There are some approaches available for assessing flood damage to buildings and critical infrastructure. However, these methods up to now cannot be adapted to a large scale because of lacking high resolution classification and characterisation approaches for the built structures. To overcome this obstacle, the paper presents, first, a conceptual framework for understanding physical flood vulnerability of buildings and, second, a methodological framework on the combination of methods for according large scale and high resolution analysis. The conceptual framework supports an in-depth understanding of the physical aspects of vulnerability and its influence on social, economic and ecological vulnerabilities. It describes key features that shape the physical flood vulnerability of buildings. Hereby, depth-impact functions are seen as a means for the interrelation between the water level and the physical impacts. They provide the basis for the subsequent derivation of depth-damage functions as basic indicator of economic vulnerability and depth-social impact function as basic indicator of social vulnerability. Geographic position of buildings is considered as a feature of exposure and hence is not part of the applied vulnerability definition. The methodological framework combines a taxonomic approach for the classification of buildings and an analysis of the physical flood vulnerability for representatives of building types. The building taxonomic approach results from classification of remote sensing data considering roof surface, topological and geometrical building characteristics. Then, representatives of the building types are selected through the similarity coefficient method. For representatives of each building type, their physical flood vulnerability is analysed based on depth-impact functions. The depth-impact function is calculated referring to the principal components of the buildings (e.g. height of storeys, building elements and their materials) affected by different water levels. All components are designed for a final integration into a technological framework.

**Bubeck, P. (Undated) Memo: Flood damage evaluation methods, accessed at file:///C:/Users/Dennis/Downloads/200711%20Bubeck\_MEMO\_flood\_damages.pdf on 1.11.14**

A paper which gives insights into flood damage evaluation in the Netherlands and parts of Germany. This paper sets out a classification of flood damages and then examines flood damage evaluation methods which include the transfer of historic data and use of synthetic data. Quality aspects of flood damage data are then discussed before the author considers flood damage evaluation in the Netherlands. This includes a discussion of the objective of damage evaluation in The Netherlands, flood damage categories considered and the 'Standard Method (HIS damage module)'. The author then goes on to examine flood damage assessment in Germany, including the HOWAS data base and damage evaluation in Nordrhein-Westfalen. Again the objective of the damage evaluations, the damage categories considered, and the methods used for damage evaluation are discussed. Finally, methods of ascribing potential flood damages to land uses in relation to the Rhine Atlas and the damage scanner are discussed.

**Bubeck, P., de Moel, H., Bouwer, L.M. and Aerts, J.C.J. (2011) How reliable are projections of future flood damage? *Natural Hazards And Earth System Sciences*, Vol 11 (12), 3293-3306**

This paper examines flood damage along the river Rhine between 1990 and 2030 in terms of different flood-damage modelling approaches. The results show that relative estimates of flood damage developments differ by a factor of 1.4. These variations, which result from the application of different modelling approaches, are considerably smaller than differences between the approaches in terms of absolute damage estimates (by a factor of 3.5 to 3.8), or than differences resulting from land-use projections (by a factor of 3). The differences that exist when estimating relative changes principally depend on the differences in damage functions. In order to improve the reliability of relative estimates of changes in the development of potential flood damage, future research should focus on reducing the uncertainties related to damage functions. Assessments are still characterized by considerable uncertainties in stage-damage functions and methodological differences in estimating exposed asset values. In this paper, the authors evaluate the reliability of estimates of absolute flood damage assessments and investigate the reliability of estimates of relative changes in the development of potential flood damage. Studies that estimate (relative) changes in flood damage over time usually address uncertainties resulting from different projections (e. g. land-use characteristics) and other factors. Flood damage modelling is an important component in flood risk management, and several studies have investigated the possible range of flood damage in the coming decades.

**Burzel, A., Dassanayake, D.R and Oumeraci, H. (2013) Spatial modelling of tangible and intangible losses in integrated risk analysis—results of the XtremRisk project. In Klijn, F. and Schweckendiek, T. (eds), *Comprehensive Flood Risk Management*, 557 -567, Taylor and Francis Group, London, ISBN 978-0-415-62144-1**

The expected climate change and associated increasing frequency of extreme storm surges may lead to larger storm surge hazards than have been observed in the past. Therefore, the German XtremRisk project aims to improve the understanding of the impact of extreme storm surges under current and future climate conditions by conducting an integrated flood risk analysis for two selected pilot sites in Germany, representing an open coast (Sylt Island) and a megacity in an estuarine area (Hamburg). The research has also been focused on developing and improving the knowledge, methods and models for the assessment of intangible losses (social and ecological), their spatial modelling as well as their integration with direct and indirect economic losses. After a brief introduction into the integrated risk analysis, the paper describes the methodologies and discusses the results with a focus on the spatial modelling of tangible and intangible losses in the pilot site Hamburg-Wilhelmsburg.

**Cochrane, H. C. (2004), Economic loss: myth and measurement. Disaster Prevention and Management: An International Journal, Vol 13 (4): 290-296**

This paper covers a number of pitfalls that could hinder the development of a common methodology for estimating flood damage. Such pitfalls include double counting, ignoring post-disaster liabilities, ignoring non-market losses (e.g. recreation, loss of leisure, damage to historic sites and cultural assets, etc.), ignoring the needs of the end user, and questions as to how indirect/systemic losses might be modelled. With one exception, much of what is discussed in the paper is based on off-the-shelf economics and will not prove to be contentious. Regional economists are likely to have different opinions as to how to best model indirect and systemic loss; it is this that will lead to a lively debate as to how to proceed. Assessments of economic fallout from the World Trade Center attack are used to illustrate some of the problems reported in this paper.

**de Moel, H and Aerts, J. (2011) Effect of uncertainty in land use, damage models and inundation depth on flood damage estimates, Natural Hazards Vol 58 (1), 407-425**

Land use and inundation depth present a certain degree of uncertainty which propagates through the calculation of flood damage and accumulates in the final analyses of damage. There are uncertainties in the exposure, value and susceptibility components. For the flood hazard component, inundation depth has been varied systematically to estimate sensitivity. With the recent transition to a more risk-based approach in flood management, flood risk models-being a key component in flood risk management-are becoming increasingly important. In this study, an effort has been made to assess the influence of uncertainty in these four components on the final damage estimate. Different land-use data sets and damage models have been used to arrive at flood damage estimates. The results indicate that, assuming the uncertainty in inundation depth is about 25 cm (about 15% of the mean inundation depth), the total uncertainty surrounding the final damage estimate in the case study area can amount to a factor 5-6. The value of elements at risk and depth-damage curves are the most important sources of uncertainty in flood damage estimates and can both introduce about a factor 2 of uncertainty in the final damage estimates. Very large uncertainties in inundation depth would be necessary to have a similar effect on the uncertainty of the final damage estimate, which seem highly unrealistic. Hence, in order to reduce the uncertainties surrounding potential flood damage estimates, these components deserve prioritisation in future flood damage research. While absolute estimates of flood damage exhibit considerable uncertainty (the above-mentioned factor 5-6), estimates for proportional changes in flood damages (defined as the change in flood damages as a percentage of a base situation) are much more robust.

**Department for Environment, Food and Rural Affairs (Defra) (2001) Flood and Coast Defence Project Appraisal Guidance, Flood and Coastal Defence Project Appraisal Guidance: FCDPAG1 Overview, May, May, Defra, London, UK (includes general guidance)**

The Flood and Coastal Defence Project Appraisal Guidance (FCDPAG) series aims to provide best practice advice to flood risk management practitioners in the UK involved in the preparation of strategies and projects. The guidance contains theory, principles, methods and techniques for use in cost-benefit appraisals. Use of the guidance is intended to encourage a consistently high quality of decision-making supported by a rigorous appraisal of options so that the most appropriate scheme or strategy is proposed.

FCDPAG1 - Overview (including general guidance)

FCDPAG2 - Strategic planning and appraisal

FCDPAG3 - Economic appraisal

FCDPAG4 - Approaches to risk

FCDPAG5 - Environmental appraisal

FCDPAG6 - Post project evaluation

**Department for Environment, Food and Rural Affairs (Defra) (2008) Flood and Coast Defence Appraisal Guidance, Economic Appraisal, Supplementary Note to Operating Authorities: Valuation of Agricultural Land and Output for Appraisal Purposes, Defra, London, UK**

See above

**Department for Environment, Food and Rural Affairs (Defra) (2008) Flood and Coast Defence Appraisal Guidance, FCDPAG3 Economic Appraisal, Supplementary Note to Operating Authorities: Assessing and Valuing the Risk to Life from Flooding for the Use in Appraisal of Risk Management Measures, May, Defra, London, UK**

See above

**Department for Environment, Food and Rural Affairs (Defra) (2006) Flood and Coast Defence Appraisal Guidance, Social Appraisal, Supplementary Note to Operating Authorities: Climate Change Impacts, October, Defra, London, UK**

See above

**Department for Environment, Food and Rural Affairs (Defra) (2004) Flood and Coast Defence Project Appraisal Guidance, FCDPAG3 Revisions to Economic Appraisal on Reflecting Socio-economic Equity in Appraisal and Human Related Intangible Impacts of Flooding Economic Appraisal, Supplementary Note to Operating Authorities, July, Defra, London, UK**

See above

**Department for Environment, Food and Rural Affairs (Defra) (2003) Flood and Coast Defence Project Appraisal Guidance, FCDPAG3 Revisions to Economic Appraisal Procedures Arising from the New HM Treasury 'Green Book', Supplementary Note to Operating Authorities, March, Defra, London, UK**

See above

**Drdacky, M. (2010) Flood Damage to Historic Buildings and Structures, Journal of Performance of Constructed Facilities, Vol 24, (5), 439-445**

This paper presents typical examples of damage to immovable cultural heritage due to flooding. Flooding can damage architectural heritage, historic infrastructure consisting of individual structures. These forces can be categorized according to the types of damage that they can cause: horizontal static pressure of raised water; upward hydrostatic pressure; dynamic low velocity streams are examples. Examples of damage caused by individual actions are presented in the paper, which goes on to present some general lessons applicable for the most vulnerable categories of immovable heritage objects and buildings including objects of art standing alone or firmly attached as an integral part of buildings. All these objects are subjected to various forces and actions during floods.

**Dutta, D., Herath, S., and Musiake, K. (2003) A mathematical model for flood loss estimation, Journal of Hydrology, Vol 277, 24-49**

This paper introduces an integrated model for flood loss estimation in a river basin. The model is the combination of a physically based distributed hydrologic model and a distributed flood loss estimation model. The hydrologic model considers major processes of the water cycle through physically based governing equations, which are solved to simulate the propagation of water in each of these processes. It is designed to consider the man-made flood control structures, such as river embankments, retarding basins, etc. which affect flooding characteristics. The loss estimation model is formulated based on stage-damage relationships between different flood inundation parameters and land use features. It calculates the economic loss to different land use features based on the simulated flood parameters obtained from the hydrologic model for any flood event. A case study illustrates the real world application of the integrated model to a medium size river basin in Japan, which is frequently affected by floods. The simulated river discharge and surface inundation by the flood model show good agreement with the observations. Urban flood loss simulated by the loss estimation model with the simulated flood parameters agrees with the estimated damage using post flood surveyed parameters.

**Elmer, F., Seifert, I., Kreibich, H. and Thielen, A.H. (2010) A delphi method expert survey to derive standards for flood damage data collection, Risk Analysis, Vol 30 (1), 107-24**

For the purpose of flood damage analyses reliable, comparable, comprehensive, consistent, and up-to-date data are an indispensable need. Like in many other countries a database with this kind of datasets does not exist in Germany. To establish it, standards have to be set for flood damage data collection. We approached this problem by questioning experts about their information needs for flood damage analysis. This survey is done by applying a Delphi survey approach. The aptitude of the Delphi approach to assess, structure, and standardize expert knowledge is evaluated in this article. In the survey a panel of 55 experts working in the field of flood damage analysis for insurances, engineering companies/consultancy, public water management, and universities and other scientific institutions helped to identify common information needs. The multi-step Delphi method proved to reduce the deviation of answers thereby enabling consensual results and also enhanced the quality by modifying group answers in the direction of experience based answers. There was also a high level of congruence in information needs between experts from different fields of employment that allowed the derivation of common standards.

**Evans, E. P., Ashley, R., Hall, J., Penning-Rowsell, E., Sayers, P., Thorne, C. R. and Watkinson, A. (2004) Foresight. Future Flooding, 1 and 2 London**

A major study of future flood risk commissioned by the UK government in the early 2000s. The study considers a range of growth and change scenarios for the UK and projects the likely flood future flood losses of each. Climate change is expected to lead to a significant growth in flood risk in the UK but socio-economic change, especially land use change and rising living standards, are expected to be the major contributory factor in rising flood damage potential, which is steep in some scenarios. The report contains a range of interesting graphics demonstrating the spatial distribution of flood impacts under different assumptions.

**HEC-FDA (Flood Damage Reduction Analysis) (2008) User Guide V1.2.4**  
[http://www.hec.usace.army.mil/software/hec-fda/documentation/CPD-72\\_V1.2.4.pdf](http://www.hec.usace.army.mil/software/hec-fda/documentation/CPD-72_V1.2.4.pdf)

The Hydrologic Engineering Center (HEC) is an organization within the Institute for Water Resources of the U.S. Army Corps of Engineers and is based in Davis, California. This is a user guide for practitioners intending to use the HEC's Flood Damage Reduction Analysis (HEC-FDA) computer program as part of undertaking a cost-benefit analysis of flood damage reduction measures. The

user guide covers the data preparation and input needs of the computer program including, for example, exceedance probability functions, stage-discharge functions and depth-damage functions for a range of buildings and inventories.

**Jongman, B., Kreibich, H., Apel, H., Barredo, J. I., Bates, P. D., Feyen, L., Gericke, A., Neal, J., Aerts, J.C.J.H. and Ward, P. J. (2012) Comparative flood damage model assessment: towards a European approach, *Natural Hazards and Earth System Science*, Vol 12 (12), 3733-3752**

There is a wide variety of flood damage models in use internationally, differing substantially in their approaches and economic estimates. Since these models are being used more and more as a basis for investment and planning decisions on an increasingly large scale, there is a need to reduce the uncertainties involved and develop a harmonised European approach, in particular with respect to the EU Flood Risks Directive. In this paper we present a qualitative and quantitative assessment of seven flood damage models, using two case studies of past flood events in Germany and the United Kingdom. The qualitative analysis shows that modelling approaches vary strongly, and that current methodologies for estimating infrastructural damage are not as well developed as methodologies for the estimation of damage to buildings. The quantitative results show that the model outcomes are very sensitive to uncertainty in both vulnerability (i.e. depth–damage functions) and exposure (i.e. asset values), whereby the first has a larger effect than the latter. We conclude that care needs to be taken when using aggregated land use data for flood risk assessment, and that it is essential to adjust asset values to the regional economic situation and property characteristics. We call for the development of a flexible but consistent European framework that applies best practice from existing models while providing room for including necessary regional adjustments.

**Jonkman, S.N., Bočkarjova, M., Kok, M. and Bernardini, P. (2008) Integrated hydrodynamic and economic modelling of flood damage in the Netherlands, *Ecological Economics*, Vol 66, (1), 77-90**

This paper presents a model developed in the Netherlands for the estimation of damage caused by floods. The model attempts to fill the gap in the international literature about integrated flood damage modelling and develop an integrated framework for the assessment of both direct hazard-induced damages and indirect economic damages such as the interruption of production flows outside the flood affected area, as well as loss of life due to flooding. The scale of damage assessment varies from a specified flood-prone area in a river basin or a coastal region to the country's entire economy. The integrative character of the presented model is featured by the combination of information on land use and economic data, and data on flood characteristics and stage-damage functions, where the geographical dimension is supported by modern GIS to obtain a damage estimate for various damage categories. The usefulness of the model is demonstrated in a case study estimating expected flood damage in the largest flood-prone area in the Netherlands.

**Kreibich, H., Muller, M., Thielen, A.H. and Merz, B (2007) Flood precaution of companies and their ability to cope with the flood in August 2002 in Saxony, Germany, *Water Resources Research* Vol. 43, W03408, 1-15**

An insightful survey into fluvial flood damages in Germany indicating the type and degree of benefits that could accrue to flood risk management initiatives. The German federal state of Saxony was the most affected region during the severe flood in August 2002, and damage to companies was high. A survey of 415 companies representing a variety of sectors and sizes was undertaken to identify deficits in the flood management of companies. In August 2002, preparedness and precaution of companies was low. Additionally, 45% of the companies had not received any flood warning. Consequently, many companies were unable to perform emergency measures successfully. The

mean total damage to companies amounted to 1.1 million Euros. However, because of relatively good flood compensation, recovery advanced quickly. After the flood, preparedness and precaution increased, but there is still significant potential for more precautionary measures. The flood warning system should be further improved. Specific incentive and communication programs should be developed for the service and financial sectors, where preparedness and precaution is weakest, as well as for the manufacturing sector, which has the highest damage potential.

**Kreibich, H., Seifert, I., Thieken, A.H., Lindquist, E., Wagner, K. and Merz, B. (2011) Recent changes in flood preparedness of private households and businesses in Germany Regional Environmental Change, 11:59–71**

Another insightful piece of research into flood damages in Germany. Using the focusing event framework, a comprehensive analysis of private households' and businesses' preparedness was undertaken in the aftermath of the 2002 and 2006 flood events on the Elbe River in Germany. In August 2002, preparedness of households (n = 235) and businesses (n = 103) was low: 30% of the households and 54% of the businesses took no precautionary measures before the flood event. Many undertaken emergency measures were ineffective, since only 26% of all households knew how to react when the flood warning came, and only 9% of businesses had an emergency plan in place. Due to this extreme flood, double-loop learning occurred in many households and businesses, so that many did implement precautionary measures. The distribution of adopted precautionary measures for households fits well to Preisendorfer's low-cost hypothesis, but does not apply for businesses. Only 10% of the households (n = 112), but still 29% of the businesses (n = 41) were unprepared before the flood in 2006. Significant improvement in flood preparedness activities is still necessary. Particularly for businesses, regulatory programs and programs encouraging proactive behaviour should be implemented. The focusing event framework proved to be a useful tool for a differentiated analysis of the responses to and learning due to a disaster also in the commercial and private sector.

**Kreibich, H., Seifert, I., Merz, B., Thieken, A.H. (2012) Development of FLEMOcs - a new model for the estimation of flood losses in the commercial sector, Hydrological Sciences Journal, Vol 55, (8), 1302-1314**

The estimation of flood damage is an important component for risk-oriented flood design, risk mapping, financial appraisals and comparative risk analyses. However, research on flood-loss modelling, especially in the commercial sector, has not gained much attention so far. Therefore, extensive data about flood losses were collected for affected companies via telephone surveys after the floods of 2002, 2005 and 2006 in Germany. Potential loss determining factors were analysed. The new Flood Loss Estimation MOdel for the commercial sector (FLEMOcs) was developed on the basis of 642 loss cases. Losses are estimated depending on water depth, sector and company size as well as precaution and contamination. The model can be applied to the micro-scale, i.e. to single production sites as well as to the meso-scale, i.e. land-use units, thus enabling its countrywide application.

**Leahy, A. and Crop, A. (Undated) Cost Benefit Analysis of Urban Flood Protection consulted at [https://www.waternz.org.nz/Folder?Action=View%20File&Folder\\_id=92&File=Allan%20Leahy.pdf](https://www.waternz.org.nz/Folder?Action=View%20File&Folder_id=92&File=Allan%20Leahy.pdf) on 28/07/14**

This paper is co-authored by engineers working in a local authority environment in New Zealand. In New Zealand engineers are often asked to make decisions on the spending of public money to provide flood protection to existing at risk urban structures. Historically, and currently, in New

Zealand there has been limited quantitative information available on which to base these investment decisions. This has led to these decisions often being based on ad hoc assessments or political pressure rather than value for money.

This paper describe a simple flood damage analysis of a residential area. The methodology is based on a modified version of the US Army Corps of Engineers HEC-Flood Damage Analysis methodology – which provides a quantified cost benefit approach to flood protection investment decisions. The paper describes the flood scenario, the approach adopted and the sources of flood damage cost information used. It also describes the limitations of available information on social impacts and the work needed to provide more robustness in this area.

**Logtmeijer, C. (2006) Guidelines for socio-economic damage evaluation , Institute for the Protection and Security of the Citizen, EUR 22637 EN European Commission Directorate-General Joint Research Centre Institute for the Protection and Security of the Citizen, Ispra, Italy**

The major purpose of these guidelines is to give guidance for practitioners of governmental authorities and executing bodies dealing with ex-ante flood damage evaluation in order to appraise public flood defence projects or strategies on different spatial scales. Since such appraisals involve private and public goods, flood damage evaluation is mainly described from a broader economic perspective. Although the other perspectives will be mentioned and referred to time and again, these guidelines aim at becoming a practical guide for policy makers by demonstrating how to proceed appropriately in flood damage evaluation in order to use it as an important source of information for flood defence and its decision making process. Since there is a large diversity of methods existing for all types of damages within the EU & as research of Meyer and Messner (2005) revealed for four EU countries & another purpose of the guidelines is to give some orientation, which flood damage evaluation method should be used, and which damage types should be included for which kind of policy issues under consideration of case-specific requirements regarding time horizons, spatial precision requirements and budgetary restrictions. While it is not the goal to present one harmonised flood damage evaluation method, we aim at proposing a harmonised set of assessment principles and general procedures of flood damage evaluation studies in order to advance the quality and the comparability of such studies within Europe.

**Maiwald, H. and Schwarz, J. (2014) Damage models for extreme flood events - Part 1: Modeling and validation based on the 2002 flood, Bautechnik, Vol 91, (3), 200-21**

An engineering based flood damage model was developed in different research projects at the Earthquake Damage Analysis Center (EDAC) at the Bauhaus-Universitat Weimar. In the context of cost-benefit analysis the paper show the demand for development of new resilient damage functions for each usage class. Conventional loss models are limited to the relationship between flood height and damage. The actual 2013 flood events illustrate the importance of the flood protection measures planned and partly already implemented after the 2002 flood.

**Merz, B., Kreibich, H., Thielen, A. and Schmidtke, R. (2004), Estimation uncertainty of direct monetary flood damage to buildings, Natural Hazards and Earth System Science 4: 153-163**

Traditional flood design methods are increasingly supplemented or replaced by risk-oriented methods which are based on comprehensive risk analyses. Besides meteorological, hydrological and hydraulic investigations such analyses require the estimation of flood impacts. Flood impact assessments mainly focus on direct economic losses using damage functions which relate property damage to damage-causing factors. Although the flood damage of a building is influenced by many factors, usually only inundation depth and building use are considered as damage-causing factors. In

this paper a data set of approximately 4000 damage records is analysed. Each record represents the direct monetary damage to an inundated building. The data set covers nine flood events in Germany from 1978 to 1994. It is shown that the damage data follow a Lognormal distribution with a large variability, even when stratified according to the building use and to water depth categories. Absolute depth-damage functions which relate the total damage to the water depth are not very helpful in explaining the variability of the damage data, because damage is determined by various parameters besides the water depth. Because of this limitation it has to be expected that flood damage assessments are associated with large uncertainties. It is shown that the uncertainty of damage estimates depends on the number of flooded buildings and on the distribution of building use within the flooded area. The results are exemplified by a damage assessment for a rural area in southwest Germany, for which damage estimates and uncertainty bounds are quantified for a 100-year flood event. The estimates are compared to reported flood damages of a severe flood in 1993. Given the enormous uncertainty of flood damage estimates the refinement of flood damage data collection and modelling are major issues for further empirical and methodological improvements.

**Merz, B., Kreibich, H., Shwarze, R. and Thielen, A. (2010) Review article. Assessment of economic flood damage, *Nat. Hazards Earth Syst. Sci.*, 10, 1697–1724**

Damage assessments of natural hazards supply crucial information to decision support and policy development in the fields of natural hazard management and adaptation planning to climate change. Specifically, the estimation of economic flood damage is gaining greater importance as flood risk management is becoming the dominant approach of flood control policies throughout Europe. This paper reviews the state-of-the-art and identifies research directions in economic flood damage assessment. Despite the fact that considerable research effort has been spent and progress has been made in flood damage data collection, data analysis and model development in recent years, there still seems to be a mismatch between the relevance of damage assessments and the quality of the available models and datasets. Often simple approaches are used, mainly due to limitations in data and knowledge on damage mechanisms. The results of damage assessments depend on many assumptions e.g. selection of spatial and temporal boundaries, and there are many pitfalls in economic evaluation e.g. the choice between replacement costs or depreciated values. Much larger efforts are required for empirical and synthetic data collection and for providing consistent, reliable data to scientists and practitioners. A major shortcoming of damage modelling is that model validation is rarely performed. Uncertainty analyses and thorough scrutiny of model inputs and assumptions should be mandatory for each damage model development and applications, respectively. In our view, flood risk assessments are often not well balanced. Much more attention is given to the hazard assessment part, whereas damage assessment is treated as some kind of appendix within the risk analysis. Advances in flood damage assessment could trigger substantial methodological improvements in other natural hazard areas with comparable time-space properties.

**Merz, B. and Kreibich, H. (2013) Non-linear and non-parametric modeling of flood damage, In Klijn, F. and Schweckendiek, T. (eds), *Comprehensive Flood Risk Management*, 599-602, Taylor and Francis Group, London, ISBN 978-0-415-62144-1**

The usual approach for flood damage assessment consists of stage-damage functions which relate the relative or absolute damage for a certain class of objects to the inundation depth. Other characteristics of the flooding situation and of the flooded object are rarely taken into account, although it is clear that flood damage is influenced by a variety of factors. In this paper we apply a group of data mining techniques, known as regression trees, to flood damage assessment. A very comprehensive data set of more than 2000 damage records of private households in Germany is

used. Each record contains details about a large variety of potential damage-influencing characteristics, such as hydrological and hydraulic aspects of the flooding situation, state of precaution of the household, early warning and emergency measures undertaken, socio-economic status of the household. Regression trees derive water depth, return period, duration of inundation, precaution, building floor space and net income of the household as the dominating damage-influencing variables. We show that regression trees are a flexible and powerful alternative to traditional damage assessment approaches such as stage-damage functions.

**Messner, F., Penning-Rowsell, E., Green, C., Meyer, V., Tunstall, S. and van der Veen, A. (2006) Guidelines for Socio-economic Flood Damage Evaluation, Project Contract No: GOCE-CT-2004-505420, FLOODsite, Report T9-06-01 Co-ordinator: HR Wallingford, UK (Project website: [www.floodsite.net](http://www.floodsite.net))**

The major purpose of these guidelines is to provide guidance for practitioners of governmental authorities and executing bodies dealing with ex-ante flood damage evaluation in order to appropriately appraise public flood defence projects or strategies on different spatial scales. Therefore these guidelines address a large community. On the one hand, they give guidance to countries just starting with flood damage evaluation studies. For this group the guidelines demonstrate how to proceed step by step in flood damage evaluations (especially chapters 3-4). Chapter 3 describes the state-of-the-art in evaluating direct, tangible flood damages. This chapter can be used by practitioners of countries with few or even no experience in flood damage evaluation in order to find an appropriate start into the endeavour of applying flood damage evaluation as a decision support tool. Chapter 4 reveals the principal rules and the procedure of building up a proper flood damage data base in order to ensure a consistent set of flood damage data, which is needed if flood damage evaluation is to be used as a long-term decision support tool. On the other hand, there is a need to address flood damage evaluators in countries which already possess some experience in this field and so the guidelines to them as a checklist and to inspire them to improve their evaluation methodology, e.g., by including methods for damage types which have been neglected hitherto in their work (especially chapters 5-9). Chapter 5 outlines the approaches for evaluating flood effects on industrial production. Chapter 6 indicates possible procedures to include social flood effects. Environmental flood effects and methods of their evaluation are described in chapter 7. Thereafter, chapter 8 focuses on damage reducing effects of flood warning in order to support specific decisions on flood warning systems. Chapter 9 gives an overview of flood damage categories which have not been considered in more detail in these guidelines and indicates relevant literature sources for further reading. Last but not least to provide fundamental standard knowledge, key principals are specified for economic evaluation of damages and reveal the sources of uncertainty that need to be considered.

**Meyer, V. and Messner, F. (2005), National Flood Damage Evaluation Methods, A Review of Applied Methods in England, the Netherlands, the Czech Republic and Germany, UFZDiskussionspapiere21/2005**

This Report is the first deliverable of FLOODsite task 9, which is on flood damage evaluation methods. It summarises both the outcome of a literature survey on flood damage evaluation methods in selected EU countries and the major results of complementary expert interviews. The overall objective is to identify the methodological diversity regarding the practical application of flood damage evaluation methods in EU countries, which are known to have a leading position in this field. The results of this report are an important prerequisite for the major deliverable of task 9, which aims, among others, at proposing harmonised state-of-the-art methods and principles for flood damage analysis in EU countries. The report shows that the four countries, England, the

Netherlands, the Czech Republic and Germany, which feature very different histories of flood protection policy and different institutional settings, use sophisticated methods of flood damage valuation. These in principle follow the same idea, namely trying to put economic values to elements of flood risk in order to estimate the benefits of flood protection measures in terms of prevented flood damage. In detail, though, the methods exhibit many different approaches. The major differences in flood damage evaluation methods relate to the damage categories considered, the degree of detail, the scale of analysis, the application of basic evaluation principles (e.g., replacement cost versus depreciated cost), and the application or non-application of results in benefit-cost and risk analyses. This diversity of flood damage evaluation methods, even in riparian states which share a major river, indicates that there is still a lack in transboundary cooperation in flood policy decision making in the EU.

[http://www.floodsite.net/html/partner\\_area/project\\_docs/DP\\_Meyer\\_Messner\\_national\\_flood\\_damage\\_evaluation\\_methods24112005.pdf](http://www.floodsite.net/html/partner_area/project_docs/DP_Meyer_Messner_national_flood_damage_evaluation_methods24112005.pdf), accessed on 21.10.14

**Parker, D J and Thompson, P M 1988 An 'extended' economic appraisal of coast protection works: Hengistbury Head, *Journal of Ocean and Shoreline Management*, Vol 11, 45-72**

An assessment of the benefits of both flood protection and coastal erosion prevention at an environmentally sensitive location on England's south coast where storm surges could erode the narrow neck of land joining Hengistbury Head to the mainland. The assessment was innovative at the time because it not only estimated flood damage potential consequent upon a breach of the coastline near Hengistbury Head but it also combined an assessment of the ecological, recreational, nature conservation, geological and archaeological impacts.

**Parker, D.J., Green, C.H. and Thompson, P.M. (1987) Urban flood protection benefits. A project appraisal guide, Gower Technical Press Ltd., Aldershot, UK (ISBN 0-291-39707-7)**

Obtaining value for money is a key objective of any capital investment and the techniques for assessing this developed rapidly prior to this publication. Flood protection projects present particular benefit-costs appraisal difficulties and the Flood Hazard Research Centre at the then Middlesex Polytechnic (now Middlesex University) has been to the forefront in developing methods for overcoming these problems. One particular difficulty is that some of the benefits of minimising a flood risk are indirect: examples are traffic disruption, industrial production loss, utility outages, emergency service costs and so on. This volume addresses this difficult area and presents methods of making rational assessments and a range of depth-damage and depth-duration-damage data. Together with a volume published in 1977, known as the 'Blue Manual', which primarily presents direct damage data, this volume known as the 'Red Manual' made available are family of techniques for assessing the benefits of urban flood protection in a structured manner. Then volume presents data which may be applied throughout the United Kingdom. In some cases these data may be transferable to parts of continental Europe but the principles, methods and techniques are more generally applicable elsewhere.

**Penning-Rowsell, E. C. and Chatterton, J. B. (1977) The benefits of flood alleviation. A manual of assessment techniques, Gower Publishing Co. Ltd, Aldershot, UK (ISBN 0-566-00190-X)**

This volume, which rapidly became the practical desk-top manual for flood engineers undertaking flood alleviation benefit assessments in the United Kingdom, provides a detailed set of principles, methods, techniques and data principally on the assessment of direct benefits. The manual provides depth-damage data for a range of residential properties common throughout the British Isles and similar data for different types of non-residential property. Methods and data for assessing the

agricultural benefits of flood alleviation are also included. The manual is a product of research undertaken at the Flood Hazard Research Centre of Middlesex Polytechnic (now Middlesex University) following receipt of a research grant from the UK Natural Environment Research Council. The manual became known as 'the Blue Manual'.

**Penning-Rowse, E C and Parker, D J 1987 The indirect effects of floods and benefits of flood alleviation: evaluating the Chesil Sea Defence Scheme, Applied Geography, Vol 7, 263-88**

An assessment of the potential flood damage and loss impacts of sea flooding at an environmentally sensitive location and settlement on England's south coast. Chesil beach is a natural shingle beach which, under wave attack, could be breached and/or overtopped inundating the settlement of Chiswell on the Isle of Portland with both shingle and seawater. The settlement had become semi-abandoned after recent sea floods. This study assessed the direct and indirect benefits of protecting the settlement. The innovative element of the study was the analysis of the indirect effects of a breach of the important road connection behind the beach which joins the Isle of Portland to the mainland at Weymouth. Important defence work, a prison and other commercial activities on the Isle would be disrupted by erosion and flooding of the road. The assessment eventually led to an innovative sea defence project at this location.

**Penning-Rowse, E.C., Green, C.H., Thompson, P.M., Coker, A., Tunstall, S.M., Richards, C. and Parker, D.J. (1992) The economics of coastal management. A manual of benefit assessment techniques, Belhaven Press, London and Florida (ISBN 1 85293 161 2)**

This manual provides principles, methods, techniques and data for evaluating the benefits of investing in coast protection (i.e. protection of the coastline from erosion) and sea defence (i.e. protection of the coastline from sea flooding). It also makes an important contribution to the valuation of recreational gains and losses at the coast. This manual is the third produced by the Flood Hazard Research Centre at Middlesex Polytechnic (now Middlesex University) and is known as the 'Yellow Manual'. The manual provides chapters on theoretical perspectives, coastal erosion losses and benefits, the impacts of coast protection and sea defence projects on recreation at the coast, the benefits of sea defences, the environmental gains and losses from sea defence and coast protection projects, integrated computer-based analysis and five UK coastal case studies.

**Penning-Rowse, E.C., Johnson, C., Tunstall, S. M., Tapsell, S.M., Morris, J., Chatterton, J., and Green C. (2005) The benefits of flood and coastal risk management. A manual of assessment techniques, Middlesex University Press, London (ISBN 1 904750 52 4)**

This manual, produced by the Flood Hazard Research Centre at Middlesex University and jointly funded by the Defra and the Environment Agency (England and Wales), is known as the 'Multi-Coloured Manual' and is a direct 'descendant' of the 'Blue', 'Red' and 'Yellow' manuals also produced by this Centre. It is accompanied by the Multi-Coloured Handbook and CD. Like its predecessors this manual sets out principles, methods, techniques and data for assessing the benefits of flood and coast flood risk management and it provides updated data and new experimental methods on data filtering and assessing environmental resources. It reflects important policy shifts away from flood and coast 'protection' towards flood and coast 'flood risk management'. The manual presents updated data on flood damages to residential and non-residential properties in the UK and includes methods and data on utilities, roads, railways and emergency service costs. The parallel Handbook and CD are provided for those intending to apply the methods and data in project appraisals.

**Penning-Rowse, E.C., Priest, S.J., Parker, D.J., Morris, J., Tunstall, S.M., Viavattenne, C., Chatterton, J., and Owen D. (2013) Flood and Coastal Erosion Risk Management. A manual for economic appraisal, Routledge, London (ISBN 978-0-415-81514-4 (hbk) 978-0-203-06639-3 (ebk))**

This manual draws on collaboration between the Flood Hazard Research Centre at Middlesex University, Defra, the Environment Agency and other stakeholders and is known as the 'Multi-Coloured Manual (MCM)'. It is an update of the 2005 manual of this name but includes a range of brand new methods and data. The manual is accompanied by MCM-Online which provides everything available in the manual plus a vast array of benefit data together with methods, techniques and guidance for its application. MCM-Online is available to professional users under licence agreement although there is also a free to use public division of this website. This updated version of the MCM provides a completely new set of potential; flood damage data for non-residential properties (including retail and office businesses, industry, logistics and public buildings). It provides methods for assessing benefits in sectors not previously covered by the MCM. It also provides a single compendium of research by the Flood Hazard Research Centre.

**Penning-Rowse, E., Chatterton, J., Wilson, T. and Potter, E. (2002), Autumn 2000 floods in England and Wales: assessment of national economic and financial losses, Flood Hazard Research Centre, Middlesex University**

A research report which collates evidence on the damage caused by the extensive Autumn 2000 floods in England and Wales. The report draws together all of the data available in order to present an overall assessment.

**Penning-Rowse, E.C. and Green, C.H. (2000) New insights into the appraisal of flood alleviation benefits (1): flood damage and flood loss information. J. Institution of Water and Environmental Management. 14 (October), 347-353**

New approaches to the appraisal of flood alleviation investment have been developed over the last twenty-five years. This has led to (a) increased precision in benefit-cost analysis as better data have become available, and (b) a more rational approach to decision-making as the UK Government has clarified and enhanced the decision criteria. This paper presents a detailed account of some of these developments, with an emphasis on the data on flood damages and losses avoided by flood alleviation schemes, and draws out lessons for those involved in this form of investment appraisal.

**Penning-Rowse, E.C. and Green, C.H. (2000) New insights into the appraisal of flood alleviation benefits (2): the broader context. J. Institution of Water and Environmental Management 14 (October), 354-362**

During the last twenty-five years new approaches to the appraisal of flood alleviation investment have developed. This paper (a) identifies some of the key data inputs to this process, and (b) explores the issues concerning the relationship between flood losses and flood probability including in the Thames floodplain West of London. The paper draws upon a range of project appraisals undertaken by the Flood Hazard Research Centre in London.

**Penning-Rowse, E.C., Priest, S.J. and Johnson, C. (2013) The evolution of UK flood insurance: incremental change over six decades, International Journal of Water Resources Development, at <http://www.tandfonline.com/doi/abs/10.1080/07900627.2014.903166#.VG9IYfmsXtU>**

In this paper, the authors' theorizing shifts away from the catalytic role of the flood itself – or other crises – towards a deeper understanding of the relationship between change and stability, taking the example of UK flood insurance and the agreements – and the implicit policy approaches – between

the actors involved: private insurers and the government. The study relies upon in-depth analysis of policy agreements governing flood insurance since the 1960s, and semi-structured interviews with six current or former flood insurance professionals. The important agents of change have been, firstly, threats to existing household insurers from new entrants unencumbered by agreements to insure all comers. Secondly, technological changes have made exposure more explicit and pricing risk both easier and less expensive. The slow pace of change and the relatively stable role of the different actors and coalitions is now clearer. Many windows of opportunity created by major flooding or financial crises have not significantly affected the pace or direction of policy change. The overriding importance of the London location for – and the profitability of – the insurance industry, both to government and to the insurers, explains the extraordinary policy stability described here. This history suggests that the UK may not be a good model for imitation elsewhere.

**Penning-Rowsell, E.C. and Pardoe, J. (2014) The distributional consequences of future flood risk management in England and Wales, *Environment and Planning C: Government and Policy* 2014, Vol 32**

Much flood risk management (FRM) research has examined the predicted increased burden of risk from future climate change. In contrast, this paper examines the changing funding regime for FRM and arrangements for flood insurance in the UK today. These changes, after the 1998–2013 period of severe and repeated flooding, may considerably increase the burden for at-risk households, but affect different groups differently, raising the question as to how to manage the risk and who should pay for this risk management. We explore this through scenarios incorporating modelled changes both to government investment to reduce risk and to flood insurance. The key findings are that moving towards a more risk-based approach could move the burden hugely, particularly onto financially deprived at-risk households, such that both investment and insurance could be unaffordable or unavailable. As insurance becomes more risk based, deprived households are less likely to purchase cover, but higher costs might incentivise those at risk to adapt to the risk they face. In the end, society has to decide whether to promote more substantial incentives discouraging occupation of the floodplain, with the likely adverse consequences for those there who are financially deprived, or retain the current discouragement of self-help.

**Pielke, R.A. (2000) Flood Impacts on Society, Damaging floods as a framework for assessment, In Parker, D.J. (ed) *Floods*, Vol 1, Chapter 8, 133-155, Routledge, London**

This chapter usefully goes back to fundamentals and asks what is flood damage and what are the problems of measurement? Pielke addresses some key issues including the problems of multiple-order impacts, causation, spatial scale and comparison. A case study of the 1993 Midwest floods in the United States is employed to exemplify some of the issues.

**Scawthorn, C., Flores, P., Blais, N., Seligson, H., Tate, E., Mifflin, E., Thomas, W., Murphy, J. and Jones, C. (2006) 'HAZUS-MH flood loss estimation methodology, 1: overview and flood hazard characterization', *Natural Hazards Review*, Vol. 7, No. 2, 60-71**

See below

**Scawthorn, C., Flores, P., Blais, N., Seligson, H., Tate, E., Mifflin, E., Thomas, W., Murphy, J. and Jones, C. (2006) 'HAZUS-MH flood loss estimation methodology, II: damage and loss assessment', *Natural Hazards Review*, Vol. 7, No. 2, 72-81**

These related papers describe the HAZUS-MH Flood Model and related software first developed in the United States in the 1990s. The first paper covers flood hazard characterization and the second

paper reports on damage and loss estimation capability of the Flood Model. The Flood Model employs depth-damage functions to estimate benefits: these functions being provided by the Federal Insurance Administration. Additionally, depth-damage functions developed by the US Army Corps of Engineers are also considered suitable in selected instances. The Flood Model incorporates data on direct, indirect and intangible impacts of flooding. It covers lifeline systems, damages to vehicles, damage to crops and the damage-reducing effects of flood warnings which should be taken into account in estimating flood damage reduction potential. Social damages and induced damages are also considered.

**Schröter, K., Kreibich, H., Vogel, K., Riggelsen, C., Scherbaum, F. and Merz, B. (2014) How useful are complex flood damage models? *Water Resources Research*, Vol 50, Issue 4, 337**

We investigate the usefulness of complex flood damage models for predicting relative damage to residential buildings in a spatial and temporal transfer context. We apply eight different flood damage models to predict relative building damage for five historic flood events in two different regions of Germany. Model complexity is measured in terms of the number of explanatory variables which varies from 1 variable up to 10 variables which are singled out from 28 candidate variables. Model validation is based on empirical damage data, whereas observation uncertainty is taken into consideration. The comparison of model predictive performance shows that additional explanatory variables besides the water depth improve the predictive capability in a spatial and temporal transfer context, i.e., when the models are transferred to different regions and different flood events. Concerning the trade-off between predictive capability and reliability the model structure seem more important than the number of explanatory variables. Among the models considered, the reliability of Bayesian network-based predictions in space-time transfer is larger than for the remaining models, and the uncertainties associated with damage predictions are reflected more completely.

**Su, H-t. and Tung, Y. K. (2013) Incorporating uncertainty of distribution parameters due to sampling errors in flood-damage-reduction project evaluation, *Water Resources Research*, Vol 49, (3), 1680-169**

A decision making framework considering the epistemic uncertainty is proposed. The effects of sample size on potential risk of alternatives and ranking result. The ranking of project alternatives can be changed by adjusting the sample size. Epistemic uncertainty is a result of knowledge deficiency about the system. Sampling error exists when limited amounts of hydrologic data are used to estimate a year event quantile. Both the natural randomness of hydrologic data and the sampling error in design quantile estimation contribute to the uncertainty in flood damage estimation. This paper presents a framework for evaluating a flood-damage-mitigation project in which both the hydrologic randomness and epistemic uncertainty due to sampling error are considered in flood damage estimation. Different risk-based decision-making criteria are used to evaluate project merits based on the mean, standard deviation, and probability distribution of the project net benefits. The results show that the uncertainty of the project net benefits is quite significant. Ignoring the data sampling error will underestimate the potential risk of each project. It can be clearly shown that adding data to existing sample observations leads to improved quality of information, enhanced reliability of the estimators, and reduced sampling error and uncertainty in the project net benefits. Through the proposed framework, the proper length of the extended record for risk reduction can be determined to achieve the required level of acceptable risk.

**Sugden, R. (2007) Developing the Cost-Benefit Framework for the Appraisal of Flood and Coastal Erosion Risk Management Projects R&D Project Record FD2018/PR1 Joint Defra/EA Flood and Coastal Erosion Risk Management R&D Programme, Environment Agency and Defra, London**

Cost-benefit analysis can be described in two different ways – as a calculus of willingness-to-pay (WTP) or as a calculus of social costs and benefits (SCB). The current UK Defra FCDPAG3 framework adopts the calculus of social costs and benefits, as it seeks to measure the costs to be incurred, and the benefits created by a project in national economic terms. The willingness to pay approach differs in that it measures the net welfare change brought about by the project under consideration for each individual interest group. The summation of individual welfare changes leads to the same valuation of net social costs and benefits as the SCB approach. The principle advantage of the WTP approach is that it leads naturally to a presentation of results which makes clear how a project impacts on the members of different economic interest groups (e.g. in a flood defence context house owners, farmers, taxpayers), how it impacts on different financial budgets (e.g. the budgets of different branches of government, and those of project partners), and how far the benefits created by the project are of the kind for which the relevant public funds have primarily been allocated (through for example the Spending Review process). With the SCB approach, in contrast, whilst it would be possible to disaggregate results in many cases some significant transfers between groups are not generally evaluated and these distinctions are liable to be hidden in the aggregation of resource costs and benefits.

**Thieken, A.H., Muller, M., Kreibich, H. and Merz, B. (2005) Flood damage and influencing factors: New insights from the August 2002 flood in Germany, Water Resources Research, Vol. 41, W12430, doi:10.1029/2005WR004177**

In the aftermath of a severe flood event in August 2002 in Germany, 1697 computer aided telephone interviews were undertaken in flood-affected private households. Besides the damage to buildings and contents a variety of factors that might influence flood damage were queried. It is analyzed here how variables describing flood impact, precaution, and preparedness as well as characteristics of the affected buildings and households vary between the lower and upper damage quartiles of all affected households. The analysis is supplemented by principal component analyses. The investigation reveals that flood impact variables, particularly water level, flood duration, and contamination are the most influential factors for building and for content damage. This group of variables is followed by items quantifying the size and the value of the affected building/flat. In comparison to these factors, temporal and permanent resistance influences damage only to a small fraction, although in individual cases, precaution can significantly reduce flood damage.

**Thompson, P M, Wigg, A and Parker, D J 1991 Urban flood protection post-project appraisal in England and Wales, Project Appraisal, Vol 6, (2), 84-92**

A post-project analysis of the impacts of several flood alleviation schemes in England and Wales. Post-project appraisals are designed to find out whether the originally estimated benefits and costs of flood alleviation schemes were actually realised sometime after the projects or schemes had been implemented: such studies are few and far between yet can be informative. In this appraisal a number of flood alleviation schemes were revisited.

**Veldhuis, T. (2011) How the choice of flood damage metrics influences urban flood risk assessment Journal of Flood Risk Management, 2011, Vol 4, (4), 281-287**

Damage includes material damage to buildings and infrastructure; intangible damage includes damages that are difficult to quantify exactly, such as stress and inconvenience. The data used in

examples of lowland flooding incidents with return periods up to 10 years. The results show that monetarisation of damage prioritises damage to buildings in comparison with roads, cycle paths and footpaths. What is needed is the kinds of damage metrics to quantify flood risk which provide the opportunity to weigh tangible and intangible damages from an economic and societal perspective. This study presents a first attempt to quantify tangible and intangible flood damage according to two different damage metrics: monetary values and number of people affected by flooding. When damage is expressed in terms of numbers of people affected by a flood, road flooding is the main contributor to total flood damage.

**Walliman, N.S.R, Ogden, R., Baiche, B., Tagg, A. and Escarameia, M. (2013) A tool to predict the costs of reinstatement of individual buildings after flooding, In Klijn, F. and Schweckendiek, T. (eds), Comprehensive Flood Risk Management, 529-536, Taylor and Francis Group, London, ISBN 978-0-415-62144-1**

A review of the literature from Europe, USA and Australia, revealed that existing flood damage estimation methods are not sufficiently detailed to be reliably used at the individual building scale, so a more detailed tool was developed. A balance had to be drawn between excessive complexity and accuracy. The major inputs to the model are the depth, duration and dynamic qualities of the flooding, and the types of construction system, the building materials used and their positions within the construction, their drying characteristics and ease of repair or replacement. The output of the model expresses the damage in cost form as a percentage of the cost of new construction. This enables calculations to be made in order to assess the cost/benefit analysis of installing flood mitigation measures to the building and/or its surroundings. This paper provides examples of its application in several case studies.

**Wedawatta, G., Ingirige, B. and Proverbs, D. (2014) Small businesses and flood impacts: the case of the 2009 flood event in Cockermouth, Journal of Flood Risk Management, Vol. 7, Issue 1, 42–53**

Flooding can have a devastating impact on businesses, especially on small- and medium-sized enterprises (SMEs) who may be unprepared and vulnerable to the range of both direct and indirect impacts. SMEs may tend to focus on the direct tangible impacts of flooding, limiting their ability to realise the true costs of flooding. Greater understanding of the impacts of flooding is likely to contribute towards increased uptake of flood protection measures by SMEs, particularly during post-flood property reinstatement. This study sought to investigate the full range of impacts experienced by SMEs located in Cockermouth following the floods of 2009. The findings of a questionnaire survey of SMEs revealed that businesses not directly affected by the flooding experienced a range of impacts and that short-term impacts were given a higher significance. A strong correlation was observed between direct, physical flood impacts and post-flood costs of insurance. Significant increases in the costs of property insurance and excesses were noted, meaning that SMEs will be exposed to increased losses in the event of a future flood event. The findings from the research will enable policy makers and professional bodies to make informed decisions to improve the status of advice given to SMEs. The study also adds weight to the case for SMEs to consider investing in property-level flood risk adaptation measures, especially during the post flood reinstatement process.

## **Loss of life impacts**

**Brown, C. A. and Graham, W. J. (1988), Assessing the threat to life from dam failure, Water Resources Bulletin, 24 (6), 1303-1309**

To facilitate decisions regarding the need for modification of potentially unsafe dams, the U.S. Bureau of Reclamation developed procedures for assessing the threat to human lives posed by the failure of individual dams. The procedures provide a conceptual model of the variables influencing the loss of life from dam failure and a method for predicting loss of life based on the size of the population at risk from failure and the amount of warning time available for that population. The prediction equations are based on an analysis of 24 dam failures and major flash floods occurring since 1950. Adjustments to the predictions to reflect special local conditions are also discussed.

**Jonkman, S.N., van Gelder, P.H. and Vrijling, J.K. (2003) An overview of quantitative risk measures for loss of life and economic damage, Journal of Hazardous Materials A99 (2003) 1–30**

A comprehensive overview of methods to quantify and limit risks arising from different sources is still missing in literature. Therefore, a study of risk literature was carried out by the authors. This article summarises about 25 quantitative risk measures. A risk measure is defined as a mathematical function of the probability of an event and the consequences of that event. The article focuses mainly on risk measures for loss of life (individual and societal risk) and economic risk, concentrating on risk measurement experiences in The Netherlands. Other types of consequences and some international practices are also considered. For every risk measure the most important characteristics are given: the mathematical formulation, the field of application and the standard set in this field. Some of the measures have been used in a case study to calculate the flood risks for an area in The Netherlands.

**Jonkman, S.N., Maaskant, B. and Levitan, M. (2008) Loss of life caused by the flooding of New Orleans after Hurricane Katrina: a preliminary analysis of the relationship between flood characteristics and mortality, International Symposium on Flood Defence: Managing Flood Risk, Reliability and Vulnerability Toronto, Ontario, Canada, May 6-8**

In late August 2005, the New Orleans metropolitan area suffered the destructive power of hurricane Katrina. Large parts of the city flooded. This article utilizes the available data regarding Katrina related fatalities for Louisiana to analyse the relationship between flood characteristics and mortality. Available data regarding the recovery locations of Katrina related fatalities is presented and discussed. From this data, it is inferred that many, but not all, of the fatalities occurred inside the flooded areas. Insight in various characteristics of the flood has been gained based on available flood depth maps and hydrodynamic simulations that provide information in flood characteristics such as flow velocity, rise rate of the water and arrival time of the water. Combining the fatality data with the flood simulation results, the relationship between the flood characteristics and mortality is assessed. Similar to historical flood events, mortality rates were highest in areas near severe breaches and in areas with large water depths. Based on similar previous work a relationship between mortality and flood characteristics is derived for the New Orleans data. It is important to note that the presented results and analyses for New Orleans are preliminary, but they give important insights in the relationship between mortality and flood characteristics.

[http://www.hkv.nl/site/hkv/upload/publication/Loss\\_of\\_life\\_caused\\_by\\_the\\_flooding\\_of\\_New\\_Orleans\\_after\\_hurricane\\_Katrina\\_BM%281%29.pdf](http://www.hkv.nl/site/hkv/upload/publication/Loss_of_life_caused_by_the_flooding_of_New_Orleans_after_hurricane_Katrina_BM%281%29.pdf), accessed on 21.10.14

**Jonkman, S.N. and Kelman, I. (2009) Deaths during the 1953 North Sea storm surge**

From 31 January to 1 February 1953, a North Sea storm surge devastated coastal areas of the United Kingdom, Belgium, and the Netherlands. Apart from enormous economic damage and severe societal disruption, over 2,000 people died across the three countries. This paper discusses the

available data on loss of life in these three countries and examines the application of these data for loss of life estimations and general flood management practices

<http://www.rigsystems.co.uk/members/content/documents/1cd05-6547a.pdf>, accessed on 21.10.14

**Jonkman, S.N., Maaskant, B., Boyd, E., and Levitan, M.L. (2009) Loss of Life Caused by the Flooding of New Orleans After Hurricane Katrina: Analysis of the Relationship Between Flood Characteristics and Mortality, Risk Analysis, 29, 5, May, 676–698**

In this article a preliminary analysis of the loss of life caused by Hurricane Katrina in the New Orleans metropolitan area is presented. The hurricane caused more than 1,100 fatalities in the state of Louisiana. A preliminary data set that gives information on the recovery locations and individual characteristics for 771 fatalities has been analyzed. One-third of the analyzed fatalities occurred outside the flooded areas or in hospitals and shelters in the flooded area. These fatalities were due to the adverse public health situation that developed after the floods. Two-thirds of the analyzed fatalities were most likely associated with the direct physical impacts of the flood and mostly caused by drowning. The majority of victims were elderly: nearly 60% of fatalities were over 65 years old. Similar to historical flood events, mortality rates were highest in areas near severe breaches and in areas with large water depths. An empirical relationship has been derived between the water depth and mortality and this has been compared with similar mortality functions proposed based on data for other flood events. The overall mortality among the exposed population for this event was approximately 1%, which is similar to findings for historical flood events. Despite the fact that the presented results are preliminary they give important insights into the determinants of loss of life and the relationship between mortality and flood characteristics

**Jonkman, S. N. (2003) Loss of life caused by floods: an overview of mortality statistics for worldwide floods**

Large parts of the Netherlands lie below sea-level, and the hazard of large-scale floods leading to extensive damage and loss of life is always present. In this paper a framework for estimation of loss of life caused by floods in the Netherlands is proposed. The method takes into account the effect of evacuation during the flood and various mechanisms which lead to fatalities during a flood. The relationships between flood characteristics and number of fatalities are based on data from the 1953 North Sea flood disaster, during which the south western part of the country was flooded causing 1,836 deaths. The method is applied in two case studies to give a first estimate of the number of fatalities caused by a river dyke breach near Rotterdam and failure of coastal defences near Katwijk, both leading to a flood in Central Holland. [http://www.library.tudelft.nl/delftcluster/theme\\_risk.html](http://www.library.tudelft.nl/delftcluster/theme_risk.html) Accessed: 16/11/05

**Jonkman, S. N. and Kelman, I. (2005), An analyses of the causes and circumstances of flood disaster deaths, Disasters, Vol 29 (1), 75-97**

The objective of this paper is to investigate and to improve understanding of the causes and circumstances of flood disaster deaths. A standardised method of classifying flood deaths is proposed and the difficulties associated with comparing and assessing existing information on flood deaths are discussed. Thirteen flood cases from Europe and the United States, resulting in 247 flood disaster fatalities, were analysed and taken as indicative of flood disaster deaths. Approximately two-thirds of the deaths occurred through drowning. Thus, a substantial number of flood disaster fatalities are not related to drowning. Furthermore, males are highly vulnerable to dying in floods and unnecessary risk-taking behaviour contributes significantly to flood disaster deaths. Based on

these results, recommendations are made to prevent loss of life in floods. To provide a more solid basis for the formulation of prevention strategies, better systematic recording of flood fatalities is suggested, especially those caused by different types of floods in all countries.

**Jonkman, S. N., van Gelder, P. H. and Vrijling, J. K. (2002), Loss of life models for sea and river floods. In Wu et al. (Eds) Flood Defence 2002, Science Press, New York Ltd.**

In this article an overview is given of methods in the literature to estimate the loss of life caused by floods. The methods are described and applied to a case study in the Netherlands. The paper presents a framework for future research on loss of life modelling.

<http://www.waterbouw.tudelft.nl/public/gelder/paper120b-v10210.pdf>

**Jonkman, S.N., Vrijling, J.K. and Vrouwenvelde, A.C. (2008) Methods for the estimation of loss of life due to floods: a literature review and a proposal for a new method, Natural Hazards, Volume 46, Issue 3, 353-389**

This article deals with methods for the estimation of loss of life due to flooding. These methods can be used to assess the flood risks and to identify mitigation strategies. The first part of this article contains a comprehensive review of existing literature. Methods have been developed for different types of floods in different regions. In general these methods relate the loss of life in the flooded area to the flood characteristics and the possibilities for evacuation and shelter. An evaluation showed that many of the existing methods do not take into account all of the most relevant determinants of loss of life and that they are often to a limited extent based on empirical data of historical flood events. In the second part of the article, a new method is proposed for the estimation of loss of life caused by the flooding of low-lying areas protected by flood defences. An estimate of the loss of life due to a flood event can be given based on: (1) information regarding the flood characteristics, (2) an analysis of the exposed population and evacuation, and (3) an estimate of the mortality amongst the exposed population. By analysing empirical information from historical floods, new mortality functions have been developed. These relate the mortality amongst the exposed population to the flood characteristics. Comparison of the outcomes of the proposed method with information from historical flood events shows that it gives an accurate approximation of the number of observed fatalities during these events. The method is applied to assess the consequences for a large-scale flooding of the area of South Holland, in the Netherlands. It is estimated that the analysed coastal flood scenario can lead to approximately 3,200 fatalities in this area.

**Jonkman, S.N., and Vrijling, J.K. (2008) Loss of life due to floods, Journal of Flood Risk Management, Vol 1, Issue 1, 43–56**

This article gives an overview of the research on loss of life due to floods. The limited information regarding this topic is presented and evaluated. Analysis of global data for different flood types shows that the magnitude of mortality is related to the severity of the flood effects and the possibilities for warning and evacuation. Information from historical flood events gives a more detailed insight into the factors that determine mortality for an event, such as flood characteristics and the effectiveness of warning and evacuation. At the individual level, the occurrence of fatalities will be influenced by behaviour and individual vulnerability factors. Existing methods for the estimation of loss of life that have been developed for different types of floods in different regions are briefly discussed. A new method is presented for the estimation of loss of life due to floods of low-lying areas protected by flood defences. It can be used to analyse the consequences and risks of flooding and thereby provide a basis for risk evaluation and decision-making. The results of this

research can contribute to the development of strategies to prevent and mitigate the loss of life due to floods.

**Kellar, D.M.M. and Schmidlin, T.W. (2012) Vehicle-related flood deaths in the United States, 1995–2005 *Journal of Flood Risk Management*, Vol 5, Issue 2, 153–163**

Vehicle-related deaths comprise more than half of all flash flood fatalities in the United States. Using the publication Storm Data from the United States National Climatic Data Center, we found 555 vehicle-related flood deaths that occurred in 355 flooding events during 1995–2005. Males accounted for 60% of the deaths. The difference in death rates between the sexes was small at ages 19 and younger but males died at twice the rate of females for ages 40 and older. Elevated death rates were found for both males and females under age 5 and over 60. Flooding events classified as flash floods accounted for most of the fatalities. Vehicle-related flood deaths were concentrated in the Texas Hill Country, the desert Southwest, the Ohio River Valley, and eastern North Carolina.

## **Health and social impacts**

**Convery, I. and Bailey, C. (2008) After the flood: the health and social consequences of the 2005 Carlisle flood event, *Journal of Flood Risk Management*, Vol 1, Issue 2, 100–109**

In this paper we consider the health and social impacts of the flooding caused to a number of Carlisle households following the January 2005 floods and storms. In so doing we consider such impacts from a 'lived, local experience' perspective. We reflect on the need for both informal support and locally accessible and ongoing, post-flood information and support centres. Such centres can provide one point of contact for potentially multiple, emotional and practical problems. Crucially we suggest that these centres require both strong multi-partnership and multi-agency working and highly skilled support centre personnel who have local knowledge and understanding of the affected community. In this way, post-disaster local needs may be contextualized and responded to in a way that both draws on existing local knowledge and expertise and further strengthens long-term community-based support.

**Du, W., Fitzgerald, G., Clark, M. and Hou, X. (2010) Health impacts of floods. *Orhospital and Disaster Medicine*, 25(3), pp.265-272**

Direct health impacts of floods on households occur during the flood itself and are caused by coming in contact with flood water (these are the impacts which are normally felt immediately the flood event occurs), it could also result from direct exposure to the flooded environment, these includes; mortality from drowning, heart attacks, injuries from debris, chemical contamination and hypothermia. Most of the deaths associated with drowning are recorded during a flash flooding event as against the slower riverine flooding even. Drowning often occurs as a result of individuals under-estimating the velocity of the flood water or the depth of the flood water during late evacuation or attempted salvage. Death by drowning can also occur when people are swept away from their home while attempting to cross a bridge, rafting or sailing in storm water drains. Flood related injuries may occur as individuals attempt to escape from floating objects or building collapse. Disruption of health infrastructure including public health structures, such as clean water and proper waste disposal system, all these have the potential to significantly contribute to social disruption.

**Green, C. H. and Penning-Rowsell, E.C. (1986), "Evaluating the intangible benefits and costs of a flood alleviation proposal", *Journal of the Institution of Water Engineers and Scientists* 40 (3), 229-248**

Experimental approaches to evaluating intangible impacts of floods (e.g. on health) are presented and discussed with some case study evidence.

**Green, C. H. and Penning-Rowsell, E. C. (1989), "Flooding and the Quantification of 'intangibles'", *Journal of the Institution of Water and Environmental Management* 3 (1), 27-30**

Sources of both systemic and parameter uncertainties in flood alleviation cost-benefit analysis are discussed. Cost-benefit analyses are assessments of the future effects of different scheme options; consequently, there are inherent uncertainties. The omission of consideration of some impacts as 'intangibles', because it has not been possible to measure them, is a form of systemic uncertainty.

A significant omission in the past from flood alleviation cost-benefit analyses has been the non-monetary impacts of flooding upon households. It is shown that these impacts are both large and more important to the households affected than are the direct monetary losses.

**Hajat, S., Ebi, K. and Kovats, S. (2003) A Review: The human health consequences of flooding in Europe: *Applied Environmental Science Public Health* 1, 13-21**

Floods are the most common natural disaster in Europe. The adverse human health consequences of flooding are complex and far-reaching: these include drowning, injuries, and an increased incidence of common mental disorders. Anxiety and depression may last for months and possibly even years after the flood event and so the true health burden is rarely appreciated. Effects of floods on communicable diseases appear relatively infrequent in Europe. The vulnerability of a person or group is defined in terms of their capacity to anticipate, cope with, resist and recover from the impact of a natural hazard. Determining vulnerability is a major challenge. Vulnerable groups within communities to the health impacts of flooding are the elderly, disabled, children, women, ethnic minorities, and those on low incomes. There is a need for more good-quality epidemiological data before vulnerability indices can be developed. A comprehensive, risk-based emergency management program of preparedness, response, and recovery has the potential to reduce the adverse health effects of floods, but there is currently inadequate evidence of the effectiveness of public health interventions.

**Joseph, R., Proverbs, D., Lamond, J. and Wassell, P. (undated) A critical synthesis of the intangible impacts of flooding on households, University of the West of England, Bristol, UK <http://iiirr.ucalgary.ca/files/iiirr/222.pdf>, accessed on 22.10.14**

The frequency and magnitude of flood events has increased significantly in the last few decades. This can be linked to a number of causes, including changes in climate patterns and urban development. The occurrence of a flood event brings about a range of impacts including tangible or measurable effects and intangible, less quantifiable aspects. The tangible impacts of flooding has generally received greater attention in policy, the media and society, while the intangible impacts have received less attention possibly because they are more difficult to encapsulate and they are generally health related issues. However, there is a growing awareness by flood risk managers that intangible impacts of floods have been underestimated in post-flood appraisals. In an attempt to conceptualise the intangible impacts of flooding on households, a critical synthesis of literature is presented towards developing a deeper understanding of the extent of the effect of flooding on the health of households. The review highlights that the health of households is affected by the stress and disruption caused by having to vacate homes following flood event. This is especially true for the more vulnerable members of the communities and the finding also reveal that the effect could last for months and even years. The implications of these findings are that the health impacts of flooding on households could be greatly reduced by flood mitigation measures such as the take up of

property level flood adaptation measures as this will reduce the amount of time households will need to vacate their home for repair works following flood events. There is therefore a need for further research towards improving the quantification of these long term health impacts for the purpose of cost benefit appraisals.

**Lane, K., Charles-Guzman, K., Wheeler, K., Abid, Z., Graber, N. and Matte, T. (2013) Health effects of coastal storms and flooding in urban areas: a review and vulnerability assessment, *Environ Public Health*, 913064. doi: 10.1155/2013/913064**

Coastal storms can take a devastating toll on the public's health. Urban areas like New York City (NYC) may be particularly at risk, given their dense population, reliance on transportation, energy infrastructure that is vulnerable to flood damage, and high-rise residential housing, which may be hard-hit by power and utility outages. Climate change will exacerbate these risks in the coming decades. Sea levels are rising due to global warming, which will intensify storm surge. These projections make preparing for the health impacts of storms even more important. We conducted a broad review of the health impacts of US coastal storms to inform climate adaptation planning efforts, with a focus on outcomes relevant to NYC and urban coastal areas, and incorporated some lessons learned from recent experience with Superstorm Sandy. Based on the literature, indicators of health vulnerability were selected and mapped within NYC neighbourhoods. Preparing for the broad range of anticipated effects of coastal storms and floods may help reduce the public health burden from these events.

**Ohl, C.A. and Tapsell, S.M. (2000) 'Flooding and human health: the dangers posed are not always obvious', *British Medical Journal*, 321, 1167-8**

The long term effects of flooding on psychological health may perhaps be even more important than illness or injury and therefore the benefits of trying to avoid such impacts are likely to be high. For most people the emotional trauma continues long after the water has receded. Making repairs, cleaning up, and dealing with insurance claims is stressful. If there is a lack of support during the recovery process, stress levels may increase further. This paper is a short editorial which makes the case for those providing medical care – of both a physical and mental kind – to become more aware of the particular health issues relating to flood occurrences.

**Orellana, C. (2002) Germany counts cost of flood damage to health-care services, *The Lancet*, Vol 360, Issue 9334, 698, 31 August**

Torrential rain led to widespread floods across several countries in central Europe including Germany, Austria, and the Czech Republic. Across the region, 100 people died, hundreds were injured, and thousands were evacuated. In Germany the bill for repairing the flood damage is estimated to be €15 billion. Germany's national healthcare service has started to assess the impact of the floods. In Saxony, in eastern Germany, 31 doctor's surgeries were destroyed and 22 were severely damaged, leaving a €50 million repair bill, according to a spokesman from the Dresden Medical Association. "Doctors who haven't lost their surgeries are taking patients over or lending rooms to their colleagues", he said, "but health care will suffer if the damaged surgeries are not restored soon". Following German reunification doctors in eastern Germany took on substantial loans to build new surgeries in line with western standards. "The payments are still running and some doctors have lost the means to pay these loans". Local doctors are discussing possible financial solutions with local authorities. The damage to local healthcare services has compromised the ability of doctors to deal with the increased risk of flood-related disease. According to Angela Wirtz and Wilfried Oettler, health experts at the Social Ministry in Saxony, the immediate danger comes from

gastrointestinal infections, especially where houses were flooded with sewage from treatment plants and blocked drains. "It is always possible that conditions will favour the spread of more serious faecal-to-oral transmitted diseases", they warned. So far the levels of infectious disease are below the seasonal average, according to Wirtz and Oettler. Nearly all water-treatment plants are working again and there is little or no risk of faecal matter contaminating drinking water supplies, they said. However, there are some serious outstanding issues. Flooded factories and chemical plants in eastern Germany and the Czech Republic spilt toxic chemicals into the flood waters. Mercury concentrations in the Elbe have doubled but remain below the WHO limit. The long-term effects of this pollution remain to be seen. "We can infer that high levels of heavy metals, such as lead, mercury, arsenic, or cadmium, are likely to persist on cultivable land which will no longer be suitable for growing food", said Siegmund Fröhlich, East Frisia Technical University, Emden.

**Penning-Rowell, E.C., Tapsell, S.M. and Wilson, T. (2005) Policy Implications of the Health Effects of Floods, accessed at <http://eknygos.lsmuni.lt/springer/154/207-223.pdf> on 22.10.14**

The frequency and extent of flooding world-wide, and the accompanying losses and related human health impacts, are expected to increase over the next 50 to 100 years owing to the effects of global warming and other factors. There is cause for concern here, as the impacts of floods are serious and far-reaching. These impacts include impacts on health, as elaborated in this chapter. In turn these have implications for policies for flood defence, the environment and the provision of local services to help people recover from flood emergencies and their aftermath. This chapter outlines some of the research undertaken at Middlesex University Flood Hazard Research Centre on the health effects of floods in the UK, and describes how these effects might be mitigated by policies and strategies to identify those who might be worst affected, to warn people of the impacts that they might suffer, and to help them during and after flood emergencies.

**Tapsell, S.M., Penning-Rowell, E.C., Tunstall, S.M. and Wilson, T. (2002) Vulnerability to flooding: health and social dimensions, *Phil. Trans. R. Soc. Lond.* 360, 1511-1525**

This paper presents research results on the impacts that floods can have on the people affected, thus complementing the existing data on the monetary losses liable to occur in flood events. Both datasets should be used when deciding on investment in flood defence measures. We report on research on the vulnerability of flood-affected communities to adverse health effects, and the development of an index of community vulnerability based on extensive focus-group research and secondary-source census data.

**Tunstall, S., Tapsell, S., Green, C., Floyd, P. and George, C. (2006) The health effects of flooding: Social research results from England and Wales, *Journal of Water and Health*, Vol. 4, (3), 365-380**

This paper presents interview survey data by social scientists using established health measures on the health effects of flooding for residents in 30 locations in England and Wales. First, it examines the extent to which flooded residents reported suffering physical and psychological health effects during and after the event. Second, it explores the issue of whether these effects were long-lasting by comparisons with the general population and with those at risk but not flooded. In the study, about two thirds of the flood victims were found to have scores on the General Health Questionnaire-12 scale indicative of mental health problems (scores of 4+) at their worst time after flooding. The evidence of the study also suggests that some flood victims suffered long term mental health effects as a result of their experience of flooding. The study examines the influence of a wide range of factors: characteristics of the flood event, types of property, and socio-demographic and the intervening factors such as the extent of family or community support that may explain the

health effects of flooding. It finds that a complex set of social and other factors are involved and that some factors susceptible to human intervention such as having adequate flood insurance cover are important factors in the stress experienced by flood victims.

## **Benefits of non-structural measures**

**Carsell, K. M., Pingel, N. D. and Ford, P. E. (2004), Quantifying the benefit of a flood warning system, Natural Hazards Review, August 2004, 131-140**

A flood warning system yields direct and indirect, tangible and intangible benefits. To achieve this, the system includes hardware, software, plans and procedures, and personnel that work in an integrated manner to increase the mitigation time available prior to the onset of flooding. This mitigation time increase is a consequence of a reduction in the time required to collect data, to evaluate and identify the flood threat, to notify emergency personnel and the public, and to make decisions about the appropriate response. The direct tangible benefit—the inundation damage reduction—can be computed with standard expected damage computation procedures, using modified depth-damage functions that include mitigation time as an independent variable and accounting for improvements to the efficiency of response due to the implementation of the flood warning system. This proposed method is applicable for benefit evaluation for any flood warning system; it is illustrated here with an example from the Sacramento River basin of central California.

**Defra (2008) Developing the Evidence Base for Flood Resistance and Resilience. Joint Defra/EA Flood and Coastal Erosion Risk Management R&D Programme, R&D Summary Report FD2607/TR1, Entec**

It is estimated that around 470,000 properties in England are currently located in areas subject to a significant (greater than 1.33% annual probability) risk of main river and/or coastal flooding. This estimate excludes properties which could be at a similar risk of flooding from minor rivers, surface water run-off and/or groundwater. The economic cost of flooding in these areas is considerable, currently reaching around £1.15 billion per annum (£747 million residential and £401 million commercial). Although some of these properties could be provided with community-level flood protection by the Environment Agency over the coming years, in other areas the numbers of properties are so small or the cost of defences so large that the cost of additional protection is unlikely to be justified. Climate change is likely to increase the pressures on these properties and increases the need to consider a wider portfolio of flood management approaches. The greater use, by individual households and businesses, of flood resistance (i.e. measures to prevent entry of water into a building fabric) and flood resilience measures (i.e. measures to limit the impact of flood water within a building). A key element of the project was the examination of the effectiveness of property based resilience and resistance measures in reducing flood risk. This involved developing a new economic model to quantify the costs and benefits of resilience and resistance at a property level. The model was developed for both residential and selected commercial properties and facilitated the quantification of property-scale benefits and costs for different packages of flood resistance and resilience measures.

**Environment Agency (2012) Evaluation of the Defra Property-level Flood Protection Grant Scheme: JBA Consulting, Assessing the Economic Case for Property Level Measures in England, Committee on Climate Change Economics of flood risk adaptation measures, Final Report 9X1055, EA, Bristol**

This report sets out the methodology and results of the investigation into the potential for Property Level Measures (PLM) to enable adaptation to flood risk at present and into the future, addressing

the first aim of the study. Section 2 discusses the two key pieces of previous research into the costs and benefits of PLMs, setting the context for this study. Section 3 sets out the methodology for the study. Firstly this details the development of the PLM model for six packages of measures, six property types, three installation scenarios and both an economic and a financial perspective. Secondly the approach taken to obtain a national estimate of the number of properties that would find it cost beneficial to install PLMs now and in the future is described. Section 4 gives the results of the PLM model for the various combinations of PLM measures, property type, installation scenario, and economic or financial perspectives. Section 5 discusses sensitivity analysis of the PLM model, testing the key assumptions regarding assessment of the costs and benefits of the measures. These include variability in the cost of measures, the limiting height of resistance measures, assumptions regarding seepage of resistance measures and discount rates used for the financial model. Section 6 outlines the results of the national assessment for England indicating for how many properties it would be cost beneficial to install these measures at present. This assessment considers those properties that are currently at risk from flooding from rivers or the sea. At present there is insufficient data to make similar assessment for properties at risk from surface water flooding. Section 7 presents the assessment of how the number of properties in England that could benefit from these types of measures may change in the future due to climate change, funding of flood defences and property development. Section 8 summarises the key findings of the study and gives recommendations for future work that could improve the understanding of the cost and benefits of PLMs, and how this could be assessed at the national scale.

**Joseph, R., Proverbs, D., Lamond, J. and Wassell, P. (2014) Application of the concept of cost benefits analysis (CBA) to property level flood risk adaptation measures, Structural Survey Volume 32, Issue 2, 102**

There has been a significant increase in flooding in the UK over the past ten years. During this time, Government policy has moved from investment in flood defences towards encouraging property owners to take responsibility for reducing the impact of flooding. One of the ways in which this can be achieved is for homeowners to adapt their properties to flood risk by implementing property level flood risk adaptation (PLFRA) measures. While there has been some attempt to develop an understanding of the benefits of such measures, these previous studies have their limitations in that the intangible benefits have not been fully considered. As such, there remains a need for further development of these studies towards developing a more comprehensive understanding of PLFRA measures. It is against this background the purpose of this paper is to present a conceptual cost benefit analysis (CBA) framework for PLFRA measure. This framework brings together the key parameters of the costs and benefits of adapting properties to flood risk including the intangible benefits, which have so far been overlooked in previous studies. Design/methodology/approach – A critical review of the standard methods and existing CBA models of PLFRA measures was undertaken. A synthesis of this literature and the literature on the nature of flooding and measures to reduce and eliminate their impacts provides the basis for the development of a conceptual framework of the costs and benefits of PLFRA measures. Within the developed framework, particular emphasis is placed on the intangible impacts, as these have largely been excluded from previous studies in the domain of PLFRA measures. Findings – The framework provides a systematic way of assessing the costs and benefits of PLFRA measures. A unique feature of the framework is the inclusion of intangible impacts, such as anxiety and ill health, which are known to be difficult to measure. The study proposes to implement one of the stated preference methods (SPM) of valuation to measure these impacts, known as the willingness to pay method, as part of a survey of homeowners. The inclusion of these intangible impacts provides the potential to develop a more comprehensive understanding of the benefit cost ratio (BCR) for different stakeholders. The newly

developed CBA conceptual framework includes four principal components: the tangible benefits to insurers; the tangible benefits to the government; the tangible benefits to homeowners; and the intangible benefits to homeowners. Originality/value – This tool offers the potential to support government policy concerned with increasing the uptake of PLFRA measures through increasing the information available to homeowners and thereby supporting the decision-making process.

**May, P.G. and Chatterton, J.B. (2012) Establishing the Cost effectiveness of Property Flood Protection: FD2657, JBA Consulting, Defra, London.**

Although the focus of this report is on cost-effectiveness the data on benefits may be employed in cost-benefit appraisal. A new and extended model has been developed that builds on the strengths of a previous study undertaken by Entec UK in 2007-08. It incorporates the latest data on the economic damage from flooding and the costs and benefits of a range of flood protection measures, updated to a 2011 price base perspective. Innovative, automatic (or passive) protection measures are compared to manually deployed measures. Factors such as the service life and reliability of such systems have also been addressed. Assumptions on damage savings have been re-visited and improved, using the 2010 Multi-Coloured Manual data. Additional damage-saving categories have been incorporated, including emergency costs and the cost of electricity during the post-flood drying- out process. The wider social impacts of flooding and the intangible health and well-being benefits and reduced levels of stress that can be gained from property-level flood protection are also considered. The introduction of such measures can help to reduce the severity of these losses compared to an unprotected property. It is also important to recognise that, unlike a traditional flood defence scheme, these measures do not alter the likelihood of floodwater reaching the property. They do however aim to manage the consequences once this happens. Financial and economic models have been developed to analyse the costs relative to the benefits of six packages of flood resistance and resilience measures. These have been applied to a wide range of property types, for various levels of social deprivation and for different thresholds of flooding. Improvements and extensive revisions have been made to the previous economic model developed in 2008, to provide for an interactive model that can be used to explore the impacts of altering a range of key variables. Further analytical tools have also been suggested that could provide a simple to use spreadsheet tool that could also contain spatial links using GIS to help local authority scheme appraisal decisions. The analysis has been extended to explore the implications of applying the new Partnership Funding approach, to determine and make comparisons between over 22,000 possible scenario outcomes, made in terms of benefit cost ratios and typical Partnership Funding Outcome Scores. This has provided an assessment of cost effectiveness and the approaches that could qualify for government funding, together with the levels of contributions that might be necessary from developers or home owners for a scheme to proceed. The study found (a) compelling evidence for the cost effectiveness of manually deployed flood resistance measures, with high benefit cost ratios and high Partnership Funding Outcome Scores for typical flood thresholds of up to 2.5% annual exceedance probability (1 in 40 year); (b) the higher cost of Automatic Resistance measures results in lower benefit cost ratios but there are still significant cost effective opportunities for schemes with appropriate levels of contribution, but at typically lower flood thresholds of 5% annual exceedance probability (1 in 20 year); (c) the high cost of resilience measures indicates that these are a less cost effective option for Government intervention, unless flooding of a property occurs at greater than a 20% annual exceedance probability (1 in 5 year); (d) manual resistance measures are more than twice as cost beneficial as automatic measures, achieving some very high benefit cost ratios; (e) the effects of reliability have been examined but found not to have significant impacts on the overall outcomes.

**Meyer, V., Priest, S.J. and Kuhlicke, C. (2012) Economic evaluation of the structural and non-structural flood risk management measures – examples from the Mulde River, Natural Hazards, Vol 62, (2) 301-324**

The concept of flood risk management, promoted by the EU Floods Directive, tries to mitigate flood risks not only by structural, hydraulic engineering measures, but also by non-structural measures, like, e.g., land-use planning, warning and evacuation systems. However, few methods currently exist for the economic evaluation of such non-structural measures and, hence, their comparison with structural measures. The objective of this paper is to demonstrate the potential benefits of employing a wider range of economic appraisal methods for flood projects, in particular, it provides examples and applications of methodologies which may be employed to evaluate non-structural measures and their transaction costs. In two case studies at the Mulde River, Germany, two non-structural measures, a resettlement option and a warning system, are evaluated and compared with structural alternatives with regard to their effectiveness, cost-effectiveness and efficiency. Furthermore, a simple approach is tested in order to show the transaction costs of these measures. Case study results show that the choice of evaluation criteria can have a major impact on the assessment results. In this regard, efficiency as an evaluation criterion can be considered as superior to cost-effectiveness and effectiveness as it is also able to consider sufficiently the impacts of non-structural measures. Furthermore, case study results indicate that transaction costs could play an important role, especially with non-structural measures associated with land-use changes. This could explain why currently these kinds of measures are rarely selected by decision makers.

**Parker, D J 1991 The Damage-Reducing Effects of Flood Warnings, Report prepared for Halcrow and National Rivers Authority in connection with the Anglian Region's Regional Telemetry Scheme Appraisal, Middlesex Polytechnic, Enfield**

A relatively early piece of research on the damage-reducing effects of flood warnings in both the residential and non-residential property sectors. This research report combines previous research on residential property inventories in the UK with empirical evidence of the damage saving effects of flood warning responses in the UK to generate relationships between the proportion of damage likely to be saved with 2, 4, 6 and 8 hour flood warning lead times. The result is a set of empirically informed synthetic curves, mainly for the residential property sector. Subsequent research by the author and others at the Flood Hazard Research Centre in London now suggest that these curves are too optimistic in terms of the amount of damage which is likely to be saved by flood warning responses in the UK.

**Parker, D.J., Tunstall, S.M. and McCarthy, S. (2007) New insights into the benefits of flood warnings: Results from a household survey in England and Wales Environmental Hazards, Vol 7, 193–210**

The flood defence agency in England and Wales has been pursuing a programme of flood warning system enhancement, engaging householders at risk in improving their warning responses. The immediate aim of this paper is to test and revise a model of economic benefits of warnings, but the survey data also generate insights into the constraints acting upon flood warning responses. Damage saving is less than previously anticipated: warning reliability and householder availability problems limit savings. Warnings are less likely to be received by those in lower social grades, and flood warning lead time is a factor in avoiding damage. The survey data indicate the complexities involved in improving flood warning response, and provide policy pointers.

**Parker, D.J. and Priest, S. J. (2012) The Fallibility of Flood Warning Chains: Can Europe's Flood Warnings Be Effective? *Water Resources Management* August , Volume 26, Issue 10, 2927-2950**

Taking a broad overview, this paper explores recent evidence on flood forecasting, warning communication and public warning response in Europe between 1995 and 2010 which underpins the benefits of flood warnings. Key flood warning chain deficiencies are identified together with the effect these deficiencies have on flood warning effectiveness and loss reduction. Europe-wide data on flood forecasting and warning communication are examined alongside recent in-depth research evidence from various parts of Europe on flood warning receipt, warning response and warning effectiveness. Using the latest flood warning benefit assessment methodologies, the results of case studies of flood loss avoidance through warnings reveal the damage saving potential of flood warning. Although these savings are significant, currently they are inhibited by a series of shortcomings which transfer through the warning chain limiting warning impact. Flood forecasting, warning and warning response systems are inherently fallible and so it is doubtful that they will ever be consistently effective. Sole reliance upon them to protect life and property carries inevitable risks and governments should not be surprised when flood warnings are only partially effective. Although Europe's flood forecasting and warnings have been improving, the scope for further improvement is large. Extending flood forecasting and warning coverage, extending warning lead times by combining meteorological and hydrological forecasts, building greater redundancy into warning communication, and crucially also building it into cooperative strategies designed to engage at risk communities in flood warning response, are all likely to be important.

**Parker D J, Priest, S J, Schildt A, Handmer J, 2008. Modelling the damage reducing effects of flood warnings, FLOODsite Report No. T10-07-12, FLOODsite: HR Wallingford**

A research report from the EC commissioned Floodsite research project, in this case focusing upon devising a new methodology for understanding and assessing the various benefits that potentially flow from installing and operating flood warning systems. The research examines the development of flood warning systems in France and the Czech Republic. The central concept developed in this research is the Flood Warning Response Benefits Pathway Model (FWRPBM) which conceptualises each of about eight pathways through which flood warnings may generate benefit. The model is applied to some hypothetical cases and to the town of Grimma in South Eastern Germany to demonstrate how warning benefits may be estimated. There is also a national level of assessment of flood warning benefits in England and Wales.

**Priest, S.J., Parker, D.J. and Tapsell, S M. (2011) Modelling the damage reducing effects of flood warnings using European cases, *Environmental Hazards*, 10, 2, 101-120**

Flood warning systems are now centre-stage in flood risk management strategies in Europe. This is due to advances in flood forecasting and the rapid communication of flood risk information, coupled with a growing understanding that communities need to find better ways of co-existing with rivers and the realization that structural flood defences are insufficient on their own to prevent flooding. However, not enough is known about the potential and actual benefits of flood warnings for avoiding property damages. This paper presents an extended approach to the estimation of potential flood damage reduction benefits of flood warnings for fluvial and tidal floods, drawing upon research completed for the European Commission's Floodsite project. Its aim is to demonstrate the potential economic benefits of coupling flood warnings to a combination of structural and non-structural flood risk management measures. Previous research in this area is critiqued, including that which suggests that flood warnings are futile, and the features, strengths and weaknesses of the extended approach are presented and discussed. Two case studies, a

national-level (England and Wales) and a local-level (Grimma, South-Eastern Germany) assessment of flood damage-saving potential, are presented to illustrate the new approach. Although a number of data quality issues need addressing, the model outputs and estimations of potential damage savings may be used to make wise decisions about investment in flood warning systems, and to identify those areas, such as public flood risk awareness, that need attention to achieve the full scope of potential benefits in practice.

## **Agricultural impacts**

**Morris, J. and Brewin, P. (2014) The impact of seasonal flooding on agriculture: the spring 2012 floods in Somerset, England *Journal of Flood Risk Management*, Vol 7, Issue 2, 128–140**

Exceptional rainfall in spring 2012 caused widespread flooding and damage to agricultural grasslands in Somerset in south western England, much of them farmed under agri-environment agreements. The seasonal timing of the flood and its relatively long duration (in excess of 4 weeks in some areas) led to a serious loss of grazing and winter feed in 2012. A survey of farmers, combined with the development of a framework to estimate the impact of seasonal flooding, identified the effects on farm businesses and the ways that farmers coped. Impacts on agri-environment outcomes were valued at the cost of funding stewardship schemes. The methods and estimates can help inform strategies to deal with changes in flood risk in areas of agricultural and environmental interest, whether induced by changes in catchment land use or climate.

**Posthumus, H., Morris, J., Hess, T.M., Neville, D., Phillips, E. and Baylis, A. (2009) Impacts of the summer 2007 floods on agriculture in England, *Journal of Flood Risk Management*, Vol 2, Issue 3, 182–189**

Exceptional rainfall during the summer of 2007 caused widespread flooding in parts of England. While the focus of attention has been correctly placed on the impact on densely populated urban areas, large tracts of rural land were seriously affected by flooding. Summer flooding is particularly damaging to farming. This paper presents the results from an evaluation of the impacts of the summer 2007 flood events on agriculture. High financial losses were incurred in the horticultural sector. Arable farmers incurred direct losses in the form of crop loss or yield reduction due to flooding and associated waterlogging of fields. Livestock farmers incurred indirect losses in the form of additional housing and feeding costs for livestock. Although total costs to agriculture were small compared with urban flood costs, they were typically large at the individual farm scale. Such impacts should be properly acknowledged in future strategies for flood risk management.

## **Environmental benefits**

**Bateman, I.J., Carson, R.T., Day, B., Hanemann, M., Hanley, N., Hett, T., Jones-Lee, M., Loomes, G., Mourato, S., Ozdemiroglu, E., Pearce, D.W., Sugden, R. and Swanson, J. (2002) *Economic Valuation with Stated Preference Techniques: A Manual*, Edgar Elgar, Cheltenham, UK**

This manual offers a detailed, up-to-date explanation of how to carry out stated preference techniques. The techniques use surveys to ask individuals how much they would be willing to pay or willing to accept in compensation for gains or losses of non-market goods and services. Applicants of the technique include changes in air and water quality; noise nuisance; health care; risk; recorded heritage; cultural assets; habitats; landscape and so on. The resulting valuations can be used for a number of purposes including, but not limited to, demonstrating the economic value of environmental and cultural assets; cost-benefit analysis; setting priorities for environmental policy;

design of economic instruments; green national/corporate accounting; and natural resource damage assessment. Compiled by the leading experts in the field, this manual starts by explaining the concepts. It shows how to choose the most appropriate technique and how to design the questionnaires. Detailed advice on econometric analysis is provided, as well as explanation of the pitfalls that need to be avoided. The manual is essential reading for those who apply, commission, teach and study stated preference techniques.

**Department for Environment, Food and Rural Affairs (2010) An introductory guide to valuing ecosystem services, Defra, London**

This Guide provides an introduction to the valuation of ecosystem services. It builds on previous approaches to valuing the environment but takes a more systematic approach to the assessment of impacts on the natural environment. The central theme of this work is to ensure that the true value of ecosystems and the services provided are taken into account in policy decision-making. Ecosystem services are defined as services provided by the natural environment that benefit people. While there is no single, agreed method of categorising all ecosystem services, the Millennium Ecosystem Assessment framework is widely accepted and is seen as a useful starting point. Ecosystem services provide outputs or outcomes that directly and indirectly affect human well-being, and these considerations can link well to taking an economic approach. The underlying case for the valuation of ecosystem services is that it will contribute towards better decision-making, by ensuring that policy appraisals fully take into account the costs and benefits to the natural environment and by highlighting much more clearly the implications for human wellbeing, while providing policy development with new insights. Some of these ecosystem services are well known including food, fibre and fuel provision and the cultural services that provide benefits to people through recreation and appreciation of nature. Other services provided by ecosystems are not so well known. These include the regulation of the climate, the purification of air and water, flood protection, soil formation and nutrient cycling. These services are not generally considered within policy appraisal at present and represent an area where a greater and more systematic focus would be very useful. The appraisal of new policies, programmes and projects all require environmental impacts to be taken into account. The approach to the valuation of ecosystem services presented in this Guide is not intended to be an additional step within the appraisal process but, instead, a common methodology that can be used in order to consider the impact of our actions on the environment. The environmental impacts currently taken into account in policy appraisal can generally fit well within this broad framework. This broader framework allows a shift in emphasis from a focus mainly on valuing environmental damage to highlighting the value of changes in the services provided by the natural environment. Ecosystem services contribute to economic welfare in two ways – through contributions to the generation of income and wellbeing and through the prevention of damages that inflict costs on society. Both types of benefits should be accounted for in policy appraisal. With a broader focus on valuing the benefits provided by ecosystems, policy options that enhance the natural environment are also more likely to be considered that demonstrate that investing in natural capital can make economic sense.

**Eftec (2010) Valuing Environmental Impacts: Practical Guidelines for the Use of Value Transfer in Policy and Project Appraisal, Non-Technical Summary Report Submitted to Department for Environment, Food and Rural Affairs, London**

This document provides practical guidelines for valuing environmental impacts via an approach known as 'value transfer'. It augments guidance provided by Defra in An introductory guide to valuing ecosystem services, which seeks to ensure that the true value of ecosystems and the services they provide are taken into account in policy decision-making. Assessment of the impacts of policies

should be consistent and transparent. Cross-Whitehall guidance in the UK HM Treasury Green Book requires that all new policies, programmes and projects be subject to a comprehensive but proportionate appraisal. This is to ensure that interventions enacted by public sector bodies are in the best interest of society overall and provide a full analysis of potential outcomes. A key component of appraisal is the comparison of the total benefits of a proposal to the full costs incurred by Government and society. Here the Green Book requires that all relevant costs and benefits be valued in monetary terms and the net benefit or cost of the proposal be calculated. Costs and benefits of proposals, typically, are estimated using market prices. Wider social and environmental costs and benefits for which market prices are not available, requires the use of economic valuation methods (which are also known as ‘non-market valuation’ methods). There is a substantial body of evidence on the value of environmental costs and benefits. Value transfer (which is also known as ‘benefits transfer’) allows existing economic valuation evidence to be applied in a new context, such as estimating the monetary value of environmental benefits associated with a proposed policy. However, ‘quick’ and ‘lower cost’ do not mean that value transfer is easy. Judgements are required as to when value transfer can be used and the level of effort that is appropriate. Overall, the more accurate the results need to be, the more effort is required. These guidelines emphasise transparency and the appropriate use of sensitivity analysis to address concerns of accuracy. The role for value transfer promoted by the guidelines is to make the best use of available economic value and other evidence, given the time and resource constraints that limit the scope of the analysis. The core component of these guidelines is a set of ‘best practice’ steps for value transfer. These guidelines identify the basic steps in valuing environmental impacts.

**Eftec (2010) Flood and Coastal Erosion Risk Management: Economic Valuation of Environmental Effects, Handbook for the Environment Agency for England and Wales, Eftec, London**

This guidance is intended for practitioners in the EA, Internal Drainage Boards, Local Authorities and contracted consultants responsible for the appraisal of FCERM schemes. It focuses specifically on the economic (monetary) value of environmental effects associated with FCERM schemes and is intended to augment the EA FCERM-AG and the Flood Hazard Research Centre (FHRC) „Multi-coloured Manual“ and „Handbook“ (Penning-Rowsell et al., 2013). Documentation produced under the title “Economic Valuation of Environmental Effects” includes this summary, a Handbook (Parts 1-3) for practitioners with associated annexes featuring case studies and a review of economic value evidence (Part 4) , and a more detailed Technical Report (Part 5) for the interested reader. Originally completed in August 2007, this material has been revised and updated in March 2010 to reflect recent developments in the valuation of the natural environment and ecosystem services. Accessed at <http://webarchive.nationalarchives.gov.uk/20140328084622/http://cdn.environment-agency.gov.uk/geho0310bsfh-e-e.pdf> on 29.10.124

## **International and case study focus**

**Brinkhuis-Jak, M., Holterman, M., Kok, S. Jonkman, S.N. (2004) Cost benefit analysis and flood damage mitigation in the Netherlands, Heron 49(1): 95-11**

The aim of this paper is to investigate the application of cost benefit analysis methods in decision-making on a desired flood protection strategy in the Netherlands. After a discussion of history and developments in flood protection in the Netherlands the method of cost benefit analysis is presented as a useful instrument in decision-making. In the second part of the paper the economic analysis of flood protection strategies is firstly approached from a theoretical point of view. Subsequently the economic analyses carried out in practice are described for two more practical cases, the study on “emergency retention areas” and the dike reinforcement program in the river

system. The paper shows that an economic analysis, when correctly applied, can provide important rational information in the decision-making process.

**Brody, S.D., Zahran, S., Highfield, W.E., Grover, H. and Vedlitz, A. (2008) Identifying the impact of the built environment on flood damage in Texas, Disaster, Vol 32, (1),1-18.**

Floods continue to pose the greatest threat to the property and safety of human communities among all natural hazards in the United States. This study examines the relationship between the built environment and flood impacts in Texas, which consistently sustains the most damage from flooding of any other state in the country. Specifically, we calculate property damage resulting from 423 flood events between 1997 and 2001 at the county level. We identify the effect of several built environment measures, including wetland alteration, impervious surface, and dams on reported property damage while controlling for biophysical and socio-economic characteristics. Statistical results suggest that naturally occurring wetlands play a particularly important role in mitigating flood damage. These findings provide guidance to planners and flood managers on how to alleviate most effectively the costly impacts of floods at the community level.

**Chadburn, O., Ocharan, J., Kenst, K, and Venton, C. (2010) Cost benefit analysis for community based climate and disaster risk management: synthesis report, August, consulted at [http://www.preventionweb.net/files/14851\\_FinalCBASynthesisReportAugust2010.pdf](http://www.preventionweb.net/files/14851_FinalCBASynthesisReportAugust2010.pdf) on 28/07/14**

This is a comprehensive evaluation of the strengths and limitations of cost benefit analysis contributed to by a range of experts from organisations which include Oxfam America, Tearfund, British Red Cross, International Federation of Red Cross and Red Crescent Societies and the Mercy Fund. The synthesis is focused on the application of CBA to community-based initiatives for disaster and climate risk management. Initiatives may be structural or non-structural, hard or soft, but are part of a community driven process for disaster reduction management and are very much bottom-up.

A variety of case studies looking at the impacts, costs and benefits of Community Based Disaster Risk Management (CBDRM) and Climate Change Adaptation (CCA) have been undertaken over recent years. Further, Non-Governmental Organisations (NGOs) and others are beginning to look more closely at the applicability of CBA as a tool to sit alongside existing processes, such as Vulnerability and Capacity Assessment (VCA) and Monitoring and Evaluation Frameworks (M&E), to help project partners examine in greater detail the quantifiable, as well as the more qualitative impacts of their programming.

The aim of this report is to present a synthesis that takes stock of the significant efforts on Cost Benefit Analysis of community based disaster reduction management, reflecting not only on findings, methodological approaches and lessons learned, but also addressing the implications for where and when CBA may be usefully applied at a community level, and pointing to gaps and methodological constraints that could usefully be addressed going forward. A variety of case studies from countries including India, Pakistan, Nepal and Samoa are drawn upon.

The synthesis concludes that there is broad consensus that the CBA process can be useful at a community level but that there is also no doubt that it has its limitations. Among the key issues identified are: (a) the valuation of non-monetary benefits is a significant constraint in applying CBA; (b) a clear understanding of risk is inherent to conducting CBA, and yet the probability of hazard occurrence, and associated impacts, can be very difficult to estimate, particularly when the analysis is taking place at a community level; (c) climate change adds another level of complexity to

probabilistic risk modelling; (d) the distribution of benefits from risk reduction is very important from a development perspective, with many projects focusing on the most vulnerable, including women, children, the elderly and disabled: CBA does not traditionally account for distributional impacts; and (e) for backward looking CBAs, the timing of the study with respect to implementation of project interventions can significantly impact on methodology and results.

**Hinkel, J., Lincke, D., Vafeidis, A.T., Perrette, M., Nicholls, R.J., Tol, R.S., Marzeion, B., Fettweis, X., Ionescu, C. and Levermann, A. (2014) Coastal flood damage and adaptation costs under 21st century sea-level rise, *Proceedings National Academy of Science, USA*, 111(9), 3292-7. doi: 10.1073/pnas.1222469111. Epub.**

Coastal flood damage and adaptation costs under 21st century sea-level rise are assessed on a global scale taking into account a wide range of uncertainties in continental topography data, population data, protection strategies, socioeconomic development and sea-level rise. Uncertainty in global mean and regional sea level was derived from four different climate models from the Coupled Model Intercomparison Project Phase 5, each combined with three land-ice scenarios based on the published range of contributions from ice sheets and glaciers. Without adaptation, 0.2-4.6% of global population is expected to be flooded annually in 2100 under 25-123 cm of global mean sea-level rise, with expected annual losses of 0.3-9.3% of global gross domestic product. Damages of this magnitude are very unlikely to be tolerated by society and adaptation will be widespread. The global costs of protecting the coast with dikes are significant with annual investment and maintenance costs of US\$ 12-71 billion in 2100, but much smaller than the global cost of avoided damages even without accounting for indirect costs of damage to regional production supply. Flood damages by the end of this century are much more sensitive to the applied protection strategy than to variations in climate and socioeconomic scenarios as well as in physical data sources (topography and climate model). Our results emphasize the central role of long-term coastal adaptation strategies. These should also take into account that protecting large parts of the developed coast increases the risk of catastrophic consequences in the case of defense failure.

**Islam, K.M.N. (2000) Micro and macro level impacts of floods in Bangladesh, In Parker, D.J. (ed) *Floods, Vol 1, Chapter 9, 156-171, Routledge, London***

The author reviews unit-loss and linkage effect models for assessing flood losses, and develops an economic assessment approach which utilises both. The principal focus is upon inter-sector linkages and flood impacts in the Bangladesh economy. At the micro-level the author presents household flood damage estimates for five different Bangladeshi house types in three types of floods – fluvial (river), flash (pluvial/fluvial) and tidal floods. These damage data are complemented by similar data for industrial properties breaking down damage potential into structure, machinery, stock and primary indirect damages. At the macro-level the author assesses production deviations in agricultural and manufacturing industry from the trend in order to try to identify flood impacts.

**Islam, K.M.N. (2004) *Assessment Methods and Standard Loss Database for Bangladesh, Flood Loss Potentials in Non-agricultural sectors, Palok Publishers, Dhaka, Bangladesh***

This book is the outcome of the author's research undertaken at the Flood Hazard Research Centre, UK. The research has two main components. The first set out to investigate a number of questions. One of the key questions was whether flood loss, assessment methods developed in the advanced countries can be applied in a developing country such as Bangladesh. Another broad question concerned whether the non-agricultural impacts of flooding are important in Bangladesh, given that it continues as an agricultural economy. In particular the study investigates the linkage effects of

flooding in the national economy and seeks to identify how important they are. The second component aimed to reveal, conceptualise and categorise various non-agricultural impacts of floods. Different impacts caused by different types of floods (i.e. flash floods, river floods and tidal floods) are examined and thereby a sound knowledge base of the main impacts at the micro and macro scales is constructed. Different mitigation measures are also examined. The author concludes that, with some modifications, the advanced countries impact assessment methods can be applied in a developing country such as Bangladesh. One of the main contributions of the study is the construction of appropriate potential loss data sets from field level surveys and estimates of actual damages. The research assessed the linkages effects of flooding through construction of output multipliers estimated from a national Input-Output table. Unlike in many countries (e.g. the USA) the linkage effects of flooding in industries in Bangladesh appear to be quite high especially in the cotton and textile industries.

**Islam, K.M.N. (2006) Impacts of Flood in Urban Bangladesh. Micro and Macro Level Analysis, A H Development Publishing House, Dhaka, Bangladesh**

This book is mainly intended for use by water and regional authorities in order to facilitate the assessment of flood losses at both the micro and macro level in Bangladesh. Knowledge of potential flood damages is expected to contribute towards a rational allocation of resources in a flood-ravaged country. The research on which this book is based investigated households and business and industrial enterprises in three urban areas in Bangladesh. The three urban areas represented different types of flood: major river flood (Tangail), flash flood (Bahubal, Habiganj) and tidal flood (Khatunganj, Chittagoing). Different household impacts are also examined according to different socio-economic groupings. The study focused upon the 1988 flood in Tangail, the 1993 flash flood in Bahubal and the 1991 tidal surge in Khatunganj). Per household residential flood damages per five different house types are presented for each case study area. Linkage impacts in the economy are also assessed.

**Jones, E., Sumner, K. and Gochfeld, M. (2013) Residential Flood Damage After Hurricane Floyd, Mold, Household Remediation, and Respiratory Health, Remediation Journal, Vol 24, Issue 1, 10 10**

We conducted a retrospective, cross-sectional study of flooding, mold exposure, remediation, and respiratory symptom prevalence on a random sample of respondents from Bound Brook, New Jersey, a community that received extensive flood damage from Hurricane Floyd in September 1999. Over 3,000 homes were impacted, some with water damage to the second floor. Many required condemnation. In 2001 to 2002 we conducted a randomized telephone survey of 29 families still living in flood-damaged and repaired homes and 18 families who had not experienced flood damage from Floyd. Flood status was the last question on the interview, leaving the interviewer effectively blinded as to status. Flood damage was a strong predictor of mold growth ( $p < 0.001$ ), and there was a strong association between flooding and physician-confirmed respiratory symptoms in the aftermath of the flood (28 of 29 cases vs. 10 of 18 referents;  $p < 0.001$ ). There was also an association between flood status and continued symptom prevalence in the month prior to the interviews (22 of 29 cases vs. 6 of 18 referents;  $p < 0.01$ ). Most flooded homes required removal and replacement of various building materials, which was usually delayed for days or weeks pending re-occupancy. Many occupants participated in the renovation without adequate personal protection. Persons assisting with clean up work were more likely to report five or more symptoms ( $p < 0.002$ ). Smokers with mold damage reported five or more symptoms in the 30 days before the interviews, more frequently than nonsmokers with mold damage. These results are consistent with previous reports of flooding, mold, and illness, but demonstrate that self-remediation of mold (particularly with lack of training and personal protective equipment) and smoking are significant risk

factors for mold-related symptoms. Exposure during clean up of moldy materials was a significant contributor to symptoms, and recommendations should include more reliance on professionals and enhanced personal protective equipment.

**Khan, D.M., Rahman, S.M.M., Haque, A.K.E., Chen, A.S., Hammond, M.J., Djordjevic, S. and Butler, D. (2013) Flood damage assessment for Dhaka City, Bangladesh, In Klijn, F. and Schreckendiek, T. (eds), Comprehensive Flood Risk Management, 537-545, Taylor and Francis Group, London, ISBN 978-0-415-62144-1**

Flood damage assessment is a key component in the development of city flood risk management strategies. A flood damage assessment model is being developed by combining flood hazard information (depth, extent, velocity, duration, etc.) with geographic information (land use/cover, buildings, infrastructure, etc.), social-economic data and population demographics to estimate urban flood impacts. In this paper, Dhaka city is adopted to demonstrate the approach for damage modeling. Analysis shows that coarse resolution modeling in such a densely developed urban area can lead to either over- or underestimation of the flood damage, depending on the thresholds to distinguish building and non-building cells in modeling. Increased accuracy can be achieved by fine resolution modeling but this would lead to large data sets that require long computational times. The paper demonstrates some key issues for damage assessment using advanced technology for a City like Dhaka.

**Kazama, S., Sato, A., and Kawagoe, S. (2009) Evaluating the cost of flood damage based on changes in extreme rainfall in Japan, Sustainability Science, Vol 4, (1), 61-69**

We estimated the cost of flood damage using numerical simulations based on digital map data and the flood control economy investigation manual submitted by the Ministry of Land, Infrastructure... , Transportation, and Tourism in Japan. The simulation was carried out using a flood model incorporating representative precipitation data for all of Japan. The economic predictions, which estimate flood... damage caused by extreme rainfall for the return periods of 5, 10, 30 50, and 100 years, are as follows: (1) the cost of flood damage increases nearly linearly with increases in extreme precipitation; (2... and assuming that flood control infrastructures will be completed within the 50-year return period and will be able to protect from flooding with a 50-year return period; (4) urban and rural areas are predicted to suffer high and low costs of damage, respectively. These findings will help to derive measures to enhance flood protection resulting from climate change. Assuming that flood protection is completed for a 50-year return period of extreme rainfall, the benefit of flood protection for a 100-year return period of rainfall is estimated to be 210 billion.

**Kowalewski, I. and Ujeyl, G. (2013) Estimating direct and indirect damages from storm surges: The case of Wilhelmsburg/Hamburg. In Klijn, F. and Schreckendiek, T. (eds), Comprehensive Flood Risk Management, 568-584, Taylor and Francis Group, London, ISBN 978-0-415-62144-1**

This paper estimates the economic costs from a storm surge scenario in the city of Hamburg. It combines hydrodynamic simulations and damage models, which are used for the assessment of direct damages to residential and commercial buildings and equipment, and an economic model accounting for the indirect impacts due to the interruption of production processes. Thus, a large part of total economic costs from flooding are captured in the presented result. The approach is constitutes a helpful tool to assess the potential damages from storm flood scenarios on the city scale and, thus, the effectiveness of possible protection measures.

**Middelmann-Fernandes, M.H. (2010) Flood damage estimation beyond stage–damage functions: an Australian example, Journal of Flood Risk Management, Vol 3, Issue 1, 88–96**

A number of factors influence the direct consequence of flooding. The most important are depth of inundation, velocity, duration of inundation and water quality and the interaction of these factors with human society. Although computer modelling techniques exist that can provide an estimate of these variables, this information is seldom used to estimate the impact of flooding on a community. This work describes the first step to improve this situation using data collected for the Swan River system in Perth, Western Australia. Here, it is shown that residential losses are underestimated when stage–damage functions or the velocity–stage–damage functions are used in isolation. This is because the functions are either limited to assessing partial damage or structural failure resulting from the movement of a house from its foundations. This demonstrates the need to use a combination of techniques to assess the direct cost of flooding.

**Miller, A., Jonkman, S.N. and van Ledden, M. (2013) Risk to life due to flooding in post-Katrina New Orleans, In Klijn, F. and Schweckendiek, T. (eds), Comprehensive Flood Risk Management, 547-556, Taylor and Francis Group, London, ISBN 978-0-415-62144-1**

After the catastrophic flooding of New Orleans due to hurricane Katrina in the year 2005, the city's hurricane protection system has been improved to provide protection against storms with at least a 100 year return period. The aim of this article is to investigate the risk to life in the post-Katrina situation for the New Orleans metro bowl. In a risk-based approach the probabilities and consequences of various flood scenarios have been analysed to estimate the risk to life. A two-dimensional hydrodynamic model has been used to simulate flood characteristics. Results indicate that - depending on the flood scenario - the estimated loss of life in case of flooding ranges from about 100 to nearly 500. The highest life loss value is found for breaching of the river levees. Probability and consequence estimates are combined to evaluate the individual risk and societal risk for New Orleans. When compared to risks of other large scale engineering systems (e.g. other flood prone areas, dams and the nuclear sector) and acceptable risk criteria found in literature, the evaluated risk exceeds acceptable risk levels. Thus despite major improvements to the flood protection system, the flood risk of post-Katrina New Orleans is expected to be significant. Effects of risk reduction strategies on the risk level are investigated to assist in providing bases for decision making. Results indicate the necessity of further discussion regarding the management and reduction of the city's risk to flooding.

**Li, Z., Wu, L., Yu, J., Wang, Z. and Liu, C. (2010) GIS-based Rapid Loss Assessment on Flood Disaster: June 21 Flood of Fuhe Basin, Information Science and Engineering (ICISE), 2010 2nd International Conference, 6642 – 6645, 4-6 Dec., IEEE, Hangzhou, China. DOI: 10.1109/ICISE.2010.5691248**

In consideration of the serious loss of floods in our country, this paper established the method for assessing the water depth and duration of flood referring to the vulnerability curve of hazard bearing body, based on the concept of rapid flood loss assessment and from the perspective of regional disaster system theory. A model of rapid assessment on the loss of hazard bearing body was set up. The method for assessment of induced factor was established after analyzing the data acquirability. The vulnerability curves of hazard bearing bodies were summarized, and then models for rapid assessing the hazard bearing bodies were built up using the overlay method of GIS. Taking the "6•21" flood of Fuhe basin as an example, this paper assessed the loss of crops, the damage of buildings and the affected population. The assessment results are basically in accordance with the reported data from investigation.

**Liu, R.1. and Liu, N. (2002) Flood area and damage estimation in Zhejiang, China, Journal of Environmental Management, Vol 66, (1), 1-8**

A GIS-based method to estimate flood area and damage is presented in this paper, which is oriented to developing countries like China, where labour is readily available for GIS data collecting, and tools such as, HEC-GeoRAS might not be readily available. At present local authorities in developing countries are often not predisposed to pay for commercial GIS platforms. To calculate flood area, two cases, non-source flood and source flood, are distinguished and a seed-spread algorithm suitable for source-flooding is described. The flood damage estimation is calculated in raster format by overlaying the flood area range with thematic maps and relating this to other socioeconomic data. Several measures used to improve the geometric accuracy and computing efficiency are presented. The management issues related to the application of this method, including the cost-effectiveness of approximate method in practice and supplementing two technical lines (self-programming and adopting commercial GIS software) to each other, are also discussed. The applications show that this approach has practical significance to flood fighting and control in developing countries like China.

**Nascimento, N., Machado, M., Baptista, M. and De Paula E Silva, A. (2007) The assessment of damage caused by floods in the Brazilian context, Urban Water Journal, Vol 4, 3, 195-210**

The present paper describes theoretical aspects and the main results on the development of a methodology for the global evaluation of direct damage caused by floods. This methodology is based on the use of standard flood damage curves versus depth of inundation on dwelling, commerce and service sectors. The research was developed based on field surveys in the city of Itajubá, located in the valley of the Sapucaí River, in Minas Gerais state in the southeast region of Brazil. In January 2000, this city suffered severe floods where more of 70% of the urban area was affected; with depths of inundation higher than 3 m in certain areas. The empirical data were obtained through questionnaires applied in the ravaged area in 2002. The questionnaires allowed the characterization of the dwellings and their content, as well as the different categories on commercial and service activities. The generic curves obtained from the data in the survey were used at the same site to evaluate the amount of potential flood damage in relation to different hydrologic risks.

**Parker, D. J., Islam, N. K. M. and Chan, N. W. (1997) Reducing vulnerability following flood disasters: issues and practices, in Awotona, A (Ed) Reconstruction after disaster: issues and practices, Chapter 3, Ashgate, Vermont, USA, 23-44, ISBN 1 85972 551 1**

This chapter examines flood impacts within the context of reconstruction in the developing world. Primary, secondary and multiplier impacts examined together with the factors that breed different types of vulnerability to flood hazards. Urban flood damage values for five different house types commonly found in Bangladesh are provided for river floods, flash floods and tidal floods. Building materials have a key effect on flood damage potential. The chapter goes on to look at the potential in benefits of residential flood proofing in the New Territories of Hong Kong.

**Parker, D. and Thompson, P. (2000) Floods in Africa: Vulnerability, Impacts and Mitigation. In Parker, D. (ed.) Floods, 188-203, London, Routledge**

This chapter provides a general overview of the kinds of flood impacts, and thus potential benefits of flood alleviation, in the African continent. Anyone wishing to draw up a list of potential benefits for further investigation is likely to find this chapter generally useful. The chapter examines the causes and types of floods and associated hazards in the African continent as well as the important role of floodplains, identifying the major floodplains. The vulnerable state of African societies is a major contributory factor to the hazard as is environmental degradation. The recorded impacts of a range of floods between 1976 and 1990 are tabulated. Floods frequently cause homelessness and

infrastructure disruption as well as food shortages. They also have major impacts upon human health. The acute effects of floods, including mortality are discussed as well as the long term effects and secondary exposures and effects. Mitigation and preparedness measures are explored focusing upon reducing infrastructure vulnerability, compensation for flood-induced food shortages and ways of reducing health impacts.

**Penning-Rowsell, E.C, Haigh, N., Lavery, S. and McFadden, L. (2013) A threatened world city: the benefits of protecting London from the sea, *Natural Hazards*, 66, 1383–1404, DOI 10.1007/s11069-011-0075-3**

This paper describes the options appraisal undertaken in the UK within the major TE2100 project to investigate the future of protecting London from flooding from the sea. An economic analysis, within a Benefit-Cost framework complemented by Multi-Criteria Analysis, shows that improving the existing flood defences and, in 2070, constructing a new Thames Barrier downstream of the existing one are the “front runner” options for addressing the increase in flood risk that is anticipated in the future. Both sensitivity and scenario analysis have little effect on option choice. Inevitably uncertainties remain, however, when looking so far ahead but it is clear that continuing to protect this area from the sea is highly cost-beneficial. Also the very high standard of protection now, and the robustness of the existing flood defences, mean that major new interventions will not be required from some time (i.e. until c. 2070). There is therefore time to monitor the situation, carefully plan measures to maintain and enhance the existing defences, and to seek to restrain the growth of risk in the estuary and in London through carefully-designed and implemented resilience-building flood plain management measures. Rather than having to rush to new engineering works, because what is needed has not been anticipated but being forced to respond hastily to a “crisis” situation, the adaptive approach that is now possible is a key legacy of the TE2100 project.

**Shabman, L., Stephenson, K., Thunberg, E. and Dietz, B. (1998) Comparing benefit estimation techniques: residential flood hazard reduction benefits in Roanoke, Virginia March, IWR Report 98-R-2, for U.S. Army Corps of Engineers, Institute for Water Resources, Alexandria, VA**

The purpose of this research project was to evaluate the differences and potential strengths and weaknesses of different methods for evaluating consumers’ willingness to pay for a public good, i.e., a flood hazard reduction project. Three methods are compared and contrasted both collectively and against the theory of revealed consumer preference. These are the Property Damages Avoided (PDA) approach, Hedonic Price Method (Land Price Analysis), and the **Contingent Value Method** (CVM). The report consists of nine sections, a bibliography, and two appendices. The sections provide historical and other situational background information on the location of the proposed project, an overview of the revealed preference approach and P&G guidance for evaluating willingness to pay, a detailed description of each method and its application in the study, and the resulting findings. The first appendix displays the contingent valuation survey forms and procedures used, while the second appendix presents the questions asked to subject consumers of the study concerning a bond referendum to pay for the proposed project.

**Suriya, S., Mudgal, B.V. and Nelliya, P. (2012) Flood damage assessment of an urban area in Chennai, India, part I: methodology, *Natural Hazards*, Vol.62 (2), 149-158**

This paper is Part I of a two-part series in which the objectives and methodology are discussed in Part 1 and results are discussed in Part 2. Based on the objectives and methodology developed for the study, a comprehensive flood management strategy is evaluated. This paper focuses on flood damage assessment of an urban area in Chennai, India and explores the economic loss through social investigation in Velachery, a part of urban Chennai.

**Wagemaker, J., Leenders, J. and Huizinga, J. (undated) Economic valuation of flood damage for decision makers in the Netherlands and the Lower Mekong river basin**

Economic activities in flood-prone areas are increasing around the world. At the same time we face changing weather conditions and a rising sea level as a result of climatic change. If no measures are carried out both probability and impact of floods will increase severely. In the Netherlands flood hazard and flood damage are combined in a risk-approach using a cost-benefit analysis for proposed measures. In this approach, risk is defined as the probability of flooding and impact of flooding. Could this approach also be applied in the Lower Mekong river basin? As far as flood damage is concerned one can imagine the flood damage for instance in Chiang Rai in Thailand has other characteristics than a given polder in the Netherlands. One can also imagine that decision-makers in the Lower Mekong would make different choices about how to evaluate flood damage compared with their counterparts in the Netherlands. This paper presents some considerations on how the Dutch damage assessment tool 'Hoogwater Informatie System – Schade en Slachtoffermodule (HIS-SSM) and its underlying economic evaluation model may be adjusted to serve the preferences of decision makers in the Lower Mekong river system. It first discusses various economic valuation techniques that are available to determine flood damage and the role of the decision maker Next the backgrounds on risk analysis and cost-benefit analysis in the Netherlands are described and opportunities and limitations of such an approach being used in the Lower Mekong are discussed. Finally, reference is made of a pilot model where the applicability of the Dutch approach is assessed. [http://www.hkv.nl/site/hkv/upload/publication/Economic\\_Valuation\\_Flood\\_Damage\\_WEBSITE\\_JW\\_JL\\_JH.pdf](http://www.hkv.nl/site/hkv/upload/publication/Economic_Valuation_Flood_Damage_WEBSITE_JW_JL_JH.pdf) accessed on 28.10.14

## **Multi-criteria analysis**

### **General overview and theory**

**Belton V. and Stewart, T.J. (2002) Multiple Criteria Decision Analysis: An Integrated Approach, Kluwer Academic Publishers, Boston**

The field of multiple criteria decision analysis (MCDA), also termed multiple criteria decision aid, or multiple criteria decision making (MCDM), has developed rapidly over the past quarter century and in the process a number of divergent schools of thought have emerged. This can make it difficult for a new entrant into the field to develop a comprehensive appreciation of the range of tools and approaches which are available to assist decision makers in dealing with the ever-present difficulties of seeking compromise or consensus between conflicting interests and goals, i.e. the "multiple criteria". The diversity of philosophies and models makes it equally difficult for potential users of MCDA, i.e. management scientists and/or decision makers facing problems involving conflicting goals, to gain a clear understanding of which methodologies are appropriate to their particular context. Our intention in writing this book has been to provide a comprehensive yet widely accessible overview of the main streams of thought within MCDA. We aim to provide readers with sufficient awareness of the underlying philosophies and theories, understanding of the practical details of the methods, and insight into practice to enable them to implement any of the approaches in an informed manner. As the title of the book indicates, our emphasis is on developing an integrated view of MCDA, which we perceive to incorporate both integration of different schools of

thought within MCDA, and integration of MCDA with broader management theory, science and practice.

**Department for Communities and Local Government (1999) Multi-criteria analysis: a manual, DCLG, London**

Since 2000 it has become more widely recognised in government that, where quantities can be valued in monetary terms, MCA is not a substitute for cost-benefit analysis, but it may be a complement; and that MCA techniques are diverse in both the kinds of problem that they address (for example prioritisation of programmes as well as single option selection) and in the techniques that they employ, ranging from decision conferencing to less resource intensive processes. This manual provides guidance for Government officials and other practitioners on how to undertake and make the best use of multi-criteria analysis (MCA) for the appraisal of options for policy and other decisions, including but not limited to those having implications for the environment. It covers a range of techniques which can be of practical value to public decision makers and are increasingly being used in the UK and in other countries. They are described in this manual as multi-criteria analysis (MCA) techniques. The manual is about techniques which do not necessarily rely on monetary valuations. It therefore complements guidance on those techniques which primarily use monetary valuations, namely financial analysis, cost effectiveness analysis (CEA, and cost-benefit analysis (CBA). These monetary techniques have been extensively used in UK government circles, and are the subject of a number of guides and manuals. One source of confusion to those new to the field is the variety of different techniques, often with rather similar sounding titles, that appear to be available, such as multi-criteria decision analysis, multi-attribute utility theory, the analytic hierarchy process, and fuzzy set theory. The manual outlines the relationships between the different techniques and indicates the ones which can yield the most fruitful applications, in contrast to those which may be of theoretical interest but little practical value. Chapter 6 shows how to undertake a full multi-criteria decision analysis by involving scoring of each option on each criterion, and then combining the scores by means of a system of weights to yield an overall ranking for each option. Chapter 7 provides some case studies.

**Department for Environment, Food and Rural Affairs and Environment Agency (2004) Evaluating a multi-criteria analysis (MCA) methodology for application to flood management and coastal defence appraisals Case studies report, Joint Defra/EA Flood and Coastal Erosion Risk Management R&D Programme R&D Project Record FD2013/PR1, Risk and Policy Analysts Ltd (RPA), Defra, London**

This case study report sets out the work undertaken to develop the MCA-based methodology, its application to two sets of case studies and the implications of the research findings for the production of guidelines for the application of the methodology. The intention of the case studies was to test the methodology to answer two different questions: (a) does the methodology provide information in a format that can be used to inform a range of different decisions? and (b) does the methodology have added value over current approaches, i.e. would it help ensure that decisions are more robust and sustainable and/or can it help to take the views of all stakeholders into account such that conflicts that have arisen can be addressed specifically in the assessment? This report constitutes one of the two milestones identified for the second phase of the MCA project. A second report 'guidelines for the implementation of the MCA-based methodology for flood defence and coastal management' runs in parallel and complements this case study report.

**Flood Hazard Research Centre/Risk and Policy Analysis Ltd (2002) Multi-Criteria Analysis in the Context of Flood and Coastal Defence – Scoping Report, Report prepared for the Environment Agency, Bristol**

Cost-benefit analysis (CBA) for flood management and coastal defence is well established but there is growing concern that it fails to take full account of social and environmental factors. One method of including these impacts is by using a MCA approach. A scoping study was therefore undertaken in 2001/02 to look at the existing appraisal and decision framework and whether the use of a MCA approach would be appropriate and acceptable. The conclusion from this study was that flood management and coastal defence appraisal needed the 'best of both worlds'. Any method should retain the rigour of CBA, particularly in regard to demonstrating that the chosen option is a good use of resources, but should also provide a framework within which social and environmental issues can be more explicitly included in the decision-making process.

**Huanga, I., Keislerb, J. and Linkov, I. (2011) Multi-criteria decision analysis in environmental sciences: Ten years of applications and trends, *Science of The Total Environment*, Vol 409, Issue 19, 3578–3594**

Decision-making in environmental projects requires consideration of trade-offs between socio-political, environmental, and economic impacts and is often complicated by various stakeholder views. Multi-criteria decision analysis (MCDA) emerged as a formal methodology to face available technical information and stakeholder values to support decisions in many fields and can be especially valuable in environmental decision making. This study reviews environmental applications of MCDA. Over 300 papers published between 2000 and 2009 reporting MCDA applications in the environmental field were identified through a series of queries in the Web of Science database. The papers were classified by their environmental application area, decision or intervention type. In addition, the papers were also classified by the MCDA methods used in the analysis (analytic hierarchy process, multi-attribute utility theory, and outranking). The results suggest that there is a significant growth in environmental applications of MCDA over the last decade across all environmental application areas. Multiple MCDA tools have been successfully used for environmental applications. Even though the use of the specific methods and tools varies in different application areas and geographic regions, our review of a few papers where several methods were used in parallel with the same problem indicates that recommended course of action does not vary significantly with the method applied.

**Köksalan, M., Wallenius, J. and Zionts, S. (2013) An Early History of Multiple Criteria Decision Making, *Journal of Multi-Criteria Decision Analysis*, Vol 20, Issue 1-2, pages 87–94, January-April Water management (ISSN 1741-7589) Vol., 161, No.5 261-266**

A useful discussion of the origins and early history of multi-criteria decision analysis and its disciplinary roots.

**Montibeller, G. (2005) From (and To) a New Generation of Multi-Criteria Decision Analysts: An Introduction to the Field and a Personal View on its Future, in Meyer E (Ed.) (2005) Keynote Papers – YOR 14 Conference, University of Bath, 4-6 April, Birmingham: The Operational Research Society (ISBN 0 903440 33 4) accessed at [http://personal.lse.ac.uk/MONTIBEL/YOR14\\_Decision%20Analysis.pdf](http://personal.lse.ac.uk/MONTIBEL/YOR14_Decision%20Analysis.pdf) on 31.10.14**

An interesting article which informs about the development of Multi-Criteria Decision Analysis (MCDA) and which should be of interest to those considering applying it to flood risk management. MCDA is now considered to be mature, with several well-developed methodologies, a growing number of real world interventions and a strong society that joins together researchers and practitioners all over the world. We believe that a new generation of multi-criteria decision analysts is emerging – interested in doing research and/or employing MCDA methodologies into practice –

and also hope that, somehow, we could engage even more people in forming this new generation. It is within this scene that the paper was conceptualised. It has a dual aim of i) introducing the field to “young” researchers and practitioners, which may be interested in further developing MCDA methodologies, applying them into practice, or combining them with other decision methods; and ii) reflecting on potential further developments of the field that may be pursued by this new generation.

**Triantaphyllou, E. (2000) Multi-criteria decision making methods: a comparative study, Springer, US, ISBN 0792366077, 9780792366072**

Multi-Criteria Decision Making (MCDM) has been one of the fastest growing problem areas in many disciplines. The central problem is how to evaluate a set of alternatives in terms of a number of criteria. Although this problem is very relevant in practice, there are few methods available and their quality is hard to determine. Thus, the question ‘Which is the best method for a given problem?’ has become one of the most important and challenging ones. This is exactly what this book has as its focus and why it is important. The author extensively compares, both theoretically and empirically, real-life MCDM issues and makes the reader aware of quite a number of surprising ‘abnormalities’ with some of these methods. What makes this book so valuable and different is that even though the analyses are rigorous, the results can be understood even by the non-specialist. The audience for this book includes researchers, practitioners, and students; and it can be used as a textbook for senior undergraduate or graduate courses in business and engineering.

## **Flood impacts and coastal defence**

**Ball, T., Black, A., Ellis, R., Hemsley, L., Hollebrandse, F., Lardet, P. and Wicks, J. (2012) A new methodology to assess the benefits of flood warning, Journal of Flood Risk Management, Vol 5, Issue 3, 188–202**

A new assessment methodology is presented for the benefits of flood warning that applies both tangible and intangible benefits from warning generation and dissemination using a multi-criteria analysis (MCA). The resulting decision support tool allows benefits to be scored transparently, reinforced by Geographical Information System (GIS) procedures. A wide range of benefits are scored including: protection of key infrastructure, avoided social impacts, timely operation of flood defences and avoided risks to life from the flood hazard. Pilot testing on some 22 sites at a variety of scales (catchments and flood warning areas) showed that the method works effectively when making ‘like for like’ comparisons, considering a wholly new system for large catchments, or upgrades to warning and dissemination systems in sub-catchment flood warning areas. The methodology promotes consultation and data interchange between the warning organisation and end-users in order to prioritise particular areas of need for new or improved systems.

**Hall, J. and Solomatineb, D. (2008) A framework for uncertainty analysis in flood risk management decisions, International Journal of River Basin Management, Vol 6, Issue 2, accessed at <http://www.tandfonline.com/doi/abs/10.1080/15715124.2008.9635339#.VFPbMvmsXtU> on 31.10.14**

Modern flood risk management involves responding sustainably to flood risk with portfolios of structural and non-structural measures. Under these circumstances of multi-attribute choice between portfolios of options, the motivation for uncertainty analysis becomes more compelling than ever. Uncertainty analysis is required in order to understand the implications for decision makers of limited data, model uncertainties, changes in the flooding system over the long term, incommensurate scales of appraisal and potentially conflicting decision objectives. In recognition of

the importance of uncertainty analysis as an integral aspect of sustainable flood risk management, a new framework for uncertainty analysis within flood risk management decisions has been established. The proliferation of methods for uncertainty analysis can be placed within the coherent framework. As well as estimating the amount of uncertainty associated with key decision variables, the framework supports the decision making process by identifying the most influential sources of uncertainty, and the implications of uncertainty for the preference ordering between options. The challenges posed by severe uncertainty about the potential for long term changes in the flooding system are discussed and robustness analysis is advocated in response to these uncertainties.

**Jonkman, S. N., Jongejan, R. and Maaskant, B. (2011) The use of individual and societal risk criteria within the Dutch flood safety policy - nationwide estimates of societal risk and policy applications, Risk Analysis, Vol.31 (2), 282-300**

The Dutch government is in the process of revising its flood safety policy. The current safety standards for flood defences in the Netherlands are largely based on the outcomes of cost-benefit analyses. Loss of life has not been considered separately in the choice for current standards. This article presents the results of a research project that evaluated the potential roles of two risk metrics, individual and societal risk, to support decision making about new flood safety standards. These risk metrics are already used in the Dutch major hazards policy for the evaluation of risks to the public. Individual risk concerns the annual probability of death of a person. Societal risk concerns the probability of an event with many fatalities. Technical aspects of the use of individual and societal risk metrics in flood risk assessments as well as policy implications are discussed. Preliminary estimates of nationwide levels of societal risk are presented. Societal risk levels appear relatively high in the south western part of the country where densely populated dike rings are threatened by a combination of river and coastal floods. It was found that cumulation, the simultaneous flooding of multiple dike rings during a single flood event, has significant impact on the national level of societal risk. Options for the application of the individual and societal risk in the new flood safety policy are presented and discussed.

**Karin Hansson, K., Larsson, A., Danielson, M., and Ekenberg, L. (2011) Coping with Complex Environmental and Societal Flood Risk Management Decisions: An Integrated Multi-criteria Framework, Sustainability, 3, 1357-1380; doi:10.3390/su3091357**

An integrated water resource management approach would be beneficial in order to take both the best interests of society and of the environment into consideration. One improvement consists of models capable of handling multiple criteria (conflicting objectives) as well as multiple stakeholders (conflicting interests). A systems approach is applied for coping with complex environmental and societal risk management decisions with respect to flood catastrophe policy formation, wherein the emphasis is on computer-based modelling and simulation techniques combined with methods for evaluating strategies where numerous stakeholders are incorporated in the process. The resulting framework consists of a simulation model, a decision analytical tool, and a set of suggested policy strategies for policy formulation. The framework will aid decision makers with high risk complex environmental decisions subject to significant uncertainties.

**Kenyon, W. (2007) Evaluating flood risk management options in Scotland: a participant-led multi-criteria approach, Ecological Economics, Vol 64, 70-81**

The characteristics of flood risk management include complexity, large spatial scales, inter-temporal issues, plural values and conflicts of interests. It is argued that issues with such characteristics require public participation in the decision making process. This study builds on existing deliberative processes to develop a new participant-led multi-criteria method to evaluate flood risk management

options in Scotland. The results show that participants preferred regeneration or planting of native woodland to other flood management options, and least preferred building flood walls and embankments. The design of the workshops allowed a rich dataset to reveal the thinking behind such results and provided a deeper understanding of why participants came to these conclusions.

**Levy, J. (2005) Multiple criteria decision making and decision support systems for flood risk management, Stochastic Environmental Research Risk Assessment, 19, 438-447**

Multiple criteria decision making (MCDM) is a collection of methodologies to compare, select or rank multiple alternatives that typically involve incommensurate attributes. MCDM is well-suited for eliciting and modelling the flood preferences of stakeholders and for improving coordination among flood agencies, organisation and affected citizens. A flood decision support system (DSS) architecture is put forth that integrates the latest advances in MCDM, remote sensing, GIS, hydrologic models, and real-time flood information systems. The analytic network process (ANP) is discussed with application to short-term flood management options for the middle reaches of the Yangtze River. It is shown that DSS and MCDM can improve flood risk planning and management under uncertainty by providing data displays, analytical results and model output to summarise critical flood information.

**Meyer, V., Haase, D. and Scheuer, S. (2007) : GIS-based multi-criteria analysis as decision support in flood risk management, UFZ-Diskussionspapiere, No. 6/2007**

In this report a GIS-based multicriteria flood risk assessment and mapping approach is developed. This approach has the ability a) to consider also flood risks which are not measured in monetary terms, b) to show the spatial distribution of these multiple risks and c) to deal with uncertainties in criteria values and to show their influence on the overall assessment. It can furthermore be used to show the spatial distribution of the effects of risk reduction measures. The approach is tested for a pilot study at the River Mulde in Saxony, Germany. Therefore, a GIS dataset of economic as well as social and environmental risk criteria is built up. Two multi-criteria decision rules, a disjunctive approach and an additive weighting approach are used to come to an overall assessment and mapping of flood risk in the area. Both the risk calculation and mapping of single criteria as well as the multi-criteria analysis are supported by a software tool (FloodCalc) which was developed for this task.

**Schroter, K., Ostrowski, M., Velasco, C., Nachtnebel, H.P., Beyene, M., Rubin, C. and Gocht, M. (2008) Effectiveness and Efficiency of Early Warning Systems for Flash-Floods (EWASE) CRUE Research Report No I-5, CRUE ERA-NET, Prepared by the Joint Project Consortium, Coordinator John Goudie, Defra, London**

This is the final report of the EC funded EWASE research project. In this report the wider benefits accruing to flood warning schemes are the subject of qualitative MCA which can be found on pages 103-106. Otherwise the report presents a detailed assessment of the benefits of flood warning. EWASE evaluated the efficiency and the effectiveness of early warning systems (EWS) in small river basins that have short hydrological response times. EWASE provided information for optimal alerts through the analysis of the trade-off between the benefit of an increased lead time and the simultaneous decrease of warning reliability. The increase in lead time may provide valuable time for the completion of preventive measures, whereas the decrease of warning reliability will cause economic loss in case of a false alert. Two study basins in Austria and Spain are presented to illustrate the application of the methodology proposed and to identify the key information required to integrate this approach into comprehensive flood risk management strategies. In this way EWASE

synthesises data and experiences to help flood managers in finding better solutions for the operation of early warning systems.

In the light of current knowledge given the assumptions and region of investigation of this study, no FRM strategy appears to be more efficient than the combination of local protection and early warning. Early warning as discussed in EWASE offers a significant potential to transfer responsibilities from the state to the individuals. The extent to which individuals are enabled to care for their safety and to optimise their benefit from the warning depends to a large part on the distribution of the warning. Particularly in the economic sectors high potential benefits can be realised, because of the ongoing presence of people at least during the day. As 60 to 70% of the risk arises in the economic sectors, there is a high potential for damage reduction due to early warning. It is therefore a promising means to implement the EWASE approach on the company level supporting managers to decide about releasing an alert for optimising their benefit from early warning. Early warning systems as a non-structural protection measure induce very low detrimental effects on the natural environment. Therefore the implementation of early warning is a good opportunity to reconcile the Water Framework Directive and the Floods Directive.

Early warning is well in line with the protection of the weak. In fact timely warning may be the only possibility to evacuate the sick, the elderly, the children and the pupils from hospitals, resorts, kindergartens and schools.

**Sugden, R. (2007) Integrating Cost-Benefit Analysis and Multi-Criteria Analysis of Flood and Coastal Erosion Risk Management Projects R&D Project Record FD2018/PR2, Joint Defra/EA Flood and Coastal Erosion Risk Management R&D Programme, Environment Agency and Defra, London**

In the UK, flood and coastal defence (FCD) projects are subjected to economic appraisal, using the cost-benefit methodology described in Defra's Flood and Coastal Defence Project Appraisal Guidance, Part 3: Economic Appraisal (FCDPAG3). The feasibility of changing this appraisal framework from the traditional 'calculus of social costs and benefits' to the 'calculus of willingness to pay (WTP)' has been examined. The main virtue of the calculus of WTP is that it allows the impacts of a project to be disaggregated between economic interest groups (e.g. government and taxpayers, businesses, households). This makes it easier to consider the distributional effects of projects and to identify the role of contributions from project partners (e.g. property developers), while retaining the essential logic of cost-benefit analysis (CBA). A radically different appraisal methodology, multi-criteria analysis (MCA), is proposed in this report which is a preliminary assessment of the compatibility of CBA (using the WTP calculus) with the kind of MCA proposed by evaluating MCA. The report provides a very useful comparison of CBA and MCA and ways of reconciling these appraisal methods.

**Tkach, R. and Simonovic, S. (Not Dated) A New Approach to Multi-criteria Decision Making in Water Resources, Journal of Geographic Information and Decision Analysis, Vol 1, No.1, 25-43 at [http://publish.uwo.ca/~jmalczew/gida\\_1/Tkach/Tkach.htm](http://publish.uwo.ca/~jmalczew/gida_1/Tkach/Tkach.htm) on 27.08.14**

Spatial comparison of floodplain management alternatives in a raster GIS environment is conceptualized as a multi criteria decision making problem. A spatial MCDM technique is developed by combining the conventional Compromise Programming technique with GIS technology. This new technique is referred to herein as Spatial Compromise Programming (SCP). The main contribution of the proposed technique is its ability to address uneven spatial distribution of criteria values in the evaluation and ranking of alternatives. SCP is used to determine the best alternative for each geographic location within the region of interest. The analysis of floodplain management strategies for the Red River Valley region is chosen as a case study to illustrate application of the Spatial Compromise Programming technique.

**Yalcin, G. and Akyurek, Z. (Not Dated) Multiple criteria analysis for flood vulnerable areas, at <http://proceedings.esri.com/library/userconf/proc04/docs/pap1097.pdf> on 29.08.14**

This paper integrates the use of Multi-Criteria Decision Analysis with (MCDA) with Geographical Information Systems (GIS). Cell-based Multicriteria Evaluation (MCE) methods are used to analyse the flood vulnerable areas. In ArcView 8.2 all data are stored and the criterion values are generated for all criteria that are seen as map layers. The criterion maps are converted into grids and the mathematical processes are applied to the criteria with MapCalculator. Ranking Methods are used to rank the every criterion under consideration in the order of the decision maker's preferences and the Pairwise Comparison Method (PCM), which is designed as a user interface to calculate the weights from input preferences with Visual Basic Application (VBA) program embedded in ArcGIS 8.2 is used. At the end of the application, the composite maps are created using Boolean Approach, Ranking Method, PCM and Ordered Weighted Averaging (OWA) Method including fuzzy concept on standardization of the criterion values and are compared.

**Yazdandoost, F . and Bozorgy, B. (2008) Flood risk management strategies using multi-criteria analysis, Proceedings of The Institution of Civil Engineers and Water Management, Vol 161 (5), 261-266**

The concept of 'resilience', also introduced in other research, is appropriately addressed. The application of multi- criteria decision making in flood risk management is demonstrated in a case study of the lower Rhine River. Flood risk management strategies other than the current strategy are defined, some based on the concept of resilience, and ranking of the strategies based on the flood risk management evaluation criteria is presented. The results are supported by uncertainty analyses. Flood risk management is investigated in the context of a decision making problem. Various flood risk management strategies are considered and evaluated using multi-criteria analysis.

## **Environmental focus**

**Cinelli, M., Coles, S. R. and Kirwan, K. (2014) Analysis of the potentials of multi criteria decision analysis methods to conduct sustainability assessment. Ecological Indicators, Vol 46, 138-148. ISSN 1470-160X**

Sustainability assessments require the management of a wide variety of information types, parameters and uncertainties. Multi criteria decision analysis (MCDA) has been regarded as a suitable set of methods to perform sustainability evaluations as a result of its flexibility and the possibility of facilitating the dialogue between stakeholders, analysts and scientists. However, it has been reported that researchers do not usually properly define the reasons for choosing a certain MCDA method instead of another. Familiarity and affinity with a certain approach seem to be the drivers for the choice of a certain procedure. This review paper presents the performance of five MCDA methods (i.e. MAUT, AHP, PROMETHEE, ELECTRE and DRSA) in respect to ten crucial criteria that sustainability assessments tools should satisfy, among which are a life cycle perspective, thresholds and uncertainty management, software support and ease of use. The review shows that MAUT and AHP are fairly simple to understand and have good software support, but they are cognitively demanding for the decision makers, and can only embrace a weak sustainability perspective as trade-offs are the norm. Mixed information and uncertainty can be managed by all the methods, while robust results can only be obtained with MAUT. ELECTRE, PROMETHEE and DRSA are non-compensatory approaches which consent to use a strong sustainability concept, accept a variety of thresholds, but suffer from rank reversal. DRSA is less demanding in terms of preference

elicitation, is very easy to understand and provides a straightforward set of decision rules expressed in the form of elementary “if ... then ...” conditions. Dedicated software is available for all the approaches with a medium to wide range of results capability representation. DRSA emerges as the easiest method, followed by AHP, PROMETHEE and MAUT, while ELECTRE is regarded as fairly difficult. Overall, the analysis has shown that most of the requirements are satisfied by the MCDA methods (although to different extents) with the exclusion of management of mixed data types and adoption of life cycle perspective which are covered by all the considered approaches.

**Tiwaria, D.N., Loofb, R., and Paudyal, G.N. (1999) Environmental–economic decision-making in lowland irrigated agriculture using multi-criteria analysis techniques, *Agricultural Systems*, Vol. 60, Issue 2, 99-112**

The continuing debate about sustainability has raised wide concerns towards integration of environmental and economic aspects into the development decision-making process. This paper develops a framework for environmental–economic decision making that includes the environmental and economic sustainability criteria, and local people's preferences in the context of a lowland irrigated agriculture system using multi-criteria decision-making techniques. Several criteria, such as land capability/suitability, energy input/output ratio, water demand and environmental costs, are considered as environmental sustainability criteria. Economic sustainability is measured from farmers', governments and societal viewpoints using extended cost-benefit analysis. The Geographic Information System (GIS) technique has been used to evaluate spatial sustainability criteria. The involvement of local people at various levels of the decision-making process is emphasized and their opinions are sought in the decision-making process using a two-stage field survey. The results of the multi-criteria analysis combining both environmental and economic sustainability criteria are discussed, and economic incentives for sustainable intensification of lowland irrigated agriculture are outlined.

## **International and case study focus**

**Costa, C., da Silva, P. and Correia, F. (2003) Multi-criteria evaluation of flood control measures: The case of Ribeira do Livramento, Working Paper LSEOR 03.62, Department of Operational Research, London School of Economics and Political Science, London ISBN 07530 16842**

This paper describes the multi-criteria process used to evaluate flood control options for the Livramento Creek in Setubal peninsular, Portugal. Environmental, social and technical dimensions are identified. The MACBETH approach – Measures Attractiveness by a Categorical Based Evidence Technique – was employed to construct a quantitative evaluation model based on qualitative value judgements formulated by a group of experts from diverse fields. This model allows the overall benefits accruing to each option to be estimated and extensive sensitivity analysis to be performed.

**Ghanbarpour M. R., Salimi, S. and Hipel, K.W. (2013) A comparative evaluation of flood mitigation alternatives using GIS-based river hydraulics modelling and multi-criteria decision analysis, *Journal of Flood Risk Management*, Vol 6, Issue 4, 319–331, December**

A multi-criteria framework is developed for the selection of optimal flood mitigation and river training measures in a selected reach of Zaremroud River in Northern Iran. A river model, Hydrologic Engineering Center River Analysis System, combined with geographic information system analysis is used to simulate water levels for steady, gradually varied flow and mapping inundated flood extents. The modelling is performed for four different alternatives, considering various channel modifications

with different dimensions and levee construction. Flood inundation area, flood level, flow velocity and stream power on the downstream and outside of the river bend are used as decision criteria for each alternative. Economic analysis is conducted to evaluate the cost-effectiveness of each alternative. The decision analysis method, technique for order of preference by similarity to ideal solution, is used to compare different flood hazard mitigation measures based on risk, and environmental and economic impacts criteria. The findings of the analysis are that a levee construction at the right side of the river bank adjacent to the residential area is superior to the other three alternatives, which is confirmed using a scenario analysis of different flood mitigation measures.

**Kuba, C., Haase, D., Meyer, V. and Scheuer, S. (2009) Integrated urban flood risk assessment – adapting a multi-criteria approach to a city, *Nat. Hazards Earth Syst. Sci.*, 9, 1881–1895**

Flood risk assessment is an essential part of flood risk management. As part of the new EU flood directive it is becoming increasingly more popular in European flood policy. Particularly cities with a high concentration of people and goods are vulnerable to floods. This paper introduces the adaptation of a novel method of multi-criteria flood risk assessment, that was recently developed for the more rural Mulde river basin, to a city. The study site is Leipzig, Germany. The “urban” approach includes a specific urbantype set of economic, social and ecological flood risk criteria, which focus on urban issues: population and vulnerable groups, differentiated residential land use classes, areas with social and health care but also ecological indicators such as recreational urban green spaces. These criteria are integrated using a “multi-criteria decision rule” based on an additive weighting procedure which is implemented into the software tool FloodCalc urban. Based on different weighting sets we provide evidence of where the most flood-prone areas are located in a city. Furthermore, we can show that with an increasing inundation extent it is both the social and the economic risks that strongly increase.

**Meng, Y., Xin, Q., Yuchao, Z., Jinbao, S., Dengle, S. and Yi, G. (2011) Spatial Multicriteria Decision Analysis of Flood Risks in Aging-Dam Management in China: A Framework and Case Study *Int J Environ Res Public Health*. May 8 (5), 1368–1387. Published online May 4, 2011. doi: 10.3390/ijerph8051368 consulted on 28.9.14**

Approximately 30,000 dams in China are aging and are considered to be high-level risks. Developing a framework for analysing spatial multi-criteria flood risk is crucial to ranking management scenarios for these dams, especially in densely populated areas. Based on the theories of spatial multi-criteria decision analysis, this report generalizes a framework consisting of scenario definition, problem structuring, criteria construction, spatial quantification of criteria, criteria weighting, decision rules, sensitivity analyses, and scenario appraisal. The framework is presented in detail by using a case study to rank dam rehabilitation, decommissioning and existing-condition scenarios. The results show that there was a serious inundation, and that a dam rehabilitation scenario could reduce the multi-criteria flood risk by 0.25 in the most affected areas; this indicates a mean risk decrease of less than 23%. Although increased risk (<0.20) was found for some residential and commercial buildings, if the dam were to be decommissioned, the mean risk would not be greater than the current existing risk, indicating that the dam rehabilitation scenario had a higher rank for decreasing the flood risk than the decommissioning scenario, but that dam rehabilitation alone might be of little help in abating flood risk. With adjustments and improvement to the specific methods (according to the circumstances and available data) this framework may be applied to other sites.

**Meyer, V., Scheuer, S. and Haase, D.A. (2009) Multi-criteria approach for flood risk mapping exemplified at the Mulde river, Germany, *Natural Hazards*, Vol 48 (1), 17-39**

A multi-criteria approach for flood risk mapping exemplified in the Mulde river, Germany. The approach is applied to a pilot study for the River Mulde in Saxony, Germany, heavily affected by recent floods, most notably in 2002. Various flood damage reduction measures are evaluated. A GIS-based multi-criteria flood risk assessment and mapping approach is developed. This approach includes flood risks which are not measured in monetary terms. A GIS database of economic, social and environmental risk criteria was created. Two different multi-criteria decision rules, a disjunctive and an additive weighting approach, are utilised for an overall flood risk assessment in the area. For implementation, a software tool (FloodCalc) was developed supporting both, the risk calculation of the single criteria as well as the distribution of multiple risks, and it is able to deal with uncertainties in criteria values and to show their influence on the overall flood risk assessment.

**Musungu, K and Motala, S. (2012) Participatory Multi-Criteria Evaluation and GIS: An Application in Flood Risk Analysis, FIG Young Surveyors Conference - Workshop 1.2, 6204 1/14, Knowing to create the Future Rome, Italy, 4-5 May**

Many of the rural-urban migrants in Cape Town have settled in informal settlements because they cannot afford to rent or buy decent housing. A number of these settlements are however located on poorly drained land that is often prone to flooding after prolonged rainfall. However, current flood risk management techniques implemented by the authorities of the Cape Town City Council (CTCC) are not designed to support informal settlements. In fact, owing to inadequate information about the levels of flood risk within the individual informal settlements the CTCC has often implemented inappropriate remedies within such settlements. This study sought to investigate a participatory methodology that the CTCC could use to improve flood risk assessment in informal settlements. This study responded to calls in various research papers calling for the adoption of participatory methodologies in developing a Geographic Information System (GIS). Using a case study of an informal settlement in Cape Town, this study proposed a methodology involving sourcing and integrating of community-based information into a GIS that can be used by the CTCC for risk assessment. Also, this research demonstrated the use of a participatory multi-criteria evaluation (MCE) for risk assessment. The MCE method of choice was the pairwise comparison method. Risk weights were subsequently calculated using pairwise comparisons for each household and mapped in the GIS to show the spatial disparities in risk between the households.

**Musungu, K., Motala, S., and Smit, J. (Not Dated) Using Multicriteria Evaluation and GIS for Flood Risk Analysis in Informal Settlements of Cape Town: The Case of Graveyard Pond at <http://idl-bnc.idrc.ca/dspace/bitstream/10625/49834/1/IDL-49834.pdf> on 30.8.14**

Rural-urban migrations have contributed to the steady increase in the population of Cape Town. Many of the migrants have settled in informal settlements because they cannot afford to rent or buy decent housing. Many of these settlements are however located on marginal and often poorly drained land. Consequently, most of these settlements are prone to flooding after prolonged rainfall. Current flood risk management techniques implemented by the authorities of the Cape Town City Council (CTCC) are not designed to support informal settlements. In fact, owing to a lack of information about the levels of flood risk within the individual settlements, either the CTCC has often been uninvolved or it has implemented inappropriate remedies within such settlements. This study sought to investigate a methodology that the CTCC could use to improve flood risk assessment. Using a case study of an informal settlement in Cape Town, this study proposed a methodology of integration of community-based information into a Geographic Information System (GIS) that can be used by the CTCC for risk assessment. In addition, this research demonstrated the use of a participatory multi-criteria evaluation (MCE) for risk assessment. A questionnaire was used to collect community-based information. The shack outlines of the informal settlement were

digitised using CTCC aerial imagery. The questionnaires were captured using spreadsheets and linked to the corresponding shacks in the GIS. Risk weights were subsequently calculated using pairwise comparisons for each household, based on their responses to the questionnaires. The risk weights were then mapped in the GIS to show the spatial disparities in risk.

**Penning-Rowsell<sup>1</sup>, E.C., Yanyan, W., Watkinson, A.R., Jiang, J. and Thornes, C. (2013) Socioeconomic scenarios and flood damage assessment methodologies for the Taihu Basin, China, Journal of Flood Risk Management Taihu Basin Foresight Project Special Issue, Vol 6, Issue 1, 23–32**

The assessment of flood risk is now widely recognised to need research and data on both the probability and the consequences of flooding; the research reported here concentrates on the latter data input. Building on the UK Foresight Future Flooding project, this paper describes the development of future scenarios through which to assess possible future flood risk in the Taihu Basin area of China. In addition, we describe the flood damage assessment model that was developed there to build on these scenarios so as to calculate anticipated risk. Acknowledged methodological limitations remain, but some important developments have resulted. First, the pre-existing flood loss data that were available from Shanghai meant that this aspect of the risk model's input was more regionally appropriate than would otherwise have been the case. Second, the damage assessment has been related both to constructed scenarios and to an agreed National Plan, so that the two can be compared. Third, the scenario construction was linked in Taihu to the statistical base contained in the 2006 Yearbook and the Fifth National Socio-economic Survey data, giving a sounder 'base case' of current flood vulnerability than used in the UK Foresight Future Flooding project. Finally, much more attention was given here to agricultural production and flood risk, given the importance of agriculture in the Chinese economy and its focus on food production for a growing population.

**Raaijmakers, R.J.J. (2006) A spatial multi criteria analysis methodology for the development of sustainable flood risk management in the Ebro Delta : A FLOODsite case study. University of Twente MSc Thesis, at <http://essay.utwente.nl/57138/> on 26.08.14**

This thesis derives a methodology which combines spatial multi criteria analysis with risk assessment in order to support decision making for sustainable flood risk management of coastal zones. A trade-off is made between the reduction of tangible and intangible damage and the conservation of commodity (CO) and non-commodity output (NCO), for risk management strategies. In this case these strategies are land use changes. This is a trade-off between risk and benefit, where a reduction of risk often implies a reduction of benefit. This trade-off is often influenced by the perception of risk, which influences the preference for one of the opposing interests. Flood risk management policy scenarios are judged on the criteria, reduction of tangible and intangible damage and conservation of COs and NCOs in a spatial multi criteria analysis. Worry, awareness and preparedness, three parameters for risk perception are used to determine the weighting of the first two criteria versus the last two. Afterwards pairwise comparison can be used to fine tune the weighting. The methodology should guide a policy maker toward sustainable flood risk management but not make the decision for the best flood risk management policy alternative itself.

**Raaijmakers, R., Krywkow, J., and van der Veen, A. (2008) Flood risk perceptions and spatial multi-criteria analysis: an exploratory research for hazard mitigation, Natural Hazards Journal of the International Society for the Prevention and Mitigation of Natural Hazards 10.1007/s11069-007-9189-z at <http://link.springer.com/article/10.1007/s11069-007-9189-z/fulltext.html> on 29.08.14**

The conventional method of risk analysis (with risk as a product of probability and consequences) does not allow for a pluralistic approach that includes the various risk perceptions of stakeholders or lay people within a given social system. This article introduces a methodology that combines the virtues of three different methods: the quantifiable conventional approach to risk; the taxonomic analysis of perceived risk; and the analytical framework of a spatial multi-criteria analysis. This combination of methods is applied to the case study 'Ebro Delta' in Spain as part of the European sixth framework project 'Floodsite'. First, a typology for flood hazards is developed based on individual and/or stakeholders' judgements. Awareness, worry and preparedness are the three characteristics that typify a community to reflect various levels of ignorance, perceived security, perceived control or desired risk reduction. Applying 'worry' as the central characteristic, a trade-off is hypothesized between Worry and the benefits groups in society receive from a risky situation. Second, this trade-off is applied in Spatial Multi-Criteria Analysis (SMCA). MCA is the vehicle that often accompanies participatory processes, where governmental bodies have to decide on issues in which local stakeholders have a say. By using risk perception-scores as weights in a standard MCA procedure a new decision framework for risk assessment is developed. Finally, the case of sea-level rise in the Ebro Delta in Spain serves as an illustration of the applied methodology. Risk perception information has been collected with help of an on-site survey. Risk perception enters the multi-criteria analysis as complementary weights for the criteria risk and benefit. The results of the survey are applied to a set of scenarios representing both sea-level rise and land subsidence for a time span of 50 years. Land use alternatives have been presented to stakeholders in order to provide the regional decision maker with societal preferences for handling risk. Even with limited resources a characteristic 'risk profile' could be drawn that enables the decision maker to develop a suitable land use policy.

**Van der Veen, A., Raaijmakers, R. and Krywkow, J. (Not Dated) Flood Risk Perceptions Applied to a Spatial Multi-Criteria Analysis in the Ebro Delta in Spain at <http://www.newwater.uni-osnabrueck.de/caiwa/data/papers%20session/B1/riskPaperCAIWA01.pdf> accessed on 27.08.14**

The conventional method of risk analysis (with risk as a product of probability and consequences) does not allow for a pluralistic approach that includes the various risk perceptions of stakeholders or lay people within a community or region. In river basins, it is often an expert-based economic analysis of land use values that serves as the underlying estimation of costs. Intangibles such as nature development, biodiversity and cultural heritage are difficult to include in the calculation. Yet, local knowledge can be used to develop a realistic approach to outweighing tangibles and intangibles of land use values, as well as developing new approaches to risk management. This can be important to find appropriate solutions for the mitigation of risk. This presentation introduces a methodology that combines the virtues of three different methods used for risk analysis: the quantifiable conventional approach to risk, the taxonomic analysis of perceived risk and the analytical framework of a spatial multi-criteria analysis. The combination of these methods is applied to the case study 'Ebro Delta' in Spain as part of the European 6th framework project 'Floodsite'. The new approach using this combination is the incorporation of risk perceptions and its application and operation in a multi-criteria analysis. Risk perception is derived from the psychometric paradigm that distinguishes a variety of risk characteristics. Due to a number of similarities among these risk perceptions all known risk characteristics can be condensed into three higher order risk characteristics - awareness, worry and preparedness. This reduction of risk characteristics enables scientists to employ them as weights in a multi-criteria analysis. Risk perception information has been collected with help of an on-site survey. The result is significant levels of 'worry' and 'awareness' of the flood risk with an increasing demand for 'preparedness'. Risk perception enters the multi-criteria analysis as complementary weights for the criteria risk and benefit. The results of the survey are applied to a set of scenarios representing both sea level rise and land subsidence for a time span of fifty years. Land use alternatives that are based upon the given scenarios have been

presented to stakeholders and evaluated. For effective land use policy in flood prone areas it can be useful to compare land use alternatives based upon their performance with respect to risk and benefit. In this way the regional decision maker has been given an overview of preferences for handling risk. Even with limited resources a characteristic 'risk profile' could be drawn that enables the decision maker to develop a suitable land use policy or at least provide a basis for further social learning processes.

**Yahaya, S. (Not Dated) Multicriteria analysis for flood vulnerable areas in Hadejia-Jama'are river basin, Niigeria at <http://www.asprs.org/a/publications/proceedings/portland08/0088.pdf> accessed on 27.08.14**

Flood disaster is considered as a major natural hazard due to its devastating effects on the affected area. Multicriteria Evaluation (MCE) methods are used to analyse the flood vulnerable areas. Geographical Information System (GIS) is integrated with Multicriteria Decision Analysis (MCDA). The aim is to provide more flexible and more accurate decisions to the decision makers in order to evaluate the effective factors. Some of the causative factors for flooding in the watershed are taken into account: annual rainfall, basin slope, drainage network, land cover and the type of soil. In this study two main MCE approaches employed in GIS are used, namely Boolean and Weighted Linear Combination (WLC). In MCE, two methods, pairwise comparison method (Analytical Hierarchy Process-AHP) and Ranking Method are used to calculate the weights of each factor. Using AHP the weightage derived for the factors were, Rainfall 33.9%, Drainage network 25.5%, Slope of the river basin 19.7%, Soil type 15.2% and Land cover 5.7%. A case study of flood vulnerable areas determination in Hadejia Jama'are River Basin, Nigeria is employed to illustrate the different approaches. At the end of the study a Map of flood vulnerable areas in the river basin was generated with a view to assisting decision makers on the menace posed by the disaster.

**Yazdandoost, F. and Bozorgy, B. (2008) Flood risk management strategies using multi-criteria, analysis, Proceedings of the ICE - Water Management, Vol 161, Issue 5, 01 October, 261 –266**

Flood risk management is investigated in the context of a decision making problem. Various flood risk management strategies are considered the alternatives; the evaluation criteria of such strategies, previously defined in other research, are considered the decision criteria. The concept of 'resilience', also introduced in other research, is appropriately addressed in this regard. The application of multi-criteria decision making in flood risk management is demonstrated in a case study of the lower Rhine River. Flood risk management strategies other than the current strategy are defined based on the concept of resilience, and ranking of the strategies based on the flood risk management evaluation criteria is presented. The results are supported by uncertainty analyses to show the effect of uncertainties on the ranking order of the strategies.