



Flood Risk Management in Europe: the flood problem and interventions

Colin Green, Carel Dieperink, Kristina Ek, Dries Hegger, Maria Pettersson, Sally Priest and Sue Tapsell

Date: 11th June 2013
Report Number: D1.1.1
Revision number: 4

Milestone Number: 1
Due date for deliverable: 15th June 2013
Actual submission date: 13th June 2013

STAR-FLOOD receives funding from the EU 7th Framework programme (FP7/2007-2013) under grant agreement 308364

Document Dissemination Level
PU Public

Co-ordinator: Utrecht University
Project Contract No: 308364
Project website: www.starflood.eu



Document information

Work Package	1
Consortium Body	WP Team
Year	2013
Document type	Draft Deliverable
Status	Draft for Approval
Date	11 th June 2013
Author(s)	Colin Green, Carel Dieperink, Kristina Ek, Dries Hegger, Maria Pettersson, Sally Priest and Sue Tapsell

Document History

Date	Revision	Prepared by	Organisation	Approved by	Notes
11/06/13	V4	CHG	MU	UU	
10/06/13	V3	CHG	MU	UU,LTU	
07/06/13	V2	CHG	MU	UU, LTU	
15/05/13	V1	CHG	MU	UU, LTU	

Acknowledgement

The work described in this publication was supported by the European Community's Seventh Framework Programme through the grant to the budget of the Integrated Project STAR-FLOOD, Contract 308364.

Disclaimer

This document reflects only the authors' views and not those of the European Community. This work may rely on data from sources external to the STAR-FLOOD project Consortium. Members of the Consortium do not accept liability for loss or damage suffered by any third party as a result of errors or inaccuracies in such data. The information in this document is provided "as is" and no guarantee or warranty is given that the information is fit for any particular purpose. The user thereof uses the information at its sole risk and neither the European Community nor any member of the STAR-FLOOD Consortium is liable for any use that may be made of the information.

© STAR-FLOOD Consortium. This report should be referred to as follows:

Green, C, Dieperink, C, Ek, K, Hegger, D.L.T, Pettersson, M, Priest, S, Tapsell, S, 2013, Flood Risk Management in Europe: the flood problem and interventions (report no D1.1.1), STAR-FLOOD Consortium, Utrecht, the Netherlands. ISBN: 978-94-91933-02-8

Keywords

Catchment
Integrated Water Resource Management
Change
Variability
Shock
Multi-layered

Author information

Prof. Colin Green is professor of Water Economics at the Flood Hazard Research Centre of Middlesex University.

Dr. Carel Dieperink is assistant professor in Environmental Governance at the Copernicus Institute of Sustainable Development, Faculty of Geosciences at Utrecht University.

Dr. Kristina Ek is a researcher in Environmental Economics at the Division of Social Sciences at Lulea University of Technology.

Dr. Dries Hegger is post doc researcher in Environmental Governance at the Copernicus Institute of Sustainable Development, Faculty of Geosciences at Utrecht University.

Maria Pettersson LL.D and MSc is a researcher in Environmental and Natural Resources Law at the Division of Social Sciences at Lulea University of Technology.

Dr. Sally Priest is a senior research fellow at the Flood Hazard Research Centre of Middlesex University.

Sue Tapsell, MSc is head of the Flood Hazard Research Centre of Middlesex University.

Preface

This report is the first deliverable of the EU 7th Framework Project STAR-FLOOD (see www.starflood.eu for an outline of the project). STAR-FLOOD focuses on flood risk governance. The project investigates strategies for dealing with flood risks in 18 vulnerable urban regions in six European countries: Belgium, the UK, France, The Netherlands, Poland and Sweden. The project is assessing the institutional embedding of these strategies from a combined public administration and legal perspective, with the aim to make European regions more resilient to flood risks.

Within the first Work Package of STAR-FLOOD, four reports have been prepared providing an extended problem analysis related to flood risk governance in Europe:

- i) **Flood Risk Management in Europe: actual flood risks in the STAR-FLOOD consortium countries (report no D1.1.1, this report);**
- ii) Flood Risk Management in Europe: governance challenges related to Flood Risk Management (report no D1.1.2);
- iii) Flood Risk Management in Europe: European flood regulation (report no D1.1.3);
- iv) Flood risk management in Europe: similarities and differences between the STAR-FLOOD consortium countries (report no D1.1.4).

The four reports together aim to provide a problem analysis of flood risk governance in Europe. In so doing, they give a further specification of the scope of the STAR-FLOOD project and raise some preliminary conclusions, expectations and assumptions to be challenged in the subsequent Work Packages of the project. Furthermore, the reports identify relevant issues, questions and themes that are considered to be in need of further research and will be taken up in WP2 and WP3 of STAR-FLOOD.

Reports number D1.1.1 and D1.1.2 focus on the main trends and challenges that occur. This report (D1.1.1) discusses the nature of the flood risks as well as the developments to be expected therein (e.g. increased vulnerability due to urbanisation and climate change) and the current state of the art in considering ways and means of intervening to reduce the risk. D1.1.2 approaches multi-level, multi-sector and multi-actor governance challenges related to Flood Risk Management from a theoretical perspective. Report number D1.1.3 focuses on European flood regulation, including the Water Framework Directive and the Floods Directive. The report discusses, amongst other things, the relationship between the Floods Directive and the Water Framework Directive as well as national law, how different EU Member States deal with the FD, the state of affairs concerning implementation of the FD in these Member States and what this may tell about their ambitions regarding the FD. Report D1.1.4, highlights essential similarities and differences between the STAR-FLOOD consortium countries. Issues addressed include: i) the countries' background situation in terms of their flood experiences; ii) potentially relevant factors for understanding the institutional organisation of water governance in each country, including the competent authorities for different Flood Risk Management Strategies and their actual competences, and the way in which the discourse on flood management has actually evolved in these countries; iii) the Flood Risk Management Strategies that are in place. The report conveys the message that each strategy is not feasible (appropriate) everywhere. It also raises some preliminary assumptions regarding the factors explaining (lack of) appropriateness. These findings are surely of interest to actors at the national and regional level in EU Member States.

Yours sincerely,
Prof. Colin Green
Leader of WP1

Prof. Peter Driessen
STAR-FLOOD Project Coordinator

Executive Summary

This report has been compiled as part of the STAR-FLOOD project, a European FP7 project focused on flood risk governance. The project investigates strategies for dealing with flood risks in 18 vulnerable urban regions in six European countries: England and Scotland in the UK, Belgium, France, The Netherlands, Poland and Sweden. The report is the first of the four reports that make up the first deliverable of the project. It summarises current thinking on:

- What is the Flood Risk Management problem?
- How are floods produced and propagated?
- What are we trying to achieve through Flood Risk Management?
- How can we achieve these objectives? What do we need to do?

Thus, it focuses upon the nature of the problem and the actions that can or should be taken to address the flood problem in the wider context of the thinking that led to the development of the Water Framework Directive. In methodological terms, the significance of this report is in directing our thinking to the analysis of the governance issues: what is necessary in order to deliver sustainable Flood Risk Management and what are the obstacles to be overcome in order to do so? Thus, within the project, a purpose of this deliverable is to provide a basis for the subsequent work packages, notably work package 2 which is developing a research protocol for the case studies. This work package has been co-evolving with work package 1 with a great deal of cross-fertilisation occurring between the work packages. The simplest summary question that follows from this report for the case studies is:

- What kinds of competences are necessary to develop appropriate and resilient Flood Risk Management Strategies? Do the actors that are involved have those competences, or alternatively, can additional actors that do have the competences be involved?
- Does the designated 'Competent Authority' have those competencies?

Table of contents

Table of contents.....	1
List of figures and Tables.....	2
1 Introduction.....	3
2 The problem of floods	4
2.1 The absolute risks in Europe	4
2.2 The comparative risk from flooding.....	4
2.3 The production of floods.....	5
2.4 The catchment approach	6
2.5 Floods as a shock.....	8
2.6 Increasing risks.....	8
2.7 The consequences of flooding	9
2.8 The problem of vulnerability.....	12
3 Managing the risks from flooding	13
3.1 The general principles.....	13
3.2 Options for Flood Risk Management	13
4 Concluding remarks.....	16
References.....	18

List of figures and Tables

Figure 1: Recent major floods in Europe (Kundzewicz et al. 2013).....	4
Figure 2: The effect of a flood as a shock.....	7

1 Introduction

Compared to other natural hazards, floods are both a high frequency event and spatially widespread in occurrence. Hence there are widespread discussions of how best to address the risks of flooding (e.g. Jha 2011; Kobayishi and Porter 2012; Asian Development Bank 2005); much of that literature is available on the ProVention Consortium web site (<http://www.preventionweb.net/english/professional/contacts/v.php?id=177>). Flood Risk Management (FRM) is part of Integrated Water Resource Management (IWRM) (GWP 2000), the problem in water management being to cope with the variability in precipitation and consequently with the variability in stream flows, and not to treat flooding as an independent problem (Technical Support Unit 2003). IWRM is necessarily also closely coupled to other policy areas, notably to spatial planning; the problem is simultaneously to make the best use of water and of land. Water management generally is increasingly being framed in terms of a complex systems approach (Pollard and du Toit 2008).

A flood is a shock, an external perturbation, to socio-economic-ecological systems, which propagates through those systems, where those systems then recover over some time scale from that shock. Whilst the overall intention in FRM is to enhance the functioning of the catchment in all senses, the emphasis is on reducing the magnitude of the initial shock, how it propagates through the systems, and/or to promote a more rapid recovery by those systems than would otherwise occur. Thus, we wish to enhance the resilience of systems to the shock of a flood whilst not degrading their resilience to other shocks. These risks are increasing notably as a result of technological change and economic growth and specifically through one consequence of those changes: anthropogenic climate change. At the same time, it is necessary to shift to an adaptive approach in the face of climate and the other changes that are or may occur as well as to make the wider transition towards sustainable development. We have to make decisions which will play out in a future which is essentially unknowable. Hence, we have to seek to make decisions which are 'future proof'. In doing so, we have to recognise both the physical nature of the challenge presented and seek to achieve societal objectives, notably whilst making the transition to a sustainable development path which produces enhanced well-being (Stiglitz et al. 2009). Decision making is also increasingly being understood as involving a process of stakeholder engagement (European Commission 2003).

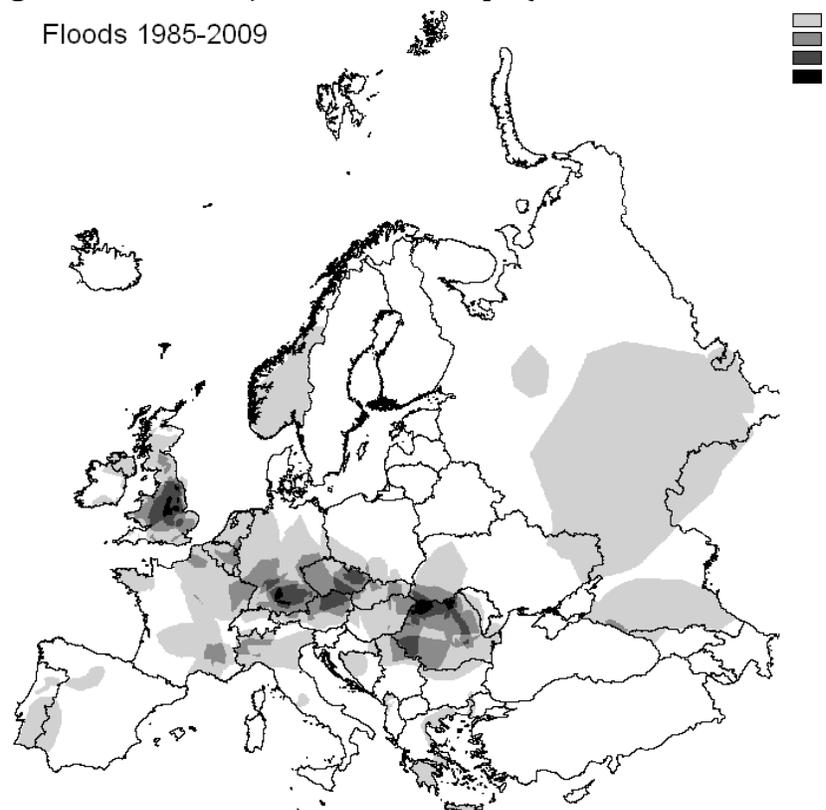
These then are the first two parts of the issue; what is the problem? And, what are we trying to achieve? Intervening effectively then requires both the capacity to intervene and the means to intervene, there being an interplay between the courses of intervention which would change the risk and the governance arrangements which enable each form of intervention. The central research question of the STAR-FLOOD project being: what are the appropriate and resilient flood risk governance arrangements for dealing with flood risks in vulnerable urban agglomerations? The specific problems of governance arrangements, including those of the fit between those arrangements and the scale of the problem are developed in the second of these reports (D1.1.2: Dieperink et al. 2013).

2 The problem of floods

2.1 The absolute risks in Europe

Of all the natural hazards, floods are typically found to be the most frequently experienced (Munich Re 2012) and consequently result in the largest proportion of annual losses (Guha-Sapir et al. 2012). Unlike other natural hazards, such as earthquakes, no country is free of the risk of flooding; indeed, the most violent floods are often found in arid climates. The economic losses from floods are rising (Barredo 2009) and lives are still being lost in floods. In addition to the 1953 floods affecting the Netherlands and England, other significant events include the Hamburg flood in 1962 (315 deaths); the Barcelona flood of 1965 (400-700 deaths); and the Lisbon flood of 1967 (404 deaths).

Figure 1: Recent major floods in Europe (Kundzewicz et al. 2013)



2.2 The comparative risk from flooding

The significance of floods as a national problem varies greatly between the countries of the European Union both in terms of average annual flood loss and the extreme potential loss. In England, for example, the direct losses from the floods of 2012 and 2007 have been fractions of a per cent of national income (e.g. a loss of £3 billion) and far less than the annual costs of fires: estimated for 2004 as £7 billion (Office of the Deputy Prime Minister 2005). Figure 1 shows the results of one recent study of the major recent floods in Europe (Kundzewicz et al. 2013) and the European Commission Joint Research Centre (2009) have mapped the future flood loss potential across the EU.

Countries differ in terms of the relative magnitude of the potential consequences of floods, both in comparison to other hazards and relative to other countries. Large proportions of the land area and populations of Hungary and the Netherlands are exposed to the risk of flooding whilst in England and Wales only 15% of the population is at risk. None of these four countries is at any significant risk of earthquakes but Italy and Greece experience frequent earthquakes. Hence, the relative degree of attention and resources a country should give to FRM depends upon where floods sit within the portfolio of hazards or other risks facing that country. For example, the UK government in a review of the comparative threat from different hazards flooding was not regarded as either the most likely or that with the greatest consequences (Cabinet Office 2012).

2.3 The production of floods

Flooding is the product of meteorology times land form, where land form is modified to some extent by land use. Importantly, only the latter is something we can influence in the short term. Precipitation is essentially produced either by deep depressions or by frontal systems, although these frontal systems are often connected to a depression. The size, depth and track, including the speed of movement, of depressions are all important in determining the response of a catchment. Coastal flooding can essentially be considered to be the product of a deep depression producing a tidal surge.

Meteorology has been described as the '*Dance of the Air and Sea*' (Taylor 2011), with the sea as the dominant sink of solar energy and playing the primary role. Since the atmosphere has a lower thermal capacity than the seas, atmosphere conditions, or 'weather', is more volatile than the sea. There are large differences between regions both in rainfall intensities (Larsen et al. 2008) but also in inter- and intra- year variability in rainfall (McMahon et al. 1987). High variability means that floods are the water resource and there has to be a large measure of storage if there is to be water in the dry season.

Land form then determines what proportion of precipitation does not infiltrate the soil and hence remains as runoff, that runoff draining off to watercourses and lakes. The rates at which rainfall can infiltrate the soil depends upon a number of factors (Pielou 1998) and crucially infiltration rates are time varying and fall as rain continues (Giudice et al. 2012; Merz and Bloschl 2009). In consequence, the proportion of precipitation that runs off the surface of the land, the runoff coefficient, also varies both during a rainfall event (Wainwright and Parsons 2002) and over a season of rainfall (Ettrick et al. 1987). The longer that rain continues the greater the proportion of that rainfall which will run off the land and therefore the more likely it is that a flood will be produced. That all soils act as 'sponges' comes at a cost: dryland plants require aerobic soils (ones containing oxygen) and if the root zone in the soil is saturated with water during the growing season, the plants are harmed. Thus, crops are often lost before surface water flooding is seen (Hess and Morris 1986).

Runoff is driven by gravity, both in terms of direction and the speed at which it travels; the speed of travel being affected by the frictional resistance offered by the surface over which it travels. Thus, surface waters are the concentration of runoff, it being the quantity and timing of runoff that determines whether the watercourse 'floods'. Steep slopes, and low frictional resistance, result in the time to concentration, the delay between runoff starting and the watercourse flooding, being short and produce 'flash' floods. That pulse of runoff then travels downstream under the force of gravity and again influenced by frictional resistance, the flood pulse tends to attenuate. Flood pulses on the different tributaries of a river will progressively begin to meet and build and combine into a downstream flood pulse. The form of the land at each point influences what type of flood results; from mudslides on upland slopes to wide floods in the lowlands.

Land use has an effect on the proportion of precipitation that becomes runoff but in the case of non-urban uses, the effect is limited. The current view is that in non-urban catchments the effect is only marked in small catchments in high frequency events (Calder 2000; O'Connell et al. 2007) where extreme events overwhelm the capacity of the soil to infiltrate the water. But since all catchments are made up of small sub-catchments, this may understate the usefulness of modifying land use. Diffuse runoff storage may, for example, be introduced (Landstrom et al. 2011).

Where the effect of land use change is more dramatic is in urban areas; urbanisation is equivalent in effect to converting woodland or arable land to a granite outcropping. The proportion of precipitation that becomes runoff is enhanced and, in addition, drainage systems are designed both to make the best use of gravity and to provide the least frictional resistance. Consequently, urban areas are very effective producers of floods in urban water channels.

Thus, what happens downstream, the likelihood and magnitude of a flood, depends upon what has happened uphill and upstream and also the interactions between the responses of the different sub-catchments that feed into the main river. Consequently, effective Flood Risk Management requires taking a catchment-wide perspective and approach.

2.4 The catchment approach

Catchments are systems of exchanges between land and water; those exchanges being of water, soil and entrained pollutants. As just discussed, the response of catchments is both spatially and temporally dynamic. The management problem is therefore to cope with the variability of the system as a whole and with all of these exchanges across that system. Flooding is thus simply part of the variability of flows as a whole and not a distinct problem from either water resources or the risk of drought. But whilst variability is a problem for people, ecosystems have developed around the prevailing water regime. To conserve the existing riparian ecosystems, it is necessary to maintain a corresponding degree of variability that of 'Environmental Flows' (Acreman and Ferguson 2009). Whilst riparian and wetland systems are adapted to variability, dryland ecosystems are damaged by floods (Old 2008). In addition to soil saturation harming plants and sub-soil animal species, the deposition of nutrients by flood water can be harmful (Gowing nd) as, obviously, can the deposition of sand by flood waters.

The minimum requirement in any intervention is that the action taken should not create worse consequences: either at another location or at another time. Situations which, for example, simply shift the flood problem downstream and magnify it there (as happened on the Rhine, (Te Linde et al 2010)), or address the flood problem at the cost of increasing the risk of drought, as can happen with afforestation (Calder 2006), need to be avoided. The ideal is to enhance the overall functioning of the catchment, the principle of Integrated Water Resource Management (IWRM) (GWP 2000) as embodied in the WFD. Specifically, the purpose of Flood Risk Management has been shown to be to enhance the functioning of the catchment as a whole and not to minimise flood losses (Green et al. 1993). For example, it is not desirable if flood losses are reduced but environmental damages are increased by a greater amount or drought risk is greatly increased. Taking a catchment approach creates the possibility of synergies. For instance, adopting a conservation tillage approach (FAO 2000) may provide some benefits in terms of flood risk reduction but it will also address the serious problems of soil erosion and also that of diffuse agricultural pollution.

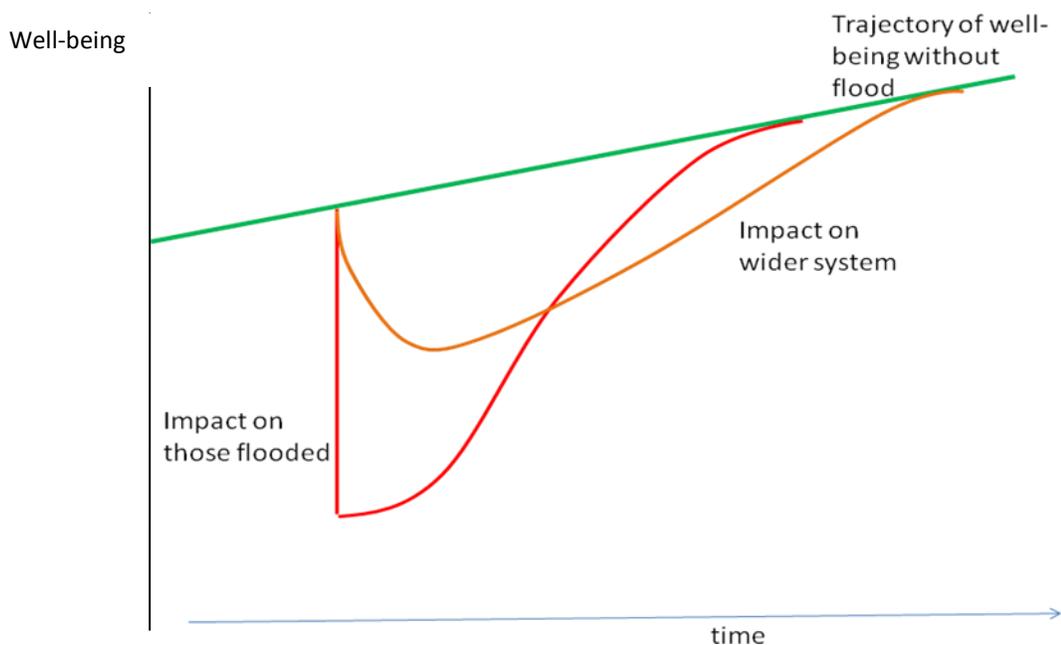
Adopting a catchment approach changes the direction of sight. The traditional approach was to look downstream and at the channel: how can we get rid of the flood pulse? A catchment approach directs sight upstream: how can we reduce the flood pulse? That refocuses the attention initially towards looking at runoff and then towards examining how the flood pulse is built up in the network of tributaries that create the flow at any particular point.

Considering each flood pulse, at any point, a given volume of water requires a particular cross-sectional area in order to convey it; that area is influenced by the velocity of flow which in turn is determined by the slope and frictional resistance of the channel through which it flows. So, flood plains are partly just the natural reflection of an increased inflow requiring an increased cross-section. However, if at any point the inflow exceeds the outflow then the excess water is stored upstream: backwater flooding. There, the flood plain is being used as a flood storage area. Increasing that storage reduces the area required for the outflow and vice versa. In extreme floods, it is inevitable that some area will be required for flood storage; the only potential choice is which area that will be.

But in a catchment, the flood pulses from each tributary gradually combine as the different branches of the main river stems meet. In the worst case, the flood pulses from each catchment arrive at the same time at some point down stream. Avoiding such a coincidence of flood pulses, delaying some and perhaps speeding up others, is a central problem.

Urban areas then either contain or sit within a sub-catchment; in the former instance, floods are internally generated and may also be propagated downstream. In the latter, the urban area is generally the recipient of the flood waves generated upstream. In all cases it is necessary to address the flood risk in a particular area in the context of its position in a catchment or sub-catchment.

Figure 2: The effect of a flood as a shock



2.5 Floods as a shock

Within the overall goal of enhancing the functioning and the performance of the catchment or coastal zone, a flood is a shock or perturbation which disturbs the behaviour of the system for some period of time, causing a fall from the pre-event path of achievement of desired objectives. Increasingly, the overall societal objective is defined in terms of 'well-being' (European Commission 2009; Stiglitz et al. 2009). The initial shock results in a fall in well-being for those who are flooded but the consequences then ripple outwards through the connected systems resulting in falls in well-being elsewhere (Figure 2). Thus, the flooding in Thailand is said to have resulted in a global increase in the price of hard disk drives as a result of the shortage of such drives as a consequence of the flooding of critical factories in the supply chain (Mearian 2012). Similarly, Li et al. (2012) showed the impacts upon the automobile component industry in China of the earthquake/tsunami in Japan in 2012.

The economic loss resulting from a flood is the difference in the areas under the trajectories of well-being with and without the flood, and the aim of all interventions is to minimise this difference whilst taking account of the affect on the trajectory of well-being over the long term (Green et al. 2011). The intervention is justified if the reduction in economic loss is greater than the cost of the intervention. This is the concept of resilience, originally developed in ecology (Resilience Alliance 2007), with the overall desire being that each of the eight components of well-being will recover to their pre-flood trajectory.

2.6 Increasing risks

In European and Global terms, floods are both frequent (and becoming more so) and damaging events (Guha-Sapir et al. 2012; Munich Re (2012)). However, the ratio of flood losses to national income has been found to be holding constant in a number of countries (Barredo 2009; Pielke et al. 2002). But in the absence of interventions, losses from floods can be anticipated to increase at a rate faster than the rate of economic growth for a number of reasons:

1. The amount available to spend on dwellings and their contents is what is left over after food has been bought; the proportion of income spent upon food falling as incomes rise (Houthakker 1957). Thus, in those countries where the proportion of household income spent upon food (the Engel coefficient) is still above 15% we should expect that as incomes rise the value of household assets will rise faster than the rate of growth in national income.
2. The value of the assets which may be damaged or destroyed in a flood is the product of net capital formation. Although household savings ratios differ markedly between countries, in those countries where national bureaus of statistics produce estimates of the net value of capital assets, the ratio of the net value of capital assets to national income appears to stabilise in the ratio of 3-3.5:1 for High Income Countries (Linham et al. 2010).
3. Changes in the physical susceptibility to damage by water of assets. This is most clearly seen in the case of cars. Forty years ago, cars which were submerged in water could be economically repaired. Now, the high proportion of the value of a car which is made up of electronic components means that a car can now be a write-off even after shallow flooding (National Salvage Vehicle Reporting Program nd).
4. Economies of scale have resulted in increasing specialisation and concentration as well as the adoption of dedicated supply chains – a car requires between 35,000 and 50,000 components and there are rarely alternative sources of supply for each of those components.

Climate change is only expected to magnify the problem (Kundzewicz 2012; Schneider et al. 2013), shifts in averages being less important than increases in variability and in the extremes. Climate change is generally anticipated to make water management more difficult by increasing both inter- and intra-variability in rainfall (IPCC 2007). The latter two are influenced by the large scale atmospheric and oceanic structures. Thus, the variations in the North Atlantic Oscillation have been shown to influence the flood risk in Scotland (Werrity et al. 2002); research in Belgium on climate change and water management has shown the variations in atmospheric circulation are associated with variations in extreme rainfall intensity in Belgium (Ntegeka et al. 2008); and flood events in the UK have been associated with the position of the jet streams in the upper atmosphere (JBA/Meteorological Office 2012). In turn, Ntegeka et al (2008) have shown that the jet streams are changing position.

Land use change, particularly urbanisation, is also changing the proportion of precipitation which becomes runoff and also reducing the delay between precipitation and the runoff reaching a watercourse. Most of Europe is anticipating simultaneously a fall in population and an increasingly aged population (Giannakouris 2008). With an ageing population, the proportion of the population who are in one or another way disabled will increase. This in turn reduces the proportions of the population who are able to, for example, erect temporary flood proofing or evacuate independently. Simultaneously, the ending of the Cold War has reduced the size of each country's armed forces, thereby impacting on the availability of military personnel to assist in emergency flood response. In addition, the emphasis on privatisation has reduced the number of personnel available to actors such as local government.

These anticipated changes, and the resulting uncertainty, require an adaptive approach involving the use of scenarios of alternative possible futures (van der Heijden 1996) and approaches which are robust to uncertainty (Green 2003). Recent examples of the adoption of such approaches include the Thames Estuary study in England (Environment Agency 2012) and the Delta Commission (2013) in the Netherlands.

2.7 The consequences of flooding

Historically, the focus of Flood Risk Management was upon agriculture. Well into the 20th Century households were spending over 50% of their income upon food (Burnett 1979) and any reduction in food production was reflected in an increase in the cost of food. Now in most EU countries, the proportion of household income spent upon food has fallen below 20% and instead of the majority of that expenditure being upon basic foodstuffs, a large fraction of the cost of food is on processing and distribution. Thus, the recent dramatic volatility in the world prices for basic foodstuffs has translated into much lower increases in the price of foods: only about 10% of the price of a loaf of bread reflects the price of wheat. At the same time, the proportions of national production and employment contributed directly by farming have also been falling.

Now the focus is increasingly shifting to urban activities. There, the effects of a flood are a product of the nature of the challenge (the depth of flooding, velocity of flow, duration of flooding, the sediment and pollution loads carried by the flood waters and the characteristics of the land and properties affected). The built form of the land use has significant consequences in terms of susceptibility. The countries of Europe differ in the traditional forms of dwelling construction: timber, stone and masonry. These building properties differ significantly in terms of their susceptibility to flooding. Additionally, the type of properties favoured also differs significantly between countries both in terms of the proportion of dwellings which are apartments (hence a significant fraction of dwellings are above any likely flood level) and also in the proportions of buildings which incorporate basements. In general, the development of

areas below ground level is increasing. Underground car parks are the most obvious example along with underground railways.

Using the shock model in Figure 2, the initial shock is the first order effect on the economy. These losses, the 'direct damages', are proxies for the consequent effects of the loss of those assets on the trajectories of the different components of well-being. Most member states now have functions which relate these losses to one or more characteristic of the flood event, most commonly the depth of flooding (Barredo 2010). But since the economic loss resulting from the damage or destruction of an asset is determined by the resulting fall in well-being, it is not necessarily the case the estimates of the losses from different classes of assets can be simply aggregated. For example, there is increasing research as to whether SMEs (Small and Medium sized Enterprises) will be less likely to recover from a shock or the propagation of a shock than large enterprises. Whilst the loss of a single property may eliminate the total turnover of a SME as well as destroying assets, borrowing for recovery being potentially securable against either assets or revenue, the same loss for a multi-site company will have a smaller effect on both turnover and total asset value. Potentially, a flood may therefore change the economic ecology of an area, eliminating SMEs and leaving only multi-site businesses. Not only do SMEs form a large part of a market economy (Ardic et al. 2011) but they provide a larger share of total employment relative to their turnover than do larger enterprises (BERR 2008). Research on SMEs following Hurricane Katrina has revealed that SMEs have specific problems in recovering from a disaster (Turner et al. 2011).

Analysing first how a shock propagates through the different systems and then how the system responds, and hopefully recovers, poses difficult problems. These effects are often termed 'indirect losses'. Current methods to estimate indirect losses instead use a piecemeal approach, seeking to determine what the indirect losses are if a particular installation is damaged (Parker et al. 1987). Whilst it is households whose well-being is of concern, part of that well-being is created through the different actors in the economy. Critical infrastructure (Commission of the European Communities 2006) exemplifies the issues: the identification of installations where there is limited alternative capacity in the system should that installation be damaged or disrupted by flooding. The EU (CEC 2006) defines critical infrastructure as "... *physical and information technology facilities, networks, services and assets which, if disrupted or destroyed have a serious impact on the health, safety, security or economic well-being of citizens or the effective functioning of governments.*" In effect, this is primarily those aspects of the socio-economic system where there is a high degree of concentration and specialisation coupled to a high degree of dependency by other parts of the economy. In turn, the EC has emphasised the importance of addressing the issues of critical infrastructure in climate change adaptation (European Commission 2013).

In principle, the theoretical problem of predicting propagation and recovery is straightforward: any system can be defined by a matrix which specifies the input-output relationships for each node. In the case of an economy, the nodes are the individual productive and consumptive sectors and the input-output relationships are termed the 'production functions'. Such matrix models have been used in attempts to model the propagation of a shock through an economic system and its subsequent recovery (Freeman et al. 2004; Hallegatte and Ghil 2008; Rose and Liao 2005). The difficulties of doing this are three-fold:

1. There has to be a valid production function for each node;
2. The model has to have sufficient detail as to be an adequate representation of the economy in question, notably the scale of that economy;

3. There has to be the data to populate that model at that scale.

None of these problems has been resolved at present. Available production functions are defined in variants of the factors of production defined in economic theory (land, capital, labour). Moreover, whilst a very large variety of production functions have been proposed, none have any theoretical basis (Mishra 2007). Those that have been extracted on the basis of statistical analysis have been argued to be indistinguishable from statistical artefacts (Shaikh 1974). The second problem is that of detail. To illustrate this problem, there are now 148,000 chemical components registered for use in the European Union. To model fewer than this number requires that some are more or less substitutes for others. Thirdly, available data is highly aggregated both in function and in spatial resolution. In practice, industrial statistics are available in the categories of the Standard Industrial Classification, and often only at the high levels of aggregation so, for example, data may only be available for the 'Chemical Industry'. Data will also usually only be available at a national level although sometimes it is available also at a regional level.

The contribution of the loss or damage of physical assets is only one of the influences upon the path of well-being, and only that part which can be estimated on the basis of corrected market prices. The 'Tug Fork' study may be said to have been the earliest to try to take the equivalent of a well-being approach to the assessment of the consequences of flooding (Allee et al. 1980). There has been subsequent work related to some of the aspects of well-being, notably on health (Defra/Environment Agency 2005) and studies of the consequences of the Red River flood showed that these included relationship problems (International Red River Basin Task Force 2000). Although studies in Low Income Countries (LICs) have shown the consequences of a flood on household income and wealth (Jahan 2000), data on these effects of flooding in Europe is, at best, sparse and lacking in detail. More general work has shown that the other, often termed 'intangible' effects of a flood are often of greater significance to those flooded than the physical damages (Green & Penning-Rowsell 1986).

Floods continue to present a potentially major threat to life. The difficulty at present is in estimating where the threat is greatest and how large is the risk to life in each location. The conditional risk to life should a flood occur varies between locations and events over a range of between about 1 in 10 to 1 in 10,000; although both upper and lower limits are somewhat conjectural. Part of the difficulty in both being more precise and in estimating the risk in a particular event is that deaths occur through a number of mechanisms. The main ones are:

- Travelling through flood water by foot or in a vehicle (the collapse of a bridge as a result of scouring, and the deaths in the train passing over it, may be regarded as a special case);
- Being unable to escape e.g. being in a basement or metro system;
- Exposure as the result in a building (including on the roof) or location which whilst providing refuge from the flood leaves the refugees exposed to cold and wet;
- Failure of refuge area; notably when the building collapses in whole or in part as a result of the effects of the flood.

So, whilst a number of attempts have been made to provide means of predicting the number of deaths that will occur in a flood in a given location (Homeland Security 2011; Jonkman & Vrijling 2008), it is easier to define those locations where the risk to life is unusually high:

- In addition to the risk of death on unstable hillsides, the runoff from such hillsides and the collapse of such slopes combines with the runoff to generate mudflows. These are highly destructive events which where they reach a developed area pose an extreme risk to life;
- Alluvial fans: fans of debris deposited by earlier floods, the size of the debris indicating the velocity of those previous floods. Where these velocities and associated debris loads are sufficient to destroy buildings, a high casualty rate can be anticipated as in the Caracas floods of 1999 (Wieczorek et al. 2001);
- Flashy steep upland catchments; where both the time to concentration of the flood is short and velocities of flow are high;
- Failure of natural or artificial structures e.g. sand dune systems, breaches of embankments including road or rail embankments, of flood defence structures or natural or artificial dams (including those created by the blockage of bridges by debris).

2.8 The problem of vulnerability

The concept of vulnerability is becoming increasingly problematic as an analytical concept. In simple terms, vulnerability concerns the relative susceptibility of different groups, populations, areas and so forth to the effect of a shock and/or between different types of shock. The relevant relative vulnerability may be either cross-sectional or longitudinal in time. Therefore the concept of vulnerability has variously come to be distinguished from that of resilience, included within resilience, or resilience has come to be included within vulnerability. In terms of Figure 2, vulnerability has been variously used as a label for the initial vertical first order shock, or the change in the trajectory of well-being, that change being alternatively labelled as vulnerability or resilience.

However, the utility of the concept lies in the degree to which it enables the determination of what is the best means of intervening to reduce vulnerability or enhance resilience (depending upon the definition of each which is used) or the priorities for action. To determine what is the best means of intervening, or the priority for intervention, depends upon the reasons why differential vulnerability is thought to exist. Definitions of vulnerability thus are commonly necessarily a form of discourse, the ascription of the reason for high vulnerability implying the best form of intervention to adopt. Vulnerability has variously been used (Green and Penning-Rowsell 2007; McFadden and Green 2007) as:

1. A characteristic (e.g. the elderly);
2. A state (e.g. the poor);
3. A relationship (e.g. specific to some form of shock such as a flood).

In addition, descriptive uses of the term vulnerability produce very long lists of those that may be deemed to be vulnerable and so lose the utility of the term in assessing comparative vulnerability and priorities.

So the term has become so amorphous as to have lost most of its analytical value. In pragmatic terms, in seeking to identify which individuals, households, groups or other sectors are differentially vulnerable, a practical problem is the need to use secondary data, such as Census data (in those countries where Census data exists). This means that comparisons of vulnerability are limited to consideration of those parameters for which such secondary data exists.

3 Managing the risks from flooding

3.1 The general principles

In deciding what approach to take to FRM, it is necessary to combine the two aspects. To adopt a strategy which both:

- recognises the physical nature of floods; and
- is directed towards societal objectives.

In doing so, it has to take account of changes and of the intention to change: the transition to sustainable development.

The key features of floods as a problem that have been highlighted so far are:

- The requirement to treat a catchment as a dynamic system of changes;
- The problem is to manage the variabilities of the exchanges that take place in a catchment;
- A corollary is that flooding is to be understood as a process rather regarded as a state.

The overall societal objective is increasingly framed in terms of the achievement of sustainable well-being (Stiglitz et al. 2009) where sustainable development (World Commission on Environment and Development 1987) requires 'doing more with less' (UNEP 2011). A practical difficulty with all water management is that it is so closely coupled with so many other policy areas and so FRM cannot be treated as a free-standing problem. Making the transition to sustainable development involves making change and hence requires innovation (Wejnert 2002), both organisational (Argyris and Schon 1996) and social learning (Craps 2003; Ison et al. 2004) but we have to make change in the face of change, most obviously climate change. Thus, the issues of resilience, adaptive management and making decisions in the face of uncertainty have been highlighted.

The resulting principles in FRM that have been proposed (Technical Support Unit 2003) are:

- Managing all floods and not just some, and the corollary principle that it is necessary to design for failure: what is important is what happens when the FRM strategy adopted fails, different FRM options have different consequences on failure (Green et al. 1993);
- This implies the adoption of a multi-layered approach (Green et al. 2000) where there is a complementarity between the different adopted options;
- A multi-layered approach will then be successful if it is an integrated approach;
- Since the achievement of 'good ecological quality', required under the WFD, is dependent not only on water quality but also on the flow regime, the sediment load carried and deposited by a river, and the morphological form of the river, FRM practices must seek to have positive effects on all four aspects of an individual river.

3.2 Options for Flood Risk Management

Whilst humans have always sought to reduce the risks of soil saturation and flooding, how we can intervene has developed with advances in science and technology. For most of history, understanding of hydrology and hydraulics has been very limited, essential data, such as on streamflows and rainfall, was non-existent, and calculations were limited to those that could be performed on an abacus and then using logarithmic tables and slide rules. Not surprisingly, therefore, the forms of interventions adopted were limited largely to drainage channels, including canalising rivers, and dikes. But brilliant examples of

practical solutions to the problems have also been created such as the Dujiangyan combined flood management and irrigation scheme in China (Mithen 2012) and the traditional approach of discontinuous dikes and dikes designed for overtopping in Japan (Kawanaka et al. 2009).

Flood Risk Management is then variously framed as:

- A free-standing problem (as in the Floods Directive);
- A water management problem (e.g. the IWRM framing (Technical Support Unit 2003));
- One of several hazards, often specifically natural hazards (which might be argued to be the traditional French approach);
- In terms of adaptation to climate change.

The basic decision in Flood Risk Management is whether to intervene before, during or after a flood; to seek to reduce the risk of a flood, to intervene during a flood to reduce its consequences, or to intervene after a flood to enable recovery to take place more quickly. Historically, in addition to action before a flood, there was a focus on action during a flood; the creation of 'dike armies' to inspect and strengthen dikes when a flood threatened (van de Van 2004). More recently, strategies have developed which are intended to aid recovery after a flood, notably by way of soft loans and grants or public-private insurance mechanisms such as those developed in France and Spain (GAO 2005) and now being proposed in the UK (ABI 2013).

A differentiation can be made between seeking to change the environment so as to cope with flood flows and seeking to adapt the way in which we use a catchment so as to either reduce the risk of a flood or to cope with it. In loose terms, this was the basis of the distinction between 'structural' and 'nonstructural' measures (Andjelkovic 2001) introduced by geographers, notably Gilbert White (1964) in the late 1940s. 'Structural' approaches were taken to include dikes and the various forms of canalisation of rivers that were adopted well into the 20th century: dredging, widening and straightening rivers and reducing the frictional resistance of the channel by removing vegetation. Other factors, notably the importance of navigation, played a major role in these modifications. Additionally, the need to enhance agricultural production resulted in the drainage of flood plains and poldering low lying areas. These both restricted the cross section of the river and reduced the area available for flood storage.

Sometimes, dams are included in the category of 'structural' measures and an essentially artificial distinction is drawn between reservoirs and other forms of storage such as washlands, flood plain forests, and wetlands. In hydrological and hydraulic terms all forms of storage fundamentally work in the same way. It is not possible to make definitive statements about the role of wetlands in Flood Risk Management (Acreman and Miller 2006; Williams et al. 2012) because there are many different types of wetlands which develop in different locations (Cowardin et al. 1979). A wetland is defined as an area where the soil is saturated during part of the growing season of plants and in consequence hydric soil conditions and specialised plants develop (Mitsch and Gosselink 2000). So they do not necessarily occur in those areas where storage would be most useful for FRM purposes, nor do they provide greater storage capacity than the same area of land in another use (Acreman et al. 2003). Where storage is provided with controls over inflows and outflows, storage can in principle remove the cap from a flood of any magnitude and so reduce the consequences. Thus, storage can drastically reduce the extent of flooding (Perry 1994).

Increasingly, rather than simply looking at the flood plain, and how that may be modified, either by dikes or restoring the natural storage capacities of the flood plain, a shift is taking place to a catchment

approach; looking at managing runoff. In urban areas, this has provided part of the emphasis on the adoption of SuDS (Sustainable Drainage Systems) although that shift has been driven partly by the desire to deliver sustainable urban water management (Howe and Mitchell 2011): seeing precipitation as a potential resource and not a problem. The catchment approach has been notably adopted in Scotland (Johnstonova 2009; WWF-Scotland 2007); encouraging farmers to either reduce runoff or provide on-farm storage (Blanc et al. 2012).

Adaptation to flood risks in the form of floating houses, raised buildings, flood resistant construction and flood proofing also have a long history in many parts of the world. In modern times, attempts to control building development on flood plains can be seen at least as early as 1896 when the metropolitan council for London obtained powers to require the floor levels of all new housing to be constructed above flood height (Humphreys 1930). More recent approaches to integrating water management and spatial planning include the Plans de Prevention des Risques d'Inondation (PPR(I)) (Fiselier and Oosterberg 2004) and the SAGE/SDAGE plans (Piegay et al 2002) in France, the Water Assessment approach in the Netherlands (van Dijk 2006), and PSS25 in England (CLG 2006). The real challenge is adapting existing settlements to the increased risk of flooding.

Recovery after a flood has traditionally been largely limited to compensation mechanisms either direct payments or soft loans, including via different forms of public-private systems of insurance (GAO 2005). What is important in all forms of intervention is the mode and consequence of failure either because it fails on demand (e.g. raised buildings collapse when their foundations are undermined, a dike collapses, or because the demand is greater than its capacity (e.g. a dike is overtopped, storage capacity is inadequate). The different intervention strategies differ dramatically in both the modes and consequences of failure; controlled storage in principle reduces the volume of flood flow in all events whilst flood proofing a building ceases to have any effect when overtopped.

Underpinning all FRM are the processes of data collection, interpretation (e.g. flood plain mapping (National Academy of Science 2009), decision making and communication between the cooperating partners (e.g. Meyer et al. 2012; Porter and Demeritt 2012) and between the public and other stakeholders. What is now increasingly argued is that the overall FRM strategy for a catchment should be multi-layered (Green et al. 2000), rather than relying upon a single form of intervention (e.g. dikes or flood warning), one which seeks to address all floods rather than just those up to some design standard of protection. Hence, a yardstick for assessing the quality of the overall FRM strategy is whether or not it is multi-layered, including a number of complementary intervention options. Notably, whether it includes options which seek to reduce the risk before a flood occurs, to reduce the impact of each flood as it occurs, and to promote recovery afterwards. Similarly, a multi-layered strategy is likely to include measures to manage runoff as well as flows in rivers. A simple categorisation approach is introduced in D4 but the test is whether the overall strategy is multi-layered.

4 Concluding remarks

Out of the interplay of the nature of the problem and the form of governance emerges the actions that can be taken to achieve the intended objectives. This report has looked at the nature of the flood problem, the intended objectives, and the consequently appropriate courses of action, in order to identify what the FRM governance system needs to be able to do. Specifically, each member state was left to designate a 'Competent Authority' to deliver on the WFD and for the Floods Directive; an issue discussed further in D1.1.3 (Bakker et al. 2013). The obvious question that arises is:

- What kinds of competences are necessary to develop appropriate and resilient Flood Risk Management Strategies?

This is to ask: do they have the necessary powers and resources to deliver the actions outlined in Section 3.2 on the basis of the principles developed in Section 3.1? These questions apply both in terms of a strategy which is integrated and multi-layered but also for each individual intervention option. Does the designated Competent Authority, for example, have the powers and resources to either construct SuDS in urban areas or to induce others to adopt SuDS? Can it deliver an effective flood warning (as opposed to a flood forecasting) system on its own? Can it deliver a multi-layered strategy in which the appropriate mix of complementary mix of intervention options are deployed, or are there intervention options it lacks to power to adopt?

What this report has emphasised is that the Floods Directive is only a daughter Directive of the WFD; it simply sets the minimum requirements for coherent Flood Risk Management in transnational catchments. From a water management perspective, it is the WFD that sets the overall framework of integrated water resource management within which FRM must be considered. So, it may be asked whether the designated Competent Authority recognises that flooding is simply part of the inherent variability of the hydrological cycle, and flooding is only one of the exchanges that take place in a catchment. That it is the dynamic nature of a catchment that presents the management challenge.

In particular, the shift towards a catchment management approach and the increased emphasis on changing the way in which we use catchments, creates a shift from a 'Competent Authority' whose capacities are centred on direct interventions to the capabilities of influencing the decisions and behaviours of others. Hence, if they do not have the appropriate powers and resources themselves, do they have the necessary skills to build partnerships with the other actors necessary to deliver the objectives of the Directive? As is discussed in D1.1.2, FRM involves multi-scales and cross-scales, and multiple actors. This requirement is increased by the shift to decision-making through stakeholder engagement.

The skills to support cooperative working (Caplan 2013; SIC adapt! 2013) will be essential because catchments nearly always cross administrative boundaries, most obviously in the case of transnational rivers. Specifically, if the spatial planning authorities are not included as part of the designated Competent Authority, then the skills to work with the spatial planning authority will be a key requirement. As decisions in FRM are increasingly made through processes of stakeholder engagement, rather than simply consulting with the stakeholders about decisions that have already been taken, the skills of co-working will become increasingly central. Hence, a key skill is the ability to undertake transdisciplinary science (Innocenti & Albrito 2011; Jacobs and Nienaber 2011; Lang et al. 2012; Lyall et

al. 2011); there are an increasing number of examples in FRM (Lane et al. 2010; Landstrom et al. 2011; McCall 2008). The emphasis is upon skills, notably social relationship skills, rather than on tools.

At the same time, the emphasis on learning, on innovation, and adaptive management requires that the Competent Authorities have those internal features which promote these behaviours.

References

- ABI (Association of British Insurers) (2013) *Flood Funding - Further Information*, written evidence, EFRA Select Committee review of Flood Funding, [online], Available: <http://www.parliament.uk/business/committees/committees-a-z/commons-select/environment-food-and-rural-affairs-committee/inquiries/parliament-2010/flooding/flood-funding---further-information/>. [11 June 2013].
- Acreman, M. C. and Ferguson, A. J. D. (2009) 'Environmental flows and the European Water Framework Directive', *Freshwater Biology*, 55(1), pp. 32-48.
- Acreman, M. C. and Miller, F. M. (2006) *Impact Assessment of Wetlands: Focus on Hydrological and Hydrogeological Issues*, R & D Technical Report W6-091/TR1, Bristol: Environment Agency.
- Acreman, M. C., Riddington, R. & Booker, D. J. (2003) 'Hydrological impacts of floodplain restoration: a case study of the River Cherwell, UK', *Hydrology and Earth Sciences*, 7(1), pp. 75-85.
- Allee, D. J., Osgood, B. T., Antle, L. G., Simpkins, C. E., Motz, A. B., Van der Slice, A. and Westbrook, W. F. (1980) *Human Costs of Flooding and Implementability of Non-Structural Damage Reduction in the Tug Fork Valley of West U.S.*, Fort Belvoir, VA: U.S. Army Corps of Engineers, Institute for Water Resources.
- Andjelkovic, I. (2001) *Guidelines on Non-Structural Measures in Urban Flood Management*. IHP-V Technical Documents in Hydrology, 50, Paris: UNESCO (United Nations Educational, Scientific and Cultural Organization).
- Ardic, O.P., Mylenko, N. and Saltane, V. (2011) *Small and Medium Enterprises: A Cross-Country Analysis with a New Data Set*, Policy Research Working Paper 5538, Washington DC: World Bank.
- Argyris, C. and Schon, D.A. (1996) *Organizational Learning II*. Addison-Wesley, Reading, MA.
- Asian Development Bank (2005) *Integrated Flood Risk Management in Asia: a Primer*, Asian Development Bank: AFMP
- Bakker, M.H.N., Green, C., Driessen, P., Hegger, D., Delvaux, B., Van Rijswick, M., Suykens, C., Beyers, J.C., Deketelaere, K., Van Doorn-Hoekveld, W. & Dieperink, C. (2013), *Flood Risk Management in Europe: European flood regulation*, STAR-FLOOD Consortium, Utrecht, The Netherlands.
- Barredo, J.I. (2009) 'Normalised flood losses in Europe: 1970–2006', *Natural Hazards Earth Systems Science*, 9, pp. 97–104.
- Barredo, J.I. (2010) 'Flood risk in Europe using Corine Land Cover Datasets', *CONHAZ Project Workshop*, 26 November 2010, London.
- BERR (Department for Business, Enterprise and Regulatory Reform), (2008) *Small and Medium-sized Enterprise (SME) Statistics for England and the Regions*, London: BERR.
- Blanc, J., Arthur, S., Wright, G., and Beevers, L. (2012) *Natural flood management (NFM) knowledge system: Part 3 – The effect of land drainage on flood risk and farming practice*, Final Report, Centre of Expertise for Waters (CREW), Edinburgh: CREW.
- Burnett, J. (1979) *Plenty & Want: A social history of diet in England from 1815 to the present day*, London: Scolar Press.
- Cabinet Office (2012) *National Risk Register of Civil Emergencies*, London: Cabinet Office.
- Calder, I. (2000) 'Land use impacts on water resources', *FAO Land-Water Linkages in Rural Watersheds Electronic Workshop*, Background Paper No. 1, Rome: FAO.
- Calder, I. R. (2006) 'Forest and Floods: Moving to an Evidence-based Approach to Watershed and Integrated Flood Management', *Water International*, 31(1), pp. 87-99.
- Caplan, K. (2013) *Taking the Mythology out of partnerships – A view from the ground up*, London: BPD (Building Partnerships for Development), Available: www.bpdws.org.

- CLG (Communities and Local Government Department) (2006) *Planning Policy Statement 25: Development and flood risk*. London: Department for Communities and Local Government.
- Commission of the European Communities (2006) *Communication from the Commission on a European Programme for Critical Infrastructure Protection*, COM (2006), 786, Brussels: CEC.
- Cowardin, L.M., Carter, V. and LaRoe, E. T. (1979) *Classification of wetlands and deepwater habitats of the United States*, Washington DC: Fish and Wildlife Services, US Department of the Interior.
- Craps, M. (ed) (2003) *Social Learning in River Basin Management*. HarmoniCOP project.
- DEFRA/Environment Agency (2005) *The appraisal of Human-related intangible impacts of flooding*, R&D Technical report FD2005/TR, London: Crown copyright.
- Delta Commission (2013) *Working on the Delta, Delta Programme 2013 – The road towards the Delta Decisions*, [online], Available: http://www.deltacommissaris.nl/english/Images/Delta%20Programme%202013%20EN_tcm310-334162.pdf [11 June 2013].
- Dieperink, C., Green, C., Hegger, D.L.T., Driessen, P.P.J., Bakker, M., Van Rijswick, M., Crabbé, A., Ek, K. (2013), *Flood Risk Management in Europe: governance challenges related to flood risk management (report no D1.1.2)*, STAR-FLOOD Consortium, Utrecht, The Netherlands.
- Environment Agency (2012) *TE2100 – Thames Estuary 2100* [Online], Available: <http://www.environment-agency.gov.uk/homeandleisure/floods/125045.aspx>.
- Ettrick, T. M., Mawdsley, J. A. and Metcalfe, A.V. (1987) 'The influence of antecedent catchment conditions on seasonal flood risk', *Water Resources Research*, 23(3), pp. 481-488.
- European Commission (2003) *Common Implementation Strategy for the Water Framework Directive (2000/60/EC): Guidance document No 8 – Public Participation in relation to the Water Framework Directive*, Luxembourg: Office for Official Publications of the European Communities.
- European Commission (2009) *GDP and beyond: Measuring progress in a changing world*, Communication to the Council and the European Parliament, Brussels: European Commission.
- European Commission (2013) *Adapting infrastructure to climate change*, SWD (2013) 137 final. Brussels: European Commission.
- European Commission Joint Research Centre, Institute for Environment and Sustainability (2009) *Flood risk*, Available: <http://floods.jrc.ec.europa.eu/flood-risk.html> [15 May 2013].
- FAO (Food and Agriculture Organisation) (2000) *Manual on integrated soil management and conservation practices*, Rome: FAO.
- Fiselier, J. and Oosterberg, W. (2004) *A quick scan of spatial measures and instruments for flood risk reduction in selected EU countries*, RIZA work document 2004.068x. Lelystad: RIZA Institute for Inland Water Management and Waste Water Treatment.
- Freeman, P. K., Martin, L. A., Mechler, R. and Warner-Merl, N. K. (2004) 'A methodology for incorporating natural catastrophes into macroeconomic projections', *Disaster Prevention and Management*, 13(4), pp. 337-342.
- GAO (General Accounting Office) (2005) *Catastrophe Risk: US and European Approaches to Insure Natural Catastrophe and Terrorism Risks*, GAO-05-199, Washington DC: United States General Accounting Office.
- Giannakouris, K. (2008) *Ageing characterises the demographic perspectives of the European societies, Statistics in focus 72/2008*, Brussels: Eurostat.
- Giudice, G. D., Padulano, R. and Rasulo, G. (2012) 'Factors affecting the runoff coefficient', *Hydrology and Earth System Sciences Discussions*, 9, pp. 4919-4841
- Gowing, D. (undated) *Impact of summer flooding on floodplain biodiversity via nutrient deposition*, Milton Keynes: Open University.
- Green, C. H. (2003) *A Handbook of Water Economics*, Chichester: John Wiley

- Green, C.H., Parker, D.J. and Penning-Rowse, E.C. (1993) 'Designing for Failure' in Merriman, P.A. & Browitt, C.W.A. (eds.) *Natural Disasters: Protecting Vulnerable Communities*, London: Thomas Telford.
- Green, C.H., Parker, D. J. and Tunstall, S.M. (2000) *Assessment of Flood Control and Management Options*, WCD Thematic Reviews Options Assessment: IV.4, Cape Town: World Commission on Dams.
- Green, C.H. and Penning-Rowse, 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), pp. 229-248.
- Green, C.H. and Penning-Rowse, E.C. (2007) 'More or less than words? Vulnerability as discourse', in McFadden, L., Nicholls, R. and Penning-Rowse, E.C. (eds.) *Managing Coastal Vulnerability*, Oxford: Elsevier
- Green, C., Viavattene, C. and Thompson, P. (2011) *Guidance for assessing flood losses*, CONHAZ final report, Available: www.conhaz.org.
- Guha-Sapir, D., Vos, F., Below, R. and Ponserre, S. (2012) *Annual Disaster Statistical Review 2011*, [Online], Available: https://www.munichre.com/app_pages/www/@res/pdf/natcatservice/annual_statistics/2012/2012_mrnatcatservice_natural_disasters2012_perc_distrib_event_by_type_touch_en.pdf. [15 May 2013]
- GWP (Global Water Partnership Technical Advisory Committee) (2000) *Integrated Water Resources Management*, TAC Background Paper 4, Stockholm: Global Water Partnership.
- Hallegatte, S. and Ghil, M. (2008) 'Natural disasters impacting a macroeconomic model with endogenous dynamics', *Ecological Economics*, 68(1-2), pp. 582-592.
- Hegger, D.L.T., Green, C., Driessen, P., Bakker, M., Dieperink, C., Crabbé, A., Deketelaere, K., Delvaux, B., Suykens, C., Beyers, J.C., Fournier, M., Larrue, C., Manson, C., Van Doorn-Hoekveld, W., Van Rijswick, M., Kundzewicz, Z.W. & Goytia Casermeiro, S. (2013), *Flood Risk Management in Europe: Similarities and Differences between the STAR-FLOOD consortium countries*, STAR-FLOOD Consortium, Utrecht, The Netherlands.
- Hess, T. M. and Morris, J. (1986) *The Estimation of Flood Damage Costs for Arable Crops*, Silsoe: Silsoe College.
- Homeland Security (2011) *Dams Sector: Estimating Loss of Life for Dam Failure Scenarios*, Washington: Homeland Security.
- Houthakker, H.S. (1957) 'An International Comparison of Household Patterns, Commemorating the Century of Engel's Law', *Econometrica*, 25, pp.532-551.
- Howe, C. and Mitchell, C. (eds.) (2011) *Water sensitive cities*, London: International Water Association.
- Humphreys, G. W. (1930) *The London Main Drainage System*, London: London County Council.
- Innocenti, D. and Albrito, P. (2011) 'Reducing the risks posed by natural hazards and climate change: the need for a participatory dialogue between the scientific community and policy makers', *Environmental Science and Policy*, 14, pp. 730-733.
- International Red River Basin Task Force (2000) *The next flood: getting prepared*, Ottawa: International Joint Commission.
- IPCC (2007) *Climate Change 2007: Synthesis Report*, Geneva: IPCC.
- Ison, R.L., Steyaert, P., Roggero, P.P., Hubert, N., Jiggins, J. (2004) *Social Learning for the Integrated Management and Sustainable Use of Water at Catchment Scale*. SLIM Final Report. Milton Keynes: Open University.
- Jacobs, I. M. and Nienaber, S. (2011) 'Waters without borders: Transboundary water governance and the role of the 'transdisciplinary individual' in Southern Africa', *Water SA*, 37(5), pp. 665-678.

- Jahan, S. (2000) 'Coping with flood: the experience of the people of Dhaka during the 1998 flood disaster', *Australian Journal of Emergency Management*, Spring, pp 16-20.
- JBA Risk Management/Met Office (2012) *UK Flooding April to July 2012*, Exeter: Meteorological Office.
- Jha, A.K, Bloch, R. and Lamond, J. (2011) *Cities and Flooding: A Guide to Integrated Urban Flood Risk Management in the 21st Century*, Washington DC: World Bank.
- Johnstonova, A. (2009) Meeting the challenges of implementing the Flood Risk Management (Scotland) Act 2009, Perth: Royal Society for the Protection of Birds.
- Jonkman, S.N. and Vrijling, J.K. (2008) 'Loss of life due to floods', *Journal of flood risk management*, 1(1), pp. 43-56.
- Kawanaka, R. Ishigaki, T., Kuroki, Y. and Ono, J. (2009) '1-D and 2-D Simulation of the Flow Around Discontinuous Dyke', *Advances in Water Resources and Hydraulic Engineering*, 3, pp. 993-998.
- Kobayashi, Y. and Porter, J.W. (2012) *Flood risk management in the People's Republic of China: Learning to live with flood risk*, Mandaluyong City, Philippines: Asian Development Bank.
- Kundzewicz, Z.W. (ed.) (2012) *Changes in Flood Risk in Europe*, Wallingford: IAHS Press.
- Kundzewicz, Z. W., Pinskiwar, I. and Brakenridge, G.R. (2013) 'Large floods in Europe, 1985-2009', *Hydrological Sciences Journal* 58(1), pp. 1-7.
- Landstrom, C., Whatmore, S.J., Lane, S.N., Odoni, N.A., Ward, N. and Bradley, S. (2011) 'Coproducting flood risk knowledge: redistributing expertise in critical "participatory modelling"', *Environment and Planning A*, 43, pp. 1617-1633.
- Lane, S.N., Odoni, N., Landstrom, C., Whatmore, S.J, Ward, N. and Bradley, S. (2010) 'Doing flood risk science differently: an experiment in radical scientific method', *Transactions of the Institute of British Geographers*, 36(1), pp. 15-36.
- Lang, D.J., Wiek, A., Bergmann, M., Stauffacher, M., Martens, P., Moll, P., Swilling, M. and Thomas, C.J. (2012) 'Transdisciplinary research in sustainability science: practice, principles, and challenges', *Sustainability Science*, 7 (Supplement 1), pp25-43.
- Larsen, A. N., Gregersen, I. B., Christensen, O. B., Linde, J. J. and Mikkelsen, P. S. (2008) 'Future development in extreme one-hour precipitation over Europe due to climate change', 11th International Conference on Urban Drainage, Edinburgh.
- Li, M., Shi, P., Fang, J., Nie, J. and Ye, T. (2012) 'The regional economic impact of catastrophe – case study on the China-Japan auto industry after the Great East Japan Earthquake', *paper given at International Disaster and Risk Conference Davos 2012*.
- Linham, M.M., Green, C.H. and Nicholls, R.J. (2010) *Costs of adaptation to the effects of climate change in the world's large port cities*, AVOID DECC: GAO215/GASRF 123 2009-2012, Southampton: University of Southampton/ Middlesex University.
- Lyll, C. Bruce, A. and Marsden, W. (2011) 'Identifying key success factors in the quest for interdisciplinary knowledge', *Edinburgh: ESRC Innogen Centre*, University of Edinburgh
- McCall, M. K. (2008) *Participatory Mapping and Participatory GIS (PGIS) for CRA, Community DRR and Hazard Assessment*, Enschede: ITC, Available: http://drm.cenn.org/Trainings/Multi%20Hazard%20Risk%20Assessment/Lectures_ENG/Session%2004%20Elements%20at%20risk/Background/PGIS%20for%20Disaster%20Risk%20Assessment.pdf [15 May 2013]
- McFadden, L. and Green, C. (2007) 'Defining "vulnerability": conflicts, complexities and implications for Coastal Zone Management', *Journal of Coastal Research*, 50, pp. 120-124.
- McMahon, T. A., Finlayson, B. L., Haines, A. and Srikanthan, R. (1987) 'Runoff variability: a global perspective', paper given at the IAHS Vancouver Symposium, Vancouver, August 1987, in 'The Influence of Climate Change and Climatic Variability on the Hydrologic Regime and Water Resources' (proceedings of the Vancouver Symposium, August 1987).

- Mearian, L. (2012) *Disk drive shipments rebound from Thai floods*, [Online], Available: http://www.computerworld.com/s/article/9231799/Disk_drive_shipments_rebound_from_Thai_floods. [15 May 2013].
- Merz, R. and Blöschl, G. (2009) 'A regional analysis of event runoff coefficients with respect to climate and catchment characteristics in Austria', *Water Resources Research*, 45, W01405.
- Meyer, V., Kuhkicke, C., Luther, J., Fuchs, S., Priest, S., Dorner, W., Serrhini, K., Pardoe, J., McCarthy, S., Seidel, J., Palka, G., Unnerstall, H., Viavattene, C. and Scheuer, S. (2012) 'Recommendations for the user-specific enhancements of flood maps', *Natural Hazards and Earth System Sciences*, 12, pp/ 1701-1716.
- Mishra, S.K. (2007) *A Brief History of Production Functions* [Online], 9 Oct 2007, Available: <http://ssrn.com/abstract=1020577> [13 May 2013].
- Mithen, S. (2012) *Thirst: Water & Power in the Ancient World*, London: Weidenfeld & Nicolson.
- Mitsch, W. J. and Gosselink, J. G. (2000) *Wetlands*, Chichester: John Wiley.
- Munich Re (2012) *Annual Statistics 2012*, [online], Available: http://www.munichre.com/en/reinsurance/business/non-life/georisks/natcatservice/annual_statistics.aspx. [11 June 2013].
- National Academy of Sciences (2009). *Mapping the Zone: Improving Flood Map Accuracy*, [Online], Available: <http://nationalacademies.org/wstb> [15 May 2013]
- National Salvage Vehicle Reporting Program (nd) *Advisory on Flood Damaged Vehicles*, [Online], Available: http://nsvrp.com/uploads/Combined_advisory_on_the_estimation_and_repair_of_flood_and_water_damaged_vehicles.pdf. [15 May 2013]
- Ntegeka, V., Willems, P., Baguis, P., Roulin, E., (2008) *Climate change impact on hydrological extremes along rivers and urban drainage systems*. Summary report Phase 1: Literature review and development of climate change scenarios, Belgian Science Policy – SSD Research Programme, CCI-HYDR project by K.U.Leuven – HydraulicsSection & Royal Meteorological Institute of Belgium.
- O'Connell, P. E., Ewen, J., O'Donnell, G. and Quinn, P. (2007) 'Is there a link between agricultural land-use management and flooding?', *Hydrology and Earth System Sciences*, 11, pp. 96-107.
- Office of the Deputy Prime Minister (2005) *The Economic Cost of Fire: Estimates for 2004*, London: ODPM.
- Old, G. (ed.) (2008) 'Methods to Assess, Model and Map the Environmental Consequences of Flooding', *Science Report SC060062*, Bristol: Environment Agency.
- Parker, D.J., Green, C.H. and Thompson, P.M. (1987) *Urban flood protection benefits: a project appraisers guide*, "The Red Manual", Aldershot: Gower Technical Press.
- Perry, C. A. (1994) *Effects of reservoirs on flood discharges in the Kansas and the Missouri River basins, 1993*, USGS Circular, 1120-E, Washington DC: US Geological Survey. Available: <http://pubs.usgs.gov/circ/1993/circ1120-e/> [15 May 2013].
- Piegay, H. Dupont, P. and Faby, J.A. (2002) 'Questions of water resources management. Feedback on the implementation of the French SAGE and SDAGE plans (1992-2001)', *Water Policy*, 4, pp239-262.
- Pielke, R.A., Downton, M.W. and Barnard Miller, J.Z. (2002) *Flood Damage in the United States. 1926-2000: A Reanalysis of National Weather Service Estimates*, Boulder CO: National Center for Atmospheric Research.
- Pielou, E. C. (1998) *Fresh Water*, London: University of Chicago Press.
- Pollard, S. and Du Toit, D. (2008) *Integrated water resource management in complex systems: How the catchment management strategies seek to achieve sustainability and equity in water resources in South Africa*, Association of Water and Rural Development (AWARD), Acornhoek, South Africa: AWARD.

- Porter, J. and Demeritt, D. (2012) *Flood Risk Management, Mapping and Planning: The Institutional Politics of Decision-Support in England*, KULTURisk, [Online], Available: www.kulturisk.eu [15 May 2013].
- Resilience Alliance (2007) *Assessing Resilience in Socio-Ecological Systems: A workbook for scientists*, Stockholm: Resilience Alliance.
- Rose, A. and Liao, S-Y. (2005) 'Modeling Regional Economic Resilience to Disasters: A Computable General Equilibrium Analysis of Water Service Disruptions', *Journal of Regional Science*, 45(1), pp. 75-112.
- Schneider, C. Laize, C. L. R., Acreman, M. C. and Florke, M. (2013) 'How will climate change modify river flow regimes in Europe?', *Hydrology and Earth Sciences*, 17, pp. 325-339.
- Shaikh, A. (1974) 'Laws of Production and Laws of Algebra: The Humbug Production Function', *The Review of Economics and Statistics*, 56(1), pp. 115-120.
- SIC adapt! (2013) *Adaptation to the Spatial Impacts of Climate Change: Policy Recommendations*, INTERREG IVB NEW Strategic Cluster, [online], Available: www.sic-adapt.eu [15 May 2013].
- Stiglitz, J. E., Sen, A. and Fitoussi, J-P. (2009) *Report by the Commission on the Measurement of Economic Performance and Social Progress*, Paris: Commission on the Measurement of Economic Performance and Social Progress, Available: www.stiglitz-sen-fitoussi.fr. [15 May 2013].
- Taylor, A.H. (2011) *The Dance of Air & Sea*, Oxford: Oxford University Press.
- Technical Support Unit (2003) *Integrated Flood Management: Concept Paper*, The Associated Programme on Flood Management, Geneva: World Meteorological Organization/Global Water Partnership.
- Te Linde, A.H., Aerts, J.C.J.H. and Kwadijk, J.C.J. (2010) 'Effectiveness of flood management measures on peak discharges in the Rhine basin under climate change', *Journal of Flood Risk Management*, 3, pp248-269.
- Turner, M.A., Varghese, R. and Walker, P.D. (2011) *Louisiana Small Businesses Five Years Post-Katrina: Assessing LDRF Program Impacts and Measuring Existing Needs*, Durham NC: PERC.
- UNEP (2011) *Decoupling natural resource use and environmental impacts from economic growth*, Nairobi: UNEP.
- Van de Van, G. P. (ed.) (2004) *Man-made lowlands: History of water management and land reclamation in the Netherlands*, Utrecht: Matrijs.
- Van der Heijden, K. (1996) *Scenarios*, Chichester: John Wiley.
- Van Dijk, J. (2006) 'Water assessment in the Netherlands', *Impact Assessment and Project Appraisal*, 24(5), pp199-209.
- Wainwright J and Parsons A J (2002) "The effect of temporal variations in rainfall on scale dependency in runoff coefficients", *Water Resources Research*, 38(12), pp. 7-1-7-10.
- Wejnert, B. (2002) 'Integrating Models of Diffusion of Innovations: A Conceptual Framework', *Annual Review of Sociology*, 28, pp. 297-326.
- Werrity, A., Black, A., and Duck, R., Finlinson, B., Thurston, N., Shackley, S. and Crichton, D. (2002) *Climate Change: Flooding Occurrences Review*, Edinburgh: Scottish Executive Research Unit.
- White, G.F. (1964) *Choice of Adjustments to Floods*, Research Paper No. 93, Chicago: University of Chicago, Department of Geography.
- Wieczorek, G.F., Larsen, M.C., Eaton, L.S., Morgan, B.A. and Blair, J.L. (2001) *Debris-flow and flooding hazards associated with the December 199 storm in coastal Venezuela and strategies for mitigation*, US Geological Survey, [online], Available: <http://pubs.usgs.gov/of/2001/ofr-01-0144/>. [11 June 2013].
- Williams, L., Harrison, S., O'Hagan, A. M. (2012) *The use of wetlands for flood attenuation*, Cork: Aquatic Services Unit, University College Cork.

World Commission on Environment and Development (1987) *Our Common Future*, Oxford: Oxford University Press.

WWF (2007) *Flood Planner: a manual for the natural management of river floods*, Dunkeld: WWF.

