Floods – vulnerability, risks and management
- a joint report of ETC CCA and ICM

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Floods – vulnerability, risks and management

General goal: Teasing out the main messages from individual studies

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Contents

1. Introduction

This report describes floods in a European context. Flooding in the sense of land being covered temporarily by water is a natural event. Many human activities and natural ecosystems benefit from and are even dependent on flooding. Adverse consequences arise when water masses cover or destroy structures and interfere with activities that do not cope with inundation. The EU Directive on Flood Risk Assessment and Management on 23 October 2007 (Floods Directive)[1] specifically addresses this problem at the EU level. The white paper "Adapting to climate change: Towards a European framework for action"[2] also identifies flooding as one of the issues that need to be considered in planning for the future.

Catastrophic events prove again and again, that our knowledge of probabilities and consequences of flooding are approximate at best. Furthermore, in the face of climate change the past is no longer a reliable guide to the future, and flood risk assessment, like natural hazards and disaster management, more generally, can no longer be based on the classical assumption of stationarity (cf. also Milly et al. 2008). Both the natural and the social sphere are changing and as a consequence also the risk and impacts of floods.

The purpose of this report is to highlight factors that contribute to the occurrence and adverse consequences of floods, and possibilities to reduce flood risks from inland waters and rainfall. It includes a discussion on the possibilities to detect changes in flood patterns and illustrates how different scenarios for climate change may affect vulnerability to floods and flood risks.. The report provides illustrative examples of flood risk management from the local to European level.

2. Floods and their impacts

Floods are complex phenomena with respect to origin, predictability, risk and consequences. A flood event as defined by the EU Floods Directive is simply the temporary inundation of land not normally covered by water.[3] Floods are usually, although not exclusively, caused by extreme weather, leading into local accumulations of rainwater or overflowing of streams and other bodies of water. Impacts arise as a consequence of the spreading and movement of the water masses. In the riverine environment, floods often have mixed impacts. They may produce benefits to some parts of the ecosystem and damages to some other parts. Regular annual floods provide water

[1] http://ec.europa.eu/environment/water/flood_risk/index.htm [May 20 2011]
[2] White Paper - Adapting to climate change: Towards a European framework for action. COM(2009) 147 final. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2009:0147:FIN:EN:PDF [August 15 2011]
[3] Directive 2007/60/EC, Chapter 1, Article 2

resources for human use and carry nutrients supporting agricultural production on flood plains.

Adverse impacts depend on the vulnerabilities of the area in question. The vulnerability of an area develops over long time frames but the impacts usually arise suddenly when the flooding passes critical thresholds. Flood damage could be greatly reduced by avoiding building close to rivers and other bodies of water, but there is often a high perceived value of living near water. Flood damages can, however, also arise due to localised extreme rainfall far from any water bodies. A good understanding of flood damages is a pre-requisite for developing efficient disaster prevention policies (EC, 2009).

2.1. Types of flooding, exposures and vulnerability

The reduction of flood risks requires an adequate understanding of the nature of the floods. A classification of different types of floods helps to identify certain characteristics that one needs to pay attention to in efforts to reduce flood risk.

Any classification of floods is somewhat arbitrary, but distinctions can be made e.g. between the following types of floods:

- Fluvial flooding. Water levels in a channel, lake or reservoir rise so that water covers nearby areas, which normally are dry land. A fluvial flood may be caused by heavy or persistent rain, snowmelt or ice jam, sometimes also by debris jam, landslide or other blockage of the channel. Flooding can be a regular feature of the yearly hydrological cycle, but rivers have different patterns of flow and the severity of flooding varies. Antecedent conditions (soil moisture, groundwater stage) may also considerably affect the severity of the flood. As to the reliability of forecasts, fluvial floods are easier to handle than other flood types.
- Pluvial flooding. Flooding resulting from intense localised rainfall, and is often considered more difficult to predict than fluvial flooding due to the difficulty in predicting rainfall patterns, lack of data on the actual hydrological status, and the short lead-times. This type of flood is intensified when the ground is saturated, frozen, compacted, paved or otherwise has low permeability. Pluvial floods often occur in urban environments and they are combined with flooding from sewers or small watersheds. Urban pluvial floods often arise due to a combination of land sealing and insufficient capacities of sewers and drainage systems.
- Flash flooding. When the inundation is very rapid, it is called flash flooding. Some pluvial floods can be classified as flash floods, particularly if heavy rain has fallen in the upper part of the catchment and a flood wave surges downstream to areas where it may not have rained at all. But in addition to pluvial origin, there are many other causes of flash floods: river or lake outbursts (linked e.g. to

landslides or ice jams), lahars and jokulhaups[4] (linked to volcanic activity), overflowing of karstic formations, dam-breaks and snow-slush flows. The forecasting of flash floods is often extremely difficult due to the same factors as mentioned under pluvial flooding.

- Coastal flooding. Sea level exceeds normal stage due to storm surges, exceptional tides or tsunamis. Flooding in deltas and river mouths may be caused by a combination of fluvial flooding with storm surges or otherwise exceptionally high sea level. Forecasting is difficult but risk analyses can be performed using models. Coastal flooding due to sea level rise, storm surges or tsunamis are covered in the (forthcoming) EEA report on coasts.
- Groundwater flooding. Underground water may emerge from either point or diffuse locations. This can be a consequence of e.g. persistent rains, high sea levels or land subsidence. If adequate data exist on groundwater flow forecasting is feasible.
- Dam failures. Man-made dams may fail due to different causes: inadequate spillway design, geological instability, internal erosion, frost damage, poor maintenance, landslides to the reservoir. The flood may be devastating, often a flash flood type. The flooding material may contain significant amounts of other substances than water such as harmful sludges. Dam failures can be modelled and assessed in advance through risk analysis, but not forecasted.

The first three flood types may occur almost everywhere in Europe. Due to the topography and the patterns of rainfall the risk of flash floods is highest in Mediterranean and mountain areas, and coastal flooding has caused largest damages in low-lying areas around the North Sea.

2.2. Factors affecting floods and flood risks

The hydrology and flood hazard (magnitude and frequency) are strongly influenced by local factors at the catchment scale such as the spatial-temporal distribution of rainfall, catchment topography, soil types and the proportion of lakes in the catchments. In addition to these basic hydrological factors, the development of land-use and infrastructure interventions (e.g. reservoirs and flood defences) also affects the flood hazard.

Few pan-European assessments of land-use impacts on catchment flood response have been undertaken, but general observations of the direction and magnitude of change can be made. The following sections describe how human activities in the form of urbanisation and land use changes influence flood risk.

[4] lahar= A landslide or mudflow of volcanic fragments on the flanks of a volcano; jokulhaup= the flood of water etc that occurs when a volcano erupts underneath a glacier.

Urbanisation

Urban areas are often particularly vulnerable to floods. Both pluvial and fluvial floods can cause significant impacts. The development of the urban form affects the vulnerability.

Increasing urbanisation results in an increase of the proportion of impermeable areas. In hydrological terms, the effects of urbanisation on catchment flood response is therefore generally considered to be an increase in runoff volume and a decrease in catchment response time; both resulting in increased peak flow. Analysis of flood data has verified this perception, and has also indicated that the effects are mostly recorded for small to medium size floods, whereas the effects become less important for large floods (e.g. Hollis, 1975; Kjeldsen, 2010). It is also clear that the effect of urbanisation is conditional on the pre-urban conditions of the catchment. For example, introduction of impervious areas on already responsive soils and landscapes is likely to have a less dramatic effect on the downstream flood response than the equivalent impervious area in a catchment dominated by a non-responsive soil type.

Flood risks are not only affected by factors that influence the hydrology. Urbanisation also affects the vulnerability as shown by the case of Athens (Box 1). The rapid urbanization Greater Athens (Box/Figure 1), peaking in the 1920s due to refugees and internal immigration, resulted in both an increase in flood occurrence (due to decreasing permeability, and the modification of urban streams) and a socio-economic segregation of the population of Athens, which still evident, to some extent, today. (Evelpidou et al. 2009) This latter effect increased flood risk due to increased adverse consequences for vulnerable populations. Urban floods also have elevated risks of adverse consequences such as the spread of diseases and pollution of water when sewers overflow and pollutants leach into the flood water.

Box 2.1: Flooding in Athens

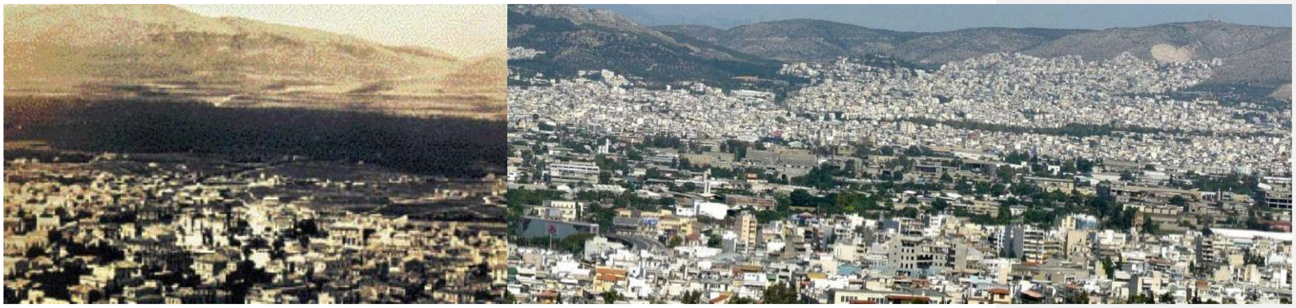

Figure 1a: Western Athens (1870) **Figure 1b: Western Athens (2007)**

The intense development of the wider Athenian urban complex, led to the degradation of many tributary streams, with the Kephisos River being the most important (Evelpidou et al., 2009). Although the river still drains 70% of its natural catchment, it suffered much due to a significant decrease in its width as a result of illegal dumping and illegal construction/industrial development on its banks (Figure 2).

Figure 2a: Structures on river bed

Figure 2b: Roads and houses on river bed

Furthermore, due to its topography (steep slopes) and climate (intense, short duration rainfall) Athens is often subject to flash floods. This increases risk - particularly in view of its significant population density: 3.000.000 people live within the 300 km^2 catchment of the Kephisos River. A total of 145 significant flood events have been reported between 1887-2007 in which more than 250 people have died, and with damage estimates in the order of hundreds of millions of euro with a surprising consistency in their location and recurrence. As can be seen in Figure 3, the implementation of flood mitigation measures in the 1990s resulted in small decrease of flood risk in some upstream areas but did not manage to eliminate main problems close to the Kephisos. Furthermore, the continuous urbanisation of the eastern suburbs and the coast increased flood risk in new areas (Kandilioti and Makropoulos, 2011)).

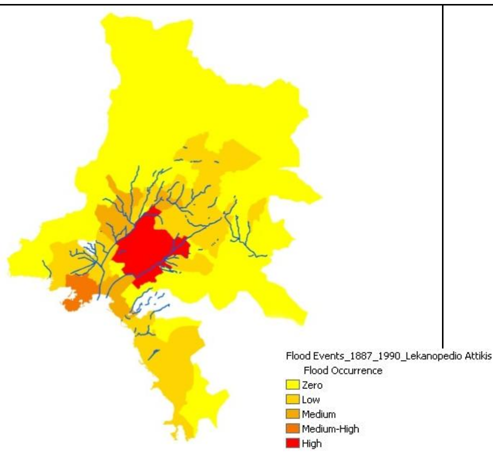

Figure 3a: Flood hot-spots between 1887-1990

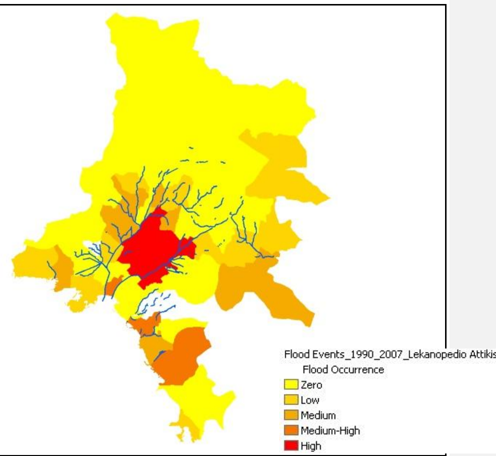

Figure 3b: Flood hot-spots between 1990-2007

Although the most recent flood event that resulted in loss of human life was in 1994 (with 9 deaths reported and a state of emergency declared for the city of Athens), there is no reason to suggest that such catastrophic events could not happen again, despite improvement in emergency planning, flood protection and awareness raising (Papathanasiou et al., 2009). This is because major flood management interventions in the main urban rivers (such as Kephisos) are still wanting. However, community hubs, such as the Kephisos River Managing Authority are attempting alliances at the local level between local authorities, business and general public initiatives and pressure groups to raise the profile and reveal the true nature of the problems pushing for control of illegal activity coupled with economic and environmental regeneration of the area.
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Land use management: Agriculture and forestry

Historically land use changes that have converted forests and wetlands to agricultural land have affected the hydrology of watersheds. The influence of more recent agricultural land-use management changes on the flood generating processes is often difficult, if at all possible, to detect in observed flood series.

In the UK, Defra (2008) concluded that there was little or no evidence linking agricultural land-use change to changes in catchment flood response. Similarly, Pfister et al. (2004) and O'Connell et al. (2006) both concluded that while land-use change might affect flooding in small catchments (headwaters), no evidence could be detected in observations on the larger river basin scale such as that of the rivers Meuse and Rhine (Pfister et al. 2004). Given the importance of agriculture and food production in Europe, more scientific research is needed on the link between flood risk and land-use from a larger sample of catchments covering a wider range of geographical and climatological conditions as well as agricultural practices within Europe.

The role of forests in controlling flooding is a complex issue spanning a variety of sectors in society with conflicting aims (e.g. Calder and Aylward, 2006; Laurance, 2007; with reply from Calder et al., 2007). As with more general land-use management issues, the discussion often concerns at what spatial scale and severity of flooding an impact can be detected. Forests constitute a major, but diverse, land-use component across Europe, conditioned by geographical and climatological factors as well as national differences. In a study of 28 forested catchments from across Europe, Robinson et al. (2003) concluded that on a broad European or regional scale, the effects of forests on extreme flows are relatively small. They further concluded that except for the particular cases of managed plantations on poorly drained soils in NW Europe and Eucalyptus in Southern Europe, forestry appears to have a minor role to play in managing regional or large-scale flood risk across Europe.

2.3. Impacts of major floods

Catastrophic floods have occurred throughout Europe, affecting thousands of people. Fatalities have occurred and the economic losses have been significant.

The occurrences of catastrophic floods on a local or regional scale are too numerous to describe in detail. Lists of recent events were compiled by EEA (2001) and EEA (2010). Across Europe, the occurrence of damaging floods has always been an ever-present peril. Several recent studies have documented historical flood events in Europe; in some cases going back several centuries (e.g. Brázdil et al., 2006; Macdonald and Black, 2010; Glaser et al, 2010). Most of the large-scale disastrous events were caused by prolonged periods of heavy rainfall, often coinciding with ice-breaking or snow melt (Glaser et al., 2010). Examples of major flood events in Europe include: February 1784 (Ellede, 2010), 1824 (Burger et al., 2006), 1997 (Kundzewicz et al., 1999), 2002 (Becker and Grünewald, 2003; Ulbrich et al. 2006).

The EM-DAT[5] Database contains floods fulfilling at least one of the following criteria:

- ten or more people reported killed
- one hundred or more people reported affected
- declaration of a state of emergency
- call for international assistance.

The EM-DAT Disaster Database, has documented 272 flood disasters in Europe (excluding Russia)from 2000 to 2010 . These floods have caused840 fatalities, affected more than 2.7 million people and caused economic damages amounting to more than 42 billion euro.

In economic terms, the two worst events in this millennium have been the Elbe and Danube flood of 2002 and the UK floods in 2007, which caused damages of 15 and 6.5 billion euros, respectively. Variations from year to year are large; in 2001, 2004, 2006, 2008 and 2009 total flood damages in all the countries that currently are members of the EU (EU27) were below one billion euros. Examples from outside the EU include floods in the Krasnodar region of Russia in summer 2002 which killed 258 people and affected almost 400,000 and flooding in Switzerland in August 2005, resulting in 6 casualties and 2.5 billion Swiss francs of damages.[6]

In the period of 2000-2010 European countries have been unevenly hit by floods (Table 1). The Mediterranean region, UK and the Black Sea have been most frequently exposed to flood disasters. The relationship between different types of impact is not linear. Thus Romania had the worst floods in terms of fatalities with more than 220 deaths directly caused by flooding in this period but the corresponding costs rank 9th in Europe. In

[5] http://www.emdat.be/database (Accessed October 30 2011)
[6] http://www.bafu.admin.ch/hydrologie/01834/02041/02043/index.html?lang=en (Accessed Oct 27 2011)

general there is very poor correlation between the costs and the number of fatalities (Fig. 1) suggesting that flood risks are complex phenomena.

Table 1. Number of flood disasters documented in the EM-DAT-data-base for 2000-2010 in Europe, excluding Russia.

Country	Number of documented flood disasters
Romania	31
France	19
Italy	17
Greece	15
United Kingdom	15
Bulgaria	12
Czech Rep	9
Hungary	9
Spain	9
Bosnia-Hercegovenia	8
Slovakia	8
Belgium	7
Germany	7
Poland	7
Ukraine	7
Austria	6
Croatia	6
Macedonia FRY	6
Portugal	6
Serbia Montenegro	6
Albania	5
Serbia	5
Moldova Rep	4
Montenegro	4
Switzerland	3
Canary Is	2
Ireland	2
Lithuania	2
Norway	2
Finland	1
Slovenia	1

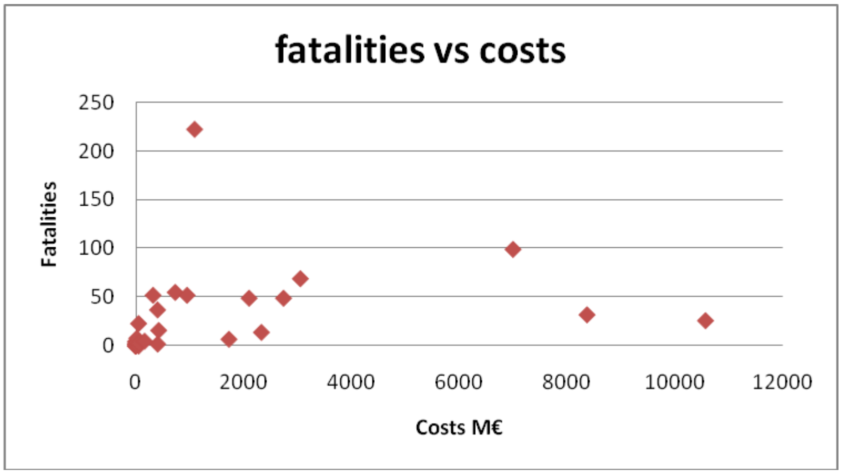

Fig. 1. Relationship between number of fatalities and the costs of the disasters. Data from the EM-DAT database on flood disasters in Europe, excluding Russia, in the period 2000-2010.

Flood damages can be divided into direct damages inside the flooded area and indirect damages occurring outside. Another distinction is made between tangible damages that can be priced, and intangible damages for which no market prices exist. The spectrum of damages is wide and includes economic, political, social, medical, psychological, ecological and environmental aspects. These cannot be analysed separately, because they form a complex network in today's societies. The flood damages are magnified particularly by higher population or more intense economic activities in flood-prone areas.

The flooding experienced in the UK in the summer of 2007 illustrates how flooding can affect multiple aspects of society as documented by Marsh and Hannaford (2007). The flood events were in large parts caused by three storms of record-breaking magnitude and spatial extent. For example, the storm of 19-20 July produced up to 140mm of localised rainfall, estimated to have an annual probability of approaximately 1 % (a “100-year flood”). The resulting river flood peaks exceeded previous maximum recorded flow in numerous locations, and in several places the levels exceed those to be expected for a 1 % annual probability.

The extensive flood damages caused by the unusual conditions in the UK are well-documented. Over 55,000 homes and 6,000 businesses were flooded; the related insurance claims were approaching £3 billion by late-2007. Many flooded and low-lying localities had to be evacuated. Flooding affected more than 300 schools and structural damage to transport and utility infrastructure was common: more than 100 sewage treatment works were affected and over 300,000 people were relying on bottled water for several weeks. Power supplies for over 40,000 homes were interrupted while temporary flood defences had to be installed at an electricity sub-station. In many towns and cities commercial activities were badly affected, too and there were significant local impacts on tourism. The extensive floodplain inundations caused widespread damage to maturing crops and required the removal of livestock to higher ground. Disruption to road and rail transport was extensive and sustained. A breakdown of the total economic costs[7] showed that households and businesses accounted for the bulk (66%) of the overall damages; followed by power and water utilities (10%); public health costs (9%); communications (7%); local government costs (7%); agriculture (2%); and emergency services (1%). Most of the health impacts were mental health costs based on estimates of people's willingness to pay to avoid exposure to the distress caused by flooding. Other health impacts of floods typically include direct injuries and outbreaks of communicable diseases and infections. Indirect effects caused by the disruption of health care services, water treatment or sewage disposal may in some cases be more serious than the direct impacts.

Total flood damages have increased in Europe over the last few decades. This trend can be attributed to socio-economic, rather than climatic, factors, such as changes in population, wealth and inflation (Barredo, 2009). Improved data collection and better reporting may also have contributed to the overall trend.

2.4. The risks of dams

Dams and reservoirs play a vital role in flood management. Especially in multipurpose projects, dams are frequently built for flood mitigation. However, devastating floods have also been caused by dam failures.

A dam failure is defined by the International Commission on Large Dams (ICOLD) as the collapse or movement of part of a dam or its foundation, so that the dam cannot retain water. There are several data bases on dam failures. DSDF-VIENNA has information on 323 failures of large dams, 445 failures of small dams and 133 failures of tailing dams since 1980[8,9]. According to the ICOLD[10], the most common cause of failure of earth and rockfill dams is overtopping (31%), followed by internal erosion in the dam itself (15%) or in its foundation (12%). With masonry dams, the most common cause is overtopping (43%) followed by internal erosion in the foundation (29%). Hydrotechnically, inadequate spillway capacity is often the factor which triggers the chain of events leading to a dam failure.

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[7] Environment Agency (2010) The costs of the summer 2007 floods in England. Final Report SC070039/R1, Bristol, UK.

[8] http://www.risk-assessment.at/en/we/services_bhdf.asp [6.7. 2011]

[9] EEA 2010. Mapping the impacts of natural hazards and technological accidents in Europe - An overview of the last decade. EEA Technical report No 13/2010.

[10] http://www.icold-cigb.net/ [6.7. 2011]

Analyses of dam failures can be very difficult, with many historical events not completely understood. The principal uncertainties in determining the outflow from a dam failure involve the mode and degree of failure. Special consideration should be given to the following factors:

- Size and shape of the breach
- Time of breach formation
- Hydraulic head
- Storage in the reservoir
- Reservoir inflow

In certain cases a dam failure can cause domino-like failure of downstream dams. Catastrophic consequences downstream are also possible with only a minor damage to the dam itself, e.g. if a landslide hits a reservoir. This was the case in Italy in 1963, when a huge landslide caused 50 million m^3 of water to overtop the Vaiont Dam, killing around 2,000 people in the river valley. The dam with a height of 260 m was damaged only slightly at the top.

2.5. Have the frequencies of flooding changed over time?

An important question for flood risk managers is to establish if the flood hazard has changed in recent decades. Available evidence suggests different patterns across Europe with increasing high flows in northern Europe, especially in western Britain and coastal Scandinavia. Regional patterns are, however, diverse, with many weak negative trends also occurring in northern Europe, and a very mixed pattern in central Europe.

In many of the regional or national studies, trends in hydrological records are associated (either qualitatively or quantitatively) with changes in atmospheric circulation patterns. Recent observed trends in central Europe are linked to changing circulation types, in particular an increase in westerly airflows (Petrow and Merz, 2010). Floods have been linked to circulation types in a number of studies (Petrow et al., 2010; Bouwer et al., 2008) and evidence suggests patterns of higher and lower flood frequency may be driven by changes in circulation patterns over long timescales (Schmocker-Fackel et al., 2010; Jacobeit et al., 2003). The North Atlantic Oscillation (NAO) has long been recognised as one of the primary drivers of European climate, and a number of studies have shown links between the NAO Index (NAOI) and streamflow at a European scale (Shorthouse and Arnell, 1999; Bouwer et al., 2008; Wrezinski and Paluszkiewicz, 2011).

Climate variability associated with the NAO has been cited as a likely driver of observed high flow trends in some national-scale studies. In the UK, Hannaford and Marsh (2008) found relationships between the NAOI and high flow indicators in western Britain, which is likely to influence the upward trends seen in these areas; Maraun et al. (2011) reach a similar conclusion in studies of extreme rainfall in the UK. The NAO has also been posited as a mechanism for influencing streamflows in central Europe. Villarini et al. (2011) found the NAO to be a significant factor explaining patterns of extreme flooding in Austria, although other studies of NAO influences on flooding in central Europe have been less conclusive (e.g., Bouwer et al., 2008; Schmocker-Fackel et al., 2010). The association of flooding with modes of large-scale atmospheric circulation raises the question whether recent changes in flood frequency reflect anthropogenic climate change or the influence of multi-decadal variability. These two factors are not mutually exclusive, though, since modelling studies suggest that the recent evolution of large-scale teleconnection patterns such as the NAO is also driven by anthropogenic forcing (e.g., Gillet et al., 2002; Dong et al., 2011).

The intensification of the hydrological cycle associated with global warming (Huntington, 2006) is expected to cause changes in intense rainfall although local variation can be significant. Rain gauge observations and reanalyses have shown an upward trend in mean rainfall, and an attendant increase intense rainfall, in many areas of Europe in the latter part of the twentieth century (Klein Tank and Konnen, 2003; Zolina et al., 2010). Recent global-scale studies have suggested that observed increases in rainfall (Zhang et al. 2007) and intense rainfall (Min et al. 2011) can be attributed at least partly to anthropogenic greenhouse gas emissions. Detection of a climate signal in hydrological observations of flood frequency is, however, extremely difficult due to the confounding effect of long-term natural variability in climate, human disturbance of catchments and river systems, as well as the relatively short period of observation in most rivers. It is important to remember that failure to identify statistically significant trends in hydrological time series is different from proving that underlying trends are not present at all (Radziejewski and Kundzewicz 2004).

A recent analysis of the floods in England and Wales in autumn 2000, based several thousand climate simulations, has shown that, for this event, anthropogenic climate change due to twentieth century greenhouse gas emissions very likely increased the risk of flood occurrence (Pall et al., 2011). The precise magnitude of this contribution remained uncertain, but in nine out of ten cases the model results suggested it was at least 20%. It is important to note, though, that many factors, anthropogenic and natural, contribute to the development of a particular flood event, and that attributing an individual event solely to climate change is not appropriate (Pall et al., 2011).

A European-wide comparison of results of local and regional studies is hampered by the wide range of different catchment selection procedures, analysis methodologies and study periods used. This led Stahl et al. (2010) to assemble a dataset of 441 catchments with near natural flow regimes from 15 countries, and analysed trends from 1932, 1942, 1952 and 1962 to 2004. These authors found evidence of increasing annual runoff in northern Europe, and decreasing runoff in southern Europe. Studies of monthly flow revealed increases were strongest in the winter half year, whereas in summer, flow has decreased across most of Europe. In a companion study, Stahl et al. (2011) analysed trends in 7-day maximum flows in the same dataset. The overall pattern found largely confirms the results of national studies – increasing high flows in northern Europe, with steepest trends in western Britain and coastal Scandinavia – but regional patterns are very mixed, with many weak negative trends also occurring in northern Europe, and a very mixed pattern in central Europe (Fig.2).

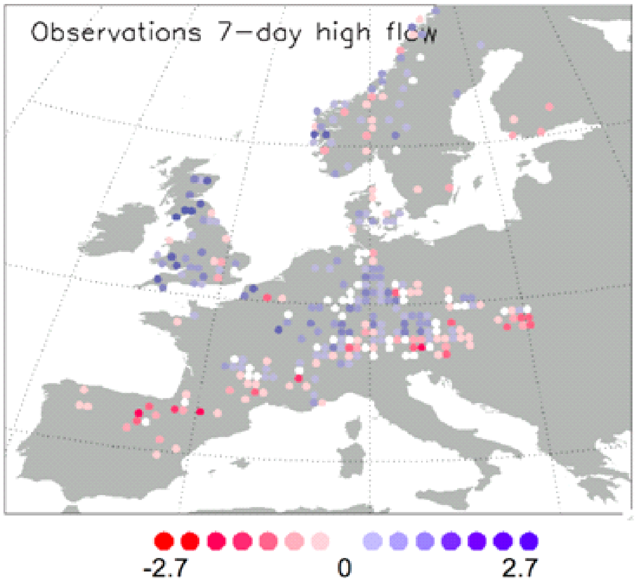

Fig 2: 7-day maximum trends across Europe, 1962 – 2004 (Stahl *et al*. 2011). Blue circles denote positive trends, red circles negative, with trend magnitude expressed in standardized units.

3. Flood Risk Management – risk analysis, assessment and governance

Flood risk management is a demanding task that requires careful analysis of the risks and their causes, assessments of the magnitude of the risks, systematic planning to reduce risks and adaptation in the face of possible change. Flood risk management requires an appropriate institutional base, technical solutions and functioning governance structures. The need for adaptation to climate change has raised an interest in alternative cost efficient approaches to flood risk management.

3.1. From flood protection towards integrated flood risk management – an overview

Traditionally flood control and protection have emphasised the design and erection of flood defences. A shift from flood control and protection relying exclusively on

flood defences towards a more integrated flood risk management can be observed in many countries across Europe, but the change has been slow.

It is impossible avoid all flood damages no matter how large investments are made in flood defence. Management strategies relying exclusively on cost-intensive technical measures and reactive top-down approaches based on large-scale engineering are regarded as an out-dated way of dealing with floods (Samuels 2006, Coninx 2008). The construction and maintenance costs of such infrastructure projects are often considerable. With the increasing awareness of the links between large-scale interventions, society and the ecosystems, there has been a general call to view flood defence in a more sustainable perspective (AFPM, OECD 2008, EC 2008, Kundcewicz, 2002). Furthermore, it becomes increasingly evident that damages seem to increase mainly due to an accumulation of assets in former flood plains that are at risk when flood defences fail (Barredo et al. 2007).

There is a search for more ***integrative, pro-active and holistic approaches,*** which include a portfolio of soft-engineering, non-structural measures (EEA 2010). Such approaches attempt to consider the complex interactions in the Source-Pathway-Receptor-Consequences (SPRC)[11] chain, the impacts of climate change and also the multiplicity of actors. The remaining risks need to be acknowledged and a tolerable degree determined with the help of societal agreements. In this way, integrated flood risk management is supposed to be able to solve conflicting interests and use synergies by making more efficient use of restricted resources (Coninx 2008).

The change in approach is increasingly reflected in many policies, strategies and projects from the local to the global level. At the EU-level strategies and legislation such as the Water Framework Directive, the Habitats Directive and the Common Agricultural Policy can support the development of green infrastructure.[12] Climate change adaptation is also closely linked to floods. European Member States and specific plans, strategies and programmes (on different administrative levels) can also support new approaches to flood risk management. National strategies such as “Making space for water” in the UK (DEFRA 2004), “Room for the River” in the Netherlands (Brouwer 2001) or other projects under the theme “Living with floods or water”, (Robinson 2007, WWF 2004) clearly communicate the willingness to develop a wider range of approaches to floods management.

EU Floods and Disaster Prevention Policies

In order to further promote Floods and Disaster Prevention Policies and introduce and realise such flood risk management in all European Member States, the ***Floods Directive*** was adopted. It developed from the “Communication on Flood risk management – flood prevention, protection and mitigation” (COM(2004) 472final of 12.7.2004) and can be seen as a contribution to the Hyogo Framework for Action (UN/ISDR 2007). Additionally, the European Commission recently released the Communication on 'A Community approach to the prevention of natural and technological disasters' (EC,

[11] see for example http://www.floodsite.net/html/faq2.htm [Sept 7 2011]

[12] Green Infrastructure. http://ec.europa.eu/environment/nature/ecosystems/index_en.htm [August 15 2011]

2009a). At a national level, one major activity has been the establishment of national strategies and national platforms for disaster risk reduction. National Platforms are multi-stakeholder national mechanisms that serve as an advocate for disaster risk reduction at different levels, from communities to the national institutions. So far, 16 European countries have established such a platform, and many more countries have established official Hyogo Framework Focal Points. In Europe, representatives of National Platforms and HFA Focal Points regularly meet at the regional level at least once a year. The meetings are hosted by a European country and are supported by UNISDR and the Council of Europe European and Mediterranean Major Hazards Agreement (EUR-OPA) (CoE, 2010). In November 2009, European HFA Focal Points and National Platform coordinators agreed to establish a European Forum for Disaster Risk Reduction (EFDRR).

The development from technical flood protection towards integrated and risk-based management is not taking place with the same intensity and at the same level across Europe. The preamble and the articles of the Floods Directive refer to integrated approaches and the literature on green infrastructure also deals with possibilities to develop more adaptive solutions to flooding problems. In practice the focus on engineered flood defences and fluvial flooding has remained strong. The actual flood risk management plans that are due by 2015 will show if a shift in approaches to flood risk management and a greater recognition that not all floods can be dealt with through engineered defences will have indeed occurred.

In the following sections the ***implications of a change*** of focus in flood risk management are further specified by focusing particularly on the establishment of risk-based approaches to managing floods (Section 3.2); on the development of a flood risk management cycle (Section 3.3); specific issues related to dam safety and urban flood management (3.4 and 3.5); on the inclusion and diversification of actors involved in flood risk management (Section 3.6), and on the consideration of new polices, measures and strategies allying with ideas of resilience and adaptation (Section 3.7).

3.2. Risk-based approach to managing floods

A risk based approach to flood management combines event probabilities and design standards with considerations of wider economic, ecological and social consequences for specific areas – including residents, infrastructures, organisations and ecosystems.

In many countries risk-based approaches are currently being developed. Risk-based management can become a central instrument in the transition towards more integrative and systematic approaches. It allows an identification of how risks should ideally be reduced, and which level of protection is appropriate in terms of cost-benefit ratios and other social, economic and environmental considerations.

A risk-based management approach analyses, evaluates/assesses, and reduces risks (Kaplan and Garrick 1981, Merz & Emmermann 2006, Bründl et al. 2009). Appropriate review/monitoring and controlling mechanisms should also be established. (DEFRA 2009, PLANAT 2009)

The Floods Directive uses a three-step approach to floods[13]:

1. Carry out ***preliminary flood risk*** (analysis and) ***assessment*** (PFRA) by 2011 for "*those areas for which they [the member States] conclude that potential significant flood risks exist or might be considered likely to occur*" (Article 5.1). Flood hazards (including the also the conditions and capacities of the current defence system), exposures, vulnerabilities and resulting risks are calculated as a product of the probability of flood events and their consequences and assessed. Assessment means also what level of risk is acceptable and how the risk could be reduced as a function of the effort and money that can be spent. Potential exposures and vulnerabilities of the elements at risks, and the capacities, measures and instruments already available and in function should be explored (Merz 2006). Historical data (Chapter 2), modelling, quantification of uncertainties, scenarios (Chapter 4), and the governance need to be considered.
2. Preparation of ***flood hazard maps*** (FHMs) and ***flood risk maps*** (FRMs) by 2013. These maps should identify areas with a medium likelihood of flooding (at least 1% annual probability) as well as extreme (or low likelihood) events. Water depths should also be shown. In areas identified as being at high risk, the number of inhabitants potentially at risk, the economic activity and the environmental damage potential must be indicated. They will later be part of the flood risk management plans, undergoing updates if the risks change.
3. Establishment of ***flood risk management plans*** (FRMPs) for areas with a significant high risk by 2015 that are to include and prioritise measures to reduce the probability of flooding and its potential consequences by addressing all phases of the flood risk management cycle, particularly focusing on prevention, protection, and preparedness. Due to the nature of flooding, much flexibility on objectives and measures are left to the Member States in view of subsidiarity. Risks should be assessed with reference to individual and collective perceptions and weighing of the acceptance / tolerability of certain risks. This complements the description of the physical flood processes described in the analysis (e.g. Wachinger & Renn 2011, Schanze 2006). Objectives and different evaluation criteria are ideally identified and selected in this phase.

Integrated approaches that include these steps have been developed Switzerland, the UK and to a certain degree the Netherlands and some German States (Bründl et al. 2009, DEFRA 2005, VenW 2006, Lebensministerium Bayern 2005, Müller 2010). Even in these countries, large amounts of resources are being invested in technical solutions without fully considering all alternatives. In the best cases technical solutions are part of an integrated approach, but often they may dominate "softer" approaches that could be more cost effective in the long run.

[13] http://ec.europa.eu/environment/water/flood_risk/index.htm [May 20 2011]

3.3. The Flood Risk Management Cycle

Practical flood risk management is a continuous process. It includes the planning and execution of preventive measures, crisis management and post flood management. Historical flood events also provide feedback that lead to the readjustment of measures and actions in all parts of the management process.

The **risk management cycle**[14] **includes** three main: preventive measures, flood event management and post-flood measures. (Müller 2010, (Fig. 3).

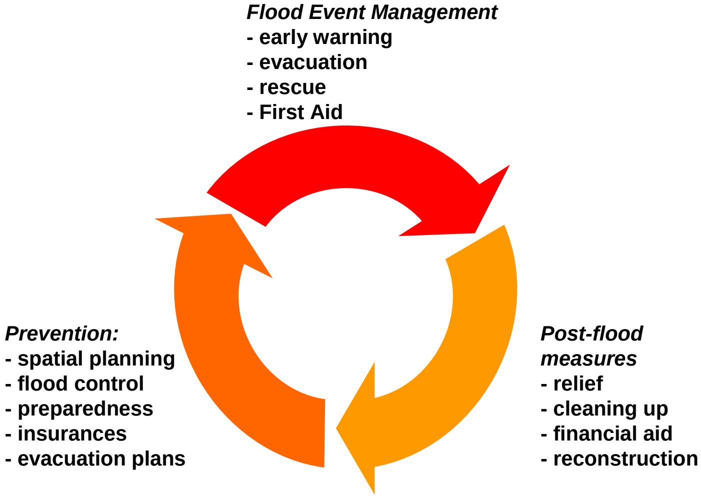

Fig. 3. The risk management cycle.

a) Preventive measures (as in DKKV 2004, Schanze et al. 2008, LAWA , …) include actions such as:

- Spatial measures: keeping constructional development out of floodplains as far as possible
- Constructional measures: ensuring appropriately adapted construction methods in areas prone to flooding
- Risk reduction measures: own financial provisions (backed by insurance)
- Behavioural measures: explaining, preparing for and practicing how to cope with flood-related danger situations

[14] These modi of course do not follow a cycle or so-called optimisation loop – because the system is ever evolving and going back to an earlier state is impossible. Imagining a helix-like structure seems therefore more appropriate.

- Informational measures: alarming, warning and informing about impending events
- Increasing natural water retention in catchment areas
- Technical flood protection: constructional facilities for water retention (dams, storage, reservoirs, flood polders).

Because it is impossible to completely eradicate the risk of flooding, society has to be prepared when things go wrong. An important component for this is a real time early warning system. This enables authorities to start implementing contingency plans, such as evacuations and mobilisation of rescue forces. Several countries have developed systems for flood warning at national, regional and local level that are connected with systems for initiating evacuation actions.

b) Three interrelated components are important in ***crisis management / in the flood event mode*** (Fig. 4)

- the technical aspects of a flood,
- the socio-psychological reaction of the vulnerable people and
- the organisational and managerial structure.

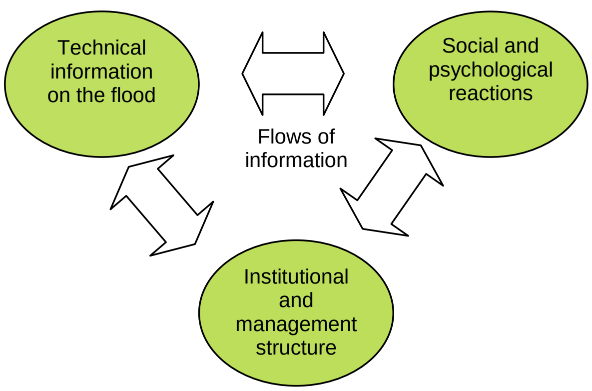

Fig. 4: The three components of crisis management

An appropriate contingency plan should ensure an optimal information flow between these three components, bringing the information together to reach a common operational picture. This means that at any time during the crisis each and every participant active in the emergency team has the same up-to-date information of the situation. The challenge is to link the domain of water (flood risk) management with the domain of crisis management. In most countries these domains are partly separated, but effective communication can overcome this obstacle. For example, Finland has a web based Watershed simulation and forecasting system which also provides real time information on floods and flood warnings.[15]

[15] http://www.ymparisto.fi/default.asp?node=11776&lan=en [Sept 20 2011]

During normal situations the water managers are responsible for maintaining the flood control infrastructure, but when water rises to critical levels and people have to be evacuated this picture changes radically. A whole range of governmental agencies come into action: the police, fire brigade, mayors and governors take their positions. Flood event management further consists of the forecasting and warning of an on-going event as a basis for flood control by operative management, deployment of temporary flood protection structures and emergency response by evacuation and rescue. This may become a major logistic issue.

c) ***The post flood mode*** encompasses disaster defence and immediate help for victims but also construction aid and reconstruction actions and financial compensations.

Once they have happened, flood events also change the risk level, put pressure on developing science and technology and new regulations and norms. Progressing climate change, changing political frameworks and societal norms and values further make it necessary to regularly reanalyse and assess current and future flood risks, evaluate new options or enhance existing measures (Merz et al. 2010).
Post flood actions also include careful documentation of the event in order to learn from the experience. General flood impact data bases such as EM-DAT[16] or NEDIES[17] exist to give a general overview, but for true learning more detailed documentation is needed. The development of such detailed flood impact data bases is going on in several EU member states and also at the European level.[18]

3.4. Dam safety

Dam safety is one of the practical issues in flood protection. Regulation of dam safety plays an important role in avoiding disasters. Dam safety concerns not only pluvial or fluvial floods but is also an essential element in industrial operations.

Many countries have a long history of regulatory frameworks for dam safety (Bradlow et al., 2002). Important aspects include the legal form of the regulation, the institutional arrangements for regulating dam safety, the powers of the regulating entity, and the contents of the regulatory scheme. The contents of the regulations relate to factors like the obligations of the regulating entities, the scope of the regulations, and the consequences of non-compliance with the stipulated obligations.

The scope of the regulatory scheme is essential as it determines what issues can be addressed. Historically some countries have focused on the safety aspect only, whereas others have also included dam construction, operation, maintenance, and surveillance. Legal systems have evolved and generally become stricter. The concern for dam safety has also resulted in the creation of organizations devoted to dam safety, for example, the

[16] http://www.emdat.be/ [30.10. 2011]
[17] http://nedies.jrc.it/index.asp?ID=91 [30.10. 2011]
[18] European Environment Agency and Joint Research Centre 2011. Draft working paper. Towards an European Flood Impact Database.

Association of State Dam Safety Officials in the US[19] in addition to organizations with a broad agenda such as the International Commission on Large Dams (ICOLD)[20].

In dam safety the hazard potential is defined as the possible adverse incremental consequences that result from the release of water or stored contents due to failure of the dam or its misoperation. In many countries dams have been classified according to the hazard potential; the class 'high' generally indicates that the failure or misoperation will probably cause loss of human life. These dams should fulfil very strict technical and hydrological criteria in their construction and maintenance. Emergency Action Plans and Early Warning Systems are necessary non-structural tools to minimize the impacts of dam failures.

The EU Floods Directive (2007/60/EC) does not specifically refer to flooding resulting from dam breaks and dike breaches and it does not deal with the technical aspects of dam safety. However, it does require flood hazard maps to be produced for floods with a low probability, implying consideration of extreme event scenarios, such as dam breaks. There are no EU wide regulations devoted to dam safety, but the Directive 96/82/EC on the control of major accident hazards involving dangerous substances (SEVESO II), as extended by Directive 2003/105/EC, addresses aspects that are relevant to dam safety, by demanding, for example, emergency plans.

3.5. Specific issues in urban flood management

Urban floods emphasise the complex interactions between hydrology and societal processes. The management of urban areas requires long-term planning and development of robust measures to deal with the possibilities of extreme flood events.

Many cities and towns are situated in locations that are prone to flooding such as deltas and flood plains**.** However, also cities that are situated remotely from water bodies prone to flooding may face problems due to pluvial urban flooding because of extensive land sealing and drainage networks with insufficient capacity.

Urban floods affect infrastructure, assets and urban activities, including transport. They also cause health risks due to overflowing sewers and intrusion of surface water into water supply systems. Urban floods also increase the risk of pollution of water courses into which storm water and flood water drains. Management measures preparing for urban floods therefore have to be holistic and address all the different aspects of urban floods.

There is a general need for measures that make urban areas more resilient to flooding. This serves adaptation to climate change and extreme weather events more generally.

[19] http://www.damsafety.org/ [6.7. 2011]
[20] http://www.icold-cigb.net/ [6.7. 2011]

Flood-proofing of buildings is a well-known measure in this respect. Green infrastructure can also provide opportunities for addressing problems caused by land sealing in urban areas (The Civic Federation for the Center for Neighborhood Technology 2007, EPA 2010).

The reduction of the vulnerability of urban areas to floods requires detailed knowledge of local conditions. Measures have to deal with water supply, waste water treatment, rain water run off and special conditions such as snow melt. There is a need for research into the effects of extreme weather events on urban drainage, water management and water treatment.

Urban water management should be developed taking into account all the positive aspects of water in the urban environment. Water is a necessary element in a sustainable urban environment, but climate change may change conditions for current practices related to urban drainage, water management and treatment. These issues are dealt with extensively in the forthcoming EEA report on cities.

3.6. Participatory management and private action

Modern flood risk management stresses increasingly the need to involve all societal actors. This has raised the need to develop participatory approaches and tools that can be used in flood management. Private instruments for risk management such as flood insurance (see Box 3.1) also change the role of different actors in the field of flood management.

In many countries flood risk management has been considered to be a public task and the exclusive task of the state. Historical counterexamples exist, for example in the Netherlands where the water boards were organised and maintained by stakeholders. Currently the involvement of multiple public and private parties is encouraged or even demanded (Christoplos et al. 2001, Walker et al. 2010). This also affects the view of how the management process should be governed and underlines the relevance of communication (e.g. Renn 2008). It generally encourages the consideration of principles of "good governance", including openness, participation, accountability, effectiveness and coherence (McFadden 2009, DEFRA; PLANAT). Medd and Marvin (2005) interpret this as a shift to a 'governance of preparedness' in which key players are brought together into 'new configurations' of institutional actors.

Box 3.1
Flood insurance – an example for the close links between public and private actors
Flood insurance and compensation systems are important parts of strategies for dealing with flood risks. The development of flood risk insurance is an example of close links between public and private actors in the management of environmental issues. The private insurance and re-insurance industry has for a long time been involved as an actor in the management of risk, but there has been no movement of governance of insurance upwards to the European level. Insurance arrangements and the relation between market

and public measures are determined at a national level and as a consequence a great diversity exists across EU member states. For example, in the UK there has been an ever increasing trend towards individualisation of flood risk, segmentation of the market and differentiation between insurance premiums depending on degrees of assessed risk at a particular location. The UK Environment Agency works with the Association of British Insurers to support the insurance industry's commitment to continue offering flood risk insurance to the vast majority of homes and businesses in flood risk areas.[21]However, in other parts of Europe exactly the opposite trend is observable. For example in France and similarly in Belgium, Spain and Norway, compulsory cover for disaster risk is shared amongst all policy holders with an identical additional percentage premium paid on top of the assessed premium for fire insurance (French Disaster Reduction Platform 2007). In both cases public-private partnerships have been central – in the UK an agreement between the government and insurance companies to ensure the continued provision of flood insurance cover even in high risk locations (although at very high prices); in France a consensual setting up and on-going monitoring of the shared risk arrangement linked to a public risk prevention policy. But importantly the outcomes of these public-private partnerships remain quite divergent and ideologically distinct (Walker et al. 2010).

Increasingly insurers and reinsurers use sophisticated probabilistic catastrophe models to price flood risk. For instance the Parameter Trigger Concept is based on the principle of a pay-out mechanism which includes a parameter that can be measured or modelled. The advantage is that funds can be made quickly available after the event because no laborious proof of damage has to be given. There is no explicit link to the loss suffered by the insured. The main challenge is to capture the majority of damaging events by the trigger definition.

More inclusive management of floods builds trust between the public, administration and research (Wachinger and Renn 2010, 46, cf. also Moser 2010, Mosert et al. 2008, Höppner et al. 2011). It may also raise people’s awareness and motivation for taking actions to mitigate the impacts of hazards (Stanghellini and Collentine 2008 and Slinger et al. 2007). When people become more aware of floods, they are more motivated to initiate protective action in participatory exercises (Wachinger and Renn 2010; Jonoski, 2002; Evers, 2008; White et al., 2010) (Box 3.2).

The inclusion of tacit or local knowledge can improve the quality of the measures for flood risk management. Many residents have had personal experience of flood events and hence may have good understanding of flooding issues in their local area (White et al. 2010). There may therefore be scope for incorporating valuable local knowledge into modelling procedures leading to potentially improved flood risk maps (Historien paper und radical method paper), Box 3.3.

Box 3.2
Example Collaborative modelling as a way of managing flood risk: the cases of the Alster (DE) and Cranbrook (UK) rivers

[21] http://www.environment-agency.gov.uk/homeandleisure/floods/31654.aspx [August 15 2011]

The **Alster** drains a natural upper catchment (Northern Hamburg and Schleswig-Holstein) and a canalized lower catchment (Hamburg) and is a tributary to the (tidal influenced) river Elbe (Figure 1).

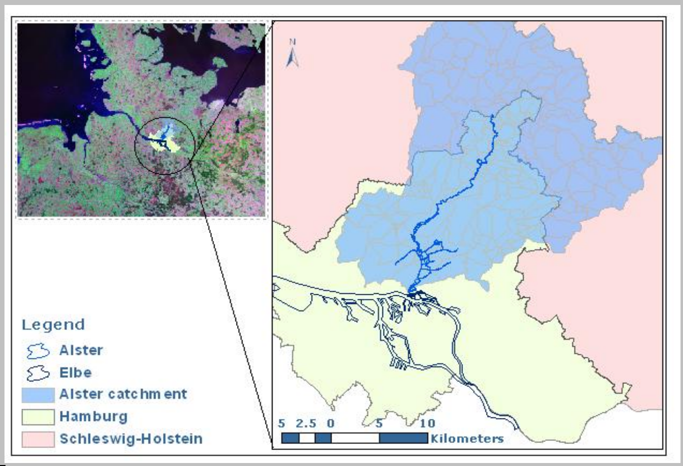

Figure 1: The Alster catchment

Comment [RD1]: Again, figures have disappeared from my version.

The lower part of the catchment is densely populated with high damage potential. Several flood events have occurred during the last 10 years with a recent flood event occurring on the 6th February 2011. This is event was comparable with the event of the 18th July 2002 which caused significant damage in the area. A peak flow of 29.3 m^3/s was recorded corresponding to a flood event with a return period of 25 years. Due to flood protection measures that have been implemented after the flood event in 2002, including stricter planning permissions, in the upper Alster and interventions along the tributaries Kollau, Saselbek and Berner Au, damages were low and an effective protection for Hamburg was maintained. So far this is standard flood management. The novelty has been in an integrative approach to stakeholder communication and collaboration. A team of researchers working within the EU funded DIANE-CM project (Cortés et al., 2011) developed an online collaborative platform (Figure 2) that allowed stakeholders to interact with a hydraulic model of the Alster and test alternatives and measures to reach a common understanding of the situation and potential solutions.

Figure 2: An online collaborative platform (http://hikm.ihe.nl/diane_cm/)

A similar approach within the same project was undertaken for the **Cranbrook** catchment (Figure 3), located within the London Borough of Redbridge, which is situated in the Northeast part of Greater London. Several flood events have been reported since 1926 with a recent example being the event of February 2009, where coincidental fluvial and pluvial flooding occurred due to heavy rainfall that caused rapid snowmelt that was still lingering in large quantities following snowfall the week before. The amount of water in the river exceeded the capacity of the channel and surface water overwhelmed the local drainage systems. Over 200 calls were received at the emergency control centre during the event. After the event, new drainage work was carried out and a new flood warning scheme was put in place. The need for more collaboration between stakeholders was identified as a means to improve resilience (Ochoa et al., 2011).

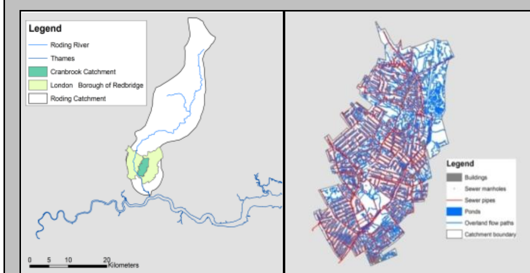

Figure 3: The Cranbrook catchment

A formal stakeholder identification approach was undertaken (Figure 4), as in the case of the Alster, to map the links between stakeholders that would take part in a collaborative modelling exercise. The process of identifying stakeholders and their links resulted in a much improved understanding of the social-administrative system and its critical points for improvement. The stakeholders were presented with alternative flood management interventions and explored their effects using online simulation tools. The interventions included: “Do nothing”, Rainwater harvesting, Improved and targeted maintenance regimes for the sewer system, Improved resistance for preventing water from entering properties and Improved rainfall and flood forecasting and warning.

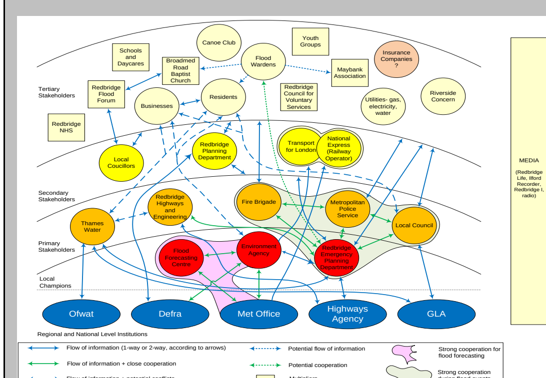

Figure 4: Stakeholder organi-sociogram, London Borough of Redbridge (UK)

This engagement of a wide variety of stakeholders in the decision-making process for flood risk management proved to make them more aware of the situation and increased their personal responsibility towards this issue and their understanding of each other's attitudes and perspectives on risk.

Box 3.3
Enhancing flood maps according to the needs of different actors (RISK MAP)
The RISK MAP project (Meyer at al. 2011) is an example of how decision makers and flood risk map producers and users (strategic planners, emergency management, affected and interested public) were involved in risk analysis through enhancement of flood risk maps in terms of content and visualisation. Multiple hazard parameters, risk criteria and symbologies were tested. This process resulted in risk maps that could be utilised more effectively and better support to public participation, both during their creation and as a tool for communication. Approaching mapping in this way and including local knowledge in addition to sophisticated model results can raise awareness, increase the acceptance of measures and strengthen trust in authorities and other actors. The project built on previous results of the RISK CATCH project and considered also different new mapping guidelines on EU and national levels (EXCIMAP 2007, EC 2010, LAWA 2010).

3.7. Developing governance: the evolution of policies, strategies, and measures

Triggered by the increasing acknowledgement of climate change combined with the limits of traditional flood protection strategies, concepts such as resilience and adaptation are stressed and solutions that are robust and flexible are sought for at all levels of governance. Solutions are sought in a combination of measures within alternative strategies to protect against flooding and to reduce vulnerability. This requires strengthening the role of local authorities, non-governmental and private actors may increase adaptive capacity, at the same time avoiding risks of overstraining limited personal and financial capacities, or limited experience and knowledge.

The understanding of risk itself appears to be changing with greater appreciation of the limitations of science and predictive models and acknowledgement of the intrinsic uncertainties of knowledge (Walker et al. 2010). Flood risk assessments, for instance, have been traditionally calculated based on historically observed flood frequency statistics and return periods (Merz and Thieken 2005), following what might be termed a 'classical' approach to risk analysis.

The introduction of the concept of resilience to the discourse on natural hazards and disasters may be understood as an attempt to deal with the inherent uncertainties of management strategies (Berkes 2007, Klein et al. 2003, Allenby and Fink 2005, de Bruijn 2004, Kuhlicke and Kruse 2009, Merz et al. 2010). The challenge is to better understand (1) the amount of disturbance a system can absorb without major disruption; (2) the degree to which the system is capable of self-organization; (3) the degree to which the system can build and increase the capacity for learning and adaptation (Carpenter et al. 2001, Klein et al. 2003).

On a practical levelthere is a growing awareness that ***combination of measures*** should be used to reduce vulnerability and disastrous flooding. This poses the question as to how the optimal combination of measures can be found. Effectiveness and costs and benefits need to be considered together with practical applicability and intangibles such as socio-cultural preferences and environmental consequences. Evaluation criteria for strategies and measures furthermore include ***robustness, flexibility, and acceptance*** (Klijn et al. 2008).

The EC (2009) has suggested a number of guiding principles for new measures:

- Perform a climate check
- Choose robust and flexible measures (focus on non-structural measures, a mixture of measures, focus on "no regret" and "win-win" measures, etc.)
- Use a catchment approach
- Take long-term developments into account
- Consider other adaptation measures and their impact on flooding

There are a number of approaches that combine technical measures with new modelling and participatory approaches in order to better deal with changing conditions. The Cranbrook and Alster cases (Box 3.2) show that it is possible to improve the resilience of communities and cities to flooding through stakeholder involvement. Such involvement deepens the understanding for and acceptance of measures that can and have to be taken. Other novel initiatives include "Making Space for Water" (Defra, 2005) and "Room for the River" (Programme Directorate Room for the River - Netherlands, 2007, see box 3.4). These can also accommodate changing conditions related to climate change as in the German KLIWAS programme (see box 3.5). In many parts of Europe transnational actions have to be taken in order to improve flood management (see box 3.6).

New approaches need to be supported by adequate legislation. Current European and national legislation does not cover all aspects of integrated flood risk management. For example the spatial planning is not as such covered by the Floods Directive. The management of flood generation areas and land-use changes that affect the magnitude of risks are only marginally covered. Flash floods and pluvial flooding in urban areas are not explicitly referred to in existing legislation, and their management depends more on evolving planning practice than on specific policies. There is thus a need to develop policies at all levels of governance recognising the multifaceted nature of flood protection.

Box 3.4

Construction of artificial side channels / flood bypasses, reconnecting old river branches and increasing the water discharge capacities (Room for the River)

After two consecutive flood peaks in 1993 and 1995 in the Netherlands, where the dikes only just held, it was decided that flood prevention was inadequate. But instead of raising the dikes, as was done so many times in the past, the Dutch government decided to create more room for the river in order to lower maximum water levels during flood peak events. The Room for the River project is a good example of a combination of a resistance and a resilience-based strategy. By lowering the floodplain, realigning the dikes and reconstructing secondary channels, the water regains more space and this leads to a reduction in high water levels.

The loss of floodplain surface area since 1850 in the Netherlands is approximately 65% of the floodplain surface area in 1850, and urban development has created several bottlenecks in the floodplain. Giving more room to rivers substantially lowered flood levels, but also help to sustain a more attractive environment, both urban and natural. This greatly influenced public and political opinions.

Room for the River was officially adopted by the Dutch government to achieve the required safety level for the river systems. In 2005, specific targets were set at the national level and local authorities became responsible for the design and construction of individual measures along the Rhine, Scheldt and Meuse rivers.

Box 3.5

Adopting a climate factor when reinforcing existing dikes (KLIWAS)

Up to 30 climate model runs (including those of the EU-FP6-Project ENSEMBLES), as well as different bias correction methods and hydrological models, were evaluated against the background of the interdisciplinary research programme KLIWAS (www.kliwas.de), which integrated ecological, economical, water quality and water quantity aspects of climate change for rivers and coastal waters which are used as waterways. The purpose was to account for different sources of uncertainty and provide a reliable basis for the assessment of various adaptation options. Historical data bases were extended for model validation and monitoring of climate change effects. A model chain was established, which couples climate models to hydrological/oceanographic, hydrodynamical / sedimentological, water quality, and ecosystem models. At each step, uncertainty was analysed in detail to assess the level of understanding of the aquatic systems and their sensitivity to low flow, floods, and other aspects of “historical” and future climate change. As a result, the design level of protection structures (e.g. against a flood of 1 % annual probability) is multiplied with a climate change factor between 1.15 and 1.25, or a generally higher freeboard is chosen (e.g. in Saxony).

Box 3.6

Reinforcement of existing dikes, compartmentalisation of flood plains, multifunctional management of dams
As a consequence of the severe flood event in summer 2002 along the Elbe River, both the Czech Republic and Germany agreed to assess and better integrate the Vltava / Moldau Dam Cascade and the Dams in Germany into the transnational flood protection scheme as stipulated in the Flood Protection Action Plan of the International Commission for the Protection of the Elbe. The snow melt flood in early spring 2006 bolstered the strategic approach to adaptively manage multifunctional dams in a national and transnational setting (Reference).

4. Scenarios for flood risks in Europe

"Nobody can predict, therefore one should not try. The only relevant discussions about the future are those where we succeed in shifting from the question whether something will happen to the question: What will we do if it happens?"
Arie de Geus, Former Head of Planning, Shell[22]

Scenarios provide a means to explore potential future developments. Rather than making predictions of what will happen, they paint a picture of how alternative futures might unfold, describing plausible trajectories of climate, environmental, socio-economic and technological conditions (Moss et al., 2010). Scenario studies can be driven by an interest in the uncertainty, probability or desirability of future developments. In the case of flood risk management scenarios, the focus is on uncertainty and (increasingly) on probability. The key question to be addressed is: What are the kinds of futures that European water managers should be prepared for?

As a consequence of climate change as well as socio-economic developments, flood risk is unlikely to remain stationary in the coming decades (Milly et al., 2008). The direction and magnitude of these changes are, however, uncertain. These uncertainties may be of different natures: epistemic uncertainties are related to imperfection of our knowledge, which may be reduced in due time by research; variability uncertainties arise from the inherent variability and unpredictability of the systems involved; while ambiguity refers to the simultaneous presence of multiple frames of reference about a system among different actors (for an overview see Kwakkel 2010).

Scenarios of future changes in flood risk can be used to better understand these uncertainties and are therefore an essential tool in flood risk management. The aim of working with scenarios is not to predict the future, but to facilitate decisions that are robust under a wide range of possible futures (Moss et al., 2010). In order to be useful

[22] Quotation reported in Schütte, P.M. 2008. Scenario thinking: accelerating strategic learning. http://schuette.nl/publications/strategicthinking1.pdf [Accessed Oct 30 2011]

and relevant, flood risk scenarios need to meet a number of criteria: they need to be physically plausible and internally consistent, they need to explore the potential range of future development, and they need to include all aspects of flood risk, not just the physical (climatological and hydrological) side of it.

Scenarios should be differentiated from short-term or even medium-range forecasts and projections. These generally allow for emergency response and interventions to reduce the likely impact of a flood event. Improved forecasting capability can, however, play an important role in mitigating an increase in flood risk.

This chapter discusses the needs that scenarios have to fulfil in order to help flood risk management, reviews current research on scenarios and presents currently available scenarios of how flood risk may develop in Europe in the future.

4.1. Integrated approaches are needed in developing scenarios for flood risk assessment and management

Flood scenarios are an essential part of flood risk management. Flood impacts depend not only on the frequency and severity of flooding but also directly on the socio-economic factors that determine the hazard, vulnerability and resilience at the location of the flood. This necessitates the involvement of main actors and stakeholders in developing future scenarios.

Comment [R2]: Need to agree on a consistent terminology – and perhaps coordinate with the droughts report.

Maybe EEA has its own definitions, otherwise ClimWatAdapt has some definitions here: http://www.climwatadapt.eu/vulnerabilityindicators although their definitions seem somewhat odd to me – what they call "exposure" is what I would call "hazard".

In order to be useful and relevant in flood risk management, scenarios should identify the key drivers that determine flood risk. Flood risks change when the hazard changes or when vulnerabilities change. A change in hazard may entail a change in the frequency (or probability) of flooding, or a different pattern of flooding. A change in vulnerability may arise from developments in land use and infrastructure, economic conditions and economic activities that are sensitive to floods. Societal factors, for example the different role authorities can play relative to private actors, may also need to be considered. When developing scenarios of flood risk, scenarios of future changes in the hydrological cycle that explore changes in hazard are thus necessary, but insufficient in to be applicable in flood risk management. Scenarios also need to consider the possible developments of the vulnerabilities, and the views of different societal actors.

The IPCC Task Group on Data and Scenario Support for Impact and Climate Assessment (TGICA, 2007) has suggested five criteria that climate change scenarios need to meet in order to be useful for impact researchers and policy makers.[23] By slightly modifying these criteria one can obtain a set of criteria for creating scenarios for flood risk assessment and management:

[23] IPCC DDC 2011. Criteria for Selecting Climate Scenarios. http://www.ipcc-data.org/ddc_scen_selection.html [August 18 2011]

- Criterion 1: Consistency with global projections. Scenarios should be consistent with a broad range of global warming projections based on increased concentrations of greenhouse gases due to anthropogenic emissions, as well as their underlying socio-economic storylines.
- Criterion 2: Physical plausibility. They should be physically plausible; that is, they should not violate the basic laws of physics. For example, the combination of changes in different variables (which are often correlated with each other) should be physically consistent.
- Criterion 3: Applicability. They should describe changes in a sufficient number of variables on a spatial and temporal scale that is relevant to flood risk assessment. Flood risk assessments typically require information on changes in those climatological variables that affect the water balance and hydrology of a catchment at relatively small spatial scales (i.e., the size of an individual river catchment) and short temporal scales (i.e., hours to days). This information is particularly relevant for regional and local flood risk management, including crisis management. However, changes in hydrological conditions alone are not sufficient. In addition, also socio-economic variables such as land use, infrastructure development and the location of specific activities should be taken into account.
- Criterion 4: Representativeness. They should be representative of the potential range of future hydrological and societal conditions. In practice this means that focusing on only one scenario is usually not sufficient. Individual scenarios do not cover inherent uncertainties. Only by exploring several scenarios a realistic range of possible risks, impacts and responses can be considered.
- Criterion 5: Participatory development. Stakeholder engagement is essential in developing scenarios. The challenge in participatory scenario development lies not only in defining the scenarios, but also in the processes for analysing them in relation to the strategies and interests of different stakeholders.
- Criterion 6: Accessibility. Scenarios should be straightforward to be obtained, interpreted and applied in flood risk and impact assessment (flood risk management). Assessment projects can include a separate scenario development component which specifically aims to address this last point.

Of these, Criterion 3 is especially challenging. It demands the use of multiple data and models and methods and should also include analyses of key uncertainties. Projections of future changes in flooding frequency are often based on hydrological models that are tuned to historical conditions, but driven with one or more scenarios of climate change and other factors contributing to vulnerabilities. Each step of this modelling chain introduces uncertainties in the results. Some of this uncertainty may be quantified, for example by following a probabilistic approach based on ensemble simulations, but this may be more difficult for structural uncertainties, such as processes that are not normally taken into account, like changes in the water use efficiency of plants under higher CO_2 concentrations, or a change in the gradient in the downstream reaches of a river due to sea level rise.

Stakeholder engagement can be based on developing storylines that form the narrative base for scenarios, highlighting the main scenario characteristics and dynamics and the relationships between key driving forces, including the water system, societal responses and external developments (see Section 3.3.2).

4.2. Research supporting the development of scenarios for flood risks in Europe

The development of scenarios of future flood risk requires input on all the different aspects of flooding at different spatial and temporal scales, from climate conditions such as precipitation pattern and intensity to hydrological processes and societal vulnerabilities. A wide range of disciplines should be involved. Comprehensive, integrated scenarios of flood risk need to include projections of:

- The climate conditions, which are based on global or regional climate models, or ensembles of models, providing projections of rainfall and its spatiotemporal distribution, temperatures and other climate variables. Note these projections are themselves dependent on scenarios of greenhouse gas emissions assuming different trajectories of future socio-economic development.
- The hydrological processes and (their) variables: river flow and its variation, snow melt, soil moisture, evaporation, water levels in lakes and reservoirs.
- Land cover, which directly interferes with hydrological processes. This includes aspects such as land sealing, dykes, dams and reservoirs.
- Patterns of land use, which affect the physical location of infrastructures such as buildings, transport routes, harbours and airports, and activities vulnerable to floods such as agriculture, aquaculture and transport.
- Economic activities that affect the value of the assets and activities at risk from flooding.
- Measures and responses that affect the hazard (e.g. flood defences) and vulnerabilities and the ability to cope with flood risks, including general adaptation to natural hazards and climate change.

The EU has funded several large research projects on flood risk, some of which focus on the basic methodological aspects such as the development and comparison of models and scenarios, whereas others explore in particular the possible future developments in flood risk, or certain key elements of it such as climate and hydrology. Many projects have combined several aspects (Table 2). The results of these projects have been synthesised in scenarios for future flood risks in Europe (See Sections 4.3 and 4.4 below).

The projects listed below differ in the geographical scale. The ones selected here are mainly Europe-wide, although some use a case study approach focusing on particular regions or trans-boundary watersheds. Many of the projects are closely linked. For examples, the results of the ENSEMBLES project and the LISFLOOD model studies are extensively used in other projects to provide projections of climate or hydrological change. In addition to the studies included in Table 2 there have also been projects with a national or local focus, although the extent to which flood risk scenarios have been developed differs from country to country.

Table 2. Overview of major projects contributing information to the development of flood scenarios for Europe with indicative information on the focus of the project: ***=major focus; ** = important; *=issue dealt with

Project acronym	Project title	Project period	Scenarios					Geographical scale	Reference (www-page and/or key publication)
			Climate	Hydro-logy	Land use	Exposure	Adaptive capacity		
CORDEX	COordinated Regional climate Downscaling EXperiment	Since 2009	***					Europe (and other regions across the globe)	http://www.euro-cordex.net/
ENSEMBLES	ENSEMBLE-based Predictions of Climate Changes and their Impacts	2004–2009	***	*	*			Europe	http://www.ensembles-eu.org/
PRUDENCE	Prediction of regional scenarios and uncertainties for defining european climate change risks and effects	2001–2004	***	*				Europe	http://prudence.dmi.dk/
STARDEX	Statistical and regional dynamical downscaling of extremes for european regions	2002–2005	***					Europe	http://www.cru.uea.ac.uk/projects/stardex/
WATCH	Water and global Change	2007–2011	*	***				Global; 4 case study catchments across Europe	http://www.eu-watch.org/
AVOID	Avoiding Dangerous Climate Change	2009–2012	***	**		*		Global	http://www.avoid.uk.net/
FLOODSITE	Integrated flood risk analysis and management methodologies	2004–2009	*	*		*	*	Europe; several case study areas	http://www.floodsite.net/
	LISFLOOD climate change impact assessments	Since 2005	**	***		*		Europe	http://floods.jrc.ec.europa.eu/climate-change-impact-assessment.html
ADAM	Adaptation and Mitigation Strategies: Supporting European climate policy	2006–2009	*	**		*		Europe	http://www.adamproject.eu/
PESETA	Projection of Economic impacts of climate change in Sectors of the European Union based on boTtom-up Analysis	2006–2007	**	**		*		Europe	http://peseta.jrc.ec.europa.eu/
ClimWatAdapt	Climate Adaptation – modelling water scenarios and sectoral impacts	2010–2011	**	**		**	**	Europe	http://www.climwatadapt.eu/

CLAVIER	Climate Change and Variability: Impact on Central and Eastern Europe	2006–2009	***	**				Central and Eastern Europe	http://www.clavier-eu.org/
CECILIA	Central and Eastern Europe Climate Change Impact and Vulnerability Assessment	2006–2009	***	**				Central and Eastern Europe	http://www.cecilia-eu.org/
ACQWA	Assessment of climatic change and impacts on the quantity and quality of water	2008–2013	**	**		*		European mountain regions	http://www.acqwa.ch/
VERIS-Elbe	Changes and management of risks of extreme flood events in large river basins - the example of the Elbe River	2005–2008	**	***	**		**	Elbe	http://www.veris-elbe.ioer.de/
AMICE	Adaptation of the Meuse to the Impacts of Climate Evolutions	2008–2013	**	***	*	*	*	Meuse	http://www.amice-project.eu/en/index.php
Rheinblick2050	Impact of regional climate change on discharge in the Rhine River basin	2008–2010	**	***				Rhine	http://www.chr-khr.org/projects/rheinblick2050

Table 2 suggests that although several projects have developed scenarios of changes in climate and hydrology, few studies have specifically included changes in land use, exposure and adaptive capabilities. Only recently studies have started to develop truly integrated scenarios of flood risk, for example in the ClimWatAdapt project (see section 4.4). There appears to be a need for European-wide scenarios of land use and other socio-economic changes. One of the difficulties with European-wide scenarios is that flood hazards and vulnerabilities are context dependent. For effective and efficient flood protection it is not sufficient to make broad brush analyses. One also needs to understand relevant interactions between economic, technical, political and hydrological processes.

The large gap in time horizon between climate studies (which typically provide projections until the end of the century) and socio-economic studies (which usually do not look further ahead than 2030/40) create further difficulties. At short time scales much of the projected climate change is still obscured by natural variability. Short-term (decadal-scale) climate projections are, however, in great demand. Meaningful long-term socio-economic scenarios would in principle be useful from a strategic point of view, but it is a difficult task due to large uncertainties caused by potential structural changes in socio-economic conditions.

4.3. Scenarios of flood hazard and frequency

Recent analyses suggest that global warming is likely to reduce flood hazard in areas that are dominated by annual snowmelt floods, except in those regions where a sharp increase in winter snowfalls outweighs the effects of a warmer and shorter snow season (Dankers & Feyen, 2009). In other parts of Europe there is considerably more uncertainty in how flood hazard will change due to climate change. Strong increases in extreme river flows have, however, been found in several studies and may occur over relatively short time spans (Kay & Jones, 2011).

It is widely accepted that heavy precipitation events will become more frequent and/or intense under global warming (Allen and Ingram, 2002; Hegerl et al., 2007). An increase in rainfall intensity may occur even in areas that are getting drier on average (Christensen and Christensen, 2004). However, this is a general pattern that may work out differently at the local scale. Climate model projections of changes in extremes are less robust than for changes in average conditions, and the models have less skill in reproducing the present-day characteristics of climate extremes (Meehl et al., 2007). Furthermore, changes in flood hazard do not only depend on changes in heavy rainfall but also on other processes such as snow accumulation and melt, and antecedent soil moisture conditions.

Climate impact studies of changes in flood hazard have been undertaken in a number of river basins across Europe, but the use of different scenarios, models and methodologies make it difficult to compare the results. Few studies have made an assessment at national or European scale. Lehner et al. (2006) made a first pan-European analysis of changes in river flooding frequency under changing climate conditions. The regions most prone to an increase in flood hazard were northern and north-eastern Europe. However, this study was based on climate anomalies from two General Circulation Models (GCMs) and any potential increase in rainfall variability was not taken into account. Owing to their coarse horizontal resolution, GCMs are not well-suited to simulate subgrid, mesoscale hydroclimatological processes that are important to flooding, nor can they provide sufficient detail in areas of complex topography and land use (Christensen et al., 2007).

A European-scale study by Dankers & Feyen (2008), based on very high resolution (~12 km) regional climate simulations used to force an off-line flood forecasting model, showed a very mixed pattern of changes in the 100-year flood level by the end of the century (2071-2100) under the A2 scenario of the IPCC. In contrast to the Lehner et al. (2006) study, a considerable decrease in flood hazard was found in the northeast of the continent, where warmer winters and a shorter snow season reduce the magnitude of the spring snowmelt peak. Elsewhere, most notably in the west and parts of eastern Europe, the return period of what is currently a 100-year flood was found to decrease to 50 years or less, while in several other rivers in central and southern Europe a decrease in extreme river flows was simulated.

In a follow-up study using an ensemble of in total eight experiments from two regional climate models (RCMs), each run with boundary conditions from two different global models and for two different emission scenarios, Dankers & Feyen (2009) found some of these patterns to be robust across the models and scenarios. Especially in north-eastern Europe, a general decrease in extreme river discharge was projected in the scenario period, due to a reduction in the hazard of extreme snowmelt floods. In the rest of the continent a consistent tendency toward a higher flood hazard in at least the majority of the model experiments was found in several major European rivers such as the Loire, Garonne and Rhone in France, the Po in Italy and the Danube in central and eastern Europe (see Fig. 4). However, at the scale of individual river basins, using a different combination of climate models or assuming a different emissions scenario sometimes resulted in a very different or even opposite climate change signal in flood hazard. Much of this uncertainty could be traced back to the driving GCM that had a larger influence on the results than the choice for a particular RCM or even the emissions scenario. Importantly, Dankers & Feyen (2009) also found that some of the changes in simulated flood hazard can partly be attributed to large, decadal-scale variability in the simulated climate and can be expected to occur naturally when comparing two 30-year time periods, even without a change in greenhouse gas forcing. This underlines the fact that there is still considerable uncertainty in future projections of changes in climatic extremes, and impact studies that rely on a limited set or even a single climate scenario are bound to underestimate this uncertainty.

Fig to be added

Fig. 4. Number of scenarios (out of total eight experiments) showing either a (a) decrease or (b) increase of more than 5% in the 100-year return level in the scenario period (2071-2100 compared to 1961-1990). Source: Dankers & Feyen (2009).

National and catchment-scale studies are obviously able to provide a more detailed and nuanced picture, especially in those areas where more data and better models are available. A national assessment for Finland by Veijalainen et al. (2010) found important regional differences in climate impact due to different climatic conditions and watershed properties. In snowmelt-flood dominated areas, annual floods decreased or remained unchanged due to decreasing snow accumulation, which is consistent with Dankers & Feyen (2008, 2009) even although the methodology was different. On the other hand, a projected increase in precipitation led to an increase in floods in the major central lakes in Finland and their outflow rivers.

Many studies have made projections of changes in river flooding for the UK, most recently by Kay & Jones (2011). Their results suggest an increase in flood risk across much of the country, particularly in East Anglia and the Upper Thames. Negative trends in flood risk, present in a small number of places, were not significant. These changes, which were derived over the period 1950-2099 under the A1B emissions scenario, are however unlikely to occur linearly over the coming century, partly because of natural variability, but possibly also due to the non-linear response of hydrological systems (Kay & Jones, 2011). The implication is that changes in flood frequency, whether caused by long-term climate change or medium-term natural variability, may potentially happen in a relatively short time span (Kay & Jones, 2011). Earlier studies in the UK have given broadly similar results. Kay et al. (2006), using only a single RCM experiment for the period 2071-2100 under the A2 emissions scenario, found an increase in flood peaks, in some cases more than 50% increase in the 50-year return level, in the north and west of the country. At the same time they found a decrease in flood peaks for a number of catchments in the south and east of England, due to higher soil moisture deficits in summer and autumn. A widespread increase in peak flow in catchments in England and Wales was also found by Bell et al. (2007) and Bell et al. (2009) under the same climate scenario. The maps of changes in future peak flows presented by Bell et al. (2009) suggest a high degree of spatial variability in the sensitivity of UK rivers to future changes in climate, with changes ranging from –60% and 100%.

In addition to these national studies, there have been many climate impact studies in individual river basins. For example in the Elbe basin, Hatterman et al. (2008) projected a shift in the occurrence of flood events from early spring to early winter due to less retention of runoff in snow. In a modelling study of the Rhine basin, Hurkmans et al. (2010) found that future annual maximum river flows at nearly all return periods were generally higher than in the reference period (1950-2000) under three different emission scenarios (B1, A1B and A2). In the most extreme scenarios, an event with the magnitude of the most extreme flooding events in the last half century occurred on average every 5-6 years in the future (Hurkmans et al., 2010). Likewise, Te Linde et al. (2010) projected a basin-wide increase in peak discharge by 2050 of 8%-17% for discharge levels with probabilities between 1/10 and 1/1250 years. For the Seine River in France, Ducharne et al. (2011) found a slight decrease in high flow levels that was, however, less robust than the general decrease found in low flows. In their simulations the 10-year return level did not change significantly during the 21st century and also the 100-year return level remained of the same order of magnitude. Similar results were found for the Loire River, where Moatar et al. (2010) found little significant change in the 10-year flood level by the middle of the century, and slightly negative trends towards the end, albeit with a large spread highlighting important uncertainties. Very few regional or national-scale modelling studies of changes in flood hazard under climate change have been undertaken in southern Europe.

4.4. Integrated scenarios of flood risk in Europe

Flood risk management needs to consider not only scenarios for changed probabilities of excess water, but also developments in exposure and vulnerability due to land-use change and infrastructure development. Scenarios for flood risk management thus have to combine socio-economic scenarios, such as projections for population growth, urbanisation and industrial developments with scenarios of changes in the likelihood of extreme hydrological events. Recent studies have suggested that climate change can add significantly to expected damages in some parts of Europe over the coming decades.

To estimate future flood risks, the ClimWatAdapt project used hydrological simulations of the LISFLOOD model (Van der Knijff et al., 2010) that was also used in the earlier studies of Dankers and Feyen (2008, 2009). To simulate climate change impacts on river flows the LISFLOOD model was forced with the bias corrected output of 11 different RCM simulations (For details see Floerke et al. 2011). These scenarios of changes in flood hazard were then combined with projections of socio-economic change. The results showed that the combination of climate change and economic growth will likely result in a strong increase in European flood damages (Floerke et al. 2011). On average higher flood damages were projected for all countries within the EU (Fig. 5).

Comment [RD3]: Are those the ENSEMBLES simulations?

Comment [RD4]: Reference missing

Comment [R5]: How was this taken into account then?

The ClimWatAdapt project focused on floods with an annual expected probability of exceedance of 1%. These "100-year floods" are extreme events, which tend to cause especially great financial damage. The level is also frequently used as an indicator for the development flood protection infrastructure. The LISFLOOD scenarios showed that the occurrence of a 100-year flood event is strongly affected by climate change. However, the uncertainty related to the spatial distribution is still large. Different climate models gave very different results. Using the ensemble mean, floods were projected to increase especially in the northwestern part of Europe (UK, western France, Belgium, Netherlands, western Germany) and on the Iberian peninsula (Portugal and Spain).

The LISFLOOD model was also used in an assessment of future changes in the cost of floods in Europe. To achieve this, changes in the frequency of floods were combined with information on exposed assets, depth-damage relations and population density to estimate economic damages as well as the number of people living in flood risk areas. Under current conditions, the Expected Annual Damage (EAD) was estimated to be ~€5.5 billion for the EU27. Taking into account both climate and socio-economic changes under the A1B scenario, the EAD was projected to increase to €20 billion by the 2020s (2011-2040), €46 billion by the 2050s (2041-2070), and €98 billion by the 2080s (2071-2100) for the ensemble mean results. A significant part of this rise will be due to socio-economic change. Nevertheless, the isolated effect of climate change alone amounted to €9 billion by the 2020s (2011-2040), €19 billion by the 2050s (2041-2070), and €50 billion by the 2080s (2071-2100).

The highest increases in climate change-related flood damage (over and above socio-economic change) were projected for the UK, Italy, Slovenia, Belgium and the Netherlands. This is due to a strong increase in the frequency of current high return period floods (e.g., the current 100-year return level was projected to become a 10- or 20-year flood by the end of this century). For several eastern European countries (e.g., Hungary and Czech Republic) the projected increase in flood damages was only related to economic development. In other words, in these areas the risk of damage per flooding event is increasing while the flood hazard itself is not changing much.

When accounting only for climate change, some regions dominated by snowmelt (for example the Vistula and Odra catchments in Poland) are likely to see a reduction in annual flood damages due to the strong reduction in snowmelt-driven and ice-jamming floods, which compensates for the increase in summer flood damage in these regions. The total number of people affected by floods (assuming protection up to a current 100-year flood event) was expected to increase by 80% in the EU27 due to the impact of climate change alone. This happened in all European countries except Denmark and Poland. The changes in people affected by flooding varied between the different European countries and were the highest in Belgium, Italy, Slovenia, and UK.

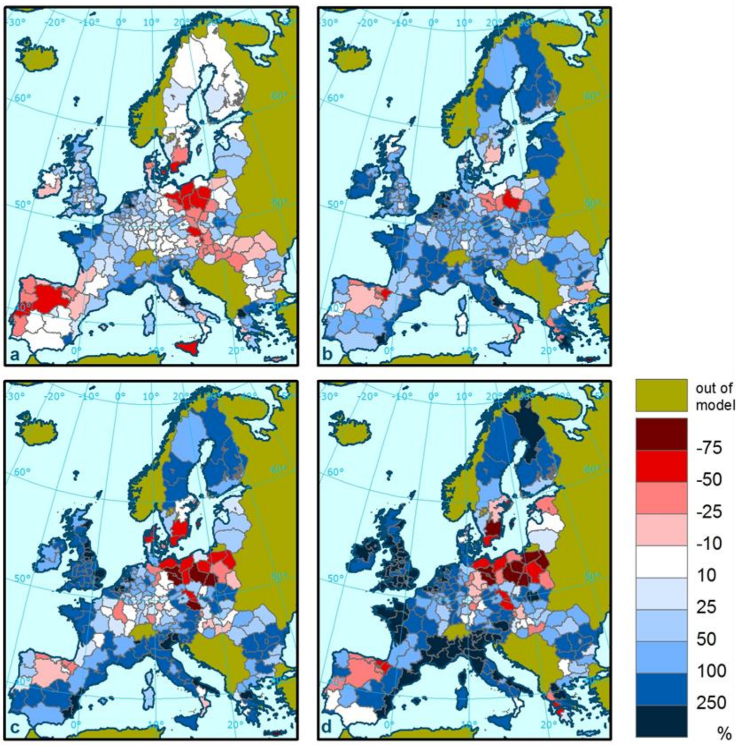

Figure 5. Relative change in expected annual flood damage due to climate change between future time slice and baseline period. a) 2000s (1981-2010); b) 2020s (2011-2040); c) 2050s (2041-2070); d) 2080s (2071-2100). Current 1 % annual flood probability level assumed as protection level in all time periods (i.e., no adaptation to future changes in flood risk).

In addition to the European-wide analysis in ClimWatAdapt, a number of studies on specific areas have started to explore how changes in climate compare to changes in land use, and particularly in exposed assets, when it comes to future changes in flood risk. Te Linde et al. (2011) projected that by 2030 the annual expected damage from flooding over the entire Rhine basin may increase by between 54% and 230%, of which the major part (~ three-quarters) could be accounted for by an increase in flooding due to climatic variables (Fig. 6). The remaining increase was due to projected changes in exposure which were based on land-use projections under two different socio-economic scenarios. In contrast, a small-scale case study in Belgium by Poelmans et al. (2011) found that although climate was the main source of uncertainty associated with projected future changes in peak flow and flood extent, the projections of potential damage were dominated by future land cover changes that occur in the floodplain.

[redacted]

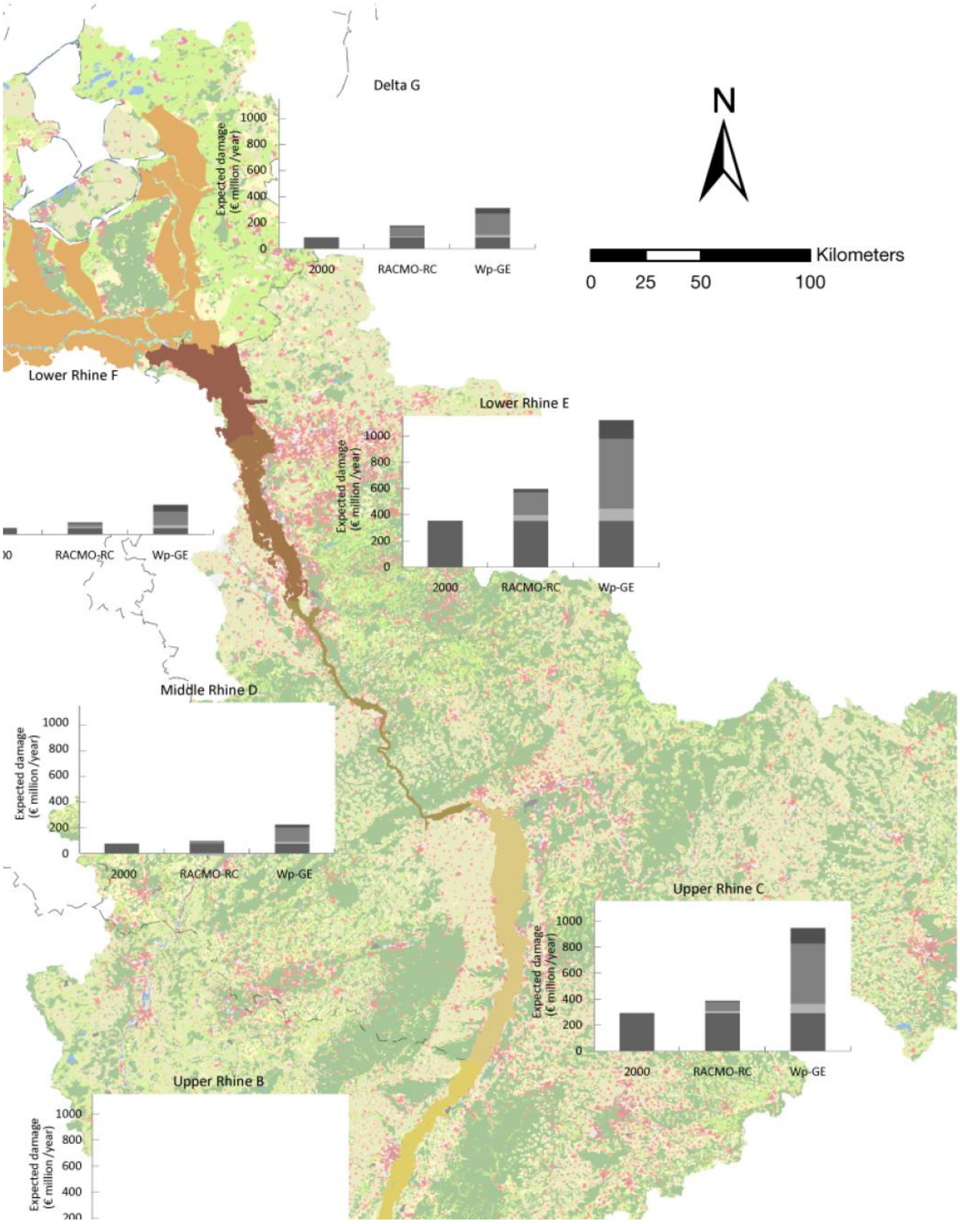

Fig. 6 Annual expected flood damage, for the reference situation and projections for 2030, aggregated into seven regions along the Rhine (Te Linde et al. 2011).

4.5. Use of scenarios in developing adaptive strategies for flood risk management

Policy makers have the task to develop a sustainable way forward in flood risk management. In doing so they must strike a balance between preparedness (considering the long lead times for certain types of measures combined with the pace of relevant changes) and economic considerations (avoiding investments in measures which by hindsight were not necessary). A promising approach is the adaptation tipping point method combined with the development of adaptation pathways (Kwadijk et al., 2010). In this approach the focus is on the flood risk management system and its ability to deal with extreme events.

Tipping points for adaptation are events where the magnitude of change of one of the relevant drivers (extreme river discharge, land use, etc.) is such that current flood risk management strategies will no longer be able to meet their objectives. When these adaptation tipping points have been identified, scenarios are used to indicate under what conditions they may be reached, and thus, when alternative strategies are needed. The trigger for taking action is therefore not climate change per se, but a high likelihood of conditions under which set objectives for flood protection can no longer be achieved.

When an adaptation tipping point is expected to be reached, a switch to a new strategy is needed. Each new strategy has its own future tipping point which, again, requires a switch to be made. In the long run water management is thus a succession of strategies. Several successions are possible, together forming adaptation pathways.

In this approach, adaptation follows pathways of strategies that are influenced by current and future climate, socio-economic developments and societal perspectives. It addresses uncertainty over future developments by incorporating flexibility and by increasing resilience to tolerate a wider range of conditions. Strategies can be designed to implement small, incremental changes which are common to all the strategies first, leaving the major irreversible investment decisions as far as possible in the future.

Learning and monitoring is essential to the adaptation tipping points approach. When monitoring reveals that changes happen more quickly than originally envisaged, the implementation of a new strategy can be brought forward in time. Likewise, under a slower change decisions can be put back in time.

5. Conclusions

Flood risk management has been seeking new directions and needs to adapt to an uncertain future. Due to the combined effects of climate change and socio-economic development flood risk is unlikely to be stationary. Detailed scenario studies are still missing in many river catchments. European-wide studies show potentially large increases in expected damages and number of people affected in the future.

Scenarios of hydrological fluvial flood hazards may indicate modestly increasing trends, or, in some parts of Europe, even decreasing trends, but flood risks may nevertheless increase if policies are unable to reduce vulnerabilities. Future studies should focus on ways to increase resilience to extreme hydrological and meteorological events and on processes that can make flood strategies adaptive in the face of changing conditions.

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To be updated

AFPM

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Appendix

Terminology

The terminology mainly follows UNISDR: UN International Strategy for Disaster Reduction Sec, 15 January 2009, http://www.unisdr.org/eng/library/lib-terminology-eng.htm. Important concepts include the following:

Adaptation: The adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.

Coping capacity: The ability of people, organizations and systems, using available skills and resources, to face and manage adverse conditions, emergencies or disasters.

Disaster: A serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its own resources.

Disaster risk: The potential disaster losses, in lives, health status, livelihoods, assets and services, which could occur to a particular community or a society over some specified future time period.

Disaster risk management: The systematic process of using administrative directives, organizations, and operational skills and capacities to implement strategies, policies and improved coping capacities in order to lessen the adverse impacts of hazards and the possibility of disaster.

Exposure: People, property, systems, or other elements present in hazard zones that are thereby subject to potential losses.

Hazard: the magnitude and probability of occurrence of a flood event.

Preparedness: The knowledge and capacities developed by governments, professional response and recovery organizations, communities and individuals to effectively anticipate, respond to, and recover from, the impacts of likely, imminent or current hazard events or conditions.

Resilience: The ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions.

Risk: The combination of the probability of an event and its negative consequences.

Risk assessment: A methodology to determine the nature and extent of risk by analysing potential hazards and evaluating existing conditions of vulnerability that together could potentially harm exposed people, property, services, livelihoods and the environment on which they depend.

Risk management: The systematic approach and practice of managing uncertainty to minimise potential harm and loss.

Scenario: A scenario is a coherent, internally consistent and plausible description of a possible future state of the world. It is not a forecast; rather, each scenario is one alternative image of how the future can unfold. A set of scenarios is oftenadopted to reflect, as well as possible, the range of uncertainty in projections. (IPCC-TGICA, 2007)

Storyline: A narrative description of a scenario (or a family of scenarios), highlighting the main scenario characteristics and dynamics, and the relationships between key driving forces. (IPCC-TGICA, 2007)

Vulnerability: The characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard.