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Flood damage, vulnerability and risk perception – challenges for flood damage research — Source link

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Flood damage, vulnerability and risk perception – challenges for flood damage research

Frank Messner and Volker Meyer

Abstract

The current state-of-the-art in flood damage analysis mainly focuses on the economic evaluation of tangible flood effects. It is contended in this discussion paper that important economic, social and ecological aspects of flood-related vulnerabilities are neglected. It is a challenge for flood research to develop a wider perspective for flood damage evaluation.

Keywords: Flood damage analysis, flood vulnerability, risk perception, cost-benefit analysis, integrated assessment.

1 Introduction

While flood research and flood protection policy has ever since been dominated by a technical world view, the social and socio-economic aspects gained in importance in recent decades due to expansive and intensified land use, rising damage potentials in floodplain areas and, thus, increasing conflicts between socio-economic land use and flood protection policy (Schanze 2002). During the last years a shift in paradigms can be observed from a technical oriented flood protection towards flood risk management, including a risk analysis methodology which takes all societal advantages and disadvantages – or in economic terms: all benefits and costs – of different flood risk management strategies into account. Such a methodology is based on flood damage analysis. However, the scientific developments and improvements in the analysis of flood damages were mainly formed by civil engineers in the past, focussing on technical and financial aspects and neglecting the significance of socio-economic factors and social science methods. If the above mentioned paradigm shift towards flood risk management will bring about a new, more interdisciplinary and holistic view on flood management and policy, some progress is also needed in the domain of flood damage analysis in order to overcome the technical alignment of this flood research field.

In this contribution it is argued that the current challenge in flood damage research consists in developing a better understanding of the interrelations and social dynamics of flood risk perception, preparedness, vulnerability, flood damage and flood management, and to take this into account in a modern design of flood damage analysis and flood risk management. Accordingly, the sections of this contribution are organised as follows: In the next section the relationship between flood damage, vulnerability and risk perception is analysed and clarified. Section three deals with state-of-the-art approaches to flood damage analysis. The fourth section discusses the shortcomings of the current approaches with a special focus on the disregard for socio-economic factors and methods. Finally, the contribution concludes with an outlook, presenting current EU research efforts to improve state-of-the-art approaches to flood damage analysis.

2 The relationship of flood damage, vulnerability and risk perception

The relationship between flood damage, vulnerability and risk perception has been recognised in a small scientific community. However, neither its relevance regarding the methods of flood damage analysis, nor its significance for the level of public flood protection and flood risk management has been widely acknowledged. It is the purpose of this section to shed some light on the convoluted relationship of these notions. Since the central terms to be used in this discussion are highly controversial in the vulnerability debate, it is essential to start with some fundamental definitions in the very beginning.

2.1 Flood Damage

The actual amount of flood damage generated by a specific flood event is time and again a driving force that stimulates politicians to strengthen flood policy measures – usually soon after flood events. Flood damage refers to all varieties of harm caused by flooding. It encompasses a wide range of harmful effects on humans, their health and their belongings, on public infrastructure, cultural heritage, ecological systems, industrial production and the competitive strength of the affected economy. Some of these damages can be specified in monetary terms, others – the so called intangibles – are usually recorded by non-monetary measures like number of lives lost or square meters of ecosystems affected by pollution. Flood damage effects can be further categorised into direct and indirect effects. Direct flood damage covers all varieties of harm which relate to the immediate physical contact of flood water to humans, property and the environment. This includes, for example, damage to buildings, economic goods and dykes, loss of standing crops and livestock in agriculture, loss of human life, immediate health impacts, and contamination of ecological systems. Indirect or consequential effects comprise damage, which occurs as a further consequence of the flood and the disruptions of economic and social activities. This damage can affect areas quite a bit larger than those actually inundated. One prominent example is the loss of economic production due to destroyed facilities, lack of energy and telecommunication supplies, and the interruption of supply with intermediary goods. Other examples are the loss of time and profits due to traffic disruptions, disturbance of markets after floods (e.g. higher prices for food or decreased prices for real estate near floodplains), reduced productivity with the consequence of decreased competitiveness of selected economic sectors or regions and the disadvantages connected with reduced market and public services (Smith/Ward 1998, 34ff.; Green et al.1994, 39ff.).

2.2 Vulnerability

The actual amount of flood damage of a specific flood event depends on the vulnerability of the affected socio-economic and ecological systems, i.e., broadly defined, on their potential to be harmed by a hazardous event (Cutter 1996, Mitchell 1989). Generally speaking, an element at risk of being harmed is the more vulnerable, the more it is exposed to a hazard and the more it is susceptible to its forces and impacts.[1] Therefore, any flood vulnerability analysis requires information regarding these factors, which can be specified in terms of element-at-risk indicators, exposure indicators and susceptibility indicators (see figure 1). In this regard, natural and social science indicators are highly significant.

2.2.1 Element-at-risk indicators

As shown in the centre of figure 1, the subject matter of any flood vulnerability analysis is the group of elements which are at risk of being harmed by flood events. Element-at-risk indicators specify the amount of social, economic or ecological units or systems which are at risk of being affected regarding all kinds of hazards in a specific area, e.g. persons, households, firms, economic production, private and public buildings, public infrastructure, cultural assets, ecological species and landscapes located in a hazardous area or connected to

[1] The notion of vulnerability is used very differently throughout the literature. Three schools of thought of vulnerability definitions can be differentiated. The first one focuses on exposure to biophysical hazards, including the analysis of distribution of hazardous conditions, human occupancy of hazardous zones, degree of loss due to hazardous events and the analysis of characteristics and impacts of hazardous events (e.g., Heyman et al. 1991, Alexander 1993). The second school of thought looks to the social context of hazards and relates (social) vulnerability to coping responses of communities, including societal resistance and resilience to hazards (e.g., Blaikie et al 1994, Watts and Bohle 1993). The third school combines both approaches and defines vulnerability as a hazard of place which encompasses biophysical risks as well as social response and action. (Cutter 1996, Weichselgartner 2001: 169 ff). The third school is increasingly gaining in significance in the scientific community in recent years. This article also builds upon the arguments of the third school of thought.

it. Based on information regarding which and how many elements are at risk of being affected by flood events, the magnitude of damage can be estimated in monetary and non-monetary units, which reflects in total the maximum possible flood damage. This is also called damage potential. And, because every element at risk is more or less exposed to flood events and more or less susceptible to them, exposure and susceptibility indicators are always related to element-at-risk indicators and contribute significantly to the analysis of flood vulnerability.

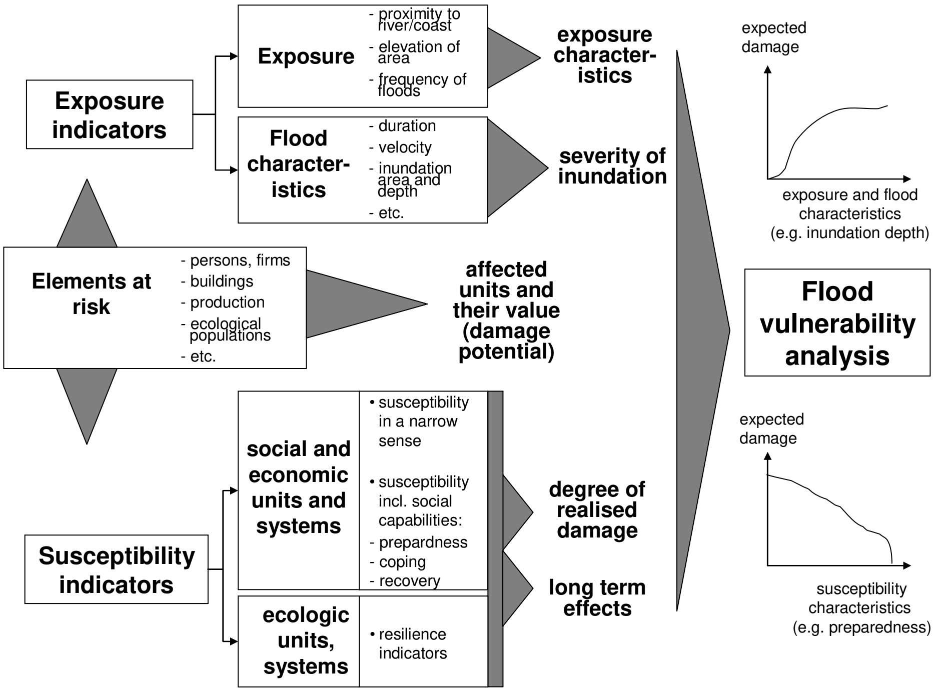


Figure 1: Indicators to be used in flood vulnerability analysis

2.2.2 *Exposure indicators*

As regards exposure indicators, two categories must be discerned. The first one is needed to typify the kind of exposure of different elements at risk. Indicators supply information about the location of the various elements at risk, their elevation, their proximity to the river, their closeness to inundation areas, about return periods of different types of floods in the floodplain and the like. Taken together, these indicators inform us of the frequency of floods n floodplains and of the threat to the various elements at risk of being inundated. The indicators of the second category focus on general flood characteristics like duration, velocity, sedimentation load and inundation depth. Considered in concert they indicate the severity of inundation as well as its distribution in space and time. Summing up, exposure indicators confer specific information about hazardous threats to the various elements at risk (e.g., Alexander 1993, Heyman et al. 1991).

2.2.3 Susceptibility indicators

Susceptibility indicators measure how sensitively an element at risk behaves when it is confronted with some kind of hazard. Figure 1 relates susceptibility indicators to the affected social, economic and ecological systems or to individual units of these systems. Regarding social and economic systems, an important group of indicators refer to susceptibility in a narrow sense, measuring the absolute or relative impact of floods on individual elements at risk. For example, the impact of inundation depth and flood duration on buildings is frequently a major issue of damage analysis and research, attempting to identify building categories that feature similar susceptibilities. And this makes sense, because wooden houses are much more susceptible to floods than stone houses and buildings with only one storey usually experience greater (relative) damage than houses with several storeys. Susceptibility indicators in a broader meaning relate to system characteristics and include the social context of flood damage formation, especially the awareness and preparedness of affected people regarding the risk they live with (before the flood), their capability to cope with the hazard (during a flood), and to withstand its consequences and to recuperate (after the flood event). Accordingly, the three relevant sets of indicators mentioned in figure 1 refer to preparedness, coping and recovery capabilities and strategies of individuals and social systems.

A lot of research work has been carried out regarding the vulnerability of social systems in terms of their susceptibility in a broader sense, and many indicators have been proposed in this context. Firstly, awareness and preparedness indicators for individuals and communities reflect the awareness and preparedness of threatened people and communities for dealing with hazardous events, including, for example, the number of households protected against physical flood impacts by means of technical measures, the number of people with insurance against flood damages, the number of persons ready for action in disaster management, as well as the quality of flood protection measures and disaster management organisations (e.g, Green et al., 1994: 47ff.). Secondly, since the ability of individuals and social systems to cope with the impact of floods is often correlated to general socio-economic indicators, coping indicators embrace general information on age, structure, poverty, gender, race, education, social relations, institutional development, proportion of population with special needs (children, elderly) and the like (e.g., Blaikie et al. 1994, Watts/Bohle 1993, Hewitt 1997, Smith 2001). This category also includes indicators for technical systems, because the social impact of floods significantly relates to the susceptibility of basic infrastructure and lifelines, which support the population´s supply of basic needs. Technical susceptibility indicators specify flood-specific weaknesses and the ability of socio-technical systems like drinking water supply, waste water treatment, communication systems and energy supply to withstand the consequences of flood events (Gasser and Snitofsky 1990, Platt 1990). Thirdly, social susceptibility in a broader sense also relates to the capability of the actors to overcome the consequences of the hazard and to re-establish previous conditions. Recovery indicators are meant to measure this aspect. Among others, indicators refer to the financial reserves of affected households and communities, the substitutability of lost items, the cohesion of social systems, and the external support provided by friends, the government and private donors. Furthermore, the long term flood impacts on the standard of living and the general health conditions can either be measured in physical units or in time units, reflecting the time required to achieve conditions which are comparable to the time before the hazardous event.[2]

Although less research has been carried out on economic systems and their susceptibility to floods in a broader sense, several susceptibility indicators do exist regarding the impact of floods on economic units and systems like firms, sectors and economic production areas. Just as in the case of social systems, the relevant indicators refer to preparedness, coping and recovery abilities and strategies. Economic preparedness indicators report on the technical and social preparedness of economic actors and systems, among others, on flood insurance and on the ability to transfer production to other locations. Coping indicators deal with the strength of actors to cope with flood events (Parker et al. 1987, Green et al. 1994). Eventually, recovery indicators give information on long term impacts like productivity, competitiveness and bankruptcy and report on the time required to re-establish previous conditions.

While the frequent occurrences of floods and their vital significance for floodplain ecosystems is often referred to as a beneficial effect of floods, there are also negative ecological flood impacts. Especially if the flood water is polluted or if large sedimentation processes occur, ecological systems can be disrupted significantly (Haase 2003). Therefore, it is reasonable to talk about the flood susceptibility of ecological systems, too. Although it is not constructive to relate the susceptibility to individual biological units, it is sensible to derive susceptibility indicators in a broader sense as they relate to ecosystems as a whole.

[2] It should be mentioned that there also exists a discourse on natural hazards and social resilience, which is closely related to the social vulnerability debate (e.g., Tobin 1999, Adger 2000, Carpenter et al. 2001, Klein et al. 2003). Social resilience can be defined as the ability of groups or communities to deal with external stress and it can, therefore, be understood as an antonym for social vulnerability (Adger 2000). The term social resilience is closely connected to the term ecological resilience, which will be defined below.

Such indicators can be derived from the debate concerning ecological resilience. Ecological resilience is a property of a system and refers to its ability to absorb external disturbances or changes and still persist (Holling 1973). In this context, indicators are important which refer to the amount of change or disruption that a system can absorb, to its capacity to be capable of self-organisation and adaptation (Carpenter et al. 2001) and to the rate at which it returns to equilibrium after a disturbance (Pimm 1984).

After having identified and quantified the most important indicators for elements at risk, exposure and susceptibility in a narrow and a broader sense, it is the task of vulnerability analysis to identify the most important relationships between expected flood damages and the exposure and susceptibility characteristics of the affected socio-economic and ecological systems. Typical results are shown in the right part of figure 1, indicating the development of expected damage to an element at risk depending on susceptibility and exposure characteristics. Hence, the above mentioned broad definition of vulnerability can be made more explicit. Vulnerability can be defined by the characteristics of a system that describe its potential to be harmed. It can be expressed in terms of functional relationships between expected damages regarding all elements at risk and the susceptibility and exposure characteristics of the affected system, referring to the whole range of possible flood hazards.

2.3 Risk perception

The notion of risk perception refers to the intuitive risk judgements of individuals and social groups in the context of limited and uncertain information (Slovic 1987). These judgements vary between individuals due to different levels of information and uncertainty, due to different intuitive behaviour, and also due to specific power constellations and positions of interest. As a consequence, the individuals of a community may assess the risk of being flooded very differently, because they do not have the same information about the probability of flood hazard events in their region, about flood mitigation measures and their effectiveness, and they perhaps have a different historical background regarding the experience of living in a floodplain and of being flooded. Due to their specific perception of flood risk individuals, social groups and also public persons like mayors, politicians and employees in the public sector dealing with flood protection and disaster management may handle this issue very differently. Experts responsible for flood protection may try to maximise their scientific information on flood hazards and flood risk in order to optimise the effectiveness of flood protection measures. Politicians may be more interested in attracting additional inhabitants or enterprises into a floodplain region in order to strengthen the regional economic development.

As a consequence, they may object to unattractive measures of flood risk management. And, finally, some individual inhabitants may feel that there is a degree of flood risk which they want to reduce by means of private measures. Others might be inclined to do nothing, either because they do not share this perception, or they believe that these measures will not pay, or they simply assume that flood protection is a public policy task. In face of the very diverse risk perceptions within society, a communication process on flood risk and flood risk perception should be encouraged as a basis for policy. If prevailing perceptions and value concepts become transparent and open to public debate, a common perception of communities may evolve and contribute to an increased acceptance of flood protection policies.

2.4 The relationship between flood damage and vulnerability

Flood damage analysis aims at quantifying flood damages for specific future scenarios with different flood events and flood policies in order to quantify the benefits of flood protection measures ex ante and, thereby, support policy decisions. In this context the concept of damage potential is crucial. The damage potential of a specific area represents the maximum possible amount of damage which may occur if the area becomes inundated. In these analyses vulnerability aspects must be considered in order to estimate the proportion of the damage potential which will finally materialise, i.e. to determine expected damages. In many instances, a vulnerability factor is derived for the most important vulnerability indicators having a substantial impact on the degree of damage produced during a flood event. In some vulnerability analyses, such a factor is derived from expert knowledge and empirical data on flood damages and then expressed on a scale between 0 (no loss at all) and 1 (total loss) in order to quantify the expected damage reduction for several categories of elements at risk (e.g., Elsner et al. 2003, Glade 2003). As will be outlined in more detail below, the most important vulnerability indicator for estimating damages in current flood damage analyses is the exposure indicator “inundation depth”.

2.5 The relationship between risk perception and vulnerability

With regard to the social and economic features of vulnerability, the notion of risk perception is crucial, too. In this context, the concept of preparedness, which has already been discussed above in the context of social susceptibility indicators, plays a specific role. If (average) flood risk perception is low in a region – perhaps due to the fact that flood events rarely occur or the level of flood protection in terms of dykes and levees is high – many laymen, experts and politicians do not think that they could ever be affected by flooding in their area. As a consequence, they would probably not take any action to decrease the risk or to prepare for the occurrence of flooding. Even if they were warned in advance of an emerging flood hazard they would probably either not believe that this could really happen, or they would just not know what to do. Conversely, if people are well aware of a flood risk – perhaps because they experience a flood with varying severity time and again – they tend to be better informed and prepared (Baan and Klijn 2004). As a rule of thumb it can be stated that regions with low levels of flood risk perception and a low degree of preparedness for coping with flood events tend to experience flood damage levels above average – their vulnerability to flood events is usually high.[3] Hence, there might exist a vulnerability factor with regard to risk perception and preparedness of communities and individuals.

3 State of the art of socio-economic flood damage analysis and evaluation

Traditionally, flood defence planning has focused on safety standards, such as dike design levels or reservoir volumes required to ensure pre-defined protection levels for the population and the economy. Protection of the community against floods with a frequency of 1250 years and more serves as a good example, as is the case with the flood protection law of the Netherlands (Baan and Klijn 2004). However, this approach neglects the amount of valuables protected by a defence system and, hence, disregards the efficiency of flood protection measures. While economic costs of alternative flood defence options are usually considered in the decision-making process, the benefits of flood protection in the form of prevented damages should be taken into account, too. The new paradigm for flood risk management (see, for example, Sayers et al. 2002 and Schanze in this book) specifically includes the economic analysis of costs and benefits of flood protection and mitigation measures in the context of risk analysis. Here, not only the safety of a defence system and its associated costs are considered, but also the damages to be expected in case of its failure. As a consequence of the application of cost-benefit and risk analysis, safety standards could better be adjusted to the specific circumstances, because it could turn out that the costs of ensuring an overall safety standard considerably exceed the benefits in some areas.

[3] One German example to illustrate this rule of thumb: In the Rhine River basin two major flood events of comparable size occurred in 1993 and 1995. While people were less aware of the flood risk in 1993, their experience of the 1993 flood increased their awareness and preparedness. As a consequence, the amount of damage was only half in 1995 compared to 1993 (Kron and Thumerer 2002).

Usually, there are two integral parts in the current state-of the-art ex ante estimation of flood damages.[4] Firstly, the flood hazard needs to be determined by means of exposure indicators, using flood parameters like expected inundation area and depth, velocity and flood duration. Secondly, the expected damage needs to be estimated. For this, all valuable property located within the endangered area, i.e. the damage potential, needs to be quantified. The expected damage is then calculated by using depth-damage-functions, which show the total damage of the valuable property (e.g. buildings, cars, roads, etc) or its relatively damaged share as a function of inundation depth. Depending on whether the functions relate to the absolute damage or the damage share, they can be called absolute or relative depth-damage functions, respectively. Over the past decades, a great variety of different methods for the ex-ante estimation of flood damages emerged. According to their scale and goal, these methods can be roughly divided into three categories: Macro-, meso- and micro-scale analyses (Gewalt et al. 1996). Macro-scale analyses consider areas of national or international scale and should provide decision support for national flood mitigation policies. Meso-scale analyses deal with research areas of regional scale, i.e. river basins or coastal areas. Here, the planning level refers to different large-scale flood mitigation strategies. The aim of micro-scale analyses is the assessment of single flood protection measures on a local level.

In the following a short overview is given over the most important state-of-the-art approaches of flood damage analysis.

3.1 First part of flood damage analysis: Determination of flood characteristics

The first part of flood damage evaluation, the determination of inundation area and depth, is necessary to get basic information about the flood hazard which generates flood damages. In this context, no clear distinction between macro-, meso- and micro-scale methods can be made – only that small-scale analyses tend to use more accurate methods. The methods vary considerably due to the character of the flooding – e.g., the simulation for storm surges is more complex than for river floods because of tidal dynamics – and with regard to the question whether the research area is protected by flood defence systems or not. The variety of methods ranges from the definition of flood plains by fixed contour lines for one or more scenarios (e.g., Ebenhöh et al. 1997; Klaus & Schmidtke 1990) to the calculation of water levels for floods with different frequencies (e.g., MURL 2000) to dynamic flooding

[4] The difference between ex-post and ex-ante estimation of damages is important. Ex-post estimations are executed after a flood in order to know the actual amount of damage to society and to compensate flood victims. Usually, these calculations are very detailed and object-specific. On the contrary, in order to assess different flood protection measures and their effects in the future, flood damages must be estimated ex-ante. These calculations refer to expert knowledge and empirical data of actual ex-post flood damages, but they use standardised functions to estimate future damages on a lower degree of accuracy.

simulations, which also take the extent of dike breaches, the flow volume and the velocity of the flooding event into account (e.g., Mai & von Liebermann 2002).

3.2 Second part of damage analysis: Estimation of damage potential and calculation of expected damages

The main differences between the three mentioned micro, meso and macro approaches relate to the spatial accuracy of damage potential analysis, to the differentiation of land use categories and to the damage functions used. Before some typical methods for the three approaches are outlined in the following, it has to be mentioned that most of the studies – regardless of whether they are performed for macro-, meso- or micro-scale – primarily focus on the estimation of direct, tangible damages, which means damages to assets which can be expressed in monetary terms. Intangible and indirect damages have been rarely considered to date, due to methodological difficulties.

3.2.1 Macro-scale approaches

One typical example of macro-scale analyses is the study for the German Coasts (Ebenhöh et al. 1997; Behnen 2000), which is based on the Common Methodology of the Intergovermental Panel on Climate Change (IPCC 1991). Here, the calculation of damage potentials is carried out for the level of municipalities. The main data sources for this evaluation are official statistics. However, sometimes data are not accessible for this level of aggregation. While for example, the number of inhabitants is directly available from the municipality level statistics, other categories of valuables, such as residential capital or fixed assets, are only published for the state level. As a consequence, these categories of valuables have to be disaggregated to the municipality level by using the number of inhabitants or employees. Of course, such a procedure generates data with a low degree of accuracy. Furthermore, the spatial distribution of the damage potential within the municipalities is not differentiated, i.e. an equal distribution of the valuables over the whole area is assumed. This increases the degree of inaccuracy. However, if the aim of the study is just to estimate the approximate level of damage related to sea-level rise, it might be sensible to apply a macro approach.

In the German IPCC-study, which intended to estimate the damage *dimension* related to an accelerated sea level rise, only the damage potential was calculated. This means, no calculations of expected damages by means of depth-damage functions were executed. In face of the degree of inaccuracy of macro-scale methods this is sensible, because an estimate of the expected damage based on aggregated data and rough macro methods with a high range of uncertainty involved could not deliver reliable data. However, rough knowledge about the dimension of potential damages of a sea level rise is useful to justify costly protection and adaptation measures.

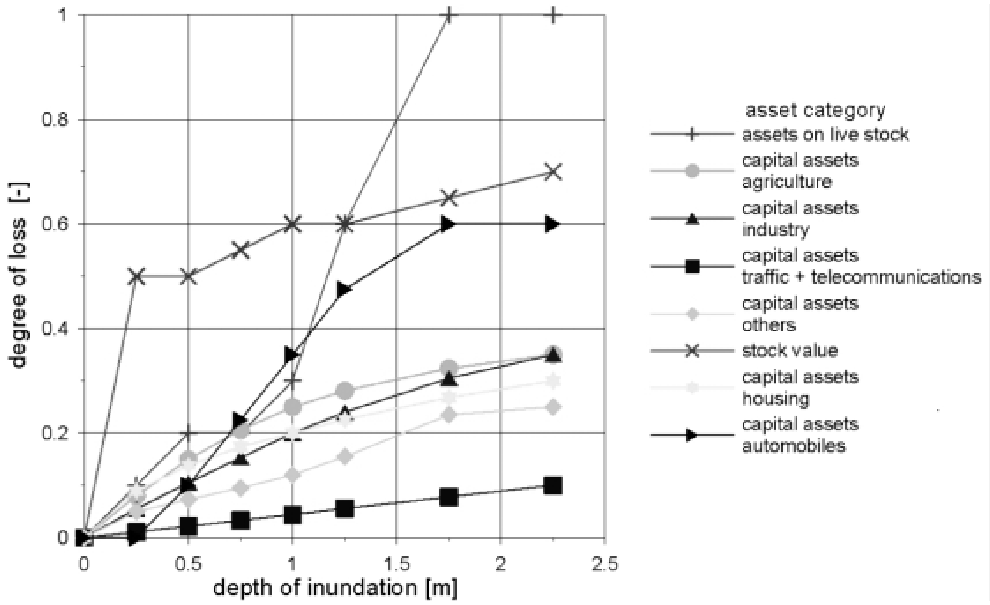
3.2.2 Meso-scale approaches

Within meso-scale analyses[5], the damage potential is derived from aggregated data, too. Just as in the macro-scale approach, the data on valuables stem from official statistics at the municipality level. However, in order to enable a more realistic localisation of the valuables within the municipalities, each of the categories for the valuables is assigned to one or more corresponding land-use categories. For example, residential capital is assigned to residential areas, fixed assets and inventories of the manufacturing sector are assigned to industrial areas and livestock is assigned to grassland. This approach allows a differentiation between areas of high value concentration, such as urban areas and especially city centres on the one hand, and areas with very low damage potential like agricultural land or forests on the other hand.

Today digital land-use data like the digital landscape model from the German ATKIS (Official Topographic Cartographic Information System) is frequently used for this approach, which allows its spatial implementation by means of Geographic Information Systems (GIS). By intersecting maps of inundation area and damage potential in a GIS and relating them accordingly, the amount of valuables or people affected can be determined. The vulnerability factor of the valuables, i.e. the share that is expected to be damaged, is in most cases exclusively related to inundation depth. Hence, relative depth-damage functions are used to calculate the expected damages. They show the damaged share of the category of the valuable as a function of inundation depth (fig. 2). Depth-damage functions can be derived from estimations of expert assessors (synthetic data) and/or from empirical flood damage data (survey data). For the meso-scale approach, aggregated sectoral depth-damage functions are used which conform to the categories of valuables derived from official statistics.

Although the meso-scale approach considers the allocation of valuables and people more accurately than the macro-scale approach, there is still a considerable degree of inaccuracy due to lacking differentiation of valuables in each category.

[5] The meso-scale approach was originally developed by Klaus & Schmidtke 1990 (see also Klaus et al. 1994) within their case study for the Wesermarsch district at the German North Sea Coast. Since then, several further studies for other German regions or states were carried out, adopting, varying and improving this approach (OSAM 1995, Hamann & Klug 1998, Colijn et al. 2000, Knogge & Wrobel 2000, MURL 2000, Kiese & Leineweber 2001, Meyer & Mai 2003)



Source: Elsner et al. 2003

Figure 2: Depth-damage-functions for different asset categories (based on Klaus & Schmidtke 1990)

3.2.3 Micro-scale approaches

Within micro-scale analyses damage potentials and expected damages are evaluated on an object level, i.e. single valuables of one category, such as specific types of residential or non-residential properties, are differentiated. Two different micro-scale approaches of damage calculation can be distinguished.

A micro-scale damage potential evaluation was used within the MERK-Project (Micro-scale Risk Evaluation for Coastal Lowlands; Reese et al. 2003), which was implemented for several cities and municipalities in the state of Schleswig-Holstein, Germany. In the context of this method the value of individual objects is considered. This means that, e.g., the total value of every single building in the research area is determined, using "normal construction costs" according to the official guideline for the assessment of property values. This approach requires a detailed site survey, whereby building characteristics such as age, construction design and type of usage are mapped. Just as in meso-scale analyses, the damaged portion of the valuable objects at risk is calculated according to relative depth-damage functions.

A different micro-scale approach was developed by the Flood Hazard Research Centre in the UK (Penning-Rowsell & Chatterton 1977; Penning-Rowsell et al. 2003).[6] This method does

[6] For the adaptation of this approach to Germany see Beyene (1992), BWK (2001)

not refer to the total value of objects, i.e. a damage potential analysis is not carried out. Instead, absolute depth-damage functions are used, which specify absolute damage amounts related to inundation depth. Since such absolute damage amounts vary strongly depending on the object or building regarded, a considerably differentiated set of damage functions is needed for this approach, as well as detailed information about building characteristics.

3.2.4 Intermediate approaches

The classification of methods mentioned above should not be interpreted too stringently. It aims at providing an outline of typical methods of flood damage analysis used for different spatial scales. Due to the great variety of damage studies, there are also many approaches with intermediate methods, which combine elements of all three types.

For instance, some studies examining large research areas, which are usually subject of macro-scale analysis, include elements of the meso-scale approach. In the international study for the River Rhine (IKSR 2001) damage potentials are evaluated on the basis of land use units derived from the Corine Land Cover database. In this way damage potentials can be better differentiated with regard to land use, although the Corine data are less detailed than the ATKIS data which are usually applied in meso-scale methods. The average capital value for each land use category is adopted from preceding meso-scale studies in the region. The study carried out for parts of the Yangtze River in China by Gemmer (2004) proceeds likewise. Due to the lack of official land use data a rough classification of land use categories is taken from Landsat Satellite data. As regards, e.g., the evaluation of settlements areas, average values are calculated on a per-household basis derived from official statistics. Both studies use relative depth-damage functions to estimate expected damages. The Rhine study derived these functions from the German HOWAS-database, which stores empirical flood damage data. In the Yangtze study such a database was not at hand such that depth-damage curves were taken from other studies and refined according to regional characteristics.

In the UK a macro-scale study carried out for England and Wales (DEFRA 2001) even tries to integrate some object-oriented estimations, which is normally part of micro-scale approaches. Here, every single building within the defined flood areas is considered and located by means of address-point data. However, the value estimation of these properties is rather undifferentiated compared to micro-scale approaches due to the use of average regional house prices, which disregard the heterogeneity of house types.

A quite similar approach is carried out by Bateman et al. (1991) in their meso-scale study for East-Anglia. Likewise, single buildings, which are located by means of maps, are assessed by average regional house prices. Some differentiation is realised through distinguishing residential and non-residential building categories.

A similar object-oriented approach is also applied in a meso-scale study for parts of the Danube River in Germany (ProAqua et al. 2001). A standardised set of absolute damage functions is used to calculate the estimated damages for different residential and non-residential building categories.

Some other attempts in Germany have to be mentioned which try to improve the accuracy of the standard meso-scale approach by integrating geomarketing data (MURL 2000, Meyer 2005). These commercial data provide information about the number of inhabitants, purchasing power, buildings and firms on a small spatial scale, i.e. for every single quarter of a city. Taking this information as an addition to the ATKIS land use data, the spatial distribution of damage potentials, especially of inhabitants and residential capital, can be determined more realistically. This approach is quite comparable to the standard method applied in the Netherlands to estimate damages and casualties in dike ring areas (Kok et al. 2004). The Dutch scientists also use small-scale socio-economic data to estimate, e.g., the number of residential buildings of a certain type or the number of employees of a certain sector within a geographical unit. For each land use category, house type or job a maximum direct and indirect damage amount is assumed, mainly based on reconstruction or replacement values. The expected damages are calculated by the use of relative depth-damage functions, also taking into account inundation velocity and – in case of casualties – water level rise rates.

In face of the great variety of methods of damage analysis, the choice of an appropriate method (or of a combination of elements of different approaches) does not only depend on the size of the area under consideration, but also on other factors like the availability of necessary data, time, manpower and/or money resources and not least on the goal of the respective study and the management level for which it should provide decision-making support. The latter factors determine the political demands regarding the accuracy of the results and, hence, will decide upon the application of micro-, meso- or macro approaches for a given study region. Table 1 provides an overview over the major characteristics of micro-, meso- and macro-scale approaches to flood damage estimation as classified above. However, as shown in the preceding paragraph, combination is possible – and it is also reasonable if distinctive aspects need to be analysed.

Table 1: Characteristics of macro, meso and micro approaches of flood damage analysis

Scale	Size of Research area	Management level	Demands on accuracy	Amount of resources required per unit of area	Amount of input data required
macro	(inter-)national	comprehensive flood mitigation policies	low	low	low
meso	regional	large-scale flood mitigation strategies	medium	medium	medium
micro	local	single protection measures	high	high	high

See also Gewalt et al. 1996, Meyer 2005

4 Shortcomings of the current state-of-the-art damage estimation methods

Despite the fact that, from an economic perspective, the application of current state-of-the-art methods of flood damage analysis is a clear progression when compared to the safety standard approach, it must be considered as well that the state-of-the-art methods presented above are characterised by several deficiencies. Particularly, the complex interrelations of flood vulnerability analysis as described in section 3 are considered only in an extremely reduced sense, while existing socio-economic evaluation approaches are not taken into account. The five most important shortcomings are portrayed in the following.

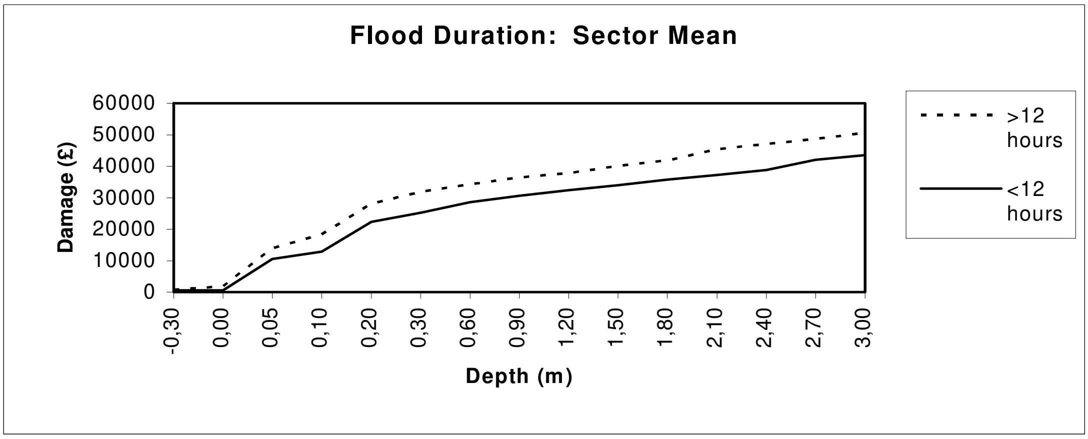
(1) Current flood damage and vulnerability analyses have a dominant focus on tangible flood effects. Despite the fact that economic methods for the evaluation of intangibles have existed and have been discussed for many years in economics literature (e.g., Hanley and Spash 1993, Brent 1996), and economic studies on the evaluation of intangible health effects (e.g., Johnson et al. 2000, Liu et al. 2000, Sendi et al. 2002), loss of life (e.g. Landefeld and Seskin 1982) and environmental effects (e.g., Bateman et al. 1999, Garrod and Willis 1999) are at hand, these methods are not (or, at most, very rarely) applied in the context of flood vulnerability analysis. A major reason for this deficiency might be that flood damages are often calculated by engineers or hydrologists with a business economics background. Therefore, economic methods regarding welfare effects of the whole economy might not be recognized. Another reason might be that the evaluation of human life in monetary terms is rejected by many people on ethical grounds. However, even if the monetisation of some of the

so-called intangibles are controversial (even among economists), it is still widely accepted that effects on health and the environment can, at least partly, be quantified in monetary terms in order to approximate the respective welfare losses. Therefore, if appropriate methods are at hand to quantify intangibles, this should be done to improve the estimations of flood damage potential and expected damages. Eventually, it might be argued that effects on intangibles are small compared to the direct material flood damage, but as long as such a hypothesis has not been tested and proved on solid grounds this assertion cannot be considered valid on a scientific basis.

(2) Indirect effects are also outside the scope of most analysts who are executing flood vulnerability and damage analyses. However, if the economic activity in a region is brought to a standstill, this does not only imply a loss of production and a decrease in supply of consumers within the affected region. It might also lead to severe consequences for other sectors within the economy, which are closely connected through intermediate products, trade, services like electricity and telecommunication and company relations. Especially if production processes for export goods are affected or the economic sectors hindered by floods are highly concentrated and/or specialised, there may be no possibility of shifting production to other national producers. As a consequence, production and sales might be lost to manufacturers in other nations, such that national value-added and exports decrease. While indirect effects in the form of production and sales losses in inundated regions are sometimes considered in flood vulnerability studies by means of average loss of value-added or additional costs, effects outside the inundation area are usually neglected – often due to a lack of empirical data (Penning-Rowsell et al. 2003, ch. 5). However, analytical methods for estimating such indirect effects are available, especially in the form of economic input-output models. Pioneer work for estimating the structural economic effects of large scale inundation by means of input-output modelling has been executed in the Netherlands (van der Veen et al. 2003), and should increasingly be applied in the context of flood damage analysis.

(3) Regarding the vulnerability relationships between expected damage and different system characteristics, as discussed in section 3 above, vulnerability factors are usually used or calculated for one exposure indicator only. Frequently, inundation depth is the main and only flood characteristic used to estimate expected flood damage by means of depth-damage curves. While it is known that other variables such as velocity, turbulence, flood duration as

well as toxic or sedimentation load can have a significant impact on flood damages[7], these variables are usually assumed to be strongly correlated with inundation depth – and therefore ignored in the analysis. Since the other variables are also difficult to measure or estimate, inundation depth is still the major variable for calculating flood damage today (Smith 1998, 40f). Only a few authors have tried to include complementary exposure variables, such as flood duration, as secondary variables in the analysis and generated depth-damage curves with specific variants for different flood durations as shown in figure 3 (Penning-Rowsell/Chatterton 1977, Penning-Rowsell et al. 2003). Accuracy of flood damage analysis could improve if such expanded depth-damage curves were to be developed and applied more frequently.



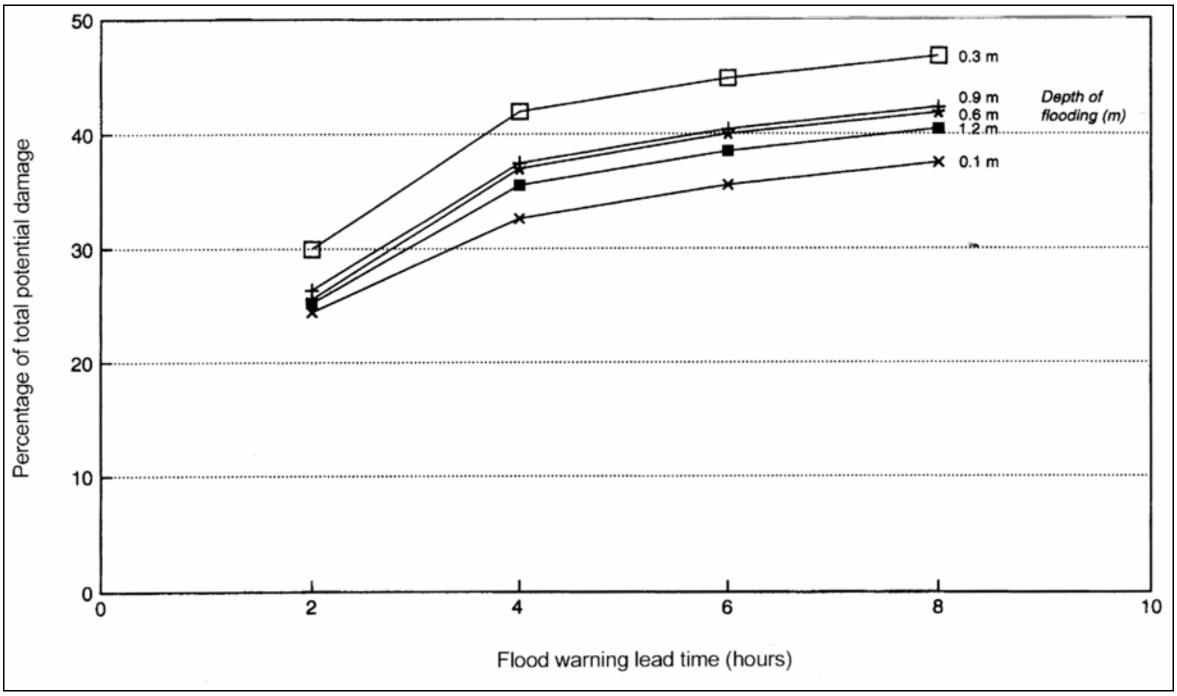
Source: Penning-Rowsell et al 2003: ch. 3

Figure 3: Depth-damage curve differentiated by flood duration

(4) Socio-economic susceptibility indicators in a broader sense are not considered, for the most part, in flood damage and vulnerability studies to differentiate and improve damage estimations. Factors such as individual and public preparedness before flood events, the quality of coping strategies during a flood and, closely linked to this, the perception of flood risks in the affected population are usually excluded from ex ante flood damage calculations. However, as evidence from the Elbe flood 2002 showed, individual preparedness in terms of

[7] To illustrate this aspect: turbulence and velocity are important variables determining the formation of road, rail track and pylon damage. The pure incidence of inundation does not lead to major damage regarding these elements at risk. Due to a lack of information and a lack of correlation to inundation depth, these damage types are usually not included in flood damage and vulnerability studies. Furthermore, experiences from the Elbe flood 2002 showed that actual damage to buildings and household contents were multiplied if toxic or sedimentation loads were involved (DKKV 2002, p. 50).

technical measures in the buildings and flood-adapted usage of the lower storeys can reduce the damage by a range of 5-30% (DKKV 2002: 46-51). Therefore, susceptibility aspects should be considered more carefully in the context of flood damage analysis. One of the rare examples to include socio-economic factors in flood damage analysis stems once again from the UK. In the Flood Hazard Research Centre, flood researchers developed an approach for estimating the impact of early flood warning lead time on damage. As can be seen in figure 4 for different levels of inundation depth, an increase in warning time by more than two hours has the potential of reducing damage by more than 10% (Penning-Rowsell et al. 2003; ch. 3). This reveals that human efforts and coping strategies during the warning lead time of a flood have a clear impact on flood damage. However, these percentages are still low compared to the efforts and investments often undertaken to improve early flood warning systems. Differentiating these curves further for different types of coping strategies and risk perception patterns could generate more evidence regarding the significance of socio-economic susceptibility indicators in flood damage analysis.



Source: Penning-Rowsell et al 2003: ch. 3

Figure 4: Impact of flood warning lead time on flood damage

(5) Last but not least, it should be emphasised that the final evaluation of flood damage should not be executed on the basis of monetary cost-benefit results alone. Even if new economic methods for estimating intangibles are applied, there will always remain a number

of intangibles which cannot be monetised or which society does not accept in monetary terms, among them for example loss of life, loss of unique valuables like diaries, loss of cultural heritage and distribution effects of floods – to name just a few. Current state-of-the-art approaches of flood damage evaluation do not consider these effects, although empirical surveys have shown that people usually bemoan these intangible flood damages most (Green et al. 1994: pp. 52 ff, Hagemeier 2005: pp. 88 ff). Therefore, in order to take these effects into account in the evaluation of flood risk management strategies, multi-criteria methods should be developed and applied in the context of flood damage analysis and risk assessment.

These five shortcomings pose a substantial challenge for flood damage and flood vulnerability research. Diminishing or even eliminating them and improving the state-of-the-art in flood research and flood risk management accordingly would be a great success.

5 Outlook

It is a challenge of flood research to find new and innovative approaches for overcoming the shortcomings of current flood damage and vulnerability analysis approaches and, thereby, to strengthen the overall approach of flood risk management with special regard to its socio-economic components. In the context of the Integrated Project FLOODsite, financed by the EU in the 6th framework programme, some of the shortcomings of flood vulnerability analysis are the object of research of a group of European social scientists. The research objectives are:

(1) providing methodological guidelines for the monetary estimation of flood effects on human health and the environment:
(2) providing methodological guidelines for the monetary estimation of indirect economic effects based on input-output modelling techniques;
(3) advancing the development of functional vulnerability relationships between expected damage and flood characteristics besides inundation depth;
(4) advancing the development of functional vulnerability relationships between expected damage and indicators of socio-economic susceptibility in a wider sense, focusing especially on risk perception, preparedness and coping indicators.
(5) developing multi-criteria tools in order to include non-monetary intangible damage into the assessment framework of flood damage analysis.

Furthermore, in order to disseminate the knowledge gained from research, an overall guideline document on the state-of-the-art flood damage and vulnerability analysis approaches will be produced, including guidelines for innovative approaches for reducing current shortcomings. This document is meant to contribute to the harmonisation and improvement of flood vulnerability methods used, and to expand their application all over the EU, especially in countries where risk analysis and flood vulnerability analysis are uncommon methods today.[8]

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[8] After being completed, the guidelines will be available at the FLOOD*site* web-page: http://www.floodsite.net.

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