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Anmerkung der Herausgeber: Diese Synopse war zu Beginn des DFNK nicht vorgesehen. dementsprechend gibt es hierzu kein spezifisches Teilprojekt. Die Mitglieder der Gruppe haben über die Arbeit in den einzelnen Teilprojekten hinaus die im Folgenden vorgestellte Methode zur vergleichenden Risikobewertung entwickelt. Dieser Text erscheint in leicht veränderter Form im Sonderband über das DFNK in der Fachzeitschrift *Natural Hazards*.

7.1 Comparative risk assessments for the city of Cologne – storms, floods, and earthquakes

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7.1.1 Abstract

In this paper a methodology for a multi-risk assessment of an urban area is introduced and performed for the city of Cologne, Germany, considering the natural hazards windstorm, flooding and earthquake. Moreover, sources of the uncertainty in the analysis and future needs for research are identified. For each peril the following analyses were undertaken: hazard assessment, vulnerability assessment and estimation of losses. To compare the three hazard types on a consistent basis a common economic assessment of exposed assets was developed. This was used to calculate direct economic losses to buildings and their inventory. The perils were compared by risk curves showing the exceedence probability of the estimated losses. For Cologne, most damages that occur frequently are due to floods and windstorms. For lower return periods (10 – 200 years) the risk is dominated by floods. For return periods of more than 200 years the highest damages are caused by earthquakes.

7.1.2 Introduction

Risk assessments for natural hazards have usually been carried out separately for the various pertinent hazards in the considered regions or cities, without attempting to combine these studies to one holistic risk assessment. There are only a few exceptions: e.g. the UNDRP study (1977) for Manila, the KATANOS report for Switzerland (BZS, 1995), the AGSO Cities project for geohazards in Australian urban communities (e.g. Granger et al., 1999) and the more recent studies for Turrialba, Costa Rica (van Westen et al., 2002) and Toronto, Canada (Ferrier and Haque, 2003). As demonstrated by Durham (2003), it is, however, such

a synoptical view that enables planners and decision-makers to make adequate decisions on risk reduction and loss prevention programs.

The methodological approaches in risk assessment studies range from very coarse indices to elaborate assessments. An example of a coarse index approach is the methodology of Ferrier and Haque (2003). Based on readily available data and expert knowledge about the hazards and their possible effects on the municipality, this method yields a ranking of the different risks in a community and provides guidance to both mitigation and preparedness priorities. Another coarse index was proposed by Munich

Re (2003) and also uses available data and expert opinion. On the other end of the spectrum are in-depth assessments which consider the complete risk chain ('triggering natural event – direct impacts on population; built and natural environment – secondary and long-term consequences') by means of complex simulation tools for hazard and vulnerability analyses. Most of them lack, however, the multi-hazard aspect (Davidson, 1999; UN/IDNDR, 2000). One example of a true multi-hazard study is given by Blong (2003) who developed a damage scale for Australia that quantifies the damage to buildings resulting from a range of natural hazards.

This study aims to provide a multi-risk assessment for the city of Cologne, Germany, performed within the DFNK (German Research Network Natural Disasters) project. Cologne was chosen as a demonstration site since there is a huge accumulation of people (1,014,837 inhabitants in 2000) and assets, such as cultural assets, industrial sites (chemical industry, vehicle construction), an important commerce and services sector (including a trade fair) providing nearly 230,000 jobs, several radio and television stations, etc. (Urban Development Authority of Cologne, 2002). Moreover, Cologne is exposed to the three hazards types windstorm, flood and earthquake, representing the most important hazards in Germany.

Storms take in a top position in damages caused by natural hazards in Germany (Munich Re, 1999). In particular extratropical cyclones are responsible for about 53 per cent of economic losses. The total insured loss from the series of gales in December 1999 exceeded €10 billion (Munich Re, 2001). Also flood events are of major concern in Germany with the highest losses of more than € 9 billion in 2002 at the Elbe river. The last severely damaging floods which also affected Cologne occurred in 1993 and 1995 with economic losses of € 530 mill. and € 280 mill., for the whole Germany. In Cologne, losses amounted to € 77 mill. in 1993 and € 33 mill. in 1995

despite similar water levels of 10.63 m and 10.69 m, respectively (Vogt, 1995; Fink et al., 1996). The significant reduction of losses in 1995 was mainly explained by an enhanced risk awareness and a better preparedness of the people at risk – a phenomenon that was also observed in adjacent catchments (Wind et al., 1999).

Whereas windstorms and floods are well known publicly, damaging earthquakes are rather rare in Germany and there is little public awareness of this risk. Nevertheless, and in spite of only moderate event magnitudes, the total losses can be considerable due to the large number and the high values of exposed objects. The 1992 Roermond earthquake (moment magnitude $M_w=5.3$, local magnitude $M_L=5.9$), northwest of Cologne killed one and injured 25 people, damaged 7,200 buildings and caused losses of € 150 mill. Paleoseismologically constrained earthquakes with M_w up to 6.7 (Camelbeeck et al., 2000) would, of course, produce much higher losses, in the order of tens of billions of €. Not the frequency of earthquakes is of concern in the risk management, but their extreme loss potential.

In order to compare the three hazard types, the following framework is used. The term **risk** is used to describe the probability that a given loss will occur. Risk encompasses three aspects: **hazard, vulnerability and exposed assets (or people)**. According to this definition the following analysis steps were performed within this study:

1. **Hazard assessment**, focusing on the probability of occurrence of potentially damaging natural events.
2. **Development of the assets inventory**, i.e. identifying the values that are exposed and vulnerable to hazard events.
3. **Vulnerability assessment**, evaluating how exposed assets will suffer by various hazard events.

4. **Loss estimation**, superimposing value distribution and vulnerability functions and assigning the corresponding scenario event probabilities. In this study only direct monetary losses were considered, i.e. indirect losses as well as intangible damages (casualties, evacuated people etc.) were completely neglected.
5. **Synthesis**, linking the loss estimates of the different hazard types. Whereas linking losses as such is easy, a true comparison of the hazards is difficult, since different risks may have very different characteristics concerning their impact on the city or their probability of occurrence.

The multi-risk assessment presented in this study differs from the few approaches for multi-risk assessment existing so far, especially in the degree of detail, and partially in the novel approach for vulnerability assessment. In the following sections, the hazard assessment for windstorms, floods and earthquakes is described. The calculation of the assets in Cologne is introduced as a common basis for all these perils. The vulnerability assessment and the loss estimation methods for each hazard type is described. The paper ends with a comparison of the three different risk curves for the city of Cologne as a common risk indicator.

7.1.3 Hazard assessment

For each of the three considered perils a hazard assessment was performed focusing on the estimation of the probabilities of occurrences of potentially damaging events and effects. At this stage, different hazard types are not comparable with each other since hazards due to windstorms, floods and earthquakes are described by different strength parameters: wind speed, discharge or inundation depth and ground motion or macroseismic intensity, respectively.

Assessment of the windstorm hazard

For studying the storm hazard two kinds of observed wind speed time series are available, gust data and time averaged wind speeds. For the region of Cologne such time series were provided by the German Weather Service (DWD) observed at the DWD station "Köln-Wahn". The first series contains hourly wind speeds, averaged over a sampling period of 10 minutes. Its length covers 30 years, from 1971 to 2000. The series of the maximum daily 3 s gusts is 45.5 years long, from 1957 to 2002. These two different measures for wind speed are to be compared with data from known damaging events. The question arises, which one is more suitable for the assessment of storm risks. The strongest gust values cannot be assigned to the occurrence of known disastrous cyclones. Therefore, a use of the gust series data would lead to an overestimation of storm damage risk. In contrast to the maximum gusts, the highest values of the mean wind speed series correspond to the well known damaging events.

Different distribution functions were taken into consideration for the extrapolation of the time series. According to Troen and Petersen (1989) the Weibull distribution estimates extreme values insufficiently. As expected, the Weibull method gave incorrect estimates for the tail of the distribution. Two other functions were tested, i.e. the Schmidt distribution (Schmidt, 1980), which was developed especially for wind speeds, and the Gumbel type I distribution (Gumbel, 1958). The accuracy of estimates following Schmidt is sufficient also at the tails. This distribution is valid for sea areas, as well as over land with a flat relief. The extreme values resulting from the Gumbel type I fit only the tail of the distribution sufficiently well. Since this is the important point here, this method was used, too, although its use has clear limitations since it allows infinitely large events and does not consider a physically existing upper bound.

The extrapolation of threshold values of wind speed for some exceedence probabilities is presented in Fig. 7.1. The mean wind speed is presented up to a return period of 300 years (Gumbel method) and alternatively up to 100 years (Schmidt method). The latter is the upper bound of extrapolations suggested by Schmidt. At first glance, both estimations seem to be small compared, e.g., with mean wind speeds of 26.1 m/s measured during the storm Lothar (26.12.1999) in Karlsruhe. The Cologne region, however, is known for weaker wind speeds in comparison to locations in the open North German lowland. This is due to the protected location of Cologne in the Lower Rhine Embayment (Dütemayer, 2000).

As described above, the mean wind speed was used to develop the loss scenarios. Losses as such, however, are more related to peak gusts than to mean wind speeds. Therefore, the peak gusts had to be derived from the mean wind speeds. A conventional gust factor G was derived as the quotient of the peak gust and the mean wind speed. According to Wieringa (1973) the gust factor was calculated as a function of the mean wind speed v_m (averaged over a period $T = 10$ minutes), the gust duration t , the roughness length z_0 (a parameter for the effect of surface roughness in turbulent flow) and the height above ground z :

$$G(t, T = 10 \text{ min}, z, z_0, v_m) = 1 + \frac{1.42 + 0.3013 \cdot \ln \left(\frac{990}{\sqrt{m \cdot t}} - 4 \right)}{\ln \left(\frac{z}{z_0} \right)}$$

The duration of the gusts was assumed to be 3 s.

Taking into account the length of the used time series, a reliable estimate for longer return periods than a few hundred years is hardly possible. On the other hand, gust speeds of up to 45 - 50 m/s were already observed in the North German lowland in the past (Cappel and Emmerich, 1975). In principle, the occurrence of even higher values is possible.

Although the occurrence of damaging tornadoes is possible in Germany (Dotzek, 2001) this risk type is not considered here.

Assessment of the flood hazard

The estimation of the flood hazard is based on an extreme value analysis of the discharge data at the gauge Cologne on the river Rhine. At this gauge a discharge series with reliable daily data from 1880 to 1999 is available. For each hydrological year (from 1st November to 31st October), the maximum discharge was determined. Different distribution functions were adapted to this Annual Maximum Series (AMS): Gumbel type I, Pearson type III, Weibull and Lognormal. The parameters of these distribution functions were estimated by the method of moments (Stedinger et al., 1992). Fig. 7.2 shows the four distribution functions as well as the observed events, whose empirical probabilities were assessed by six different plotting position formulas (Weibull, Gringorden, Cunnane, Median, Blom and Hazen) given in Stedinger et al. (1992). The four distribution functions were then weighted by a Maximum Likelihood method to construct a composite probability distribution function (Wood and Rodríguez-Iturbe, 1975), which gave the following weights θ_i for the individual distributions: Pearson type III ($\theta_1 = 0.858$), Weibull ($\theta_2 = 0.072$), Lognormal ($\theta_3 = 0.067$), and Gumbel type I ($\theta_4 = 0.003$). The Pearson type III distribution seems to be the best option for this series since it is almost identical with the composite distribution. However, in comparison with the estimates of the German Federal Institute of Hydrology, where multiple annual maximum series and the log-Pearson type III distribution have been used, the Pearson type III in combination with the AMS 1880-1999 deliver lower discharge estimates especially for return periods larger than 50 years. The estimates of the German Federal Institute of Hydrology are fairly well represented by the Gumbel type I distribution in Fig. 7.2.

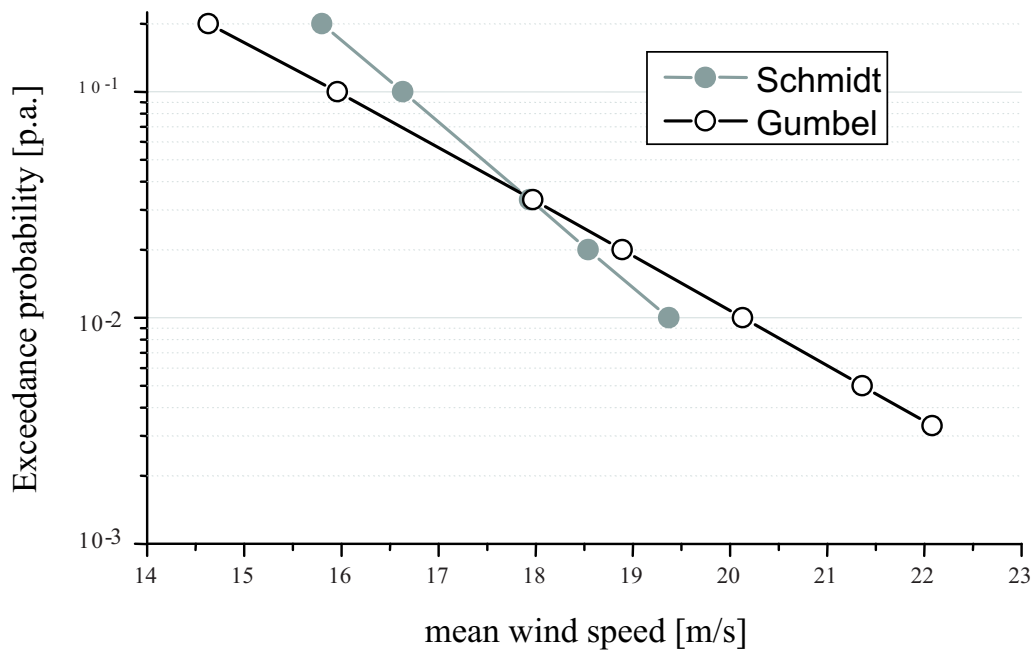


Figure 7.1: Extrapolated mean wind speeds for selected return periods up to 100 years (following Schmidt) and 300 years (following Gumbel).

In general, the uncertainty of flood frequency analysis is enormous because sample sizes are limited, the sample types [(multiple) annual maximum series or partial duration series] differ and a variety of distributions and parameter estimation methods are available (e.g. Chbab, 1995). To overcome this problem many countries published guidelines and recommended certain distributions. For example, the log-Pearson type III distribution is the most frequently used distribution in the USA, whereas the generalized extreme value distribution is popular in Great Britain, the Lognormal distribution in China and other distributions in other countries (Singh and Strupczewski, 2002).

The four highest events in the AMS 1880-1999 nearly have the same order of magnitude: 10,700 m³/s to 10,900 m³/s (Fig. 7.2). These discharges equal a water level at the Cologne gauge of 10.55 m to 10.66 m. Therefore, it seems that a discharge of around 11,000 m³/s might serve as an upper bound. However, an analysis of historic flood events in Cologne provided by Krahe (1997) reveals that the ex-

treme floods of 1342, 1374 and 1497 – with water levels and discharge values of 11.53 m (12,435 m³/s), 13.30 m (15,680 m³/s) and 11.50m (12,380 m³/s), respectively – clearly exceed the largest flood events in AMS 1880-1999. Empirical probabilities of the historic events were estimated by combining the historic events with the AMS 1880-1999 following DVWK (1999). Assuming different plotting position formulas (see above) a return period between 670 and 1350 years was assigned to the largest flood event which occurred in 1374 (Fig. 7.2). It was therefore classified as a 1000-year flood (Fig. 7.2). It has, however, to be emphasised that the discharges of the historic events were obtained with the current rating curve. Owing to morphological and hydraulic changes in the river bed these calculations are fairly uncertain.

For the estimation of flood losses certain discharges have to be converted into water levels and inundation areas. The transformation of discharges into water levels was performed by the rating curve of the Cologne gauge. Inun-

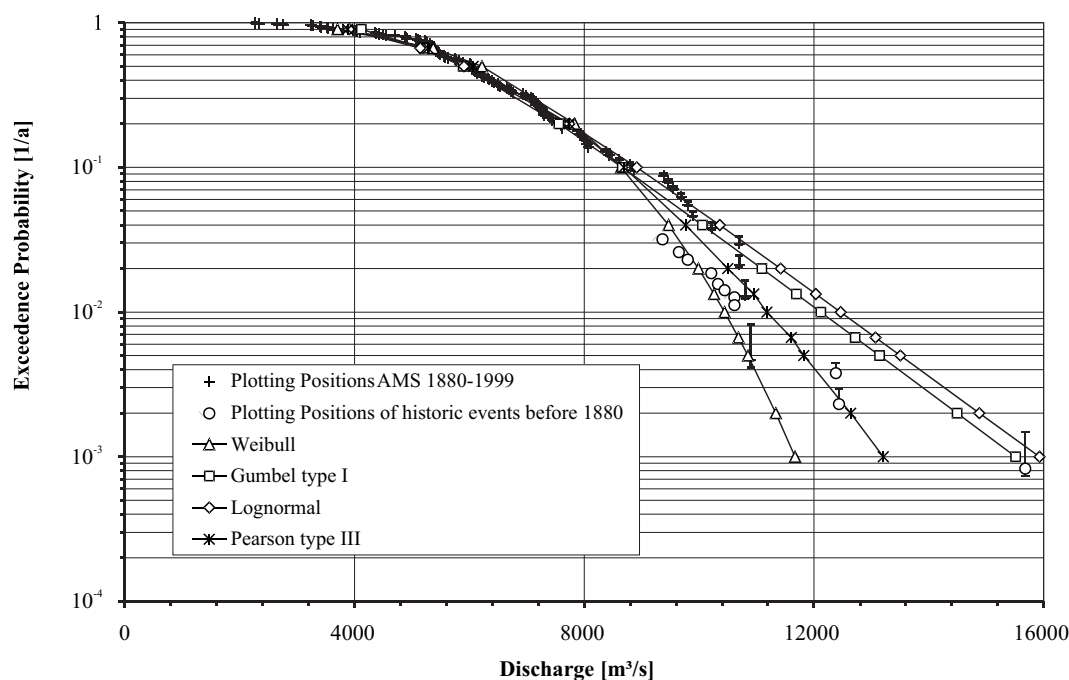


Figure 7.2: Four possible distributions of discharge at the Cologne gauge based on the annual maximum series from 1880 to 1999 (AMS 1880-1999) and empirical probabilities of observed and historic flood events estimated with different plotting position formulas (cf. text).

ation scenarios considering the flood protection outlined in Stadt Köln (1996) were provided by MURL (2000) for the water levels 11.30 m, 11.80 m and 12.50 m at the Cologne gauge. Additionally, inundation maps were calculated by interpolating the water levels given at 13 cross sections along the Rhine in Cologne and by intersecting the resulting water surface with a digital elevation model of 50 m grid size. Fig. 7.3 shows a few inundation scenarios. The resolution of the digital elevation model is, however, too coarse to calculate the impacts of the local flood protection measures and the resulting inundation areas exactly. This is relevant for water levels below 11.30 m and is a further source of uncertainty which will affect the risk assessment.

Assessment of seismic hazard

The Lower Rhine Embayment represents one of the most seismic active areas of Germany. Fairly strong earthquakes have occurred there

in the past; e.g. an intensity $I=VIII$, magnitude $M_L=6.1$ earthquake on 18 February 1756 near Düren and the $M_L=5.9$ earthquake 1991 near Roermond/Heinsberg, which had, due to the large focal depth of 20 km, an $I=VII$ only, still causing extensive damage (see introduction). Cologne lies close to the eastern border of the seismically active area.

The observed seismic record is sufficiently complete since 1250 for intensity VIII and since 1500 for intensity VII (Grünthal et al., 1998). Since the goal of the study is an intensity based risk assessment, the hazard assessment was performed for this parameter. A harmonized earthquake catalogue covering the entire western Central European area was used (Grünthal and Wahlström, 2003). Seismic source zones according to the seismotectonics of this larger area were taken from Grünthal et al. (1998), while for the Lower Rhine Embayment and the Ardennes 14 smaller seismic source zones were derived on the basis of the detailed neotectonic pattern and tectonic

Water level (gauge Cologne)

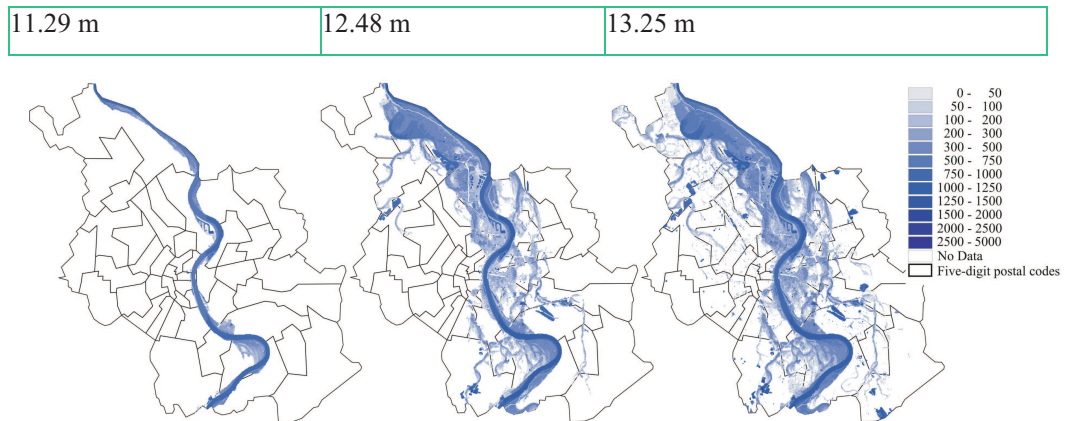


Figure 7.3: Selected inundation scenarios for Cologne. According to the current rating curve the water levels of 11.30 m, 12.50 m and 13.25 m correspond to a discharge of 12,018 m³/s, 14,247 m³/s and 15,677 m³/s, respectively.

studies (Grünthal and Wahlström, this issue). Different combinations of the 14 small source zones represent the epistemic uncertainty of the source zonation input for the probabilistic seismic hazard assessment. All the other input parameters were also treated with their uncertainties with the logic tree technique.

Intensity related fractile hazard curves for the centre of Cologne are given in Fig. 7.4. The mean hazard curve, representing the best estimate, is used here for the further procedure regarding loss estimation. Corresponding seismic hazard maps for the area of Cologne for different hazard levels are the basis for the following estimations of seismic losses. Three of these maps are shown in Fig. 7.4.

Assets assessment for the city of Cologne

In order to estimate direct losses that might be caused by various hazards, it is necessary to develop an inventory of potentially exposed assets in the area under consideration. For a consistent comparison of different risks a uniform data base of the assets is essential. Therefore the aim is to calculate values – here defined as replacement values for the reference year 2000 - for buildings and their contents in

different economic sectors, particularly in the sectors of private housing, commerce and services as well as industry. As a spatial data base the land register ATKIS, i.e. the German official topographic-cartographic information system, was used.

The assets were estimated by means of the following statistics: On the basis of data on the gross stock of fixed assets in 1997 (Statistical Office North Rhine-Westphalia, 2002) and data concerning type and expanse of land uses in North Rhine-Westphalia (MURL, 2000) a unit value [€/m²] was calculated for all economic sectors that are included in the system of national accounts from 1958. The unit values were scaled to the year 2000 by data on the development of the gross stock of fixed assets in North Rhine-Westphalia (Federal Statistical Office Germany, 2002), i.e. the figures for 1997 were multiplied by 1.0525. As assets are not distributed uniformly throughout the country, but data on the gross stock of fixed assets are only available per federal state, a measure had to be found which accounts for the high concentration of assets in the Cologne region. Therefore, the unit values for North Rhine-Westphalia were adjusted to Cologne using the gross value added per employee. The

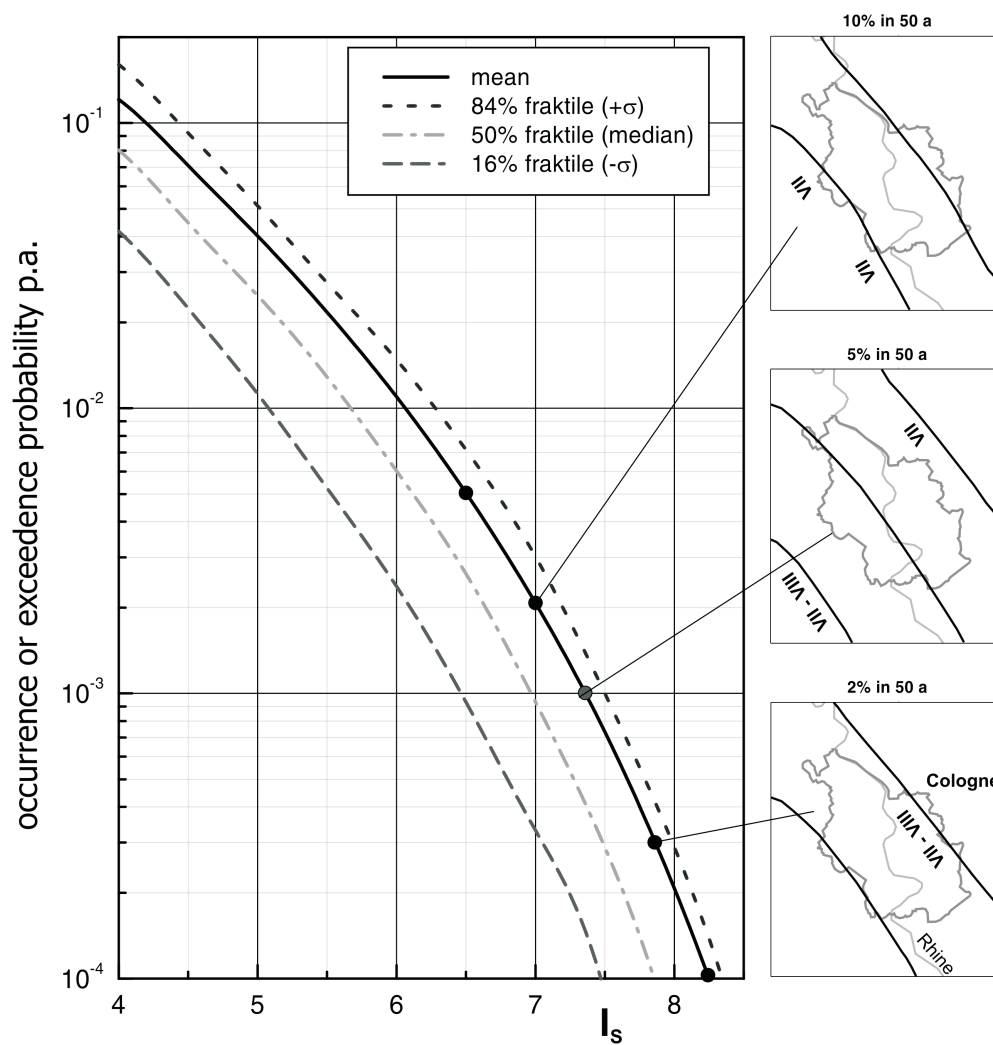


Figure 7.4: Probabilistic seismic hazard curves for the centre of Cologne in terms of intensities and their fractiles. Basis for the risk assessments are here generally the mean hazard values. Corresponding intensity hazard maps for the city of Cologne are shown as inlay maps for different probability levels.

underlying rationale is that there is a relationship between assets involved in production and value creation: The higher the asset's worth, the higher productivity will be. Gross value added per employee is a productivity measure. In 1996, the average value added per employee throughout Germany was € 50,406 (= 100%). In North Rhine-Westphalia it was € 52,821 (= 105%), and in the city of Cologne it was € 65,010 (= 129%) (Statistical Office Baden-Württemberg, 2000). The unit values for North Rhine-Westphalia were therefore multiplied by 1.23.

The use of the gross stock of fixed assets for asset assessment does not work well for the sector of private housing since the data do not include all private residential buildings. Therefore, an approach based on statistics of the Urban Development Authority of Cologne (2002) and insurance data (GDV, 2003, pers. comm.) was chosen for this sector: The number of buildings, households and cars in 2000 was each multiplied by the corresponding average insured value in Cologne. By this approach a total value of €80.25 billion and a mean unit value of 1015 €/m² was obtained (Table 7.1).

For loss estimation models a spatial distribution of the assets is needed. Therefore, the values had to be allocated to object classes within the land register ATKIS. Since there is no exact correspondence between the economic sectors in the national accounts and the ATKIS land use codes, the scheme proposed by MURL (2000) was slightly modified and used to assign ATKIS land use classifications to economic sectors. The resulting spatial pattern of economic sectors in Cologne is shown in Fig. 7.5.

By multiplying the unit value by the area of an object the economic value of each ATKIS-object was obtained. The object values were then aggregated within five-digit postal codes and for Cologne as a whole. The main results are given in Table 7.1, the total value amounts to €133 billion.

There exist other approaches for the estimation of assets. For example, an approach based on the number of inhabitants multiplied by the mean insured values per capita in Germany yields considerably higher values (i.e. an augmentation of 30 % for housing and 65 % for commerce and industry). Furthermore, data gathered by primary insurers which represent 20 % of Cologne's total portfolio for residential buildings show that the average building value in Cologne is probably higher than the value assumed here. This is due to a higher share of multi-family housing and more valuable urban housing. This leads to the conclusion that the values derived by the above described approach represent a rather low estimate of the total values. However, a validation remains difficult.

7.1.4 Vulnerability assessment and estimation of direct losses

For each of the three natural disasters a set of potentially damaging scenario events was selected. They were related to certain probability levels of the hazard assessments and were applied also for the seismic risk assessments. For these scenarios it was evaluated which assets are exposed by the hazardous events and what the effects are. In case of damaging earthquakes and windstorms the whole town is affected, as opposed to floods. Monetary direct losses to buildings and inventory were then estimated considering only the sectors of private housing, commerce and industry with a total value of €110 billion (see Table 7.1).

Vulnerability and loss estimates due to windstorms

The assessment of expected losses for different return periods was performed by use of a simple empirical damage function developed by Munich Re (Munich Re, 1993 and 2001). It is based on studies of the gust fields of disastrous cyclones like the 1990 storms Daria, Wiebke,

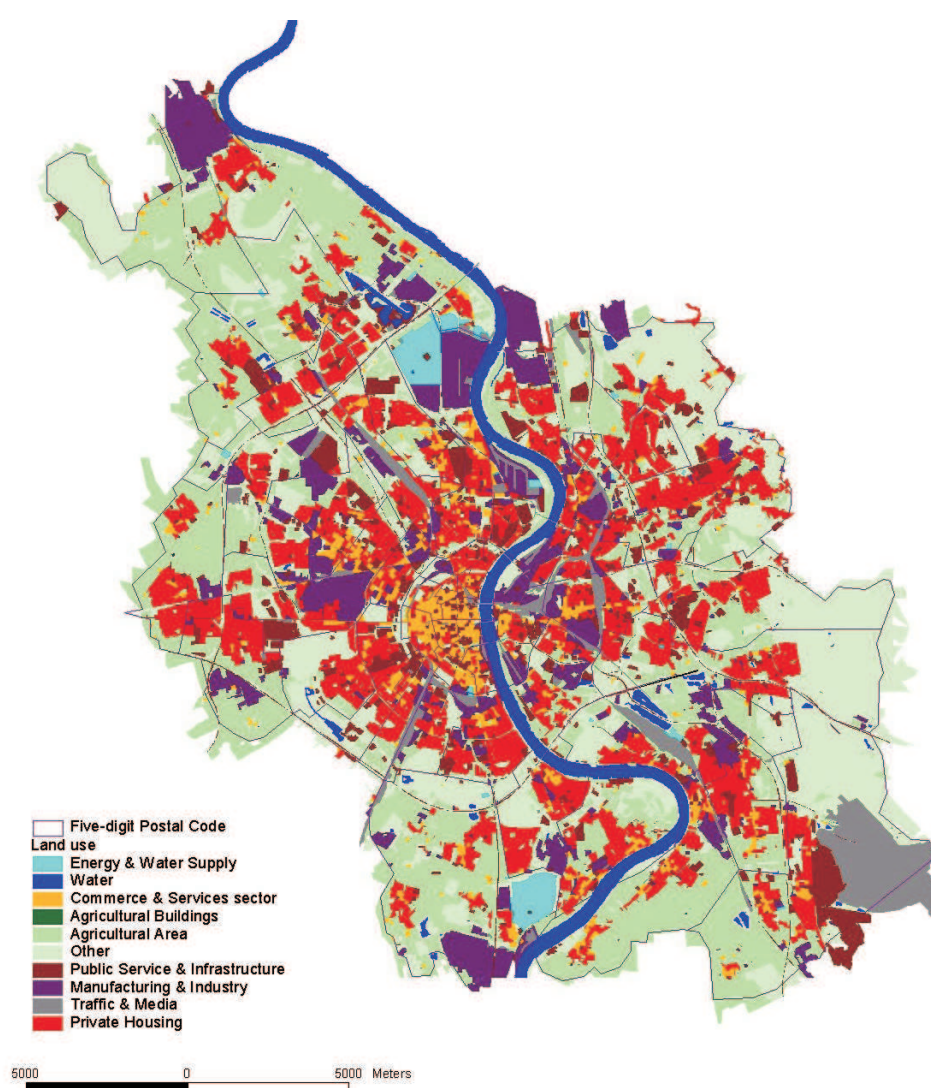


Figure 7.5: Spatial pattern of economic sectors in Cologne according to the land register ATKIS.

Economic sector	Area [km ²]	Share of total [%]	Unit economic value [€/m ²]	Total asset in Cologne [billion €]	Share of total [%]
Agricultural Area	111.01	26%	---	---	---
Other	100.38	25%	---	---	---
Private Housing	79.10	20%	1015	80.25	60%
Manufacturing & Industry	35.30	9%	362	12.79	10%
Public Service & Infrastructure	26.77	7%	467	12.49	9%
Commerce & Services Sector	14.25	4%	1179	16.81	13%
Traffic & Communication	17.87	4%	67	1.09	1%
Water	15.27	4%	---	---	---
Energy & Water Supply	5.19	1%	1785	9.25	7%
Total	405.14	100%	---	132.68	100%

Tabelle 7.1: Estimation of assets in the city of Cologne on the basis of land use information system ATKIS and unit economic values (Statistical Office North Rhine-Westphalia, 2000) (Reference year: 2000, cf. text).

Herta and Vivian and the 1999 storms Lothar, Martin and Anatol:

$$LR(v_G) = LR(80 \text{ km/h}) \cdot \left(\frac{v_G}{80 \text{ km/h}} \right)^\gamma$$

Here, $LR(v_G)$ is the loss ratio, v_G the gust wind speed. This equation is valid for speeds above 80 km/h. No significant damages occur in Germany below this value. The analysis of the 1990 data suggests a γ of 3 to 4. For the 1999 gales γ is rather in the range between 4 and 5. No differentiation between coastal area and inland was made, because the data do not support such differences.

Two estimations were made to take into account the uncertainty of the assessment. For an upper estimate a roughness length (cf. chapter 2.1) (see section 2.1) of 0.55 m and a γ of 5 in the vulnerability function was assumed; for a lower estimate a roughness length of 0.45 m and a γ of 4 (see Table 7.2). The exceedence probability for losses up to a return period of 300 years as a mean of a lower and an upper es-

timate is shown in Fig. 7.8 in comparison with the two other risks.

The maximum of the time series of 18.9 m/s represents the storm Wiebke on March 1 1990. Peak gusts derived here range between 32.2 m/s and 33.3 m/s, which correspond to observations. When applying this windspeed uniformly over the whole city area, the resulting loss ranges from €39 to 66 million.

Estimation of losses due to inundation

Direct monetary losses due to inundation were estimated by superimposing inundation patterns (Fig. 7.3) with the ATKIS land use cover (Fig. 7.5) which was transformed to a grid with a cell size of 50 m). For each grid cell the inundation depth and the economic sector were determined. As described in section 3, each economic sector corresponds to a unit economic value. Therefore, the total economic value per grid cell can be calculated easily.

The relative flood loss per grid cell was then estimated by means of stage-damage functions according to MURL (2000). For each eco-

Return period	Lower estimation	Upper estimation
5 a	20	29
10 a	24	36
50 a	37	60
100 a	43	60
300 a	70	135

Tabelle 7.2: Monetary losses in million € up to a mean return period of 300 years. The Schmidt method was used to extrapolate the mean wind speeds up to 100 years mean return period and the Gumbel method for 300 years. For the upper estimate a roughness length of 0.55 m in the gust assessment and a γ of 5 in the damage function was assumed; for the lower estimate a roughness length of 0.45 m and an exponent of 4.

conomic sector such a function shows the damage ratio on buildings and contents in dependence of the inundation depth. Monetary flood loss results from the multiplication of the damage ratio by the total economic value per grid cell. Losses per grid cell were aggregated for each economic sector and for Cologne.

For the three inundation scenarios shown in Fig. 7.3 this approach yielded total flood losses of €157 million, €3.5 billion and €5.3 billion, respectively. All in all, flood losses were estimated for 15 inundation scenarios so that a relationship between the water level at Cologne gauge and the total direct flood losses in the sectors private housing, commerce and industry was constructed. The resulting data, assumed as mean values, are shown in Fig. 7.8.

Estimation of losses due to earthquakes

The earthquake resistance of the building stock in Cologne or its vulnerability is not known. Therefore, a test area with approx. 800 buildings in the town center was surveyed in detail. Buildings were inspected and identified with respect to their building type and importance category as well as with respect to their structural system (Schwarz et al., 2002a, b). Con-

sidering the expected differences in the way that buildings will respond to earthquake shaking including factors like workmanship, state of maintenance etc., the most probable vulnerability class (A, B, C, D) was assigned to each building. Additionally, transitional classes (A-B, B-C, C-D) were introduced (Schwarz et al., 2004). This follows strictly the European Macroseismic Scale EMS-98 (Grünthal, 1998).

It has to be stressed that the building stock in Cologne was affected by severe destruction due to the second world war and its aftermath. The greatest part of the building stock was erected in the past 50 years. Consequently, buildings and construction types of low vulnerability dominate; 80 % of the buildings can be assigned to vulnerability class C and less than 14 % to vulnerability class B (Fig. 7.6).

In the sense of geo-statistical extrapolation, the composition of the building stock was applied to the entire town area with consideration of the given age structure of the buildings in the town quarters concerned.

The earthquake scenarios developed in the context of risk studies mainly building damage according to the local intensity and corresponding distributions of damage grade for

each vulnerability class. Therefore, the differences between buildings types are transformed in vulnerability classes. For each town district the composition of buildings with respect to their vulnerability classes is extrapolated. For further details of the procedure see Schwarz et al. (this issue), where also further references are given.

Losses due to earthquakes were estimated on the basis of deterministic scenarios assuming epicentres within the context of historic seismicity (Schwarz et al., this issue). Return periods of intensities were assigned in accordance to Fig. 7.4. For the purpose of the integrated approach within this study probabilistic intensity hazard maps for the city of Cologne as given by Fig. 7.4 were applied directly.

Seismic risk maps were prepared for different EMS-intensities. The impact of model assumptions and the step-wise refinement of input variables (like site conditions, building stock or vulnerability functions) on the distribution of expected building damage is considered by Schwarz et al. (this issue) in more detail. From these investigations, it can be concluded that these modifications have an impact on the distribution of damage but are of minor importance for the total loss integrated over the city of Cologne. The estimated damage distribution for the given scenarios is described using the mean grade of damage for each town district.

Within recent case studies a procedure was developed to transform the site-specific description of seismic action (within the period ranges characteristic for the dominant building types) into intensity differences introduced as "Delta-Intensities" (Raschke, 2003). On the basis of those site-specific spectral accelerations calculated in tightly spaced grid elements the local intensity is differentiated.

On the basis of the results of the site-response-analyses, differences in intensities were determined for each town district depending on the subsoil type. These intensity increments can be understood as correction values for the site

intensity and were finally inserted as such into the calculation of the mean damage grades d_m .

For the town of Cologne it seems allowable to assume uniform input values over large areas, minimizing the impact of local site conditions and the scatter of risk assessments. However, it should be stressed that in general, site effects have to be considered by refined 2- or 3-dimensional models. Thus the case of Cologne reflects rather an exceptional than the standard situation (Schwarz et al., 2002c). In the scenarios of Fig. 7.7 the influence of local site effects was not considered. Schwarz et al. (this issue) illustrate the variations for specific site conditions as well as the effect of building height. It should be repeated that by this procedure the regional damage distribution of mean damage grades is slightly modified, while the loss over the entire town will be less affected.

The assets were taken as given in Fig. 7.5 using a correlation between mean damage grade (d_m) and Mean Damage Ratio MDR (indicating the loss as percentage of the value). The correlation is based on the description of damage grades as per the European Macroseismic Scale EMS-98. The loss is summed up over the town districts. Assuming that within each town district the intensity according to scenario maps are representative the loss can be expressed in terms of annual probabilities of exceedence corresponding to the mean or other statistical fractile intensity given in Fig. 7.4. Surprisingly, probabilistic and deterministic scenarios as presented by Schwarz et al., this issue in more detail indicate only minor differences. Probabilistic results according to Fig. 7.4 and Fig. 7.7 are used for comparing earthquake losses with those of other hazards (storm, flood).

7.1.5 The synopsis of natural risks for Cologne

For the comparison of different risks it is a fundamental prerequisite to use a common risk indicator. In this study we agreed to calcu-

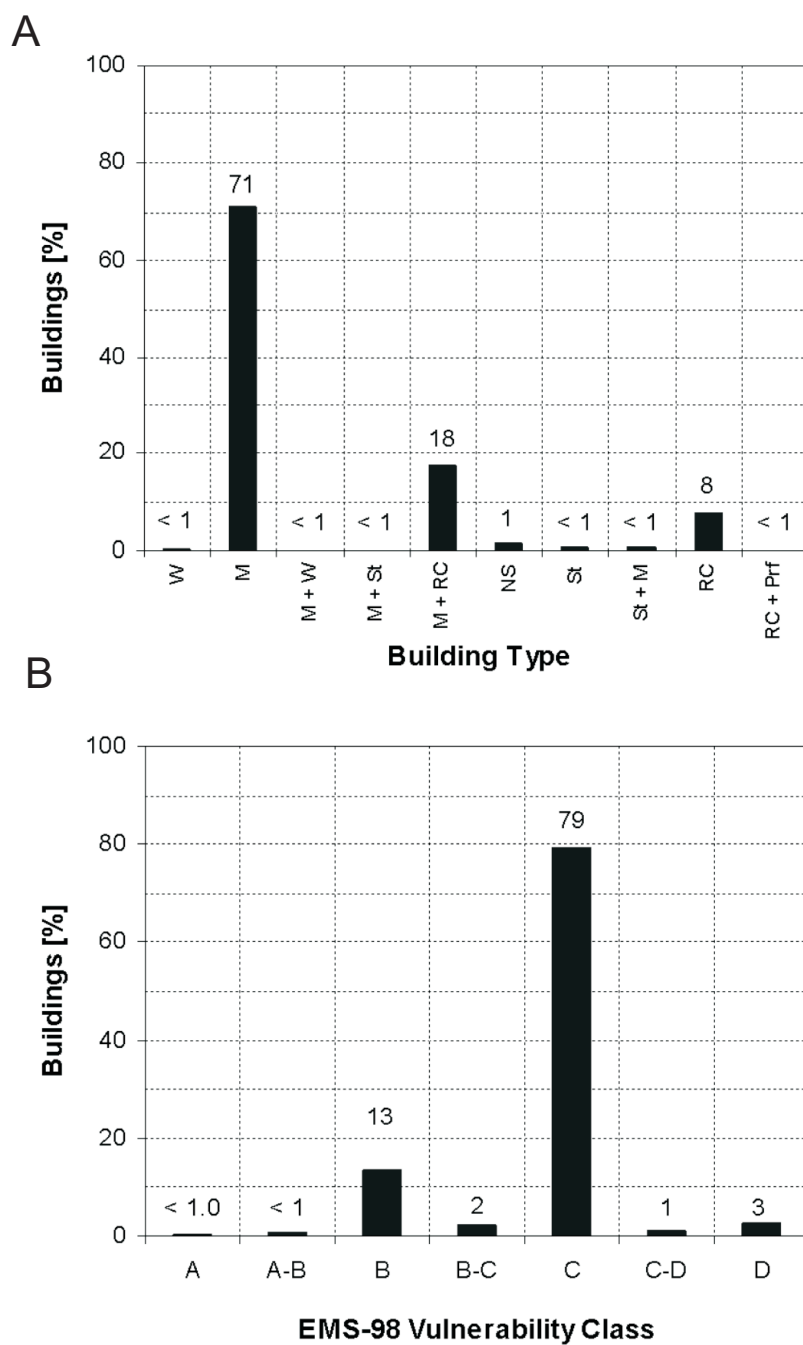


Figure 7.6: A: Composition of building types in the study area of Cologne (W-wooden; M-masonry, St-steel, RC-reinforced concrete; NS-natural stone, Prf-Prefabricated). B: Composition of vulnerability classes (EMS-98) in the study area of Cologne.

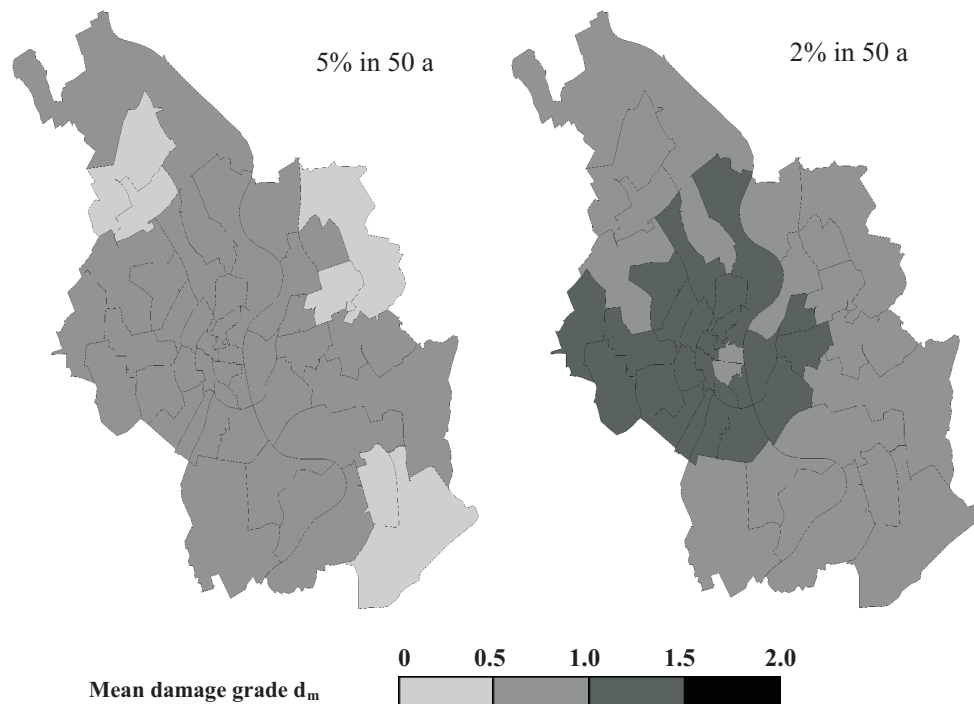


Figure 7.7: Mean damage grades d_m according to the EMS-98 in ZIP code-areas of Cologne for two different hazard levels (5% in 50 years, $T=475$ years; 2% in 50 years, $T=2,475$ years).

late a risk curve for each disaster type. Such a risk curve shows the total direct monetary losses to buildings and inventory in the sectors private housing, commerce and industry in Cologne against their exceedance probability. Different risk curves can be plotted in one graph (Fig. 7.8). This enables the direct quantitative comparison of the risks for the probability ranges which are covered by all three risk curves.

In the case of windstorm risk the curve was calculated as a mean of the lower and upper estimate shown in Table 7.2. A flood risk curve was constructed by combining the exceedance probabilities of discharges, the transformation of discharges into water levels as well as the relationship between water level and direct losses in Cologne. The seismic risk curve was derived from damage scenarios for Cologne according to determined frequency distributions of vulnerability classes in the town, which were associated to certain haz-

ard levels of the corresponding mean hazard curve.

The risk curves in Fig. 7.8 were calculated for the most probable estimates only, i.e. uncertainties were not considered. But the uncertainties can be large. The uncertainties in the estimation of hazards, of assets, of the vulnerability assessments and in the modelling of losses have to be taken into account. The uncertainties in the seismic hazard assessment were explicitly calculated (cf. fractiles in Fig. 7.4), while the ranges of different distributions considered for the windstorm hazard and the flood hazard provide a very rough first qualitative impression of their uncertainties (Figs. 7.1 and 7.2). For the 100-year flood, for example, the flood damage estimate doubles if the Gumbel type I distribution (Fig. 7.2) is assumed. To overcome the uncertainty of the flood frequency analysis it is necessary to supplement the statistical analysis by hydrologic process understanding and modelling. Thus,

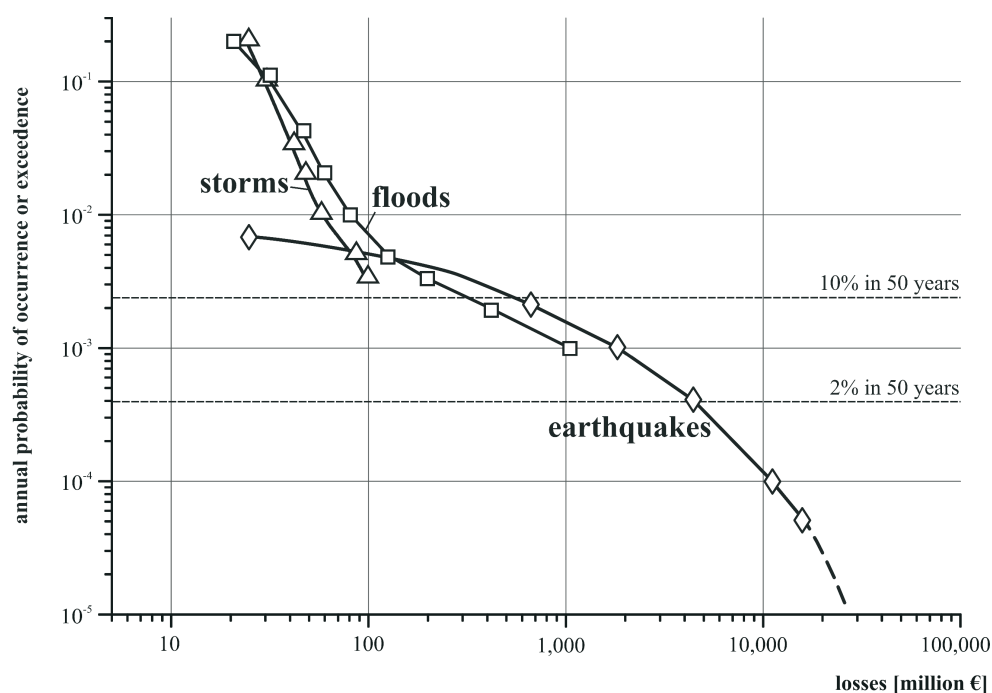


Figure 7.8: Risk curves of the hazards due to windstorms, floods and earthquakes for the city of Cologne considering losses at buildings and in the sectors private housing, commerce and industry (reference year: 2000).

special care is required when comparing the risk curves.

Nevertheless, repeated observations in the last years show that for higher occurrence probabilities the risk is clearly dominated by windstorms and floods. Due to the exposed location of Cologne at the River Rhine, the flood risk is prevailing despite the large efforts in flood protection. It should, however, be recognised that actual damages of frequently occurring floods will be smaller than estimated in this study. The flood events of 1993 and 1995 showed that preparedness can considerably reduce damages (Wind et al., 1999). Effects of early warning, adaptive behaviour and private precautionary measures are, however, neglected in the present applied loss estimation. A better model that accounts for these effects is recently under development. The flood risk losses are followed by the losses due to the frequent exposure to medium sized windstorms. Cologne itself remained less affected by the strong storms

during the last decades. For occurrence levels smaller than about $5 \cong 10^{-3}$ p.a., the course of the flood risk curve shows a drastical increase in losses for decreasing occurrence probabilities due to the failure of the flood defense system. At the occurrence level of about $5 \cdot 10^{-3}$ p.a. the earthquake risk curve exceeds that for floods. So, earthquakes seem to be of at least equal importance as floods risk for small exceedence probabilities.

When interpreting the results it must be mentioned that the city of Cologne represents only a minor fraction of the total area affected by the underlying scenario events. This is true for all three natural hazards. For example, about 12 % of the German damages due to the flood events in 1993 and 1995 occurred in Cologne. From a country-wide perspective windstorms play a very important role due to the high frequency of damages. In the period 1970-1998 75 % of the economic damages were caused by windstorms, followed by floods with 19 % (Mu-

nich Re, 1999). Earthquakes are still very important considering their high probable maximum loss potential. Altogether, the risk curves demonstrate such relationships between losses and probabilities fairly well.

As opposed to the other two natural hazards studied here the earthquake risk can be assessed with sufficient reliability even for relatively small occurrence probabilities. This is due to the distinctly longer observation period for earthquakes, as well as to the availability of paleoseismological indications and geological strain data, which confirm the respective occurrence rates, and well established distribution functions of upper bound earthquake magnitudes (Grünthal and Wahlström, this issue).

Additionally, in Fig. 7.7 the probability level of earthquake building codes (10% occurrence or exceedence within 50 years, corresponding to 475 years mean return period) is depicted as well as the 2% level in 50 years ($T=2,475$). The latter is more and more used for risk studies in low seismicity regions and is the hazard level required in the German code for water reservoirs. With regard to the high damage potential of earthquakes, there is an urgent need for a strict implementation of seismic building codes.

7.1.6 Conclusions

Experiences with decision makers (e.g. disaster management agencies, urban planners, insurers, regional and local authorities) show that they need comprehensive information which includes all relevant hazard types within a region. This case study shows that multi-risk assessments enable the comparison of different risks within an urban area and can reveal the characteristics of different disaster types. Risk curves encompassing the entire range of exceedence probabilities, with direct monetary losses as a risk indicator, provide better and more complete information for disaster mitigation than expected annual damages (EAD), since EAD is mainly influenced by the losses

due to the more frequent events. When using EAD only the damage potential of extreme events with low probabilities is easily ignored. Complete multi-hazard risk curves allow to evaluate the significance of different disaster types better, to raise awareness for the various aspects of disaster mitigation, and to develop tailor-made mitigation strategies.

For concrete planning decisions and emergency strategies, however, even more detailed information is needed. Maps which show the spatial distribution of the hazard intensities, exposed population and values, as well as expected losses due to various disasters in more detail, have to be developed in the future. Furthermore, other hazards should be included in the assessment, if pertinent. Especially, the uncertainties in the whole chain of risk assessment have to be quantified.

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7.1.8 References

- Blong, R.: 2003, A New Damage Index, *Natural Hazards*, **30**,1, 1-23.
- BZS Bundesamt für Zivilschutz: 1995, *KATANOS Katastrophen und Notlagen in der Schweiz – Eine vergleichende Übersicht*, Bundesamt für Zivilschutz, Bern, 77 pp.

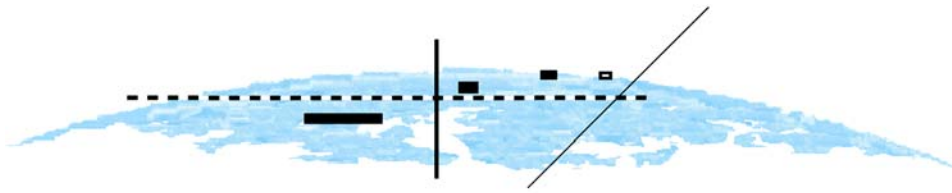
- Camelbeeck, T., Martin, H., Vanneste, K., Maghraoui, M., Verbeeck, K. and Brondeel, M.: 2000, Geomorphic evidence of active faulting in slow deformation areas: the example of the Lower Rhine Embayment, *Proceedings of the Evaluation of the potential for large earthquakes in regions of present day low seismic activity in Europe*, Han-sur-Lesse, Belgium, March 13 – 17, 31-34.
- Cappel, A. and Emmerich, P.: 1975, Zwei Wetterkatastrophen des Jahres 1972: Der Niedersachsen-Orkan und das Gewitterunwetter von Stuttgart, *reports of the German weather service* 135, Offenbach.
- Chbab, E.H.: 1995, How extreme were the 1995 flood waves on the rivers Rhine and Meuse? *Phys. Chem. Earth*, **20**, 5/6, 455-458.
- Davidson, R.: 1999, *An Urban Earthquake Disaster Risk Index*, Stanford, CA: Stanford University.
- Dotzek, N.: 2001, Tornadoes in Germany, *Atmospheric Research*, **56**, 1-4, 233-251.
- Durham, K.: 2003, Treating the Risks in Cairns, *Natural Hazards*, **30**, 2, 251-261.
- Dütemayer, D.: 2000, Urban-Orographische Bodenwindssysteme in der städtischen Peripherie Kölns, *Essener Ökologische Schriften* **12**, 171 pp.
- DVWK: 1999, *Statistische Analyse von Hochwasserabflüssen*, Wirtschafts- und Verlags-Ges. Gas und Wasser, Bonn, 42 pp.
- Federal Statistical Office Germany: 2002, Gross stock of fixed assets (annual average), 1991 to 2000, <http://www.statistik-bw.de/VolkswPreise/ArbeitskreisVGR/tab09.asp> (Date of computation: August 2002).
- Ferrier, N. and Haque, C.E.: 2003, Hazards Risk Assessment Methodology for Emergency Managers: A Standardized Framework for Application, *Natural Hazards*, **28**, 2/3, 271-290.
- Fink, A., Ulbrich, U. and Engel, H.: 1996, Aspects of the January 1995 flood in Germany, *Weather*, **51**, 34-39.
- Granger, K., Jones, T., Leiba, M. and Scott, G.: 1999, Community Risks in Cairns: A Multi-Hazard Risk Assessment, Australian Geological Survey Organisation, Canberra.
- Grünthal, G. (Editor): 1998, European Macroseismic Scale 1998 (EMS-98), *Cahiers du Centre Européen de Géodynamique et de Séismologie*, Volume **15**, 99 pp., Luxembourg.
- Grünthal, G., Mayer-Rosa, D. and Lenhardt, W. A.: 1998, Abschätzung der Erdbebengefährdung für die D-A-CH-Staaten - Deutschland, Österreich, Schweiz, *Bautechnik* **75**, 10, 753-767.
- Grünthal, G. and Wahlström, R.: 2003, An M_w based earthquake catalogue for central, northern and northwestern Europe using a hierarchy of magnitude conversions, *Journal of Seismology*, **7**, 4, 507-531.
- Grünthal, G. and Wahlström, R.: 2004, New generation of probabilistic seismic hazard assessment for the area Cologne/ Aachen considering the uncertainties of the input data, *Natural Hazards* (this issue).
- Gumbel, E.J.: 1958, *Statistics of Extremes*, Columbia University Press, 375 p.
- Krahe, P.: 1997, Hochwasser und Klimafluktuationen am Rhein seit dem Mittelalter. In: Immendorf, R. (ed.), *Hochwasser - Natur im Überfluß?* Müller, Heidelberg, pp. 57-82.
- Munich Re: 1993, Winterstürme in Europa – Schadenanalyse 1990 – Schadenpotentiale, Munich Re.
- Munich Re: 1999, Naturkatastrophen in Deutschland – Schadenerfahrungen und Schadenpotentiale, Munich Re.
- Munich Re: 2001, Winterstorms in Europe II – Analysis of 1999 losses and loss potentials, Munich Re.
- Munich Re: 2003, Topics – Annual Review: Natural Catastrophes 2002. Munich Re Group, 48 pp.
- MURL Ministry of Environment, Regional Planning and Agriculture in North Rhine-

- Westphalia: 2000, *Potentielle Hochwasserschäden am Rhein in NRW*, Final Report of the Ministry of Environment, Regional Planning and Agriculture in North Rhine-Westphalia, 32 pp.
- Raschke, M.: 2003, Die Korrelation zwischen Erdbebenstärke und Bauwerksschaden und deren Anwendung in der Risikoanalyse, *PhD Thesis*, Bauhaus-Universität Weimar, 2003.
- Schmidt, H.: 1980, Zur Extrapolation empirischer Verteilungen der Windgeschwindigkeit für Standorte im Flachland und auf freier See, *Meteorologische Rundschau*, **33**, 129-137.
- Schwarz, J. Raschke, M. and Maiwald, H.: 2001, Methodische Grundlagen der seismischen Risikokartierung am Beispiel der Stadt Schmöln/ Ostthüringen (2) Modellereignisse, lokale Verstärkungseffekte und Schadensszenarien, *Thesis Wiss. Zeitschrift der Bauhaus-Universität Weimar*, Heft 1/2, 200-219.
- Schwarz, J. Raschke, M. and Gerstenberger, A.: 2002a, Seismische Schadenspotentiale in deutschen Großstadträumen – Fallstudie Köln, In: Meskouris, K. Hinzen, K.-G. (Hrsg.) *Schutz von Bauten gegen natürlichen und technische Erschütterungen*, DGEb-Publikation Nr. 11, 69-83.
- Schwarz, J. Raschke, M., Maiwald, H.: 2002b, Seismic Risk Studies for Central Germany on the Basis of the European Macroseismic Scale EMS-98, 12th European Conference on Earthquake Engineering, Elsevier Science LTD., Paper Reference 295.
- Schwarz, J.; Raschke, M., Maiwald, H.: 2002c, Verletzbarkeit des Bauwerksbestandes in deutschen Erdbebengebieten – Ergebnisse von Fallstudien, 3. Forum Katastrophenvorsorge Potsdam (paper submitted).
- Schwarz, J.; Raschke, M., Maiwald, H.: 2004, Comparative seismic risk studies for German earthquake regions on the basis of the European Macroseismic Scale EMS-98. *Natural Hazards*, in print.
- Singh, V.P. and Strupczewski, W.G.: 2002, On the status of flood frequency, *Hydrological Processes*, **16**, 3737-3740.
- Stadt Köln: 1996, *Hochwasserschutzkonzept Köln*, Stadt Köln, Dezernat Bauen und Verkehr, 216 pp.
- Statistical Office Baden-Württemberg: 2000, *Volkswirtschaftliche Gesamtrechnung der Länder. Bruttowertschöpfung der kreisfreien Städte und der Landkreise in der Bundesrepublik Deutschland 1980, 1992, 1994 und 1996*, Stuttgart, Report 33, 215 pp.
- Statistical Office North Rhine-Westphalia: 2002, pers. communication, *Gross stock of fixed assets in North Rhine Westphalia 1997*.
- Stedinger, J.R., Vogel, R.M. and Foufoula-Georgiou, E.: 1992, Frequency analysis of extreme events, In: Maidment, D.R., *Handbook of Hydrology*, McGraw-Hill, Inc., New York, pp. 18.1-18.66.
- Troen, I. and Petersen, E.L.: 1989, *European Windatlas*, Ris.0 National Laboratory, Roskilde, Denmark.
- UNDRO (ed.): 1977, *Composite Vulnerability Analysis - A Methodology and Case Study of the Metro Manila Area*, Geneva, 55pp.
- IDNDR Secretariat, UN: 2000, RADIUS: Risk Assessment Tools for Diagnosis of Urban Areas against Seismic Disasters, Geneva
- Urban Development Authority of Cologne: 2002, *Kölner Strukturdaten 2001*, <http://www.stadt-koeln.de/zahlen/index.html> (Date of computation: 28.11.2002).
- Van Westen, C.J., Montoya, L. and Boerboom, L.: 2002, Multi-Hazard Risk Assessment using GIS in urban areas: A case study for the city of Turrialba, Costa-Rica, In: *Proc. Regional workshop on Best Practise in Disaster Mitigation*, Bali, 120-136.
- Vogt, R.: 1995, Hochwasser in Köln, In: *Proceedings Mit dem Hochwasser leben*, 48-55.

Wieringa, J.: 1973, Gust factors over open water and built-up country, *Boundary Layer Meteorology*, **3**, 424-441.

Wind, H.G., Nierop, T.M., de Blois, C.J. and de Kok, J.L.: 1999, Analysis of flood damages from the 1993 and 1995 Meuse floods, *Water Resources Research*, **35**, 11, 3459-3465.

Wood, E.F. and Rodríguez-Iturbe, I.: 1975, A Bayesian approach to analyzing uncertainty among flood frequency models, *Water Resources Research*, **11**, 6, 839-843.



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