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Assessing Vulnerability to Flood Events at a Community Level

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Assessing Vulnerability to Flood Events at a Community Level

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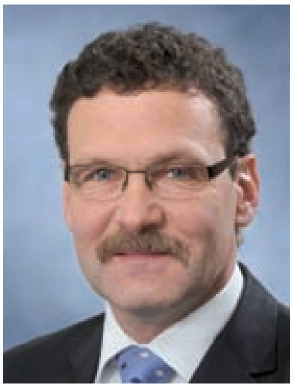

Christoph Unger
President of the Federal Office of Civil Protection
and Disaster Assistance (BBK)

Dear Readers,

Flooding represents a serious risk for many communities in Germany. Structural measures that are able to hold back a certain volume of flood water serve to protect the local population. Mobile flood protection systems, which are placed into action depending on the relevant water level, provide additional security.

Nevertheless, extreme flooding can inundate or even destroy flood defences. When this happens, the population is then faced with acute danger. It is possible to make provision in advance for these types of events in order to minimise personal injury and property damage from the flood waters. Measures to this effect are already being implemented today in local communities.

These guidelines supplement existing efforts already being made in communities. The core focus of these guidelines is to identify and reduce the vulnerability of the local population, critical infrastructures and the environment to flooding. In this context, the term vulnerability encompasses aspects such as any possible impact and susceptibility. Determining vulnerability highlights areas where there is particularly high potential for damage and thus provides valuable information for analysing risk at a community level. The knowledge gained from the study of vulnerability and risk can, for example, be utilised for optimising evacuation plans or preventative safeguards for infrastructures and the environment.

A project of this type can only be realised in cooperation with a large number of expert partners. Therefore, it was important to bring together scientists and prospective users of these guidelines - community representatives. In my opinion, this process proved to be a great success. I am pleased that the Federal Office of Civil Protection and Disaster Assistance (BBK) was not only able to make this project possible by providing the necessary funding, but also actively shaped its development through the provision of specialist support. These guidelines now act as an instrument for determining vulnerability and represent a building block for the implementation of risk analyses at a community level.

I would like to take this opportunity to offer my sincere thanks to all those who were involved in the project. It is only thanks to your commitment that it was possible to create these guidelines. My special thanks go out to Dr. Birkman, United Nations University - Institute for Environment and Human Security, who successfully and expertly headed the project. Furthermore, I would also like to particularly thank all of those representatives of the Cities of Cologne and Dresden who participated in the project. Your expertise has ensured that these guidelines have become a successful tool for practical application.

Christoph Unger

President
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Prof. Dr. Jakob Rhyner
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The clear signs of global climate change will not only lead to a rise in the average global temperature but will also in all probability result in an increase in the intensity and frequency of so-called „extreme weather events“. Europe, and thus also Germany, can expect to face increasing challenges due to flooding, heavy precipitation and heat waves. The international community, as well as numerous individual countries and communities, more and more recognise that it is insufficient to simply focus on the natural hazard alone.

In terms of preventative civil protection measures, as well as for developing preventive strategies in urban and regional development, it has become increasingly clear that integrated and holistic risk reduction strategies are required. In this context, the determination of vulnerability is an important tool for developing appropriate strategies for action.

The UNITED NATIONS UNIVERSITY Institute for Environment and Human Security, which headed this project, has come to the conclusion during numerous national and international research projects on the subjects of risk and disaster that the key starting point for limiting the risk of disaster lies in the reduction of vulnerability. Therefore, a greater level of knowledge about the opportunities available for determining and assessing the various facets of vulnerability is urgently required.

These guidelines „Assessing Vulnerability to Flood Events at a Community Level“ clearly and transparently demonstrate how the abstract term „vulnerability to flood hazards“ can be conveyed in the form of concrete indicators and criteria, as well as describing appropriate assessment methods. Although these guidelines are primarily aimed at practitioners in the areas of civil protection, local authority administration or geographical and environmental planning, they can also act as an important reference work for those involved in research, or for interested citizens concerned with questions about the determination, measurement and assessment of risk and vulnerability to flood events.

These guidelines use practical examples to illustrate the feasibility of the concept of vulnerability to flood hazards. A variety of different subject areas are discussed: population, the environment and critical infrastructures. Furthermore, the possibilities offered by remote sensing for assessing vulnerability are presented. The different approaches share one thing in common in that they operationalise and systematically utilise central factors of vulnerability within their relevant subject area:
a) exposure to the natural hazard, b) susceptibility and c) coping capacity of the exposed elements.

Overall, these guidelines act as both a central reference work and a detailed document for all those striving to develop holistic and integrated risk reduction strategies against flood events and flood hazards. The study owes its practical relevance, amongst other things, to the numerous project partners and experts in the field who participated both in its evolution and to the corresponding discussions about the study and the guidelines themselves. I would like to express special thanks at this point to the team of authors and the project manager, as well as to the Federal Office of Civil Protection and Disaster Assistance, who not only funded the study but also provided it with the required expertise gained through their practical experience in civil protection measures. These guidelines only represent one building block for continued discussions about risk management and adaptation strategies for dealing with the effects of climate change. In this regard, the reader is encouraged to promote further discussion on the subject by adding comments, supplementing the information and practically implementing these guidelines in their local community. These guidelines offer very good foundations in this area and represent a practical reference guide for taking the required action.

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It would not have been possible to carry out this study or to create these practical guidelines in their current form without the commitment of numerous partners. Therefore, the team of authors would like to offer their thanks at this point to those people, companies and institutions who made a significant contribution to the discussions for determining, measuring and evaluating vulnerability to flood hazards using the specific examples of the cities of Cologne and Dresden.

Our special thanks go to the Federal Office of Civil Protection and Disaster Assistance for funding this project, as well as for providing their valued support and expertise gained through practical experience in civil protection measures. Furthermore, we want to express our gratitude to those partners actively involved in the project in the City of Cologne and the State Capital City of Dresden – namely Mr. Vogt and Mrs. Mertsch (Flood Protection Centre, StEB Köln) and Dr. Wöllecke (BTU Cottbus, who worked for UNU-EHS at the Flood Protection Centre, StEB Köln), the Cologne Fire Department (Berufsfeuerwehr Köln), the Office for Urban Development and Statistics Cologne (Amt für Stadtentwicklung und Statistik Köln), the Environmental and Consumer Protection Office Cologne (Umwelt-und Verbraucherschutzamt Köln), the Office for Information Processing Cologne (Amt für Informationsverarbeitung Köln), Mr. Deistler (International Affairs Cologne - Internationale Angelegenheiten Köln), Dr. Korndörfer and Dr. Ullrich (Environmental Agency Dresden - Umweltamt Dresden), the Public Order and Security Office Dresden (Geschäftsbereich Ordnung und Sicherheit Dresden), the Urban Ecology Office Dresden (Amt für Stadtökologie Dresden) and the Statistical Office Dresden (Statistikstelle Dresden). In addition, we thank the Bürgerinitiative Hochwasser Altgemeinde Rodenkirchen e.V., the Hochwassernotgemeinschaft Rhein e.V., the Leibniz Institute of Ecological Urban and Regional Development (Leibnitz Institut für ökologische Raumentwicklung), the Regional Government of Cologne (Bezirksregierung Köln), the City Planning Office Andernach (Stadtplanungsamt Andernach) and the Central Office in Radebeul (Leitstelle Radebeu).

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specialist conferences and workshops and helped to further develop the project in a targeted manner. We also want to express our heartfelt thanks at this point to all of the students who assisted in this project.

On behalf of the team of authors,
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Assessing Vulnerability to Flood Events at a Community Level

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I. Chapter

Summary

Vulnerability analyses are becoming increasingly important in the areas of risk management and preventative civil protection. This is underlined, for example, by the special report "Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX)" from the IPCC (2012). Vulnerability and exposure are described here as key variables affecting the risk of a disaster that can be both estimated and changed. In particular, vulnerability analyses provide important information for civil protection measures or local government planning in order to minimise the risk of a disaster. Experience from previous flood events (e. g. England 2007 or Australia 2011) has also clearly shown that a comprehensive approach to risk management needs to be implemented for flood protection in order to be better prepared to meet the challenges posed by the projected changes to flood events as a result of climate change.

These guidelines build on this understanding and offer a systematic approach for assessing the vulnerability of urban areas to flood hazards. The methods applied are presented here based on the core areas of „critical infrastructures" (with a particular focus on the provision of electricity and drinking water), „population/social" and the „environment". These guidelines do not just focus on the European Flood Risk Management Directive 2007/60/EC about the evaluation and management of flood events in Europe that calls for the gradual development of national flood risk management plans by 2015. They focus more on an assessment of the core areas for conducting risk analyses in civil protection[1], which are used in the various regions of Europe. Therefore, these guidelines are designed to act as a powerful planning instrument for members of community administration institutions such as environmental offices, city planning departments or statistical offices, as well as for those responsible for civil protection, fire departments and other emergency services - in both Europe and beyond.

It is extremely important to consider the subject at a community level in order to guarantee that the directive will be put into effect and risk analyses for civil protection will be carried out, ensuring effective disaster prevention. Estimations for economic, ecological and social vulnerability in these guidelines are focussed at the community level. The methods, criteria and indicators can be used to identify weak points, which can then lead to the development of specific approaches e. g. for improving coping capacities. This enables the targeted implementation of local measures for removing any potential inadequacies in existing flood protection, or can build the basis for making future regional planning decisions and for realising preventative civil protection measures. The use of geographical information systems (GIS) for linking and visualising data is fundamentally important, particularly in the areas of regional planning and civil protection. Therefore, the opportunities offered by remote sensing for assessing vulnerability in urban areas is also presented in these guidelines.

In individual communities, the information contained in these guidelines relating to the data used, necessary technical infrastructures, background knowledge required by the user and information generated is designed for different audiences. A vulnerability assessment of electricity and drinking water supplies is particularly interesting for local utility companies and

[1] Methods for developing risk analyses for civil protection purposes are available in different countries. In Germany for example: German Bundestag: Report on Risk Analyses in Civil Protection (Bericht zur Risikoanalyse im Bevölkerungsschutz) 2011: Information provided by the Federal Government, BT-Drs. 17/8250 from 12.12.2011. http://dipbt.bundestag.de/dip21/btd/17/082/1708250.pdf. Germany and the other member states of the EU share infor-mation and methods in this area, as well as tried-and-tested practical experience. In this field, there is close cooperation with the European Commission. Therefore, the EU Commission is developing recommendations about methods used for mapping, assessing and analysing risk in cooperation with the member states.

also for civil protection purposes, as well as for operators of other infrastructures and the general economy as a whole while a vulnerability assessment of the population can provide fundamental information for affected citizens, city planning offices and especially those responsible for civil protection measures. In contrast, a vulnerability assessment of the environment investigates the effects of possible environmental damage that may result from flooding of sources of contamination and thus provides important information for assessing risk during planning processes. The chapter on remote sensing methods is designed to introduce the reader to the different fields of application available, which enable statements to be derived about physical vulnerability. These guidelines offer those responsible for flood protection the opportunity to use the detailed descriptions of the individual steps to clearly follow the findings and implement them in their own communities.

In terms of generating the most meaningful results possible, it is recommended that an assessment of local vulnerability is further specialised and diversified by taking into account different hypothetical flood scenarios (HQ scenarios) simultaneously. Due to the fact that the effectiveness of preventative structural measures becomes limited once certain water levels are exceeded, it is extremely important to know, when engaged in preventative planning, whether you can count on widespread infrastructure provision in the event of a flood. Questions about how many people may need to be evacuated and what environmental dangers could be expected are also central issues that play important roles in preventative civil protection measures. In order for these localised characteristics to be integrated into decision-making processes for a potential package of measures, and to optimise their implementation, it is important to actively encourage the integration of all local stakeholders affected in the event of a flood. In accordance with the European Floods Directive (2007/60/EC), both regional cooperation and an appropriate exchange of information and experience with other communities, as well as the transnational exchange of experiences, analyses and results, is not only expedient but also expressly recommended. In particular, reliable transnational cooperation - not only at a political level - within a flood area enables joint preparations to be made for future floods, as well as the continuous optimisation and further development of measures for the reduction or even prevention of negative effects on the population, environment and economic sectors.

Author: Jörn Birkmann

II. Chapter

Vulnerability Assessments to Flood Events at a Community Level

In its Fourth Assessment Report, the IPCC forecasts a change in the frequency and magnitude of flooding, depending on the region, in the coming years as part of climate change.[2] The floods on the Elbe in 2002, in England in 2007 and in the states of Queensland and Victoria in Australia in 2011 have already clearly demonstrated that people, economic sectors and infrastructure - in both industrial and developing countries - are vulnerable to extreme flood events. For example, the flooding of the river Elbe in 2002 caused damage valued at almost 17 billion US $[3] while 350,000[4] people were affected by the flooding in England in 2007 and more than 200,000[5] in Australia in 2011. Because it is not possible to control extreme flood events with technical measures alone, a methodological investigation of risk and vulnerability in combination with conventional, technical flood protection has become the central focus of considerations for disaster management and preventative planning.

In Europe, the EU Commission is developing recommendations on methods for mapping, assessing and analysing risk together with its member states. This work is based on national concepts and processes for risk evaluation.[6] Risk analyses are embedded in the legal framework in some countries like Germany and are now being used as targeted planning instruments.[7] In the development of risk analyses for civil protection purposes, the future effects of climate change and any required adaptations resulting from climate change are also being taken into account where possible and relevant.

The structured recording and evaluation, for example, of extreme events such as flooding, contribute to the identification of suitable measures and the reduction of risk. For this reason, the Intergovernmental Panel on Climate Change (IPCC) has published their "Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation" (SREX), which illustrates that: "exposure and vulnerability are key determinants of disaster risk and of impacts when risk is realized."[8] Exposure in this context describes physical exposure, for example, of settlements or infrastructures to natural hazards. The vulnerability of these components is described by their susceptibility and their (lack of) capacity to cope with extreme events. Both exposure and vulnerability are components that can be influenced in this context. Therefore, the report underlines the importance of vulnerability analyses for risk reduction. Only by estimating the vulnerability of different sectors, such as people, the environment or critical infrastructures, is it possible to identify weak points and derive approaches for risk management.

2 IPCC (2007): Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson (Eds.), Cambridge University Press, Cambridge, UK, 976 pp.

3 MunichRE NatCatSERVICE (2011): Significant natural disasters worldwide - the 10 most expensive floods worldwide for the economy as a whole. Available via: http://www.munichre.com/app_pages/www/@res/pdf/natcatservice/significant_natural_catastrophes/2011/NatCatSERVICE_significant_floods_eco_june2011_touch_de.pdf.

4 Pitt, M. (2007): Learning lessons from the 2007 floods. An Independent review by Sir Michael Pitt. The Pitt Review.

5 Australian Red Cross (2014): Queensland floods 2011. Available via: http://www.redcross.org.au/queensland-floods-2011.aspx.

6 Council of the European Union (Ed.): Draft Council Conclusions on a Community Framework on Disaster Prevention - Adoption. Brussels 2009. Available via: http://register.consilium.europa.eu/pdf/de/09/st15/st15394.de09.pdf.

7 German Bundestag: Report on Risk Analyses in Civil Protection (Bericht zur Risikoanalyse im Bevölkerungsschutz) 2011: Information provided by the Federal Government, BT-Drs. 17/8250 from 12.12.2011. Available via: http://dipbt.bundestag.de/dip21/btd/17/082/1708250.pdf.

8 IPCC, 2012: Summary for Policymakers. In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 1-19.

In this context, the Directive of the European Parliament and of the Council on the assessment and management of flood risks 2007/60/EC represents a starting point for reducing vulnerability to floods. The directive obligates all member states to introduce transnational measures for reducing or even preventing the negative effects of flood events on the population, environment and economic sectors within each relevant and potential flood zone. In order to guarantee the appropriate handling of flood events, the directive calls for a three-stage approach in which member states are obligated to cooperate and develop flood risk management provisions on a transnational basis in future. This comprises (I) a preliminary flood risk assessment of all flood risks for all member states and (II) the creation of flood hazard maps and flood risk maps by the end of 2013. The resulting data and findings must be submitted to the EU Commission and will serve as the basis for (III) national flood risk management plans to be completed by the end of 2015. The main focus of these management plans - which will be reviewed and if necessary updated every six years - is the prevention of flood events.

In addition, the development of protection measures for critical infrastructures at a national and European level also plays an important role in relation to natural hazards in general and flood protection in particular. The effect that natural hazards can have on infrastructures was clearly illustrated, for example, by the earthquake and resulting tsunami that hit the Japanese coast and the Fukushima Nuclear Power Plant in March 2011. As a result of the high level of interdependency within the network of critical infrastructures, the destruction or impairment of these systems can have far-reaching consequences. This is true on the one hand at a geographical level due to the highly integrated international and transnational networks. While on the other hand, the failure of large infrastructure systems results in high costs and a loss of income for operators, for instance, as one of the most serious flood events in the United Kingdom demonstrated in 2007[9]. In this context, the European Parliament initiated a European programme for the protection of critical infrastructures[10] in November 2005. In addition, directive 2008/114/EC *on the identification and designation of European critical infrastructures and the assessment of the need to improve their protection* was adopted. The importance of critical infrastructures has also been underlined at an international level. The International Strategy for Disaster Reduction of the United Nations (UN/ISDR)[11] has also pointed out the important role played by infrastructures following a disaster. Functioning infrastructures can reduce the costs of these types of events and improve how they are handled. For this reason, the vulnerability of critical infrastructures to flood events has been handled particularly intensively in these guidelines and a method for assessing it has been developed.

In the context of the two EU directives, these guidelines include a systematic and internationally applicable methodology for assessing vulnerability to flood events. By paying particular attention to the core areas of *population, critical infrastructures* (particularly the electricity and drinking water supplies) and *the environment,* these guidelines are particularly aimed at those stakeholders at a community level and those responsible for civil protection measures in order to provide them with answers to important questions about the security of supply for infrastructure services, preventative planning, risk and crisis management and environmental issues in the event of a flood. Alongside an assessment of local vulne-

[9] Approximately 350,000 people lost their main water supply for more than 2 weeks in the Gloucestershire region alone, while 42,000 people were affected by a power cut for 24 hours (Pitt, 2007).

[10] EPCIP (European Programme for Critical Infrastructure Protection) (2012): Summary. Available via: http://europa.eu/legislation_ summaries/justice_freedom_security/fight_against_terrorism/l33260_en.htm.

[11] UN/ISDR [United Nations International Strategy for Disaster Reduction] (2007): Words Into Action: A Guide for Implementing the Hyogo Framework, Geneva, available via: http://www.unisdr.org/files/594_10382.pdf.

rability, these guidelines also identify weak points and hotspots, as well as making it possible to derive approaches for disaster risk reduction. Therefore, they can be used to contribute to the improvement of flood risk management plans and the protection of critical infrastructures at a community, European and international level.

2.1 Methodology and central concepts

The development of methods for assessing vulnerability in such diverse areas as the local population, the provision of central infrastructure services (specifically the electricity and drinking water supplies) and the environment demands the evaluation of a wide variety of datasets and the use of diverse information sources, as well as the use of specific methods. The processes proposed in these guidelines for conducting vulnerability assessments at a community level therefore vary accordingly. While an investigation into the vulnerability of the electricity and drinking water supplies is primarily based on the structured consolidation of qualitative information from operators and local government, quantitative evaluations based on local government statistics are made in the area of social vulnerability (population). In the case of the environment, information on vulnerability is linked to geographical data to form the basis of the assessment process. In the chapter on the opportunities offered by remote sensing as part of a vulnerability assessment, the ultimate aim is to identify the possibilities and limits of this technology and to integrate it into the ensemble of different processes presented in these guidelines.

Despite the individual approaches used for the different subject areas under investigation, these guidelines are nevertheless based on common methodologies and concepts. These will receive particular attention in the following sections.

2.1.1 Vulnerability concept

The vulnerability to a flood describes, in accordance with the definition made in these guidelines, the sum of all factors and processes that determine the theoretical extent of the possible damage and functional impairments in the event of a flood. These factors and processes can take different forms ranging from damage to items of property through to poor management or governance structures. The vulnerability concept is based on the assumption that interactions between **exposure**, **susceptibility** and **coping capacities** define the extent of the vulnerability[12]. Because a wide range of different definitions are used in general literature for the central terms used below, they have been defined as follows for use within the framework of these guidelines:

Exposure describes the state where a particular asset (population, building, infrastructure element, environmental area) is subject to the effects of a flood. In the processes for assessing vulnerability presented in these guidelines (see Chapters 3, 4 and 5), the exposure of the population to flood hazards is determined using the relevant location of the place of residence, while the exposure of electricity and drinking water supplies is based on the location of infrastructure components. In determining the exposure of the environment, the location within the flood zone is supplemented by the factor „vicinity to contamination sources". Remote sensing technology makes it possible to determine exposure using satellite data. As described in more detail in Chapter 2.1.3, exposure is defined in accordance with hypothetical flood scenarios.

The term **susceptibility** describes the extent to which possible damage or functional limitations re-sulting from a flood event can occur in the case of exposure. In order to determine the susceptibility of the population, the criteria evacuation capability and evacuation time were selected, as well as sensitivity to and the level of information about flood hazards. In assessing the vulnerability of the electricity and drinking water supplies, functional susceptibility as a partial aspect of susceptibility becomes the key focus of consideration. While in the area of environmental vulnerability, environmental characteristics (relative importance of protecting the soil, need to protect groundwater and the biotope clasification) relevant to vulnerability play a central role.

For the integration of the concept of **coping capacity,** the currently available measures, resources and processes that contribute to limiting the negative effects of the flood event are described. In the study of the vulnerability of the population, the level of insurance cover, the availability of practical experience and the level to which independent flood protection measures have been taken are recognised as central aspects of coping capacity. In combination with ensuring security of supply for infrastructure services, it is primarily the replaceability of lost services through technical precautions and organisational measures that contribute to coping capacity.

[12] Also see Birkmann, J. (2006): Measuring Vulnerability to Promote Disaster Resilient Societies: Conceptual Frameworks and Definitions. In: Birkmann, J. (Ed.): Measuring Vulnerability to Natural Hazards. Towards Disaster Resilient Societies. Tokyo, pp. 9-54.

2.1.2 Use of Geographical Information Systems (GIS)

The use of geographical evaluation, linking and visualisation methods in the form of geographical information systems (GIS) is common to all of the processes for vulnerability assessment presented in these guidelines. With the exception of the process for determining the vulnerability of the electricity and drinking water supplies, the assessment methods presented in these guidelines cannot be carried out to their full extent without the use of these types of systems (even in the vulnerability assessment of utility infrastructures, managing the information and visualising the results is made significantly easier with the help of a GIS). Therefore, it is advisable to clarify before starting the assessment whether all of the required information is available in digital format, a software programme for processing the geographical information is available and the corresponding personnel and technical requirements for the use of the GIS are fulfilled. The functions described in these guidelines and the creation of the relevant maps were carried out with the aid of the programme ArcGIS in versions 9.1 and 9.2. The data was either available in the relevant format or was converted to this format. Further information on the use of this software can be found in the individual chapters. It should be noted that the programme described only represents one option. Naturally, other GIS programmes with a comparable range of functions can also be used. Even open source software packages i. e. those freely available online could also be an option in some circumstances.

2.1.3 Scenario-based methodology

In the following sections, a flood scenario describes a hypothetical flood event that covers a certain flood zone. It defines the framework conditions under which the assessment is carried out. These circumstances become particularly evident in combination with the vulnerability aspect „exposure“, which is defined as the location of an asset within a flood zone. All of the statements that can be made about the vulnerability of the population, infrastructure provision and the environment with the aid of these guidelines are always only valid with the reservation „assuming the defined flood scenario“. Or in other words: Specifying a scenario defines the scope of validity for the vulnerability statements.

The process of defining these hypothetical scenarios must precede all other steps. In order to en-sure that the workload involved in the assessment process is not increased further, the methods developed within this project initially only focus on the flooded zone as a parameter. In accordance with Directive 2007/60/EC, other optional factors such as the flood height or flow rate can also be included. However, these optional factors were consciously omitted because it cannot be assumed that the same level of information is available everywhere.

In general, the scenarios are given as HQ scenarios. These describe a flood event with a certain statistical recurrence interval.

In accordance with Directive 2007/60/EC, floods with the following probabilities should be integrated into flood hazard maps:

a) low probability (extreme event scenarios),
b) medium probability (HQ-100 scenario corresponds to a statistical flood recurrence interval ≥ 100 years)
c) high probability

However, the decisive factors are whether the scenario can be represented in map form - preferably in the form of a GIS - and whether all of the steps carried out during the vulnerability assessment consistently refer to the same scenario. If this is not the case, the results of the assessment lose their significance. Therefore, it is very important that the relevant hypothetical scenario is clearly specified in any communication with those involved in the project.

In accordance with the relevant flood scenario, an assessment should be carried out for different flood water levels simultaneously. Even if the effectiveness of preventative structural measures be-comes limited once certain water levels are exceeded (maximum protection level), it can nevertheless still be helpful during the preventative planning process to know whether one can still count on comprehensive infrastructure provision, how many people may need to be evacuated and which environmental hazards could be expected in the event of a flood.

2.2 User groups and areas of application for these guidelines

These guidelines can provide important information for a range of users in the examination of different key areas (population, critical infrastructures, environment) or the holistic analysis of the effects of the flooding as a natural hazard in urban areas (consideration of the interaction between exposure, susceptibility and coping capacity). Vulnerability assessments can be carried out for the purposes of ascertaining the current status, as well as in the next step for identifying the need for action, creating contingency plans, prioritising measures, comparing multiple planning alternatives and for continuous control purposes.

Therefore, the target group for these guidelines includes all those institutions dealing with flood events at a community level. And as water does not simply stop before it reaches certain pieces of property or administrative boundaries, it is sensible to also carry out the assessment collaboratively as part of an interdisciplinary working group. Not only are the expertise, infrastructure and datasets from a local government statistical office required in order to investigate the theme of vulnerability of the population, but also the cooperation of those bodies responsible locally for city planning, who possess both the geographical information and the personnel and technical capabilities for setting up a GIS. Integrating further findings from vulnerability assessments of the electricity and drinking water supplies (involvement of infrastructure managers) and the environment (cooperation with the environmental office or the responsible approval agency) enables the systematic collation of a comprehensive pool of data.

The resulting information platform is beneficial in the first instance for the purposes of civil protection. When planning the deployment of emergency services in the event of a flood, it is not only vital to know where people will be exposed to a flood. Important information is also provided by estimating how many people will be affected, how many people are not capable of helping themselves or, if relevant, whether facilities that cannot be evacuated are located within the flood areas and what requirements need to be met when setting up emergency accommodation. Data about those areas in which the local population and emergency services cannot rely on a functioning electricity supply in the event of a flood (including all of the consequences resulting from this issue) also contributes to a differentiated evaluation of the situation. The use of remote sensing data and methods can quickly provide information on the current situation on the ground when a flood occurs.

Providing information about and sensitising the population to floods, which is an important precondition for encouraging people to take independent precautions and for increasing the self-help potential, is an important step for minimising the negative consequences of a flood. A higher level of information and precaution amongst the population in affected areas can have a positive impact in several senses: It not only minimises material damage and supports the efforts of the emergency services but the extent to which negative physical and psychological problems arise as a result of flooding is significantly lower in well-prepared people. In the course of providing a comprehensive level of information to the population, it is also necessary to address the risk of infrastructure or utility supply failures (e. g. in the area of electricity supply). However, the vulnerability assessment proposed in these guidelines will not only provide a wide range of information for the local population, but visualisation of the results in map form will simplify the communication of this information to the wider public.

Furthermore, the local economy including operators of infrastructure facilities can also benefit from carrying out a vulnerability assessment based on these guidelines. Questions about their own exposure, accessibility to the premises, possible effects on buildings and systems, the safety of employees, the provision of infrastructure services and goods, and possible environmental hazards in the event of a flood are relevant in this case. Creating contingency plans, training personnel and carrying out targeted protection measures for specific items of property can not only contribute to minimising damage, shortening idle times and increasing occupational safety but are also confidence-building measures that send important signals to the outside world.

In addition, it is important to point out the significance of vulnerability assessments in the context of a wide range of planning processes. For example, a vulnerability assessment of the environment can provide important information for new investments in commercial and industrial sites, for defining property and land protection measures in the interests of avoiding contamination or for prioritising measures for the remediation of contaminated sites. The planning of new facilities or the targeted dismantling of existing infrastructure facilities and the construction of flood-adapted buildings, systems and infrastructure components (e. g. the integration of transport routes in flood protection systems) can assist in optimally overcoming the effects of a flood in the local area and minimise the negative consequences both now and in the future.

Apart from those beneficiaries of a vulnerability assessment at a local/community level, the results can also have international significance. The European Parliament states that „concerted and coordinated action at community level would bring considerable added value and improve the overall level of flood protection" (Directive 2007/60/EC). The transnational exchange of knowledge and data is enormously important as the basis for international cooperation and the development of transnational strategies for protection against floods.

The use of internationally applicable guidelines for assessing vulnerability at a community level can play a decisive role in achieving international cooperation in this area. Exchanging assessment data can lead to an improvement in flood management at a community and national level, as well as forming the basis for recommendations about resilience strategies.

2.3 Notes on using these guidelines

These guidelines are subdivided into different processes for carrying out vulnerability assessments of electricity and drinking water supplies, the population and the environment, as well as a methodology chapter on the opportunities offered by remote sensing. It is recommended initially that all of the proposed themes are investigated in order to be able to make the most comprehensive assessment possible. It is then possible to consider afterwards whether an investment in remote sensing data and processing capabilities makes sense and is achievable in your community. However, if you are particularly interested in an assessment of vulnerability for individual sections of these guidelines, the methods can be also be used independently of one another.

The chapters on vulnerability assessments of the named infrastructures, population and the environment contain all of the required information and describe the process for completing the assessments. However, the format of these guidelines does not allow for any comprehensive explanations and only limited space can be given to a description of the conceptual approaches. Therefore, some sections of the text make reference to the Appendix to these guidelines (see Chapter 7). The Appendix contains both check lists and calculation formulas that provide more structure to the processes, as well as additional information and examples to illustrate their application. Furthermore, this is a good opportunity to refer you once again to the publication of the complete results of this project titled „Indicators for assessing vulnerability and coping potential using the example of water-based natural hazards in urban areas“ from the series of publications „Research into Civil Protection“. Although the information contained in this publication is not necessarily required for carrying out the assessments, it nevertheless reveals the background to the project work and the conceptual considerations explored during the development of these methods that are not contained in these guidelines due to the restricted size of this format.

Background information on these guidelines

These guidelines are the result of the research project *„Indicators for assessing vulnerability and coping potential using the example of water-based natural hazards in urban areas“,* which was completed by the UNITED NATIONS UNIVERSITY Institute for Environment and Human Security (UNU-EHS), the Martin Luther University Halle-Wittenberg and the German Aerospace Center (DLR) in close cooperation with their partners from the cities of Cologne and Dresden. Alongside these guidelines, a final report on the scientific research results was also produced for this project that clearly describes the conceptual and empirical results of the work in detail and was published in the series of publications *"Forschung im Bevölkerungsschutz" („Research into Civil Protection").* It is titled **„Indicators for assessing vulnerability and coping potential using the example of water-based natural hazards in urban areas“.** It is possible to use these guidelines without the aid of this publication, although it can of course provide supplemental information for those interested.

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III. Chapter

Assessment of the vulnerability of power and drinking water supply to flooding events

Objective

This guideline aims to provide instructions for the distinct steps involved in vulnerability assessment of power and drinking water supply in the event of flooding. This procedure focuses on the time period of the flooding, gives criteria for the assessment of the situation during the event, and provides a module of comprehensive planning for risk and crisis management as regards infrastructure supply. In addition, this guideline can also be seen as an evaluation instrument as it provides options for taking action, additional checklists, notes on providing information for those affected and means of monitoring various planning alternatives.

Cooperation between municipalities and infrastructure operators

The supply of power and water is of major importance for the population, the economy and many other infrastructures. These and other infrastructures are therefore combined under the collective term *critical infrastructures* by the German Federal Ministry of the Interior (BMI) and are viewed as the "organizational and physical structures and facilities of such vital importance to a nation's society and economy that their failure or degradation would result in sustained supply shortages, significant disruption of public safety and security, or other dramatic consequence"[13]. Because both public and private agents share the ownership and operation of these infrastructures, reducing the vulnerability of critical infrastructures should be viewed as a joint task of the public and private sectors.

It is particularly this situation that this guideline aims to take into account because both during the implementation of the assessment and when subsequently dealing with the results, the utility companies and network operators have an important role to play. The companies not only maintain important databases but also have expertise regarding the processes and components involved that is essential for providing answers to specific questions. Finally, the utility companies should be included in actions and plans derived from assessment results.

On the municipal side, the level of vulnerability needs to be determined so that suitable action can be taken in the event of flooding. Whereas the data required for the implementation of this analysis may not be fully available in the municipality, the infrastructure operators have much of the relevant information at their disposal. While these operators do have the full range of information on hand, for various reasons they sometimes wish to handle certain data confidentially. How much information is available to the municipalities thus differs from case to case. The approach chosen in this assessment guideline attempts to do justice to these different interests. The questions posed in the assessment steps are formulated so that they reliably gather the necessary information without requiring the companies to supply detailed data. From the point of view of the municipality, this approach also has the advantage that the assessment does not need to be carried out by established experts. Requests for information are posed in a form comprehensible to the non-expert and the information is then systematically collated. If data is still found to be missing when carrying out the assessment, suggestions for how to deal with this situation can be found at the end of each description of a step of the procedure.

[13] German Federal Ministry of the Interior (BMI) (2009). National Strategy for Critical Infrastructure Protection (CIP Strategy). Berlin.

Similarly, after the assessment has been completed, if the question of the implementation of measures for vulnerability reduction should be raised, cooperation between the municipality and the utility companies is of particular importance. At their own facilities, municipalities can certainly set up plans for dealing with the failure of infrastructures during a flooding event or carry out protective measures independent of the utility companies and the network operators. If, however, measures are considered that make the modification of individual components or the network structure of the utility infrastructures necessary, the utility companies must also be included in this phase. In this case, it is important to remember that, whereas the municipality may be interested in carrying out certain measures, their direct costs may be borne by the operator. For example, steps aimed at increasing redundancy are necessarily accompanied by investment and maintenance costs – lowering vulnerability may therefore involve an evaluation process balancing what is technically feasible against what is economically reasonable. In the interest of improving the reliability of supply, the municipality may offer operators certain incentives, such as making land available.

3.1 Vulnerability of power and drinking water supply

To carry out a successful vulnerability assessment, the assessment procedure applied must be adjusted to the characteristic properties of the subject to be studied, here, *critical infrastructures* of the power and drinking water supply. The following sections therefore describe the different levels of analysis that need to be brought to bear when considering power and water supply, identify the criteria used for vulnerability assessment and outline the mutual interdependency of various infrastructure systems.

3.1.1 Levels of consideration

The process of supplying power and water to municipalities and their end-users can be seen as the interaction of various sub-processes. These sub-processes are implemented by components that may be located in the municipality concerned. Furthermore, these components too may have a complex structure – thus personnel, logistics and communication technology can be just as involved in the sub-processes to be carried out as buildings, data, plants or operating supplies[14]. The individual sub-processes interact, and, to a certain extent, add their own vulnerability to that of the entire infrastructure in a flooding event.

To facilitate the review of power and water supply with the help of this guideline, it is sufficient to differentiate between the general process or infrastructure level and the sub-processes or component level. This differentiation is reflected in the structure of the guideline: while the first assessment phase (Section 3.2) considers sub-processes and components, these are all brought together at the level of the general process or the infrastructure in the second assessment phase (Section 3.3). When implementing such a review, the order of the two assessment phases cannot be chosen arbitrarily. The second phase must strictly be preceded by the first phase, as the interim results originating from the first phase are carried forward to be used in the second.

[14] German Federal Ministry of the Interior (BMI) (2008): Protecting Critical Infrastructures – Risk and crisis management. A Guide for companies and government authorities. Berlin.

3.1.2 Vulnerability criteria

In view of the complex structure of power and water supply described above, as well as the large number and the varied design of the components involved, a number of criteria for the assessment of vulnerability in a flooding event are conceivable. A compilation of individual criteria for reviewing critical infrastructure can, for example, be taken from the BMI guideline *Protecting Critical Infrastructures – Risk and crisis management. A Guide for companies and government authorities*[15]. The following sections introduce and explain the choice of vulnerability criteria used in the course of this assessment.

Exposure

In the context of the present assessment, exposure is understood as the situation in which a component is exposed to the flooding event. The decisive factor is solely whether a component is located in the flooded area or not. Of course, it is conceivable to include other aspects such as water flow speed or the concentration of contaminants in the water but the data required for such analysis may not always be available. In the interest of comprehensive applicability, this criterion has not been further differentiated.

Functional susceptibility (aspect of susceptibility)

The present assessment method puts the security of supply in the event of flooding at the focus of consideration. This is not the only possible approach, but it is a sensible one from the point of view that the municipality has a vested interest in maintaining the supply and in obtaining a basis for risk planning and crisis management. The criterion combines a number of other aspects such as the effectiveness of existing protective measures or the dependence of the components on operating staff or not. These individual aspects have not been ignored but merely subsumed under one category on the basis of their impact on the overall process. The strategy is based on the assumption that, in the event of a flood, the question of which factor caused the failure of a component is not initially of crucial importance. The effect is what is included in the assessment, that is to say, either the continued functioning of the component or function failure.

There is a further reason for the pooling of individual aspects, a reason derived from the ratio between data availability and the processing capacity of the utility operators and municipal administrators. By means of such clustering, the number of individual items of information that must be provided by the operators for assessment implementation is considerably reduced. Likewise, from the municipality perspective, the time required and the demands on those processing the information are reduced. The provision of data clusters taken together with the utility operators not having to reveal any confidential detailed information means that the workload of those doing the processing is reduced but without losing information relevant to the security of infrastructure supply.

[15] See footnote14.

Functional Replaceability (aspect of coping capacity)

A combination of individual facets is concealed behind this criterion, too. The technical prerequisites for redundancy and substitution[16] as well as staff preparedness are central aspects that can be subsumed under the term replaceability. Analogous to the assessment of functional susceptibility, lots of detailed information would be required for the assessment of this individual aspect, which, on the one hand, would be treated confidentially by operators and, on the other, would bring too much data into the assessment for the municipality to process. The way out of this situation is a condensed representation of the data solely with regard to its contribution to the vulnerability assessment - that is to say, for these data, the level of replaceability in the case of component failures - and to delegate the assessment of this point to the operators as they have the relevant data and competent personnel available.

3.1.3 Power-dependency of drinking water supply

This guideline contains an assessment method that can be used for the vulnerability assessment of power and water supply at the municipal level. However, it should be borne in mind that these two infrastructure systems do not react in the same way to flooding events. While the assessment method is sensitive to these differences within the two systems, it can only partially capture the interdependencies that exist between the two infrastructures and the resulting vulnerabilities. Many other infrastructures react very sensitively, especially with regard to a failure of the power supply. Therefore, the results of the power supply vulnerability assessment should definitely be included when considering the water supply. If the implementation of the vulnerability assessment for both infrastructures is planned, it is important that initially the power supply vulnerability is assessed before attention can be given to the water supply in the next step (see the “Organization of individual steps” section below).

[16] See footnote14.

3.2 First assessment phase: vulnerability assessment of sub-processes/components

In the following sections, after giving important information on carrying out the assessment and its results, the vulnerability of power and water supply sub-processes at a municipal level will be assessed by means of several individual steps. Finally, in an interim résumé, the result of the first assessment phase will be interpreted and the second assessment phase will be prepared.

3.2.1 Flowchart

The assessment method presented here is based on the necessity of obtaining and collating important information in a fixed order. The order is particularly significant. On the one hand, it avoids the repeated input of the same information and, on the other hand, each step serves to minimize the work involved and at the same time allows local conditions to be taken into account. The systematic approach followed during the vulnerability assessment procedure is illustrated in Figure 3.1.

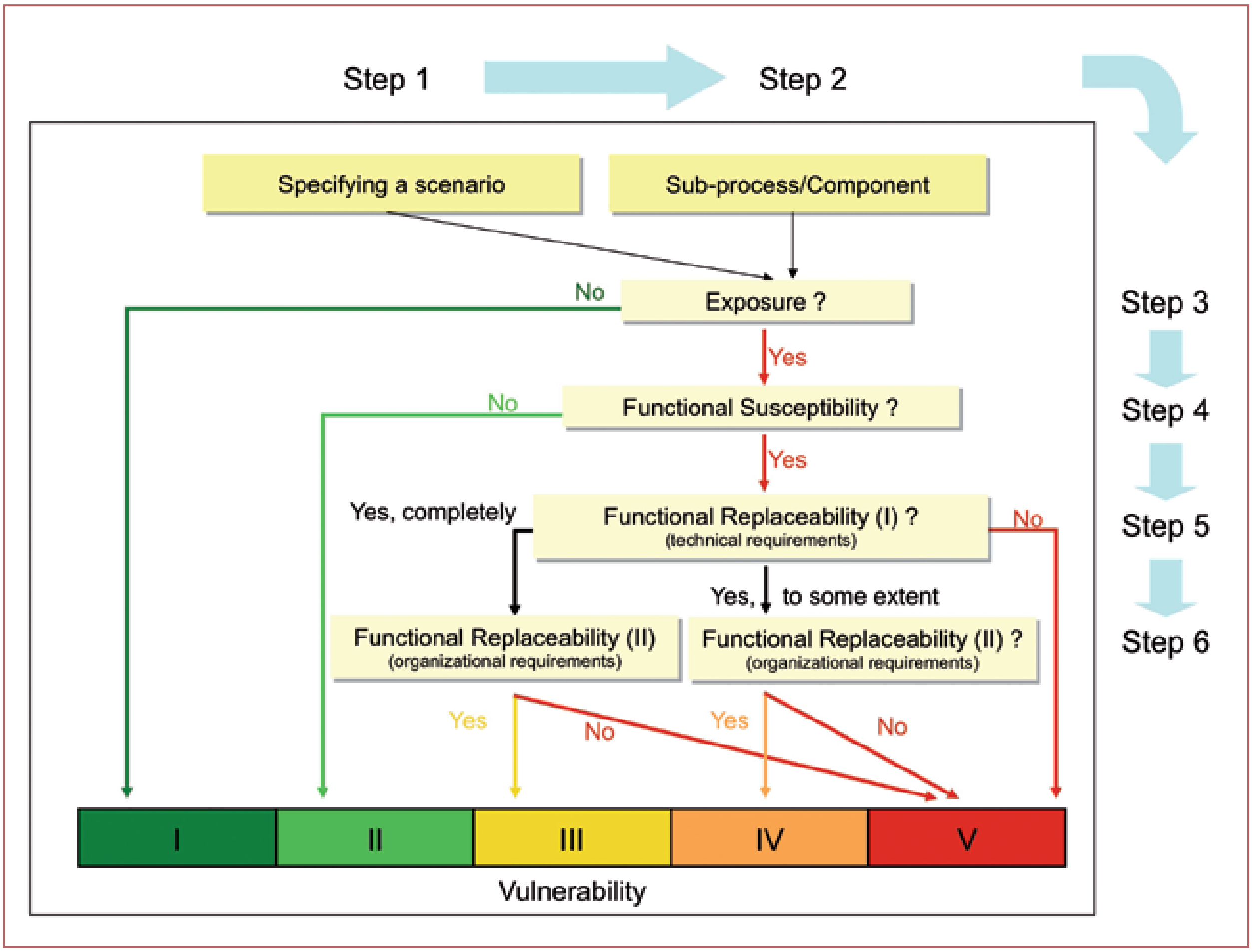


Figure 3.1: Schematic presentation of the assessment method

Figure 3.1 should be read following the arrows from the top left to the bottom right. After specifying the flood scenario to be examined, an inventory of the sub-processes/components located in your municipality (for terminology, see *Step 2*) is carried out. Following this, an exposure analysis is conducted and the assessment is concluded, taking into account functional susceptibility and replaceability. While proceeding through the steps of the assessment, depending on each result you obtain, you either reach a classification of the process in a vulnerability class (see the following section) or you move on to the next step in the assessment. The individual steps are explained below and illustrated in the examples provided in Appendix 7.3.

3.2.2 Vulnerability classes

The result of the first phase of the vulnerability assessment is a division of the individual sub-processes into five vulnerability classes which ensue from the constituent steps and make an interpretation easier for you. The meanings of the various classes are defined in the following box. Implementing the present guideline will lead to the identification of particular weaknesses in the infrastructure of power and water supply in your municipality. The resulting options for taking action can only be briefly touched on here – more detailed information on dealing with assessment results is provided for you later in this chapter.

Class I = No vulnerability or very low vulnerability level

The sub-process/component is not exposed to floodwater. For this reason, the vulnerability of the sub-process/component under consideration is to be seen as very low to non-existent.

Class II = Low vulnerability level

The sub-process/component is exposed, but its functionality is not affected. Classification in Class I cannot, however, be considered as flooding always means a potentially dangerous situation with a number of eventualities.

Class III = Medium vulnerability level

The sub-process/component is exposed, functionally susceptible and completely replaceable. This means that the sub-process/component is exposed to floodwater and suffers a function failure; it can, however, be completely replaced by other component(s). Staff is adequately prepared to implement such a replacement. Even if a supply failure is not necessarily expected, the situation still involves a relatively high number of eventualities.

Class IV = High vulnerability level

The sub-process/component is exposed, functionally susceptible and only partially replaceable. In the event of flooding, at least a partial function failure is to be expected.

Class V = Very high vulnerability level

The sub-process/component is exposed, functionally susceptible and not replaceable. In the event of flooding, a complete failure of the service provided by this sub-process/component is to be expected.

The vulnerabilities of the individual sub-processes/components do not contribute equally to the total vulnerability of power and water supply in the event of flooding. For this reason, results determined for the individual sub-processes/components must be brought together in a manner that does not obliterate the high information content but rather puts the results in a meaningful relationship to each other (second phase of the assessment).

3.2.3 Examination of available data

When carrying out the assessment, information is used that is either already available in the municipality or must be requested from the utility companies. If a lot of information is already available, for example in a geographic information system (GIS), the need for information that must be obtained is thus reduced. It should be noted that the information could be available in different departments of the administration. If there is any doubt about the available data being complete or up to date, it is advisable to take the opportunity afforded by the vulnerability assessment to ask the utility operator(s) to check the information.

The data required can be deduced from the questions to be asked in the individual steps of the assessment. These are highlighted in color in the following sections so that they can be easily used for a prior check of the data currently available. Whether the necessary information is available and has been brought together in a consistent form should be checked in advance of the assessment. If necessary, individual data sets must be digitized, or on the other hand data transmitted from a GIS must be transferred to an analog map. If in doubt, it is preferable to digitize data in the interest of enhanced applicability.

3.2.4 Structure of the individual steps

In the following we shall attempt to keep to a uniform structure (information, step(s) to be taken, notes on dealing with gaps in the data). This is, however, not always possible. The text includes various references to Checklists 1 and 2 in the Appendix (7.1 and 7.2) to be consulted if needed. These checklists enable differentiated analyses of individual aspects that are not absolutely essential for carrying out the assessment but that can refine the results, can help you with the diagnosis of weaknesses and, if applicable, serve for further planning. Examples of each individual assessment step can be found in the Appendix.

3.2.5 Form of assessment results

The results emerge from the individual steps of the assessment in two different forms. Firstly, the individual components are located in a GIS or on a map and each is assigned to a vulnerability class. Secondly, the components are arranged in a list in which they are assigned to the separate sub-processes to which they belong. Presenting the data in a list format rather than on a map makes them easier to understand and makes it possible to consider sub-processes as a whole, which is more difficult on a map. The division of the sub-processes into classes results from the assignment to classes of the components involved, where the highest vulnerability of any single component determines the class of the sub-process as a whole. This approach may appear to be drastic because even sub-processes that are only threatened by the failure of a single component are assigned to a high vulnerability class, but this guarantees that problems are detected and not prematurely underestimated. The interpretation of the assessment results is thus of special significance – whereas placement into Class V solely indicates a probable failure of a sub-process, the estimation of the possible consequences of this failure must be carried out locally in each individual case. This will be elaborated on in the second phase of the assessment. Additionally, the "Dealing with assessment results" section (3.4), later in this chapter, provides notes on tailoring assessment to specific cases.

3.2.6 Implementation of the first assessment phase step-by-step

Step 1: Specifying a flooding scenario

This step is carried out according to the approach described in the "Use of the scenario-based approach" section in Chapter 2.

Step 2: Determination of the sub-processes and components

Because the first phase of the vulnerability assessment takes place at the level of various sub-processes of the municipal supply, the sub-processes that will play a role in concrete cases need to be identified. For example, not every municipality treats water or generates power. In many municipalities, the utility companies purchase power and water from another provider outside the municipal boundaries. This step can therefore be decisive in contributing to a reduction in the workload involved in the assessment – especially in small municipalities. The utility company should, therefore, be questioned regarding which components are located within the municipality. As a point of guidance, distinctions can be made between the following sub-processes and components (deviations are possible resulting from local circumstances).

Drinking water supply:

Component	Sub-process
Wells/reservoirs	Extraction of untreated water
Waterworks	Treatment of drinking water
Pumping stations	Feeding-in of drinking water
Transfer points	Feeding-in of drinking water (from external provider)
Pressure booster stations	Adjustment of network pressures
Reservoirs / water tanks / water towers	Intermediate storage
Network control center	Monitoring / control of urban / rural network

Power supply:

Component	Sub-process
Power station	Power generation
Grid substation (1)	Transforming to high voltage (e. g., 380kV to 110kV)
Grid substation(2)	Transforming to medium voltage (e. g., 110kV to 20kV)
Network control centers	Monitoring / control of urban / rural network
Network substation	Transforming to low voltage (e. g., 20kV to 400V)
Cable distributor boxes	Distribution of power to individual power consumers

Indications regarding the identification of components:

- *Substations* can have step-down transformers transforming to high voltage (e. g., 220kV or 110kV), to medium voltage (50kV–10kV) or to low voltage (network stations, 400V). A precise distinction must be made.

- Although *power stations* may be located near a municipality, they may not feed into the municipal network. They often feed directly into the high voltage grid of a regional or national utility company. In this case, the power station does not play a direct role in the supply of the municipality. The same can apply to substations that function at the high or extra-high voltage levels. Here, too, the degree to which a power station directly contributes to the municipal supply will need to be clarified.

- The components here termed *network substations* are frequently designated differently. Thus the terms *electrical substation, distribution substation* or simply *substation* are often used. If you are not certain about the function (transforming from medium to low voltage) of such a component, the situation can be clarified in cooperation with the utility company.

- It should be kept in mind that some components that are no longer in use or are being used differently are still referred to by the original terms. Decommissioned water plants or electrical plants are frequently used for other purposes or continue to be used to some extent. You should obtain relevant information from the utility company.

Not all components that serve to supply power and water appear on the list. The urban networks are not listed. Because water and low voltage lines within the municipalities are, as a rule, underground, the networks are generally not vulnerable to flooding. A special situation can arise if power lines are laid at locations where they are exposed to severe erosion resulting from especially high flow (risk of cable exposure and potential undercutting of lines). The analysis of this danger is, however, not the subject of a generalized assessment such as that provided by this guideline. Generally, it can be inferred from the experience of past flooding events that particularly weak points are to be found where lines are installed on bridges, where they are embedded in river banks and where there are junctions between underground and surface components. In the case of cable damage in the power network, there is a release of voltage to the surrounding water (creating the risk of electrocution to people in the direct vicinity) followed by a short circuit disconnecting the affected local network and all dependent components and consumers from the supply. In the case of damage to pipes in the water supply, a fall in pressure in the network is registered. Pressure-controlled networks react to such damage with an automatic reduction of the volume of water fed in. This mechanism leads to supply outages for the consumers and, in some cases, the intrusion of contamination into the mains. In networks that are not automatically controlled, large volumes of water can escape from the opening before the leak is found. In this case, too, contamination in the water mains is to be expected.

Question: Which infrastructure components are located within the municipality and which process do they implement exactly?

Way of proceeding: Draw up a list of all the components to be considered in your municipality, arranged according to sub-processes. It could well be that the sheer number of network substations and cable distributor boxes makes a complete listing impossible. In this case, enter the total number of components in the list. See the "Examples of individual assessment steps" section in the Appendix for specific examples.

Dealing with gaps in the data:

If the utility companies have reservations regarding the disclosure of this information, it can be helpful to have an agreement with respect to the confidential use of the data, or the amount of data requested can be reduced. This can be done by presenting the utility operators with the assumed scenario and requesting that they only give information on the components in the flooded area (of the scenario). If an operator should choose this alternative, step 3 in the assessment procedure is not needed.

Step 3: Determining the degree of exposure

The scenario has now been specified and the inventory of the components/sub-processes has been made. In accordance with the flowchart in Figure 3.1 the next step is determining which of the latter are exposed to flooding. First of all, the exact location of the components must be established.

Question: Where are the individual components located?

Way of proceeding: Starting from the list of all components generated in step 2, we must now identify which of these components are exposed to flooding. To do this, you need to know the exact position of each component. If the data is available in a GIS-compatible format, you can superimpose this information onto the existing GIS. It may be advisable to produce data layers/thematic layers of the components making up the individual sub-processes (i. e., storing all network substations in one collective thematic layer). If you are using an analog map, you should enter all the components onto the map using appropriate symbols. See the "Examples of individual assessment steps" section in the Appendix for specific examples.

It can now easily be seen which of the components/sub-processes would be affected under the assumptions of the specified flooding scenario. Non-exposed components/sub-processes are classified in vulnerability Class I.

Question: Which of the components are located in the flooded area?

Way of proceeding: You must now ask which of the components would be located in the flooded area in the case of the specified flooding scenario. If a GIS is available, all affected components can be quickly extracted from the original thematic layer (using the "cut" or "clip" commands). You should save the remaining non-exposed components in a separate data layer/thematic layer with the attribute "CLASS I". These components should be colored dark green in the GIS (dark green stands for vulnerability Class I). If you are using an analog map, the individual components must be checked for their exposure. The non-exposed components can also be marked in dark green on the analog map.

It should be kept in mind that the information on the number of exposed components considered in isolation has only limited predictive value regarding supply vulnerability. The components can be designed for many different capacities and may have very different working loads. The value of knowing the number of components is primarily in assessing whether the process is to be seen as completely, partially or not exposed. Looking at the degree of vulnerability of the performance of the sub-process as a whole (contribution of the individual components to the sub-process being considered) is of higher predictive value. The performance, however, will implicitly be made the basis for the assessment in the next steps of this guideline.

Question: *Which sub-processes are carried out by exposed components?*

Way of proceeding: Before carrying out this step you should make a photocopy of the list you start off with now and keep it, as it might be helpful in the second phase of the assessment. After that, all the non-exposed components should be crossed off the copy the list which shall be used in the first phase of the assessment. If this step in the assessment shows that none of the components associated with a sub-process are exposed, then this sub-process is to be assigned to Class I (no vulnerability or very low vulnerability). You can color this sub-process dark green in your overall view. If one or more component(s) is/are exposed, the assessment must be continued and assignment to Class I is ruled out. The classification of a sub-process is always determined by its most vulnerable component. See the "Examples of individual assessment steps" section in the Appendix for specific examples.

Dealing with gaps in the data:

If no information on the exact location of the components is available, the utility company or companies should be asked to provide information about components situated in the flooded area as identified in the specified flooding scenario. It should be stressed that the query does not relate to an expected failure but is simply a request for information on the relevant locations. If information on the location of the infrastructure components is available, you should make sure that the terminology is used consistently and that the components clearly serve the general supply of your municipality.

Step 4: Determining the functional susceptibility of exposed components

After all the components potentially affected by flooding have been found in step 3, the functioning of the components in a flooding situation now needs to be clarified. The answer to this question requires differentiated consideration of the interdependencies between the components, other infrastructures, certain environmental conditions and personnel, or consideration of the already implemented protective measures. What may be the cause of the function failure is, however, of secondary importance in answering the question. Here, too, the question of whether or not additional damage occurs is not relevant – while it is true that damage plays an important role in restoring the utility supply after flooding, it is not of primary importance in the question of supply security at the time of the flood.

***Question:** Which of the components are no longer working in a flooding event?*

Way of proceeding: When carrying out this step of the assessment it is advisable to work in close cooperation with the utility companies. You must now determine whether all the components identified on the map as being exposed would be affected by function failure in the scenario you have chosen. All the components which are not functionally vulnerable can be stored on the GIS in a separate data layer/thematic layer with the extension "Class II" and colored in light green

***Question:** Which sub-processes are carried out by functionally vulnerable components?*

Way of proceeding: All components that are not expected to fail in a flooding situation should be crossed off your list. If it turns out that the components of one or more sub-processes can be completely removed from the list, then these sub-processes are automatically assigned to Class II (= low vulnerability) and marked accordingly in light green. See the "Examples of individual assessment steps" section in the Appendix for specific examples.

Dealing with gaps in the data:

If exact information is not available, you may legitimately assume that all the components that serve the power supply will not function in a flooding situation. This assumption can be justified by the necessity to switch off all live systems in the flooded area, firstly, in order to minimize the risk of short circuits, and, secondly, in order to ensure the safety of the population and relief units. Although there are options available for avoiding this (see Figure 3.2), for simplicity's sake, complete failure of the components must be assumed in order to guarantee the feasibility of this assessment.

Figure 3.2: Example of the reduction of functional susceptibility

Source: Luttermann (UNU-EHS) (2009)

In a further act of simplification, it can also be assumed that all components that are dependent on the power supply will fail. Although it is conceivable that facilities have an emergency power supply, this may not function in the event of flooding. Certain conditions must be met so that an emergency power supply can be assessed as flood-resistant (see Checklist 1 in the Appendix). Even when the emergency power supply functions, you should clarify whether risks are ruled out and over what time period the supply can be maintained – both the size of emergency power units and the size of fuel stockpiles for them can vary considerably. If there is no information available from the utility operator, a failure must be assumed.

Note on functional susceptibility of components not exposed to the flood

It must be borne in mind that interdependencies exist between the components of an infrastructure system. As a result of these interdependencies the failure of a component can have a negative impact on other components even if they are not directly affected by the flood; failures can also occur in non-flooded areas. These effects are of course important for a vulnerability assessment and must not be neglected! Regardless of this fact, in order to guarantee a structured approach it is suggested that the analysis in Step 4 be restricted to the components that are actually exposed to the flood. Functional susceptibility of those components that have not been identified as exposed to the flood will be dealt with in the second assessment phase later in this chapter.

Step 5: Determining replaceability (I) – technical requirements

The functional failure of a component can possibly be absorbed by other components. Thus several neighboring network substations can take over the functions of a failed substation. The question of replaceability is, however, not easy to answer. It requires the utility operator, on the one hand, to undertake an analysis of the network structure because only appropriately interconnected components and networks can functionally replace each other and, on the other hand, to consider exactly the capacity and load of the remaining components. Taking all the factors mentioned above into account, operators can come to the conclusion that replaceability is completely, partially or not at all possible.

***Question:** To what extent can other components take over the performance of the failed components?*

Way of proceeding: If a component is not replaceable, the component is automatically assigned to the highest vulnerability class (Class V). All components that are non-replaceable and immediately affected by a failure must be marked in red on the GIS or the map you are using. It may be useful to store these components in a separate data layer / thematic layer with the appropriate attribute. If complete or partial replaceability is possible, then the next step is to check whether employees' preparedness and the organizational framework are sufficient to guarantee complete technical replaceability.

Sub-processes cannot automatically be crossed off the list after this step because the organizational aspect of replaceability must be considered in the next step. If a component is not technically replaceable, then the whole sub-process involved must be assigned to the highest vulnerability class (Class V), and highlighted in red in the overall view. See the "Examples of individual assessment steps" section in the Appendix for specific examples.

Dealing with gaps in the data:

If data on the technical options for the replaceability of failed services is not available, the worst case scenario must be assumed and complete failure of the service expected. The utility provider, after having carried out an appropriate systems analysis, should be asked to jointly work out a plan for crisis management in a flooding situation. It is important to know what you will have to expect in the event of flooding. Only after the analysis of the actual situation can measures be planned and implemented effectively.

Note on determining replaceability in the event of flooding

When determining replaceability of components, it is necessary to take the conditions of the scenario into account. Working on the assumption that a component will function in a particular scenario may result in false conclusions being made. When in doubt, it is better to proceed on the assumption of the worst case to reduce the likelihood of underestimating problems.

Step 6: Determining replaceability (II) – organizational requirements

The first step in determining the replaceability of failed service in a flooding situation has been carried out by assessing the technical requirements. In the next step, you must check whether the necessary personnel and organizational resources for the implementation of the technical options are available. These resources are not only concerned with the presence of an adequate number of employees but equally with their qualifications, in terms of their ability to handle the situation in the event of a flood. When components fail, certain measures for the rerouting of water and power need to be carried out – ideally, the calculations required for the preparation of these measures will have been completed prior to the flooding event and the operating procedures prepared in training exercises and set down in emergency plans. It can also be extremely important to link the measures to be carried out by the employees in a flooding event to specific water levels. This is of particular importance, for example, if access roads to a component become impassable at a certain water level. Measures that have not been carried out early enough can in certain circumstances no longer be implemented; an unfavourable and potentially dangerous situation may then arise in terms of the security of supply. In addition to fulfilling the technical requirements for the replaceability of failed service, the degree of preparedness of personnel is another decisive factor for crisis management in a flooding event.

***Question:** Is the staff able to make use of the technical possibilities available for compensating for outages in a flooding situation?*

Way of proceeding: To carry out this assessment step, either the utility provider(s) can be asked to supply the information or it is necessary to go through Checklist 2 in the Appendix together with the companies.

Regardless of how you obtain the results, enter the new information on the map of the components and into the list of sub-processes. All components whose service can be replaced both technically and in terms of personnel must be crossed off the list and you should also color these components yellow (= vulnerability Class III) in the GIS or on the map. If the components of one or more sub-processes are completely crossed out, these sub-processes are assigned to vulnerability Class III. If the results show partial replaceability, the process must be assigned to vulnerability Class IV. If technical replaceability is assured, but the personnel are not in a position to take advantage of it, the sub-process must be assigned to vulnerability Class V (= very high vulnerability). See the “Examples of individual assessment steps” section in the Appendix for specific examples.

3.2.7 Taking the power-dependency of the drinking-water supply into account

The electrical power supply has special significance in terms of the functionality of other infrastructures. Many infrastructures are dependent on the power supply – this can, in certain circumstances and to varying degrees, also apply to the municipal water supply. Although in some cases a municipality receives its water under pressure from outside and thus enjoys complete self-sufficiency as far as the power supply is concerned, the water supply elsewhere is directly reliant on power because pumps or waterworks are dependent on it. This potential dependency should, without fail, be included in any analysis. This has already been done implicitly when assessing the criteria functional susceptibility and replaceability, but it can also be analyzed explicitly as described below.

The approach described here can only be realized if either the vulnerability assessment for the power supply has already been completed or if it is known from another source which areas of the municipality could no longer be supplied with power assuming the flooding scenario. Additionally, the first phase of the vulnerability assessment should already have been done for all water supply components with regard to the flooding scenario. Based on this knowledge, it is now possible to review the dependence of the water supply on the power supply separately. To this end, the previously described assessment steps are to be repeated; this time, however, focusing not on the flooded areas as the basis for assessment but on the areas affected by power failure. You should again make use of the previously generated list of all water supply components/sub-processes and reanalyze all components that are located in an area that may be subject to power failure.

The components that are dependent on the power supply now need to be identified. This can potentially involve all water supply components; it is, however, to be expected that all or some of the components are equipped, at least partially, with an emergency power supply that would prevent a function failure. For all components that are dependent on electricity and not supplied with an emergency power facility, function failure is to be assumed – the vulnerability assessment continues with the next step. For all components supplied with emergency power, the additional questionnaire on emergency power supply in the event of a flood should be used (see Checklist 1 in the Appendix). This can help in estimating the duration and reliability of the emergency supply and point to possible problems.

Whether the components identified as functionally vulnerable can be replaced, from a technical point of view, by components that are not affected then needs to be clarified. If this is the case, the assessment is continued. If this is not the case, the components must be automatically assigned to Class V because a failure is to be expected.

It is now essential to look at the organizational requirements for replaceability, in addition to the technical ones. Depending on whether complete, partial or no replaceability is possible, the sub-processes and components are assigned to Classes III, IV or V respectively (for the organizational conditions relating to replaceability, see Checklist 2 in the Appendix).

3.2.8 Interim results: vulnerability of sub-processes / components – determining options for action

The results of the assessment up to this point are based on the scenario, on the inventory of all sub-processes / components located within the municipality, on the knowledge of their exact location and thus on their degree of exposure, their functional susceptibility, and their replaceability as regards both the technical possibilities and the personnel involved. This information is available in two forms: in the form of a map or GIS as far as individual components are concerned, and in the form of a list describing the vulnerability classes of the sub-processes.

Below, what decisions can be made and what steps can be taken, derived from the results obtained so far, will be described. Which measures to adopt to reduce vulnerability can be directly construed from the vulnerability classes assigned in the first assessment phase. The options for action proposed here need to be weighed against each other in each individual case. It is impossible to decide which measure is the most practical without knowledge of the actual situation; clearly, this decision can only be made on-site.

Class I = No vulnerability or very low vulnerability level

Options for action: Reduction of the exposure is the most effective way to lower the vulnerability to flooding.

Class II = Low vulnerability level

Options for action: Accept the relatively low vulnerability (and, if applicable, plan for possible function failure),or further reduce vulnerability by reducing exposure.

Class III = Medium vulnerability level

Options for action: Accept the vulnerability (and, if applicable, plan for possible function failure), or take measures to reduce functional susceptibility and/or exposure.

Class IV = High vulnerability level

Options for action: Accept the comparatively high vulnerability and plan for function failure in a flooding event, or take measures to increase replaceability and to decrease functional susceptibility and/or exposure.

Class V = Very high vulnerability level

Options for action: Options for action: Accept the very high vulnerability and draw up plans for dealing with supply failure, or take measures to increase replaceability and to decrease functional susceptibility and/or exposure.

All of the sub-process and component vulnerabilities obtained in the first assessment phase contribute to a certain extent to the overall vulnerability of infrastructure supply at municipal levels in flooding events. The results that have been obtained up to now provide detailed information on the individual sub-processes, their vulnerability as well as precise reasons for their vulnerability. Therefore, they provide important indications about measures that can be taken to reduce vulnerability. These results are indispensable as a basis for the second assessment phase.

3.3 Second assessment phase: assessment of the vulnerability of the infrastructure

In the first assessment phase the analysis of the components and sub-processes focused on the effects of the flooding event. Considering impacts created by the interaction of components was postponed – even if this did to some degree "sneak in" when dealing with replaceability in Steps 5 and 6. In the second assessment phase the interaction of the components and sub-processes will be explicitly taken into account.

Indirect consequences

Just as under normal conditions the functioning of each individual component contributes to the functioning of a whole infrastructural system, in the case of a flooding event the failure of individual components may negatively impact other components and thus the functioning of an entire system. For example, it is possible that a network substation is not affected by the flood but still cannot function because an upstream substation is flooded. Thus the component is not directly affected by the flood but is nonetheless indirectly affected by component failure elsewhere in the system. To gain a comprehensive overview of infrastructural vulnerability it is important to integrate these indirect effects into the assessment. Unfortunately it is particularly difficult to gain a clear picture of these effects and detailed information, for instance on the structure of the network, is needed. It is therefore essential to work in close cooperation with the infrastructure operators.

Approach

To build upon the interim results of the first assessment phase, the components that have been identified already will have to be reassessed. The components should be looked at one by one, with a special focus on the relevance of the interim results for other components. Key questions in this context are the following: Which components would be affected by the complete or partial failure of this particular component? What would be the consequences? Is it possible to identify affected areas? And, if so, where would these areas be located? This step might lead to a revision of the interim results for the components, a process which needs to be documented both in the GIS and in the list. Should a clear statement on the consequences not be possible, it is necessary to expect the worst case. The photocopy of the original list of sub-processes/components compiled in step 2 in the first phase of the assessment can be helpful in the following in order to make sure that no components go unnoticed.

A general overview of the interaction of the various sub-processes of power and drinking water supply are provided in the following sections, later in this chapter. This overview can be used to optimize the order in which the reassessment is carried out. The order suggested here is based on the hierarchies inherent in the chain of processes and tries to first draw attention to those sub-processes whose failure may be assumed to have the most severe impact on related sub-processes/components. The order can, of course, be adjusted to meet local conditions. These sections also provide additional information on the sub-processes, which might be helpful in this assessment phase.

Results

The results of the second assessment phase are intended to complement the mostly component/sub-process based approach of the first phase by adding the perspective of the infrastructural system to it. These results can serve as a basis for risk management and emergency planning and provide information on measures to reduce vulnerability.

3.3.1 Interaction of power supply sub-processes

The individual sub-processes can be considered as hierarchically arranged within the power supply. The following suggestions are based on the supply chain from power generation or grid supply points down to household connections. The suggested hierarchy can be used as a basis on which to assess sub-processes but local conditions must also be taken into account that may potentially be missed if a standardized approach is blindly adopted.

First, the components that ensure that electrical power is available in municipal networks should be examined. Power supply is either accomplished through a combination of power plants and feeds from extra-high or high voltage networks or solely through these feeds. If the power supply fails, all following sub-processes will be affected. If problems are to be expected in the power supply, it is important to ask about the direct impact of the failures. If, for example, only a part of the service is available, the utility provider must react by switching off the supply to individual consumers or to whole areas. The municipality should be prepared for that and might possibly cooperate with the provider in the planning process. If the power supply fails entirely, a complete power blackout has to be expected. Thus, consideration of the basic supply of power must be given top priority in planning measures to reduce vulnerability because all other sub-processes are dependent on it.

Second, the urban and/or rural network control centers should be examined. (It should be noted that not all municipalities have such a control center; the control center for small or medium-sized municipalities may well be outside the boundaries of the municipality.) Although their failure would not necessarily lead to immediate power outages, problems would nonetheless ensue because the network would then have to operate “blind”. This situation is highly unstable, potentially dangerous and can in some circumstances lead to power outages of unpredictable magnitude.

Next, power must be transformed down to medium voltage. (The same applies as above: small municipalities may not have such a step-down transformer.) The consequences of a failure in this sub-process can vary greatly, depending on the structure of the network. How the network is structured and what problems will result from power outage can only be described by the utility operators. In many municipalities, this level will be the one of highest priority because power is taken from the high voltage grid via a grid supply point and the grid itself is operated from a remote control center.

Third, the transformation from medium voltage to low voltage at the network substations needs to be taken into consideration. It should be noted that the network substations that perform this sub-process cover a relatively limited area and therefore a significant difference exists between the failure of a grid substation and the failure of a local network substation.

The distribution of power via cable distributor boxes should then be considered. Cable distributors can often be bridged or their load can be rerouted so that their failure would not necessarily impact the power supply. Household connections should be considered last, as an outage here seldom, if ever, has repercussions elsewhere.

Finally, it should be noted that, because of their territorially limited area of influence, both the network substations and the cable distributors would be just as affected by flooding as most of the consumers whom they normally supply. Because in a flooding situation the connections to the power supply network are generally (i. e., without any adaptive measures) unusable, it is usually not large-scale failures that are expected from the flooding of these components. However, small-scale failures for consumers – who themselves may not even be affected by the flooding – can be caused by these components.

3.3.2 Interaction of sub-processes of drinking water supply

As with power supply, a hierarchically organized structure is assumed to exist for water supply. This structure can be used for orientation when weighing up the various interpretations of the interim results developed in the first assessment phase and for setting priorities when planning measures for dealing with various scenarios. As described below, the order may vary depending on what the structures of the water supply infrastructure are, that are present in the municipality.

Similar to the power supply, the actual overall provision of the drinking water is what should be reassessed first. Depending on the system structure in situ, this sub-process might be accomplished by a combination of waterworks, wells or reservoirs, or feeding-in at transfer points from a wholesale provider – the overall supplying of drinking water must be at the top of the hierarchy. Depending on the capacity of temporary water storage facilities, sooner or later the outage of drinking water being fed into the mains involves a reduction in pressure level and finally a resulting widespread failure of the drinking water supply.

Consideration should then be given to the pressure regulation pumps. These pumps keep the line pressure stable and, on occasion, fill up the temporary storage tank. A failure would be accompanied by a reduction in water pressure, for example at locations in higher elevations, and the level of water in the temporary storage tank would no longer be maintained. If pumps may be affected by approaching flood waters, the temporary storage tank should be filled as a matter of priority if adequate early warning time is given.

Because temporary storage is held in watertight tanks and frequently located at higher elevations, e. g., in elevated water tanks or water towers, these components are ascribed lower priority when considering vulnerability to flooding. This does not mean that these components are not important in terms of supply. On the contrary, it can be assumed that the interaction of all the components guarantees the functionality of the system and the temporary storage in particular provides an important buffer function during a temporary failure of components. A relatively low vulnerability of temporary storage to flooding events is expected, however, as a result of its location and watertight design – should this not be the case in your municipality, evaluating the vulnerability of these components has to be given higher priority.

Unlike in the case of power supply, the network control center for water supply could be analyzed later in the process. This is due to the fact that waterworks, pumps and storage facilities frequently communicate automatically with each other, i. e. control mechanisms function without the network control center having to initiate them. The control centers thus have a primarily monitoring function. If a control center performs a control function in the municipality being examined, it should be given higher priority in the second assessment phase!

3.3.3 Alternative approaches when considering a variety of flooding scenarios

The approaches described in the preceding two sections can be used when only one flooding scenario is examined. If you decide to include several scenarios in the vulnerability assessment, you can – alternatively or additionally – take the different likelihoods of occurrence of these scenarios into account when making decisions on preventive or reactive measures. For a flood with a high likelihood of occurrence or one with a relatively low water level, it could be practical to take extensive measures that can be quickly implemented (e. g. measures to reduce exposure). Assuming an intermediate scenario, planning on the level of individual objects could make sense (reducing vulnerability by, for example, lowering functional susceptibility by means of protective measures for individual objects). For flooding scenarios statistically predicted to occur at greater intervals and involving very high water levels, the drawing up of a crisis management plan for dealing with possible widespread infrastructure failure might become increasingly important.

3.4 Dealing with the assessment results

The method presented in the "Implementation of the first assessment phase step-by-step" section (3.2.6), earlier in this chapter, is applicable to all sub-processes/components. It must be decided, however, which measures are possible in particular cases. While a power plant would be difficult to remove from the course of a river because of the enormous costs and labor involved and because of its dependence on cooling water, such a measure could be a reasonable consideration for a substation. Decisions must thus be made on a case-by-case basis – taking into account the financial, technical and organizational details, necessary protection levels and local conditions – and having regard to whether acceptance of vulnerability (planning for failure), reduction of vulnerability (increasing replaceability or lowering functional susceptibility) or complete avoidance of exposure is the best approach. The impact of various measures on vulnerability can be examined in advance for any case based on the method presented in this guideline and included in the assessment process.

3.4.1 Use of assessment results as a basis for planning

Decisions must be taken on how assessment results can be handled within the municipality and they must be taken in close cooperation with the infrastructure operators. Results must thus be seen as important building blocks for preventive planning as well as for the development or adaptation of risk and crisis management. The following sections cover particular aspects of the assessment results which should be additionally used as a basis for planning.

Affected areas

If the results reveal that a complete or partial failure of supply is expected in one or several sub-processes, it is advisable to obtain information on the areas affected. Power supply will almost inevitably be affected. Regarding water supply, problems may occur in higher lying areas that are not actually affected by flooding. The utility companies need to be asked to provide data on such a scenario. It might be the case that these higher lying areas will have to be presented as additional locations that may be affected, and then either analyzed in a GIS or entered on the relevant analog map.

Affected facilities

In addition to assessing the vulnerability to flooding of a particular physical location, attention should also be paid to facilities located in the area. Certain facilities are highly dependent on water and/or power supply and are vital in a flooding event – for example, hospitals, sewage treatment plants and water pumping stations. Those responsible for managing these facilities should be immediately informed of any threat of failure of the infrastructure supply. The feasibility of evacuation of particular establishments is another consideration. When institutions, such as hospitals and homes for the elderly, are affected, evacuation is particularly difficult. In such cases alternative supply arrangements must be considered or detailed plans devised for dealing with the situation. You must also take into account that power companies may need to react to shortfalls in the provision of electricity by shutting down parts of the network. You should take advantage of any opportunity that may arise to influence this process, for example, so that particular facilities remain supplied for as long as possible. Water supply should also be considered in this context and included in planning measures

3.4.2 Dealing with the problem of municipal boundaries

When drawing up this guideline for assessing power and water supply vulnerability in the event of a flood, from a purely practical perspective it was necessary to limit the area examined. The guideline thus focuses on the individual municipality. It must be remembered, however, that the municipal boundaries in no way have to correspond to the boundaries of a supply area. Infrastructures frequently exceed administrative boundaries so that supply problems experienced within a municipality can actually be caused outside of it. This would be the case if no water or power reached the boundary of the municipality. It is also worth noting that vulnerability of supply in your municipality can have potentially negative effects on a neighboring municipality. If you come to the conclusion that the supply in your municipality is vulnerable and it is known that a neighboring municipality's supply is dependent on a component located within your municipality, which is at risk, it is your responsibility to inform the neighbor of the situation.

It is, therefore, advisable to discuss problems of supply dependability with utility providers and, if applicable, neighboring municipalities. In this way, it is not only possible to identify weaknesses in the supply chain that lie outside your own municipality, but mutual solutions can also be worked out. The installation of new connection points to the high or medium voltage grids, the relocation of components or the creation of connections to neighboring municipalities may all be possible solutions. From case to case, and after carefully assessing what is needed, all stakeholders should be involved in decisions on practical measures to increase the security of the power and water supply – this approach can be more cost-effective and more efficient than the solo efforts of one individual municipality.

3.4.3 Considering challenges both before and after a flooding event

Finally, it has to be noted that the assessment method presented in this chapter focuses on the time span of a flooding event. It is carried out in order to implement risk management and provide information for emergency planning. It explicitly does not cover the period of recovery and rebuilding after a flooding event. This should not disguise the fact that this period also raises a number of challenges (see Figures 3.3 and 3.4) that should be taken into consideration. These challenges could not be integrated into this guideline.

Figures 3.3 and 3.4: A flooding event occurring at Nossener Brücke power plant depot in Dresden whose legacy did not vanish without trace after the waters receded
Source: Maschinen- und Stahlbau Dresden, August 2002

Authors: Jörn Birkmann, Maike Vollmer,
Jan Wolfertz
Cartography: Torsten Welle

IV. Chapter

Assessing the vulnerability of the population to flood events

Objective

A vulnerability assessment of the population to flood hazards is a central component in the systematic development of strategies for action and protective concepts in the area of civil protection, as well as for city and regional planning. It is important to note that a vulnerability assessment should take into account multiple criteria. These criteria include the exposure of the population to flood hazards, the susceptibility of the exposed population groups and the coping capacities that these groups possess for handling the effects of flood events.

The aim of this chapter is to introduce methods that describe how to use data from local government statistics and the results of community-based surveys of residents (e. g. sample community census) to make statements about the vulnerability of the population at the highest level of spatial resolution possible. An important objective in this process is the derivation of indicators for assessing vulnerability. These guidelines provide step by step instructions on the relevant collection and calculation possibilities for key indicators. A differentiation is made here between a core set of indicators and a community-specific set of indicators. The core set of indicators can generally be calculated using data from standard local government statistics or from collecting sample community census data, while the community-specific indicators usually require the collection of additional information in purpose-made surveys of cities or communities. In addition, the guidelines use examples to show how the proposed indicators can be visualised in the form of maps in order to illustrate geographical vulnerability hotspots in a city. The results can be used as a vulnerability assessment of the population to flood hazards and are of great relevance both for preventative planning and also for resource planning.

Prerequisites

In order to calculate the indicators, it is necessary on the one hand to guarantee access to the data used and on the other hand to have access to the required computer programmes. The calculations for the key indicators were carried out, for example, using the software SPSS 17.0. Naturally, an alternative programme with a suitable range of functions could also be used. The visualisation processes in map form were completed using the program ArcGIS 9.1. It is also true in this case that alternative software offering the corresponding functions could be used.

4.1 Vulnerability of the population

The development of indicators for assessing the vulnerability and coping capacity of the population in the event of a flood is based on a systematic and process-oriented understanding of vulnerability. Alongside the question of whether the residents of a city are actually subject to flood hazards (**exposure**), it is also necessary to subsequently ask which groups would face particularly serious difficulties in the event of a flood (**susceptibility**). Placing a focus on questions about evacuation capability and the required evacuation time in the event of a flood provides important guidance for determining the different susceptibility levels within the group of exposed people or households. In order to gain a comprehensive understanding of vulnerability, it is not sufficient to merely consider *exposure* and *susceptibility* but rather to also understand that numerous residents living along major rivers also possess experience and resources (**coping capacities**) that they can utilise in the event of a flood in order to suffer as little damage as possible. After assessing *exposure* and *susceptibility,* the following sections will also integrate *coping capacity* into the assessment of vulnerability.

4.1.1 Datasets

In terms of the data used in the assessment, it is particularly necessary to distinguish between two data sources. Firstly there are the local government statistics or other community sources that generally provide the required data for developing a core set of indicators and secondly there are purpose-made independent surveys e. g. household surveys that enable the collection of additional parameters for determining vulnerability to floods in the sense of a community-specific analysis (additional „community-specific" set of indicators). The household survey carried out by the UNU-EHS (hereinafter named the UNU-EHS Household Survey), whose results have been proposed within the framework of these guidelines for the weighting of the indicator calculations, is one example.

If you are planning to complete a representative survey, it is important to ensure that the following questions - covering aspects of exposure, susceptibility and coping capacity - are included:

- **Actual exposure of the household surveyed**
  If multiple scenarios are being considered at the same time (e. g. HQ-100 and EHQ[17]), it is already important to guarantee when drawing the samples that it is possible to clearly allocate households to the exposed areas (households exposed to HQ-100 are also always exposed to EHQ at the same time!).

- **Age of every member of the household**
  Age is an important element in the calculation of some of the indicators or for classifying the households (evacuation capability and evacuation time).

- **Level of household income**
  Information on the level of household income should be collected according to different classes of income. This classification process is not only sensible for calculating the financial coping capacity but can also help to overcome existing

[17] HQ-100 areas are those that will be statistically affected by a flood every 100 years. EHQ areas are defined differently: In Cologne, a HQ-500 flood is considered to be an extreme flood (EHQ). In Dresden, a flood is considered to be a EHQ when the water level exceeds 10 m. The statistical recurrence probability of this water level is between 200-300 years.

concerns on the part of those surveyed about revealing the precise level of their household income.

- **Home ownership or living in rented property**
  This data can be used to help assess the insurance cover against flood events.

- **Length of occupancy at the place of residence**
  This information enables conclusions to be drawn about the respondents experience with floods at their place of residence.

- **Evacuation capability**
  Example: „Would you manage to get yourself and your dependants in the household to safety in the event of an evacuation without external assistance?"

- **Limited ability to walk**
  Example: „Do people live in your household who are not able to independently leave the house or who cannot manage long distances (2 km) by foot (e. g. small children, old people)?" If data on the number of mobility impaired people at a community level is available, it is sensible to phrase the question in line with the existing dataset.

- **Evacuation time**
  Example: „If you had to leave your place of residence as quickly as possible: How long would you need to get yourself, your household dependants and pets, as well as your most important documents (e. g. identity card), to safety" (it is sensible to provide different time categories.)

- **Insurance cover against flood damage (For instance in Germany that would be the "insurance against natural hazards"="Elementarschadenversicherung")**
  Example: „What insurance cover listed below do you hold?" In the subsequent list, it is particularly important to name insurance against natural hazards that covers flood damage in addition to a number of standard insurance policies (household contents insurance, residential building insurance, etc.).

- **Flood sensitivity**
  Example: „How probable do you think it is that the house in which you currently live will be affected by a flood in the future?" Use e. g. a scale from 1 to 8 for collecting the data, with 8 standing for „very likely" and 1 for „very unlikely".

- **Flood protection measures by private households**
  Example: „Have you carried out flood protection measures yourself or implemented any preventative strategies? If yes, which measures or strategies? Formulate open-ended questions in order to allow multiple measures to be named.

- **Level of information when moving into the property**
  Example: „Did you receive or obtain information about the possible flood hazards when selecting your apartment or house?" The response categories should be given as „Yes, received the information automatically", „Yes, actively obtained the information" and „No, neither received nor obtained".

4.1.2 Methodology

The methodology is divided into multiple steps, whereby these guidelines particularly focus on the collection and calculation methods for those indicators that were ultimately selected. However, certain characteristics and objectives first need to be defined that can be used to operationalise the aspects of exposure, susceptibility and coping capacity.

An iterative process is often required in which initial proposals for indicators are made and then tested e. g. based on the availability of community data and sometimes subsequently rejected. These process steps are not described in more detail here. Instead, these guidelines only present the selected indicators with a particular focus on their collection, calculation and weighting. An overview of the selected - particularly those relevant for civil protection purposes - indicators can be found in Figure 4.1.

4.1.3 Vulnerability indicators: core indicators and community-specific indicators

As previously described, these guidelines can be used to assist in the creation of two different sets of indicators. While the core set of indicators can be calculated with the aid of data that is already available in local government statistics in most communities, it is possible to develop an additional set of community-specific indicators by carrying out a targeted survey for assessing the vulnerability of the population. This process has been designed as an additional step i. e. the community-specific indicators do not replace the core set of indicators but rather supplement them. It is often possible to develop the core set of indicators to a higher level of resolution because the community-specific indicators are mostly reliant on purpose-made independently conducted surveys with correspondingly small sample sizes. Figure 4.1 shows the structure of the core and community-specific sets of indicators.

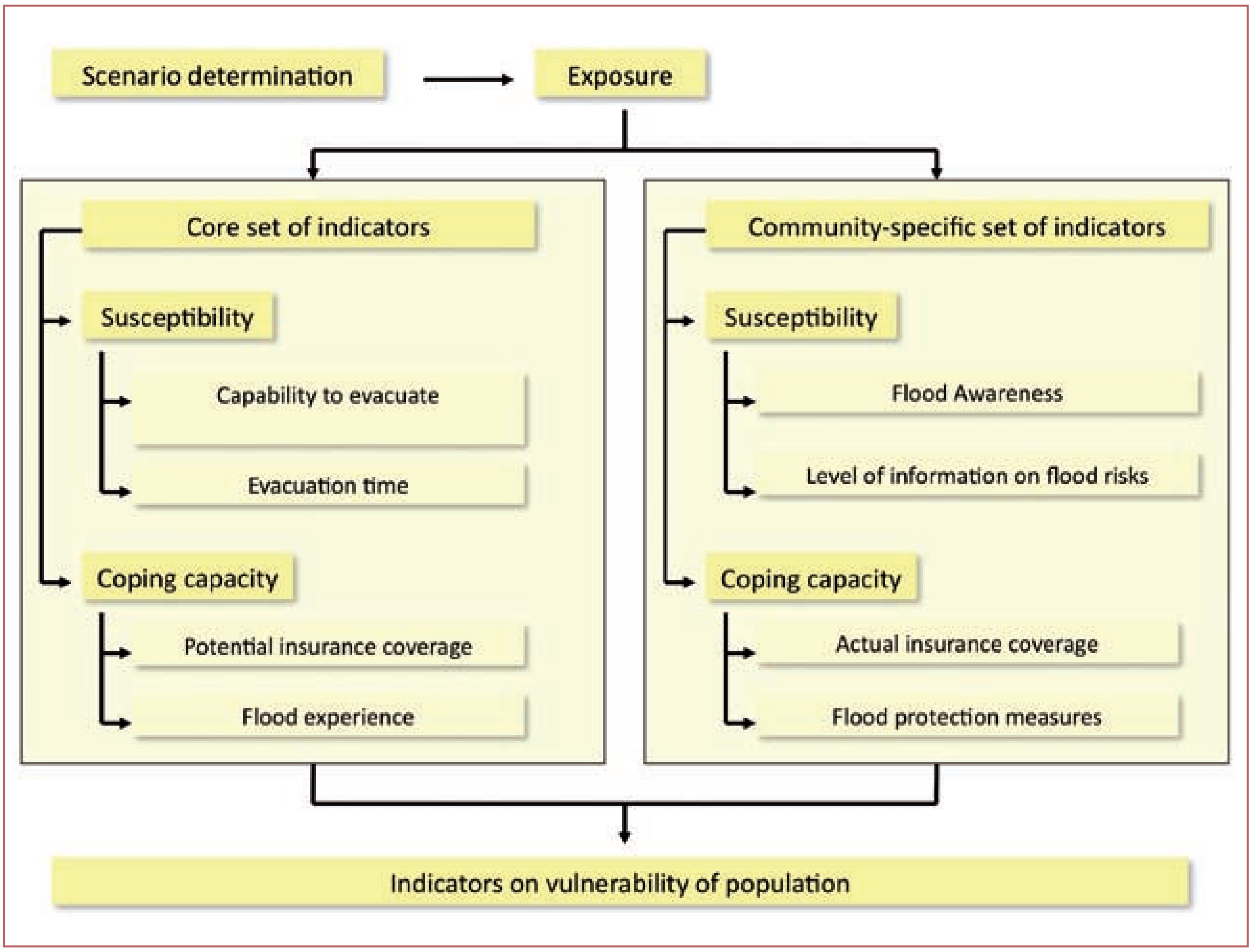


Figure 4.1: Indicators and indicator sets for assessing the vulnerability of the population to flood events based on the use for civil protection purposes

In order to calculate the core set of indicators without having to carry out a survey of the community in question, it is possible to adopt the weighting factors and regression parameters calculated in the UNU-EHS Household Survey while accepting their generalised nature. The samples from Cologne and Dresden for the exposure area HQ-100 were merged for this purpose. This step not only increases the sample size but also means that any special local characteristics lose their significance. If you plan to carry out a purpose-made independent survey then you can collect or calculate these factors and weighting parameters yourself. Information on calculating the core set of indicators using your own independent survey results is provided under the heading **Information on integrating your own independent survey results** in combination with the remarks about the individual indicators given in Chapter 4.2.

4.1.4 Overview of the core indicators

The following section includes an overview of the core set of indicators and their importance for the vulnerability assessment, as well as an explanation of the relevant datasets used and their validity. Following these brief and concise explanations, the precise calculation methods for each indicator will be explained and illustrated primarily in tabular form in Chapters 4.2 and 4.3.

Exposure

In the study of social vulnerability, exposure specifically refers to the risk of flooding faced by a person in their place of residence. The determination of exposure within the framework of a vulnerability analysis is initially carried out based on the geographical areas affected by a hypothetical flooding scenario. These areas are then used to derive the number of potentially affected households and people - as both absolute and relative numbers - within a community or city.

The exposure to flood hazards provides fundamental information for carrying out a vulnerability assessment. If there is no exposure to flood hazards, the development of strategies for dealing with flood hazards is rendered unnecessary. In the development of emergency plans, evacuation strategies and preventative urban planning, it is therefore important to collect information about exposed areas and the local population living in them in order to optimally coordinate and pool emergency services and civil protection measures[18].

[18] See e. g. German Committee for Disaster Reduction (Deutsches Komitee für Katastrophenvorsorge e.V. (DKKV)) (2003): Flood Risk Reduction in Germany. Lessons Learned from the 2002 Disaster in the Elbe Region. DKKV Publication 29. Bonn.

Indicator: *Exposure*

Definition: Specifies the absolute number and the relative proportion of all exposed people or households within a geographical reference unit (e. g. city district or borough) using a hypothetical flood scenario (e. g. HQ-100 or EHQ). It is recommended that several different flood scenarios are examined.

Dataset / source:
a) Geographical information on flood zones based on a particular flood scenario in a GIS compatible file format; available e. g. from environmental agencies, city wastewater treatment plants, flood protection centres.
b) Geographical information on the units of local government that are used as geographical reference units (e. g. city districts or boroughs).
c) Data on the place of residence of people or households from local government statistics (register of local residents).

Contribution to the vulnerability assessment:
The level of exposure given as the number and proportion of exposed households and people within a geographical reference unit is an important factor for assessing vulnerability. Identifying the exposure to flood events is fundamental for the development of all protective measures because it provides information about which measures are required in which areas. The use of different scenarios makes it possible to recognise areas that are frequently or rarely affected. While the number of exposed people provides important information for civil protection (evacuation planning, estimate of the need for relief workers and, if required, humanitarian aid) and geographical planning (prioritising measures), the relative proportion of affected people or households in relation to the total population per geographical unit is also perhaps an even more important indicator for determining vulnerability: Those people who are not affected themselves by the flood event are better able to offer assistance to others. It can therefore be concluded that there will be a greater need for external assistance in those geographical units where almost all people will be directly affected.

Validity: Uncertainties arise when evaluating the different scenarios due to recurrence probabilities. For example, the size of the HQ-100 flood zone will differ as a result of climatic change. The HQ-100 calculations should not be viewed as absolute boundaries - a certain degree of uncertainty always exists regarding the progression of a flood. The determination of the exposure level is based on the residential population because no reliable or up-to-date data is available for the number of workplaces in each geographical unit. In addition to the residential population (*night-time population*), it would nevertheless be sensible to also collect data on those people with exposed workplaces (*day-time population*) and to include this data in the assessment of exposure.

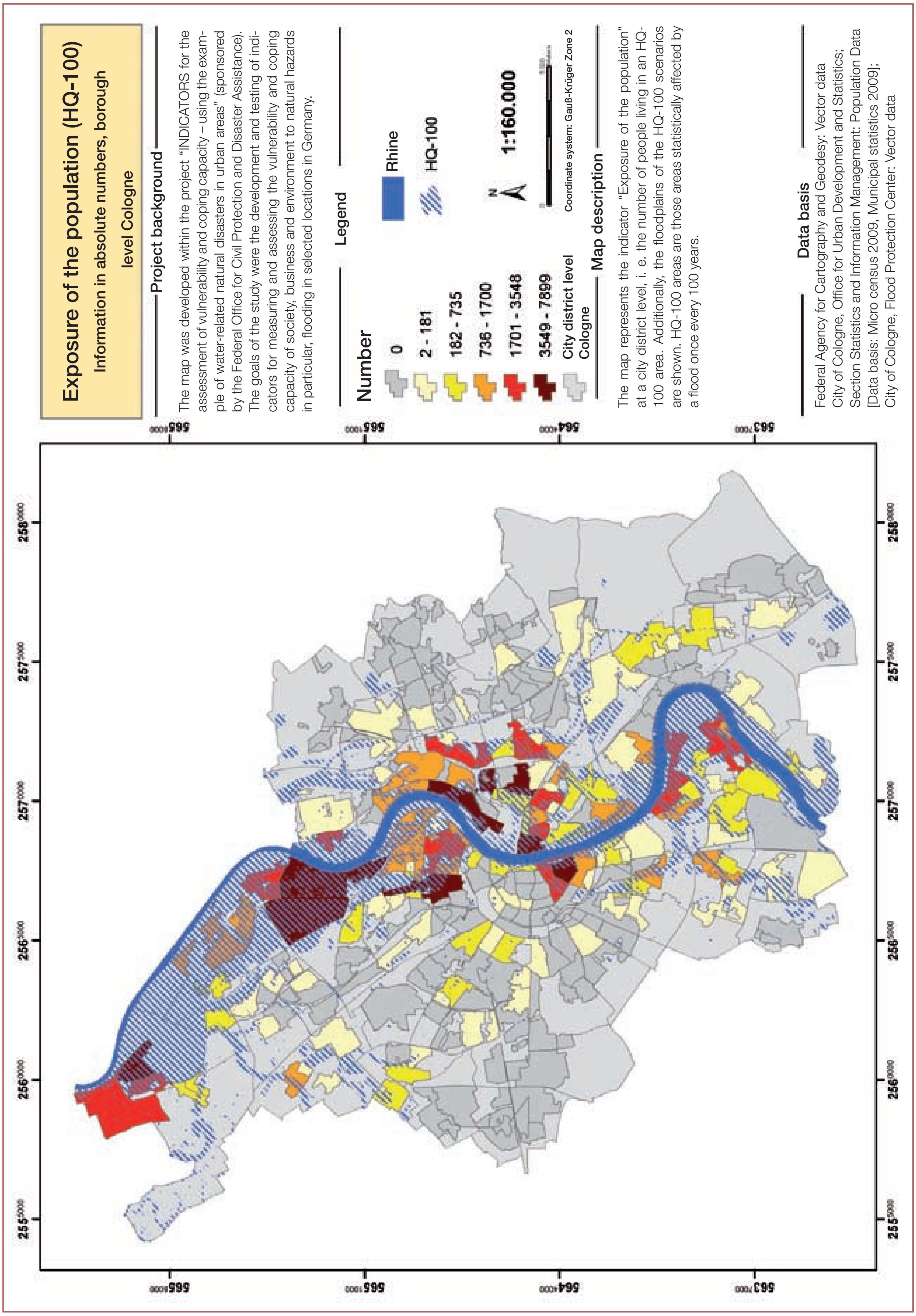


Figure 4.2: Number of exposed people in the City of Cologne in the event of a flood that corresponds to a HQ-100 scenario

Susceptibility

Past flood events demonstrate that significant differences can arise in terms of the susceptibility and coping capacities within those households actually affected. While the geographical exposure to flood hazards and the number of potentially affected people offers some initial guidance, the next stage of the vulnerability analysis must shed light on the susceptibility of those potentially affected by the flood. Alongside exposure, other information and indicators are therefore required in order to provide additional guidance for developing preventative strategies and emergency planning.

In order to estimate the level of susceptibility, it is particularly necessary to pose questions about the evacuation capabilities and evacuation times of the affected population within the framework of these guidelines. The focus on these areas places special attention on the end users of the civil protection measures. Particularly against the background of the increasing ageing society in Germany, it is especially important to investigate how this susceptibility manifests itself in terms of self protection and the ability for unaided evacuation from the flood zone.

When investigating susceptibility levels, different social groups are combined based on characteristic features. These features are specifically selected to allow estimates to be made about how many people require special help in the event of a flood, i. e. those people who cannot reach safety unaided (*evacuation capability*) or those people able to leave their place of residence unaided but nevertheless still require help (*evacuation time*). Although advance warning times of up to a number of days exist for flood hazards around the major rivers in Germany, the question of the evacuation times for potentially affected groups remains relevant because it is also necessary to take into account the danger of any unexpected or rapid failure or inundation of flood protection systems[19].

[19] See Flood Protection Centre Cologne (Hochwasserschutzzentrale Köln) (2009): Risk management. Available at: http://www.steb-koeln.de/risikomanagement html (accessed on 29.06.09).

Indicator: *Evacuation capability*

Definition: Specifies the proportion of households that would not be capable of getting themselves and all other dependants in their household to safety unaided in the event of a flood.

Dataset / source:
a) Geographical information on flood zones based on a particular flood scenario in a GIS compatible file format; available e. g. from environmental agencies, city wastewater treatment plants, flood protection centres.
b) Geographical information on the units of local government that are used as geographical reference units (e. g. city districts or boroughs).
c) Household types: Created with the assistance of the program HHGen (see Chapter 4.2.3) and based on registration data for local residents.
(Additionally for Variant 2:
d) Mobility impairment: local government statistics or a sample community census).

Contribution to the vulnerability assessment:
The more households within a geographical unit that are reliant on external assistance, the more susceptible the relevant population will be to a flood event. Local authorities also have a responsibility to organise the evacuation of those people requiring assistance in the event of a flood[20]. The geographical visualisation of the indicator *evacuation capability* can provide information about where there is a higher requirement for relief workers in the event of an evacuation. In addition, the UNU-EHS Household Survey shows that older people - who were identified as a particularly vulnerable group during the process for determining evacuation capability - are also less able to call on social networks when it comes to finding a safe haven in the event of an evacuation. This means that many of those people who are incapable of evacuating themselves unaided are also reliant on temporary emergency accommodation.

Validity: The age structure of a household has a significant effect on *evacuation capability*. In terms of the interrelation between household types and *evacuation capability*, the UNU-EHS Household Survey calculated a Cramer's V of 0.35 with a p-value of less than 0.001. In the logistic regression model, which also included information on mobility impairment, the likelihood ratio test was significant. The Pseudo R^2 was 0.31, the Wald test proved significant for every independent variable and 90.3% of the cases in the survey were correctly predicted (see Appendix 7.4 B). These values indicate the applicability of the logistic regression model for estimating the indicator. Refer to Chapter 4.2.3 for deriving the different household types from the register of local residents.

[20] De Bruin, Karin; Klijn, Frans; Ölfert, Alfred; Penning-Powsell, Edmund; Simm, Jonathan & Michael Wallis (2009): Flood risk assessment and flood risk management. An introduction and guidance based on experiences and findings of FLOODsite (an EU-funded Integrated Project).

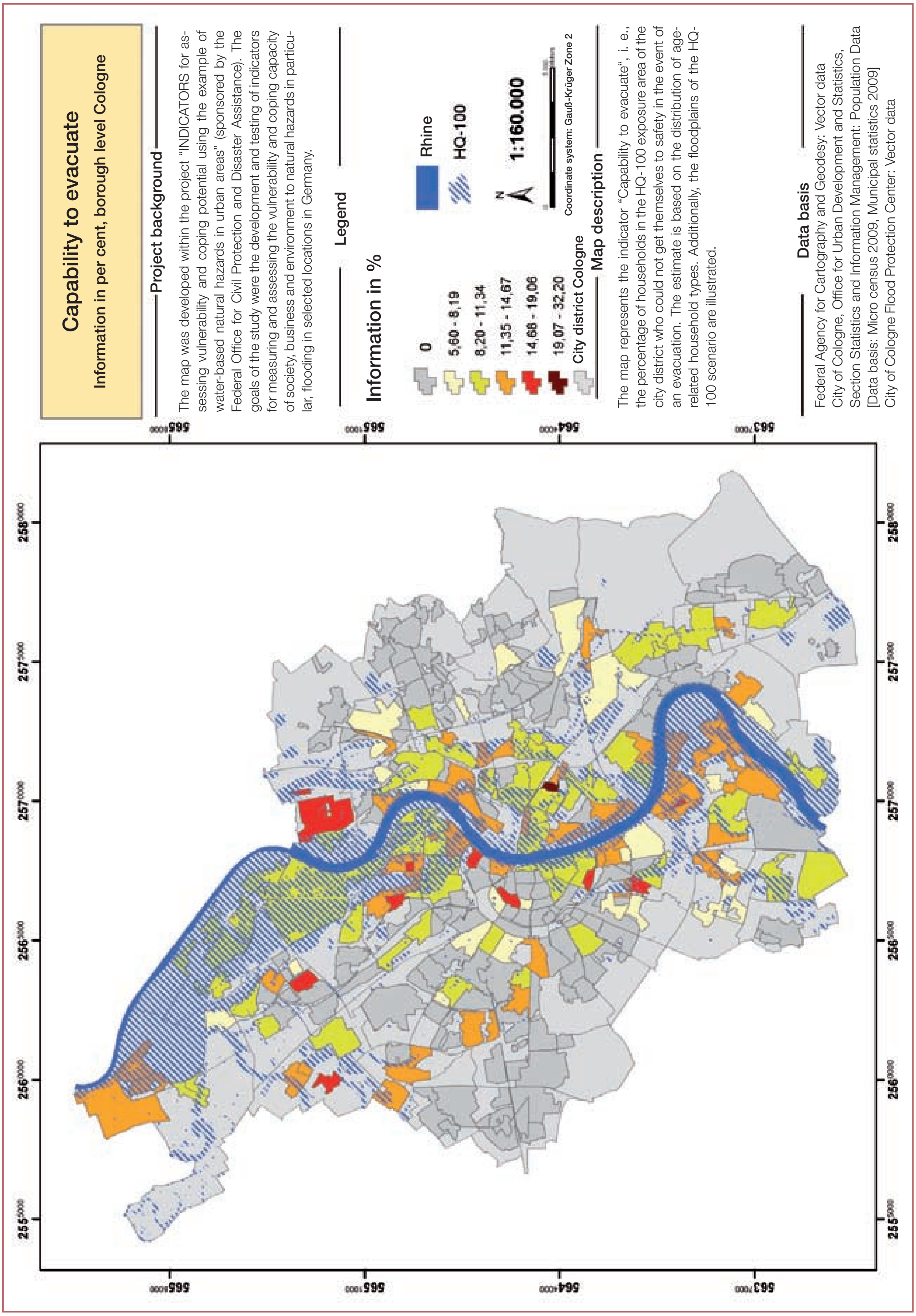


Figure 4.3: Proportion of households incapable of evacuating unaided in the HQ-100 area of the City of Cologne

Indicator: *Evacuation time*

Definition: Specifies the number of minutes required for half of the households in a geographical unit to get themselves, their pets and important documents to safety. Therefore, evacuation time is considered to be a measurement of the speed at which the residents can get themselves to safety (relative measurement – for comparing different social groups or geographical units).

Dataset / source:

a) Geographical information on flood zones based on a particular flood scenario in a GIS compatible file format; available e. g. from environmental agencies, city wastewater treatment plants, flood protection centres.

b) Geographical information on the units of local government that are used as geographical reference units (e. g. city districts or boroughs).

c) Household types: Created with the assistance of the program HHGen and based on registration data for local residents.

Contribution to the vulnerability assessment:

In the case of very short advance warning times, it is also necessary to estimate how many households and people can reach safety in what length of time for the planning of evacuation and rescue measures. The question of which city districts will be faced with special difficulties during a quick evacuation is a central issue, particularly if protection measures (e. g. dykes, mobile protective walls) fail, or are inundated, or city districts are flooded by water that has infiltrated into the sewerage system. The *evacuation time* can be viewed here as a measurement for comparing city districts and illustrating the relative level of susceptibility.

Validity: This indicator is limited by the fact that a person‘s own assessment of the time required to get themselves to safety is associated with some degree of uncertainty. Using the median as a stable average makes it possible to minimise the effect of outliers and also to allocate the estimated values for the evacuation into time frames that appear realistic. The variance analysis confirms the importance of the different household types as a distinguishing feature for the determination of the evacuation speeds (see Appendix 7.4 C), so that the *evacuation time* can be considered valid.

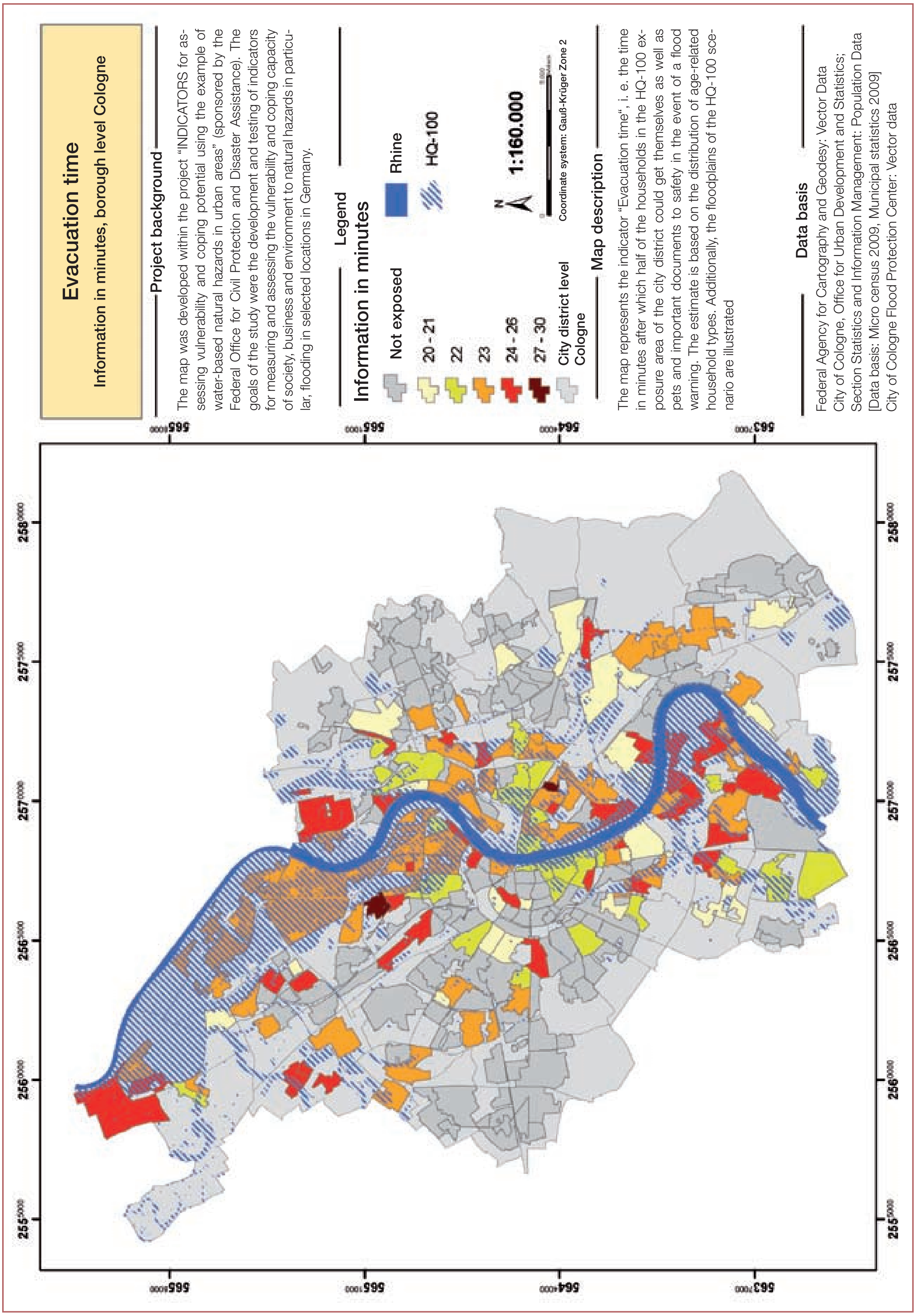


Figure 4.4: Evacuation times in the HQ-100 area of the City of Cologne

Coping capacity

Exposed and susceptible population groups possess a variety of resources and abilities that enable them to overcome extreme events. For example, although older people possibly have greater difficulty in the event of an evacuation, it is precisely this generation who may also possess important practical experience that enables them to behave in the correct manner in the event of a flood. These positive aspects - such as the example of practical experience above - should be taken into account in the vulnerability assessment as coping capacities. In an assessment of the coping capacities of different population groups, two indicators were particularly selected: *potential insurance cover against flood damage* and *flood experience*.

Indicator: *Potential[21] insurance cover*

Definition: Specifies the proportion of households that have insurance against natural hazards; estimated based on income distribution.

Dataset / source:

a) Geographical information on flood zones based on a particular flood scenario in a GIS compatible file format; available e. g. from environmental agencies, city wastewater treatment plants, flood protection centres.
b) Geographical information on the units of local government that are used as geographical reference units (e. g. city districts or boroughs).
c) Household income: e. g. sample community census
(Alternately for Variant 2:
d) Ratio of property owners to lessees: e. g. local authority statistics).

Contribution to the vulnerability assessment:

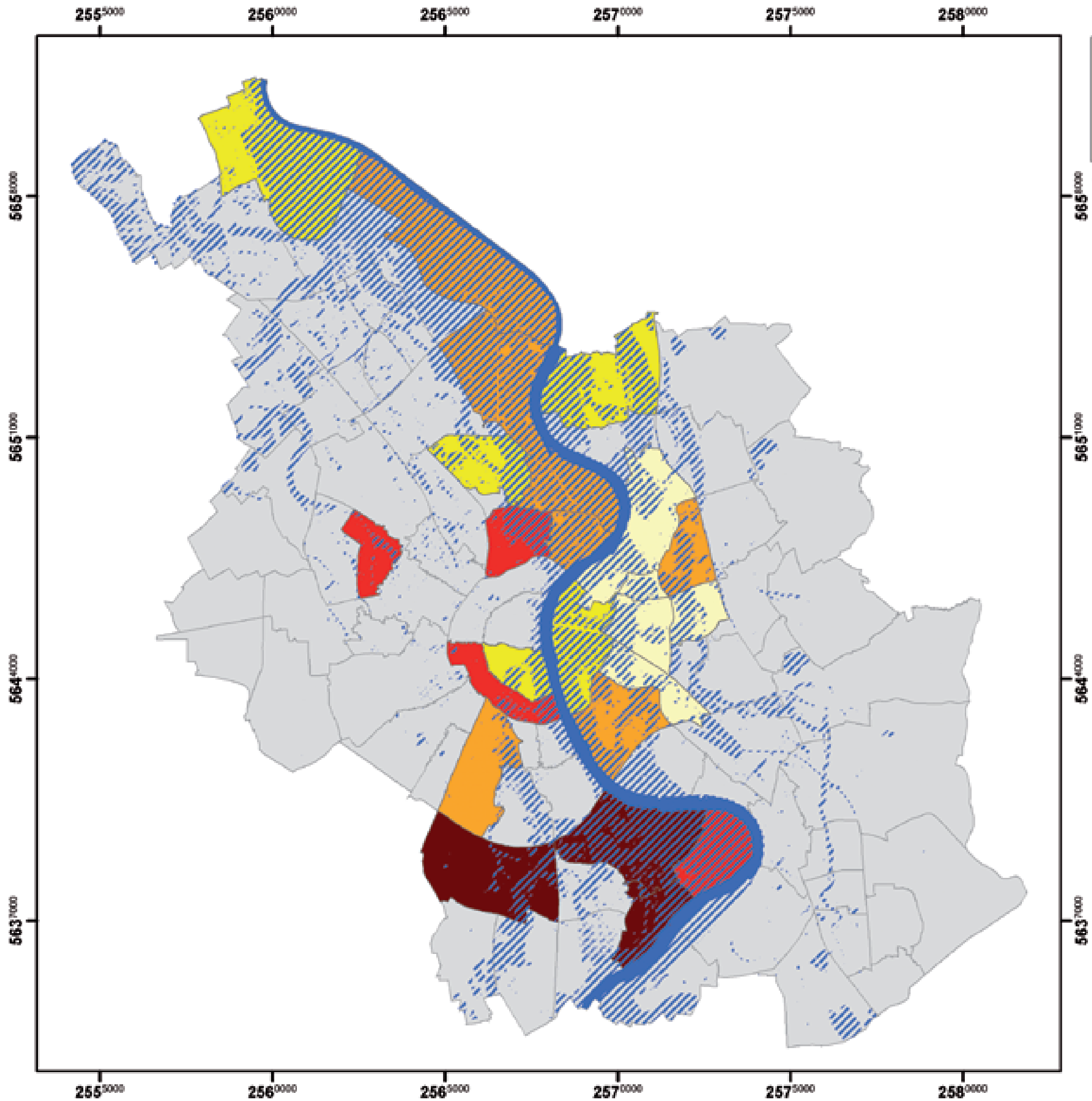
In assessing the financial ability to cope with a flood event, it is significantly important to know whether the costs of flood damage will be covered by insurance. Flood damage is not covered by standard residential building insurance or household contents insurance but requires additional insurance against natural hazards[22]. Incentives resulting from the conditions of the insurance cover (e. g. excess payments or stipulations for making personal provision) can be used to encourage insurance holders to take their own initiatives to reduce the overall potential for damage[23]. The visualisation of those geographical areas in which the population possesses high or low levels of insurance cover against flood events can also contribute to sensitising the exposed population and encouraging them to increase their financial ability to cope with the flood.

Validity: In this respect, both of the methods described in Chapter 4.2.4 for calculating the indicator contain uncertainties, meaning that the varying conditions and prices of insurance cover depending on the level of exposure - even within the HQ-100 area - need to be considered. It must be noted that it is the insurance cover held by the relevant resident that is being assessed here. Whether the owner of a rented apartment is insured against natural hazards through their residential building insurance is ignored. In the case of the UNU-EHS Household Survey, the coefficient of determination for the linear regression model based on income data was 0.68. In terms of the interrelationship between ownership status (lessee / property owner) and insurance cover, the UNU-EHS Household Survey calculated a significant Cramer's V of 0.44 (see Appendix 7.4 D). These values indicate the applicability of the process for estimating the indicator.

[21] For a description of the difference between *„potential“* insurance cover as compared to the indicator *„actual“* insurance cover, see Chapter 4.1.5

[22] Consumer Advice Centre Saxony (2007): Press release from the Consumer Advice Centre Saxony 22.06.2007. Heavy rain, wind storms, thunder and lightning - what damage is insured? Available at: http://www.verbraucherzentrale-sachsen.de/UNIQ12475 7022823134/link329282A (accessed on 14.07.09).

[23] International Commission for the Protection of the Rhine (IKSR) (2002): Flood prevention. Measures and their effectiveness. Koblenz.



Insurance coverage

Information in per cent, city district level Cologne

Project background

The map was developed within the project "INDICATORS for assessing vulnerability and coping potential using the example of water-based natural hazards in urban areas" (sponsored by the Federal Office for Civil Protection and Disaster Assistance). The goals of the study were the development and testing of indicators for measuring and assessing the vulnerability and coping capacity of society, business and environment to natural hazards in particular, flooding in selected locations in Germany.

Legend

Information in %

- Not insured or no data
- 13,0 - 16,9
- 17,0 - 19,8
- 19,9 - 21,5
- 21,6 - 26,2
- 26,3 - 28,2

- Rhine
- EHQ

N

1:160.000

Coordinate system: Gauß-Krüger Zone 2

Map description

The map represents the indicator "Potential insurance coverage", i. e. the proportion of households in the EHQ exposure area of the city district who have natural hazards damage insurance. This is estimated based on the income distribution taken in the course of a municipal micro census by the city of Cologne. For the estimation, a random sampling of at least 30 cases in the exposure area per city district was used. Additionally, the floodplains of the EHQ scenario are illustrated.

Data basis

Federal Agency for Cartography and Geodesy: Vector data
City of Cologne, Office for Urban Development and Statistics, Section Statistics and Information Management: Population data [Data basis: Micro census 2009, Municipal statistics 2009]
City of Cologne Flood Protection Center: Vector data

Figure 4.5: Potential insurance cover in the EHQ area of the City of Cologne

Additional information on insurance against natural hazards:

While property owners who live in their own house can insure both their building and also their household contents against natural hazards, only household contents insurance is relevant for lessees. In households where the resident is the property owner, there tends, as expected, to be a higher proportion of insurance cover against natural hazards than in households where the resident is the lessee. This was confirmed by the UNU-EHS Household Survey: In Cologne, 49 % of those property owners surveyed were insured against natural hazards but only 8 % of the lessees. In Dresden, there were 66 % of property owners insured compared to 30 % of the lessees. As a result of the increased risk, there is a presumption that there tends to be a higher proportion of households with insurance cover against natural hazards in those areas more frequently affected. However, it needs to be considered here that in those particularly exposed geographical areas, access to suitable insurance cover is more difficult and the insurance policies are more expensive. The areas are divided by insurance companies into four hazard classes with correspondingly expensive insurance policies. In the highest hazard classes, home owners only have very limited possibilities for taking out natural hazard insurance[24]. Since the Elbe flood in 2002, consumer associations and other groups have campaigned for insurance against natural hazards to be introduced as a compulsory insurance for residential buildings.

[24] Stiftung Warentest (2008): Insurance cover for severe weather. The skies are going crazy. Available at: http://www.test.de/themen/versicherung-vorsorge/test/-Versicherungsschutz-bei-Unwetter/1714242/1714242/1722906/ (accessed on 14.7.09).

Indicator: *Flood experience*

Definition: Specifies how many people / households within a geographical unit already have experience of flood events at their own place of residence. Estimated based on the length of occupancy of the relevant householders in their place of residence and the level of exposure.

Dataset / source:

a) Geographical information on flood zones based on a particular flood scenario in a GIS compatible file format; available e. g. from environmental agencies, city wastewater treatment plants, flood protection centres.

b) Geographical information on the units of local government that are used as geographical reference units (e. g. city districts or boroughs).

c) Number of households classified according to length of occupancy categories: local government statistics (register of local residents).

Contribution to the vulnerability assessment:

The relative coping capacity of different population groups faced with flood events has been demonstrated to depend on their *flood experience*. Therefore, clear differences were identified between those groups of people who had already experienced a flood event at their place of residence and those who had no experience, in terms of the level of independent initiatives taken for flood prevention, their knowledge about the correct behaviour in the event of a flood and the correlation with physical and mental consequences after a flood. The indicator makes it possible to estimate in which residential areas the population potentially have little experience of floods and where more effort needs to be invested in educational work and sensitisation measures about flood hazards accordingly.

Validity: The estimate of the indicator *flood experience* is based on the length of occupancy of the relevant householders in their current place of residence and the exposure of the corresponding place of residence to flood hazards (HQ-100, EHQ, etc.). A measurement of flood experience is calculated as a result that is higher both the longer the householders have lived in their current place of residence and the greater the level of exposure. However, the interrelationship found here between the length of occupancy and flood experience should only be based on the results of local surveys, which is why no concrete parameters are proposed for this indicator. They are highly dependent on the location because information about flood experience is dependent on the previous floods experienced in the relevant city or community. In the event that you will not carry out a purpose-made independent survey, alternatives are proposed in Chapter 4.2.4.

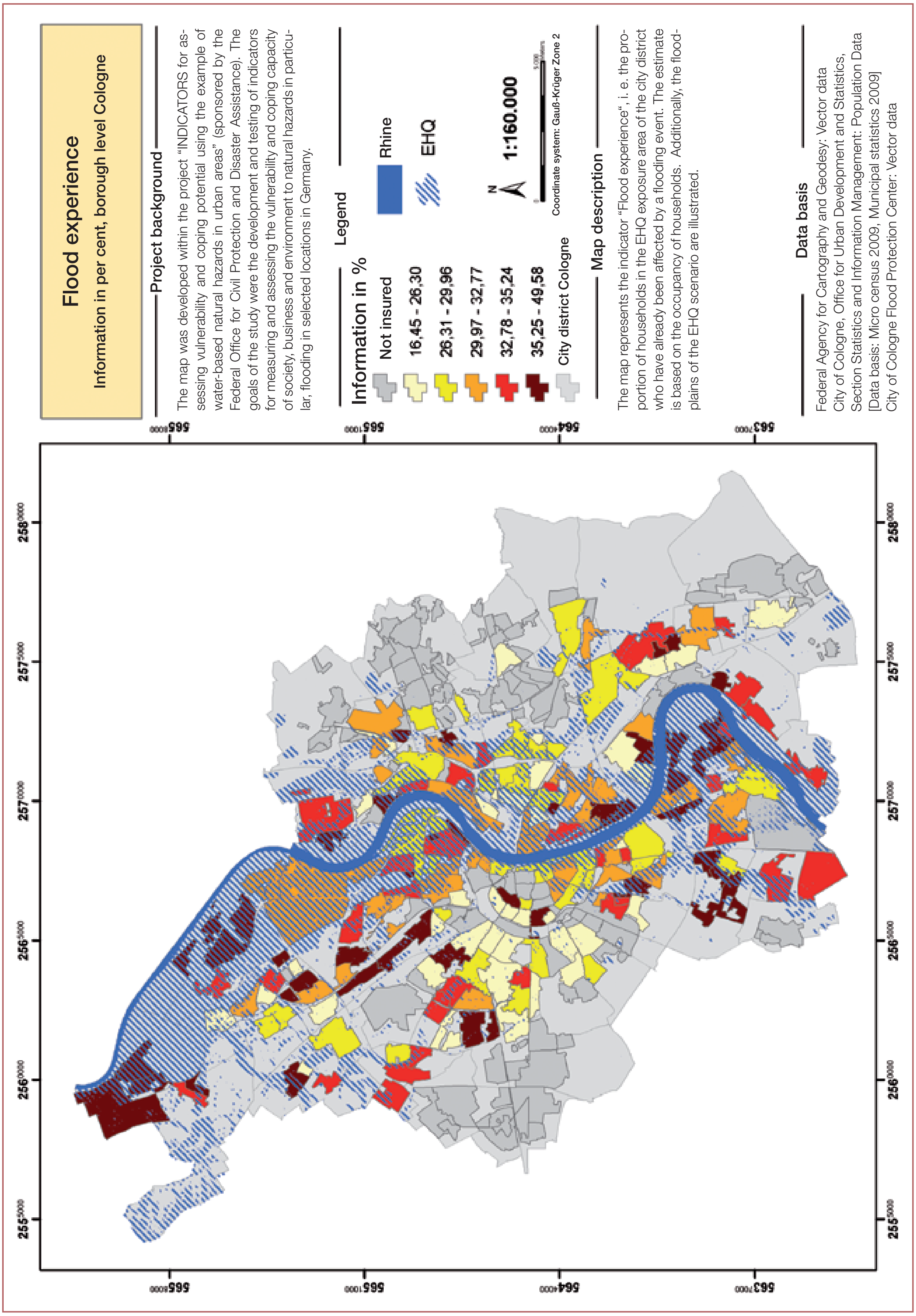


Figure 4.6: Proportion of households with flood experience in the EHQ area of the City of Cologne

Additional information on flood experience:

Because no direct data is available from local government statistics about the proportion of householders or people that have already experienced or coped with flood events in their place of residence, a measurement for flood experience is calculated as a replacement indicator, which uses the length of occupancy of the relevant householders in their place of residence and the level of exposure as the starting points for assessing *flood experience*. A fundamental assumption is made here that those householders that have only recently (i. e. within the last few years) moved into a place of residence exposed to flood events possess less knowledge of how to cope with flood events than those householders that have lived in their corresponding place of residence for a long time. The UNU-EHS Household Surveys in Cologne and Dresden demonstrated that householders with flood experience in their place of residence fare significantly better when it comes to their knowledge of flood protection measures and in terms of possessing the necessary items for coping with the flood event (e. g. Wellington boots, energy sources for light and heating in the household that are independent of the mains electricity) than those householders without relevant flood experience. Furthermore, these people tended to experience less psychological issues (anxieties, depression, etc.) as a result of a flood event. The increased occurrence of negative physical and psychological issues after the Elbe flood in 2002 is a clear indication of this interrelationship.

4.1.5. Overview of the community-specific indicators

Alongside the set of standardised core indicators (see Chapter 4.1.4) for assessing vulnerability, additional community-specific indicators are proposed that are based on the results of purpose-made independent surveys e. g. as part of a sample community census. The proposed community-specific indicators that will be explained below are:

a) flood sensitivity
b) level of information on flood hazards
c) actual insurance cover
d) flood protection measures

The indicator *flood sensitivity* is based on the assumption that those people who are aware of their own flood risk are more likely to have informed themselves about the correct behaviour in event of a flood and therefore are better prepared than those people who believe that it is highly unlikely that their place of residence will be affected by a flood. The indicator is calculated based on the evaluation of the following question: „How probable do you think it is that the house in which you currently live will be affected by a flood in the future?“ In the UNU-EHS Household Survey, answers could be selected from a scale from 1 to 8, with 8 standing for „very likely“ and 1 for „very unlikely“.

Indicator: *Flood sensitivity*

Definition: Specifies the subjective self-assessment of a householders exposure to floods based on the place of residence.

Dataset / source:
a) Geographical information on flood zones based on a particular flood scenario in a GIS compatible file format; available e. g. from environmental agencies, city wastewater treatment plants, flood protection centres.
b) Geographical information on the units of local government that are used as geographical reference units (e. g. city districts or boroughs).
c) Purpose-made independent survey or sample community census; assessment of the question: „How probable do you think it is that the house in which you currently live will be affected by a flood in the future?“

Contribution to the vulnerability assessment:
The visualisation of flood sensitivity can indicate those areas that are potentially exposed to floods yet their population only displays a low sensitivity to this problem. The UNU-EHS Household Survey tends to show that households that are sensitised to floods also possess a higher level of flood prevention. In contrast, it can be expected that people will be poorly prepared in those areas where only a low level of sensitisation amongst the population has been recorded. An evaluation of this indicator can serve to identify areas where more effort needs to be invested in educational work.

Validity: In order to produce a realistic cartographic representation of the indicator, at least 20 valid answers per geographical unit are generally required. In this example (Cologne EHQ area), there were also a low number of answers in some areas on the question of flood sensitivity - only those city districts in which there were at least 20 valid answers were illustrated.

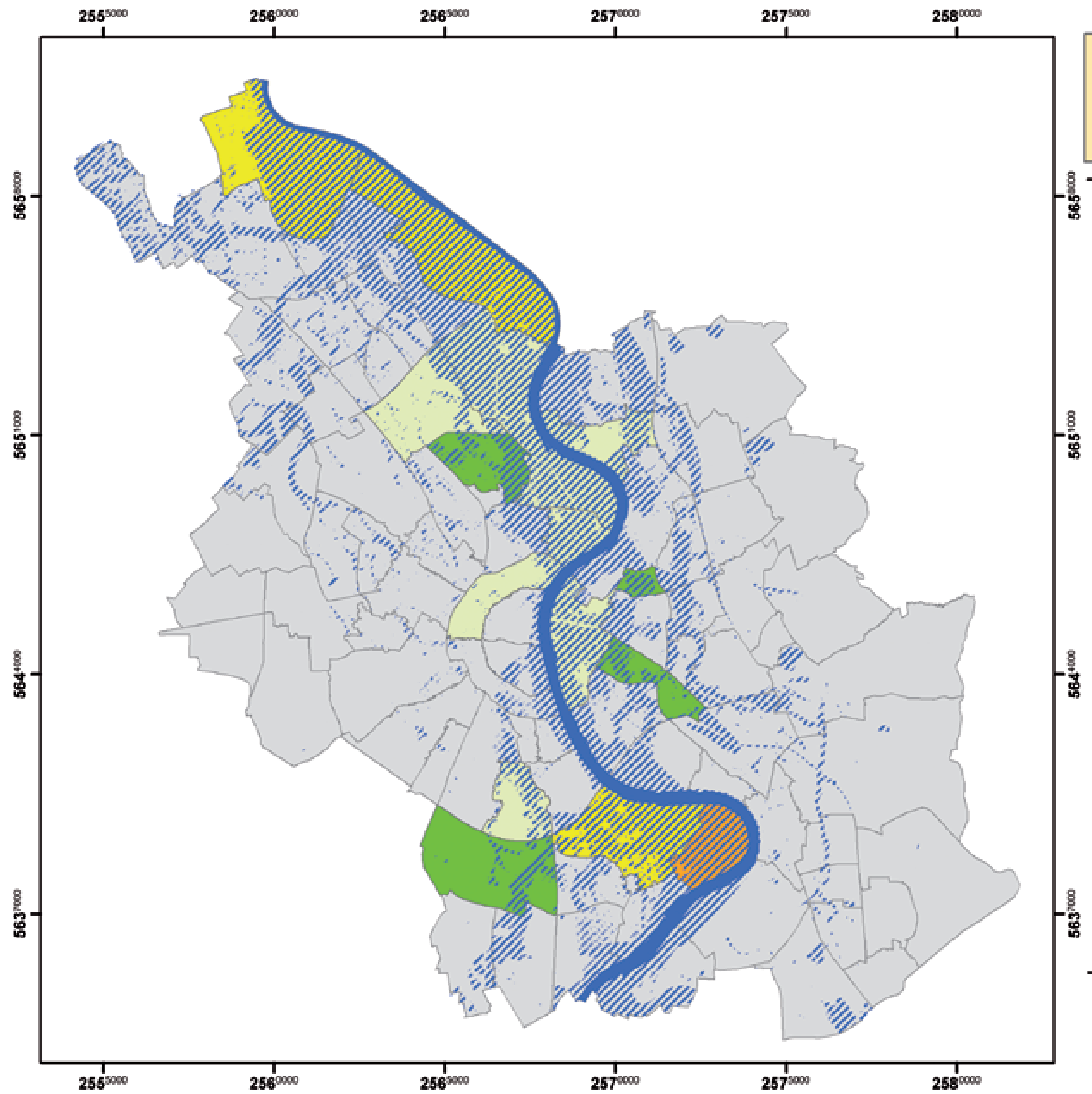


Figure 4.7: Flood sensitivity in the EHQ area of the City of Cologne

An analysis of the *level of information on flood hazards* follows on from the evaluation of *flood sensitivity*, although the focus is placed here on determining how many householders received or actively obtained information about possible flood hazards when selecting their apartment or house. This indicator builds on the assumption that people who were informed about the risk of flooding when they moved into their house or apartment are more likely to take preventative measures.

Indiator: *Level of information on flood hazards*

Definition: Specifies how many householders received or actively obtained information about possible flood hazards when moving into their apartment or house.

Dataset / source:

a) Geographical information on flood zones based on a particular flood scenario in a GIS compatible file format; available e. g. from environmental agencies, city wastewater treatment plants, flood protection centres.

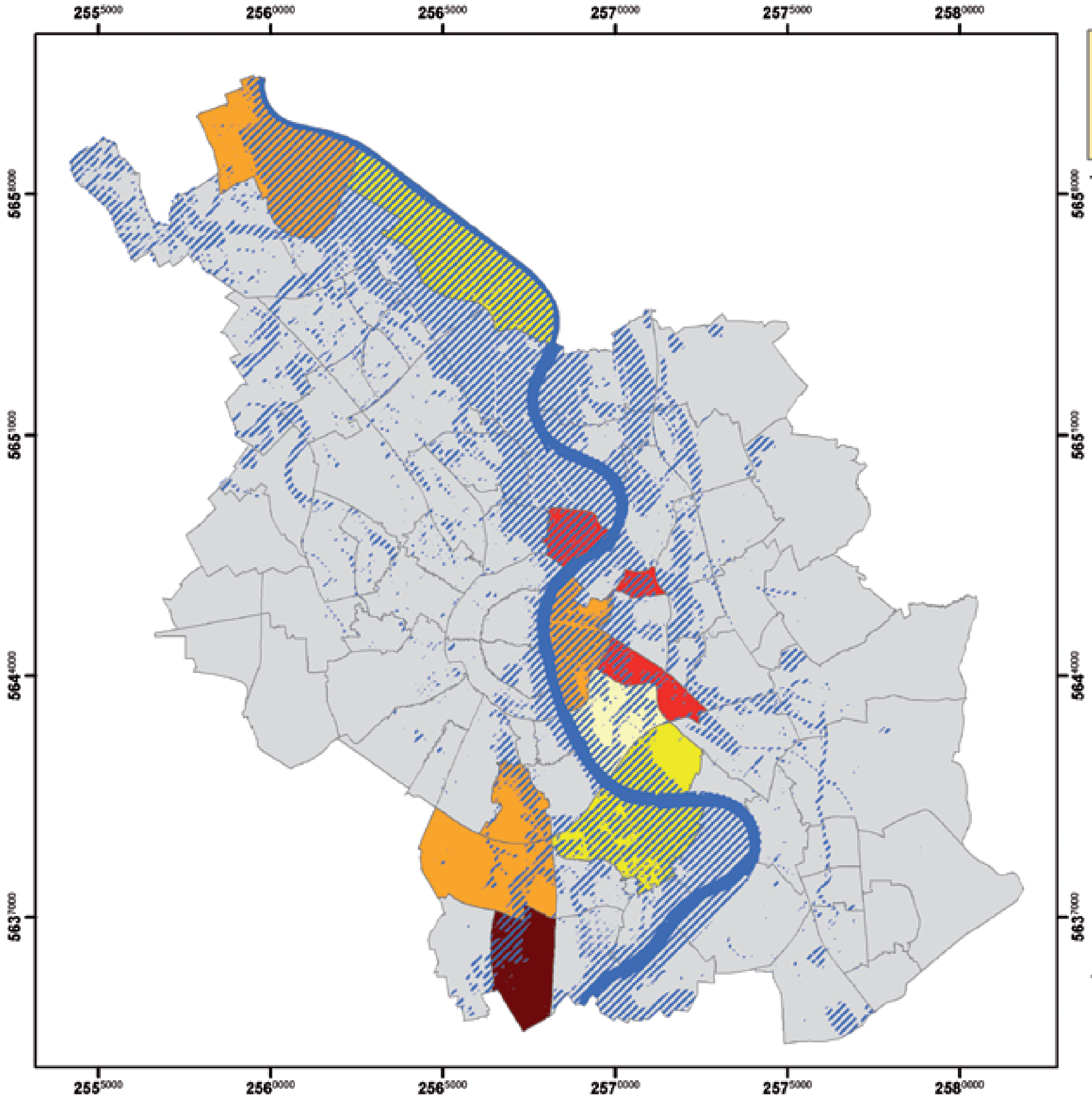
b) Geographical information on the units of local government that are used as geographical reference units (e. g. city districts or boroughs).

c) Purpose-made independent survey or sample community census; assessment of the question: „Did you receive or obtain information about possible flood hazards when selecting your apartment or house?“

Contribution to the vulnerability assessment:

Increasing the level of information or maintaining the quality of the information at a high level for those households in areas exposed to flood hazards makes an important contribution to improving flood protection and decreasing vulnerability. This is a decisive step along the way to increasing the independent preventative measures taken by exposed households. In particular, the level of information about preventative structural measures is decisive when selecting a place of residence because later modifications to the house or apartment are often more cost intensive or in some cases no longer possible. As a result, it can be assumed that households can rely on better precautionary and preventative measures in those areas in which a high level of information was already prevalent during the selection of the place of residence. The vulnerability of the population in these areas is thus reduced. In contrast, a low level of information about potential flood hazards indicates increased vulnerability.

Validity: In order to produce a realistic cartographic representation of the indicator, at least 20 valid answers per geographical unit are generally required. In this example (Cologne EHQ area), there were also a low number of answers in some areas on the question of the level of information on flood hazards - only those city districts in which there were at least 20 valid answers were illustrated.



Level of Information on flood risks

(no information received / obtained)

Information in per cent, city district level Cologne

Project background

The map was developed within the project “INDICATORS for assessing vulnerability and coping potential using the example of water-based natural hazards in urban areas” (sponsored by the Federal Office for Civil Protection and Disaster Assistance). The goals of the study were the development and testing of indicators for measuring and assessing the vulnerability and coping capacity of society, business and environment to natural hazards in particular, flooding in selected locations in Germany.

Legend

Number of HH which did not receive information or did not obtain it

- No exposure or no data
- 45
- 46 - 57
- 58 - 81
- 82 - 91
- 92 - 100
- Rhine
- EHQ

N

1:160.000

Coordinate system: Gauß-Krüger Zone 2

Map description

The map represents the indicator “Information status on flood risks“, i. e. the number of households in the EHQ exposure area of the city district who did not receive or obtain information on a possible flood risk. The information is based on a direct compilation [municipal micro census of the city of Cologne]. Additionally, the floodplains of the EHQ scenario are illustrated.

Data basis

Federal Agency for Cartography and Geodesy: Vector data
City of Cologne, Office for Urban Development and Statistics, Section Statistics and Information Management: Population Data [Data basis: Micro census 2009, Municipal statistics 2009]
City of Cologne Flood Protection Center: Vector data

Figure 4.8: Level of information (no information received / obtained) in the EHQ area of the City of Cologne

In comparison to the estimate of *potential insurance cover* in the core set of indicators, carrying out your own survey makes it possible to collect real data on the *actual insurance cover* of households to flood damage (natural hazard insurance), as long as the survey has a correspondingly representative and large sample size.

Indicator: *Actual insurance cover*

Definition: This indicator enables statements to be made about the actual availability of insurance against natural hazard amongst the population in a geographical unit.

Dataset / source:
a) Geographical information on flood zones based on a particular flood scenario in a GIS compatible file format; available e. g. from environmental agencies, city wastewater treatment plants, flood protection centres.
b) Geographical information on the units of local government that are used as geographical reference units (e. g. city districts or boroughs).
c) Purpose-made independent survey or sample community census; assessment of the question: „Have you taken out one or more of the following insurance covers for your apartment or your house?

Contribution to the vulnerability assessment:
The information provided by this indicator will also help in the estimation of the financial coping capacity of households (see also the core indicator *potential insurance cover*, see Chapter 4.1.4). The advantage in comparison to the core indicator *potential insurance cover*, which is based on income data, is that the indicator *actual insurance cover* is instead based on information collected directly in the local area. Therefore, this allows an improved picture of the actual situation to be developed.

Validity: In order to produce a realistic cartographic representation of the indicator, at least 20 valid answers per geographical unit are generally required. In this example (Cologne EHQ area), there were also a low number of answers in some areas on the question of the availability of natural hazard insurance – therefore there is no cartographic representation of the data and we refer you at this point to the illustration of the indicator *potential insurance cover*.

The final community-specific indicator deals with the number and type of *flood protection measures implemented in private households*. Despite the fact that public authorities and particularly local government have an important responsibility for relevant structural and non-structural protective measures (dykes, mobile protective walls, etc.), precautionary measures taken by private households are also important and a prerequisite for effective civil protection. Overall, the indicator highlights any differences that exist in terms of independently implemented flood protection measures between different city districts. Furthermore, it is possible to evaluate the types of measures implemented.

Indicator: *Flood protection measures in private households*

Definition: This indicator enables statements to be made about how many households within a geographical unit have independently implemented flood protection measures. In addition, it is possible to make statements about the type of flood protection measures implemented.

Dataset / source:

a) Geographical information on flood zones based on a particular flood scenario in a GIS compatible file format; available e. g. from environmental agencies, city wastewater treatment plants, flood protection centres.

b) Geographical information on the units of local government that are used as geographical reference units (e. g. city districts or boroughs).

c) Purpose-made independent survey or sample community census; assessment of the question: „Have you carried out any measures for providing protection against floods yourself or implemented preventative strategies?“

Contribution to the vulnerability assessment:

The improvement of structural and non-structural flood protection in private households can generally increase the coping capacity of exposed households and thus help to localise the use of resources within special problem areas in the event of a flood. These types of measures also have a significant importance for handling the consequences of a flood because they clearly reduce the potential for damage to the household.

Validity: In order to produce a realistic cartographic representation of the indicator, at least 20 valid answers per geographical unit are generally required. In this example (Cologne EHQ area), the overall number of answers was too low per city district on the question about flood protection measures implemented by private households - therefore there is no cartographic representation of the data. The overall results are illustrated in the form of a diagram (see Figure 4.9).

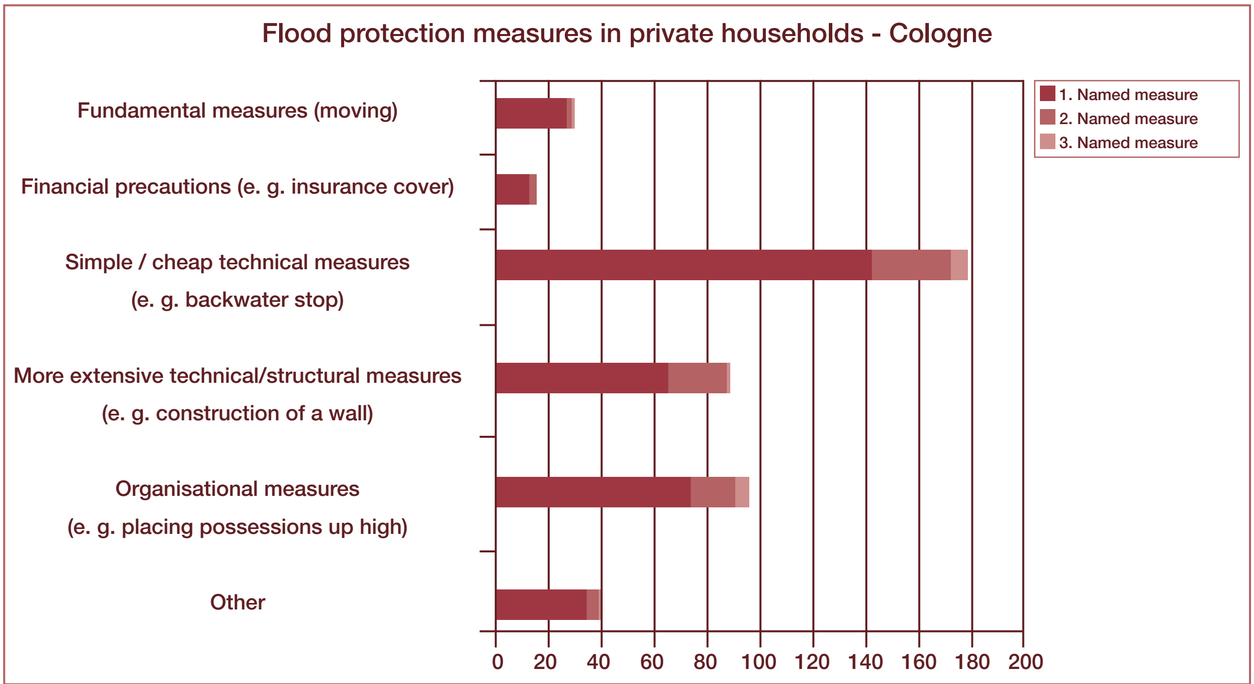


Figure 4.9: Number of named flood protection measures in private households within the sample community census 2008 / 2009 for the City of Cologne according to different categories (a total of 3.2 % of those households surveyed indicated at least one measure)

4.1.6 Levels of observation

In the following explanations, there is a differentiation between different levels of geographical observation and also between different levels of investigation for the collection of data and statistical evaluation.

The levels of geographical observation can vary according to the nature of the data used e. g. at a city district or borough level. The level of the city borough represents a higher spatial resolution (i. e. smaller unit - this corresponds to a fine level of data), while a city district generally combines a number of city boroughs together. In general, it is advisable to work with the highest possible spatial resolution. However, due to the fact that a lot of data is only available at a coarser level, it is often necessary to accept a lower spatial resolution. The same is also true if problems arise in terms of the representative nature (too small a sample size) of the data or due to data protection issues (anonymity of those surveyed is not guaranteed) at the finest level of observation. It is important to note that it is only permitted to combine data from local government statistics and geographical information in a GIS at the same levels (i. e. it is necessary to ensure that the representation in GIS is based at a city district level if the previous statistical calculations were carried out at a city district level).

A differentiation is made between people and households in the collection and calculation of statistical data. The data is collected in a household survey e. g. the UNU-EHS Household Survey in which one person is generally questioned, although characteristics about the whole household are also collected. Nevertheless, the wording of some questions can be directed at the level of an individual person instead of the level of the household. At the same time, the household level also plays a decisive role in the evaluation of some indicators e. g. for evacuation capability.

4.2 Creating a core set of indicators

As already outlined, the process for creating the core set of indicators primarily uses data from local government statistics. The following section describes which statistical and GIS-supported methods can be used to evaluate data in order to draw conclusions about the vulnerability of the population to a flood event.

4.2.1 Defining a flood scenario

This step is carried out in accordance with the process described in Chapter 2.1.3. The crucial point here is to ensure when selecting the theoretical scenario or scenarios that the exposure data is available in the form of a GIS shapefile in order for it to be integrated with the statistical data.

4.2.2 Determining the level of exposure

Exposure deals with the number or proportion of potentially affected people or households per geographical unit (e. g. city district) in the case of a hypothetical flood scenario. The proportional figure per geographical unit enables geographical differences in the level of exposure to be identified, while the absolute number is particularly important for emergency and evacuation planning.

Question: *How many people or households are exposed in the case of the theoretical flood scenario?*

Required data:

- Geographical information about the exposed areas in the case of the theoretical flood scenario (e. g. HQ-100) in a GIS compatible format
- Number of exposed persons or households per geographical unit (e. g. borough)
- and/or spatial information on residential areas e. g. number of floors in the buildings.

Process steps:

Determine the absolute number and the proportion of exposed people or households per geographical unit (city district, borough). In an ideal case, the address data can be correlated with the flood zones. If this is not possible, the number of exposed people or households can be estimated. Assuming an even distribution of the population within the observed geographical unit, this can be achieved e. g. via the proportionately defined exposed areas per geographical unit in the GIS. There is the possibility of refining this process if additional information on the position and number of floors in the (residential) building stock is available. Alternatively, the process described in Chapter 6.2.1 using remote sensing methods can be used.

Correlate the absolute and relative information about the exposed population with the corresponding geographical units in the attribute table for the GIS shapefile theme. Visualise the potential exposure level of the affected people or households per geographical unit in the event of a flood in map form (see example Figure 4.2).

You will create exposure maps that will enable you to recognise the absolute number and the relative proportion of people or households - based on the theoretical flood scenario you selected - per geographical unit that are potentially affected in the event of a flood. Classification of the data will help to identify geographical differences in the level of exposure, e. g. hotspots in which a particularly high number of people are exposed to a potential flood.

It should be noted that exposure is initially defined here only in terms of the position within the flood zone. If additional information is available e. g. height of the flood, the exposure map can naturally be refined with the help of this data. In the interests of making it as generally applicable as possible, these guidelines do not initially present those processes that cannot be implemented in every community.

If the exposure of the population per geographical unit is estimated (and not clearly defined through further correlation with the address data), it must be assumed in the following processes that population characteristics, e. g. household types or age structures, are evenly distributed within the population for a geographical unit.

4.2.3 Calculating indicators for the susceptibility of the population

The indicators *evacuation capability* and *evacuation time* represent, as described in Chapter 4.1.4, the susceptibility of the local population. They are calculated with the aid of statistical data about the types of households. A household generation process (HHGen) has been developed by KOSIS (Association of Communal Statistics Information System) in cooperation with the Federal Office for Regional Studies and Planning (BfLR, now called the The Federal Office for Building and Regional Planning, BBR), which has been available to all communities since 1993. This process makes it possible to group households based on data from registers of local residents[25]. It can be used, amongst other things, to sample the household types according to phases of life that can then be allocated - based on certain assumptions - to the four different household classes listed below (see below „Additional information on deriving household types with the help of the HHGen process“).

The main criteria for defining household types is the age of the members of the household. This represents a good starting point for calculating the indicators because age is considered to be the strongest factor influencing mobility and speed of movement. In addition, households with older members are differen-

[25] Association of Communal Statistics Information System (KOSIS) (2009): City statistics on the Internet. Available at: https://www.staedtestatistik.de (accessed on 14.07.09).

tiated based on single-person and multiple-person households because there is no possibility of providing mutual assistance in single-person households. The UNU-EHS Household Survey demonstrated that households with children and older people are more susceptible than other household according to the indicators *evacuation capability* and *evacuation time*. In the case of *evacuation capability*, the group comprising older people living alone was identified as being particularly vulnerable.

In order to guarantee that this process is as widely applicable as possible, the following household types have been classified:

1) Households with children under 6 years old
2) Households with members exclusively between the ages of 6 and 59 years old
3) Households with persons aged from 60 years old (in households with at least 2 people)
4) Single-person households from 60 years old

Additional information on deriving household types with the help of the HHGen process

The HHGen process initially calculates eleven types of household class (see Table 4.1), which can then be used to derive the four household types required for calculating the indicators. For the household classes: „Foundation phase": Couple without an additional person, younger partner < 30 years" and „Couple without an additional person, younger partner 30 years old - < 60 years old" it is assumed that the older partner is also younger than 60 years old. Similarly for the household class: „Contraction phase: Couple with an adult child without their own partner", it is assumed that all members of the household are aged under 60 years old.

In the class „Reference person without a partner, at least 1 child", there is no differentiation made about whether the children are younger or older than 6 years old but they are nevertheless allocated to the first class. Therefore, it can be expected that the statistics will be slightly biased in this area due to households with older children. It is possible to accept this fact because this class only accounts overall for a low proportion of the total e. g. below 5% in Cologne. The class „Other multi-person households without children" is allocated to the second class so that within this group some households with people over 60 years old are incorrectly included. The overall proportion accounted for by this class is also very low (e. g. below 7% for Cologne) so that the proportion of incorrectly allocated households is also relatively small. The group „Single-person households from 60 years old" accounted for almost 14% in Cologne, while the largest group is „Single-person households 30 - < 60 years old" at over 25%.

HHGen Classes	Assumptions for new classes	New classes / household types for developing the indicators
Single-person households < 30 years old	-	2)
Single-person households 30 - < 60 years old	-	2)
Single-person households from 60 years old	-	4)
Foundation phase: Couple without an additional person, younger partner < 30 years	Both < 60 years old	2)
Couple without an additional person, younger partner 30 years old - < 60 years old	Both < 60 years old	2)
Senior citizen households: Couple without an additional person, younger partner from 60 years	-	3)
Expansion phase: Couple with children, youngest person < 6 years old	-	1)
Consolidation phase: Couple with children, youngest person 6 - < 18 years old	-	2)
Contraction phase: Couple with an adult child without their own partner	All household members between 6 and 59 years old old	2)
Reference person without a partner, at least 1 child	Child is younger than 6 years old	1)
Other multi-person households without children	All household members between 6 and 59 years old	2)

Table 4.1: Assumptions in the division of household types for developing the indicators

A process will be presented for estimating the *evacuation capability* and *evacuation time* that is based on standard local government statistical data about household types (*Variant 1*). Another process is also presented for evacuation capability (*Variant 2*) that can be used if additional information about mobility impairment in the population is available (e. g. from sample census results).

Calculation of the indicator evacuation capability

Evacuation capability describes the ability to get yourself and all other members of the household to safety without external help in the event of an evacuation.

Question: How many households are capable of getting themselves to safety without external assistance?

Required data:

for Variant 1:

Age-related characteristics of the households per geographical unit, classified into:

1) Households with children under 6 years old
2) Households with members exclusively between the ages of 6 and 59 years old
3) Households with persons aged from 60 years old (at least 2 people)
4) Single-person households from 60 years old

for Variant 2:

In addition, information on the proportion of households with people who cannot walk long distances (e. g. local government statistics on mobility impairments or the results of surveys as part of a sample community census) is used.

Process steps:

Variant 1:

Estimate the number of households per geographical unit that are capable of evacuating themselves unaided with the help of your data on household types from the local government statistics and the proportional values for evacuation capability per household type from your own survey or the UNU-EHS Household Survey (see Table 7.1 in Appendix 7.4 A and Formula 1).

Variant 2:

Enter the proportional values for household types 1 to 3 (the fourth household type is thus redundant) and the proportion of households with people that cannot walk long distances into the regression model (Formula 2). The corresponding regression parameters from the UNU-EHS Household Survey can be found in Appendix 7.4 B.

Integrate the calculated values with the geographical information in the attribute tables for the GIS shapefile and visualise the results in map form (see example Figure 4.3).

Calculation of the indicator according to Variant 1:

The estimate is carried out by assigning the proportion of households capable of evacuating themselves unaided per household type (HHtype) from the survey to the number of HHtypes from the local government statistics. The number of households (HH) capable of evacuating themselves unaided in the exposure area for a geographical unit is calculated as follows:

Formula 1:

Number of HH capable of evacuating themselves unaided =
(Number of HHtype 1 * proportion of HHtype 1 capable of evacuating themselves unaided) +
(Number of HHtype 2 * proportion of HHtype 2 capable of evacuating themselves unaided) +
(Number of HHtype 3 * proportion of HHtype 3 capable of evacuating themselves unaided) +
(Number of HHtype 4 * proportion of HHtype 4 capable of evacuating themselves unaided).

The figures for the different household types are based in each case on the exposure area (e. g. HQ-100 or EHQ) for a geographical unit so that you obtain a proportional value for the evacuation capability of the population in the exposure area for each geographical unit.

Information on integrating your own survey results

1. Allocate the households from your survey to the four HHtypes.
2. Create a contingency table (cross-tabulation) using the HHtypes and the question about evacuation capability. Determine the proportional values for evacuation capability per HHtype. In addition, you can validate the interrelationships by defining a Cramer's V measurement (see Table 7.1 in Appendix 7.4 A).

Finally, determine the proportional values for visualising the results in map form - this refers to the proportion of households that CANNOT get themselves to safety unaided (subtract the households capable of evacuation from the total number of households in each case).

Calculation of the indicator according to Variant 2:

This variant can be used if data on walking capability is available; this is the case, for example, in the current study from the UNU-EHS in the City of Dresden. One advantage of this data is that it enables you to estimate the evacuation capability to a more precise degree. The information should correspond as closely as possible to the question „Do people live in your household who are not able to independently leave the house or who cannot manage long distances (2 km) by foot (e. g. small children, old people)?" because the calculations are based on precisely this question. If you are carrying out your own survey, it is of course possible to adapt the question to the relevant dataset. In the event that the concrete description of the variable on walking capability „People in households who are not able to independently leave the house or who cannot manage long distances (2 km) by foot" is substituted by „mobility impairment", it should be noted that these subgroups of the population are not identical. Households with small children or old people who, for example, view themselves as not being capable of independently managing a distance over 2 km long are not listed in the statistics for those people with a „mobility impairment". As a result, the indicators will not exhibit completely identical indicandum. Therefore, if you use statistical data on mobility impairment in combination with values from the UNU-EHS Household Survey then you must take account of these differences. The use of a logistic regression model is particularly helpful if you are using more than one independent variable to estimate a dependent nominal variable. The regression model can determine the relationship between a dependent variable and one or more independent variables. The logistic regression model is used when the dependent variable is nominal, as in this case (evacuation capability: yes/no).

Another advantage is that regression data originating from different sources (which cannot therefore be mixed) can be used for the estimate.

The logistic regression model for a binary dependent variable (binary: two possible states, here evacuation capability: yes/no) and four independent variables (here: three HHtypes – the fourth is thus redundant –, as well as a variable on walking capability), is as follows[26]:

Formula 2:

$$P(Y=1) = \frac{e^z}{1+ e^z}$$

with $z = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4$.

P(Y=1) is the probability of the occurrence of state 1 (here the evacuation capability), it takes values between 0 and 1.
x_i, i = 1,2,3,4 are the independent variables, in this case
x_1, x_2 and x_3 are the variables HHtype 1, HHtype 2 and HHtype 3 and
x_4 ist is the variable „people in the household who are not able to independently leave the house or who cannot manage long distances (2 km) by foot".
b_i, i = 0,1,2,3,4 are the regression coefficients that are estimated in the model (see Table 7.2 in Appendix 7.4 B). They determine the direction and strength of the influence exerted by the relevant independent variables[27].
The estimate of the regression model is carried out using data at a household level, while the use of the model to illustrate the indicator is carried out at the level of the geographical unit. Strictly speaking, this process is based on an average imaginary household per geographical unit. In the case of the independent variables, the proportional values for the geographical unit are used (e. g. 20 % of households should be allocated to HHtype 1). P(Y=1), or the probability of evacuation capability, is then interpreted as the proportion of households capable of evacuation in the geographical unit.
If you now want to calculate the proportional value per geographical unit, you use the proportional value (between 0 and 1) of the HHtypes and the proportional value of e. g. people with mobility impairments in Formula 2. This requires the use of the estimated regression coefficients, the values for the UNU-EHS Household Survey can be found in appendix 7.4 B.
1 – P(Y=1) gives you the proportional value of households that CANNOT get themselves to safety unaided.

[26] See. e. g. Backhaus, Klaus; Erichson, Bernd; Plinke, Wulff & Rolf Weiber (2005): Multi-variant Analyses Methods. An Application-Oriented Introduction. Berlin. Heidelberg.

[27] See also the interpretation of EXP(b) from Backhaus, Klaus; Erichson, Bernd; Plinke, Wulff & Rolf Weiber (2005): Multi-variant Analyses Methods. An Application-Oriented Introduction. Berlin. Heidelberg.

Information on integrating your own survey results

1. Allocate the households to the age-related HHtypes.
2. Create logistic regression model with the evacuation capability as the dependent variable. The independent variable are the 1st and 2nd HHtypes and a variable for walking capability (e. g. walking impediment). Use the regression coefficient from this model in formula 2.

A corresponding illustration in map form (see example Figure 4.3) shows the *evacuation capability* for each geographical unit, or in other words the percentage of households that that CANNOT get themselves to safety. Visualising the results in map form identifies spatial hotspots in which a particularly high number of people require assistance in the event of a flood. This can be useful when further interpreting the results to compare the location of retirement homes (including the occupancy figures) with the results for *evacuation capability* (can also take place in GIS). Particularly high values could be explained through this interrelationship. This is also important information for emergency services: the more precisely those requiring help can be localised, the more valuable the information is for planning.

Calculation of the indicator evacuation time

The indicator *evacuation time* specifies the number of minutes required for half of the households in a city district/borough to get themselves and their important documents to safety. The indicator is a relative measurement for comparing the susceptibility of the population in individual city districts/boroughs.

In order to estimate the *evacuation time*, the different HHtypes are once again used as structural characteristics, although all of the HHtypes with people over 60 years old are now considered together i. e. HHtypes 3 and 4 are integrated. While it is relevant whether multiple members of a household are capable of providing each other with mutual support when estimating the *evacuation capability*, this information is not decisive for the evacuation time. The time in which half of those households living in a city district or borough can be evacuated is given as the median of the individual evacuation times in minutes. Outliers, resulting in particular from misjudgements of the time required by people, hardly influence the median.

***Question:** After how many minutes have half of the households been able to get themselves and their important documents to safety in the event of an evacuation?*

Required data:

Age-related characteristics of the households per geographical unit, classified into:

1) Households with children under 6 years old
2) Households with members exclusively between the ages of 6 and 59 years old
3) Households with people from 60 years old.

Process steps:

Estimate the number of minutes in which half of the population in a geographical unit have been brought to safety with the help of your data on HHtypes and the median values per HHtype from your survey or the UNU-EHS Household Survey (see Appendix 7.3 C) using Formula 3. Integrate the information calculated in this way with the corresponding geographical units in the attribute table for the GIS shapefile. Visualise the results in map form (see example Figure 4.4).

Similar to the first calculation variant for evacuation capability, the time period after which half of the households have been evacuated is estimated as follows:

Formula 3:
Median time =
(Share of HHtype 1 * median for HHtype 1) +
(Share of HHtype 2 * median for HHtype 2) +
(Share of HHtype 3 * median for HHtype 3).

The figures for the different household types are once again based in each case on the exposure area (e. g. HQ-100 or EHQ) for a geographical unit so that you obtain a value in minutes for the population in the exposure area for each geographical unit.

Information on integrating your own survey results

1. Allocate the households to the following age-related HHtypes:
   1) Households with children under 6 years old
   2) Households with members exclusively between the ages of 6 and 59 years old
   3) Households with people from 60 years old
2. Determine the median evacuation time for every HHtype. If necessary, check the separability of the HHtypes with a variance analysis. Use the medians in Formula 3

A corresponding visualisation in map form (see example Figure 4.4) shows the evacuation time per geographical unit. Visualising the results in map form identifies spatial hotspots in which the population require a particularly long time to get themselves to safety.

4.2.4 Calculating indicators for the coping capacity of the population

Following the examination of susceptibility above, this section looks at estimating the level of the coping capacity amongst the population in exposed areas in order to be able to overcome the flood event as unscathed as possible. This criterion is represented here by the indicators *potential insurance cover* and *flood experience.*

Calculation of the indicator potential insurance cover

In order to produce an indicator for estimating coping capacity, the proportion of households that have insurance cover against natural hazards, and are thus financially protected against damage in the event of a flood, is estimated. Because information on insurance cover is not directly contained within local government statistics, the indicator for the core set of indicators is derived from income distribution. This is based on the assumption that people in higher income classes tend to have better *insurance cover*. Alternatively, this indicator can also be determined from the proportion of lessees or property owners in the occupied apartments (or the occupied houses), whereby this is also based on an assumption that property owners are more likely to have insurance cover against natural hazards. (Information on the collection of data for the indicator *actual insurance cover* in the community-specific set of indicators can be found in Chapter 4.3).

***Question:** How many households are insured against financial damage in the event of a flood?*

Required data:
Variant 1:
Data on the income distribution, as high a resolution and as differentiated as possible (e. g. from a sample community census)
Variant 2:
Proportion of apartments that are rented or owned (e. g. from local government statistics)

Process steps:
If you are using *Variant 1*, estimate the proportion of insured households per income class by entering the average value for each income class in the linear regression model (see Formula 4a). The regression model created with data from the UNU-EHS Household Survey can be found in Appendix 7.4 D. The overall proportion per geographical unit can then be calculated using Formula 4b. If no income data is available, it is also possible as a first approximation to take the relative owner-lessee ratio per geographical unit to determine the *insurance cover* against flooding (*Variant 2*). Then estimate the number of insured households with the help of the insured proportion of lessees and property owners from your own survey or the UNU-EHS Household Survey (see Table 7.3 in Appendix 7.4 E and Formula 5).

Integrate this information with the geographical information in the attribute table for the GIS shapefile. Visualise the results in map form (see example Figure 4.5).

Note: In the UNU-EHS Household Survey, it was only possible to collect information on the insurance cover against natural hazards at a household level. Therefore, only the insurance cover for the occupants was estimated i. e. whether the owner of a rental property has insured the residential building against natural hazards is ignored. Nevertheless, it is still important when examining the coping capacity of the relevant household - in this case rental households - to know whether these households are insured against natural hazards, in this case this relates to the insurance of inventory.

Calculation of the indicator according to Variant 1:

If data about household incomes is available, the proportion of households with insurance cover can be estimated with the help of a linear regression model. The corresponding formula for a linear regression model with an independent variable is:

Formula 4a:

$$\hat{y} = b_0 + b_1x_1.$$

$\hat{y}$ is here the proportion of households that are insured against natural hazards,
x_1 is the household income (net) and
b_i, i = 0,1 are the estimated regression coefficients.

Information on integrating your own survey results

1. Determine the proportion of insured households per income class.
2. Create a linear regression model using the average values for the income classes as an independent variable and the proportion of insured households as a dependent variable. This involves firstly determining the relevant average values for the income classes (e. g. 1500 Euro for the class 1000 to 2000 Euro, in the event of an open-ended 1st or 2nd upper class then an estimated value must be defined). Then determine the proportion of households (HH) with insurance against natural hazards for each income class, which generally increases along with the level of income. Finally, create a linear regression model with the average values for the relevant income classes and the proportions of households with insurance cover.

In the linear regression model, each income level can be allocated to a proportional value for the insurance cover. The overall proportion (per geographical unit) is then found using the following calculation:

Formula 4b:
Proportion of insured households =
(proportion of HH in income class 1 * proportion of insured HH in income class 1) +
(proportion of HH in income class 2 * proportion of insured HH in income class 2) +
(proportion of HH in income class 3 * proportion of insured HH in income class 3) +
… (plus further income classes and their relevant proportions of insured households).

The proportion of HH in the income classes is based in each case on the exposure area (e. g. HQ-100 or EHQ) for a geographical unit so that you obtain a value for the population in the exposure area for each geographical unit.

Calculation of the indicator according to Variant 2:

Alternatively, if there is no income data available, it is possible to use data about the number of property owners and lessees in a geographical unit as the starting point for estimating the *potential insurance cover*. The use of this process can be justified by the fact that a significantly higher proportion of the group of property owners in the UNU-EHS Household Survey were insured against natural hazards than was the case amongst the group of lessees. In households occupied by the property owners, greater financial damage is experienced because there is also often significant damage to the house in addition to the contents of the household. Therefore, it is not only possible that property owners who live in their own houses have an additional insurance against natural hazards within their household contents insurance but are also covered within the framework of their residential building insurance. In the case of lessees, it is usually only household contents insurance that is relevant.

Similar to the use of the contingency table (cross-tabulation) in the calculation of evacuation capability, the formula for calculating the indicator *potential insurance cover is*:

Formula 5:
Share of insured households =
(proportion of rental apartments * proportion of insured lessees) +
(proportion of apartments occupied by their owner * proportion of insured property owners).

The proportion of rental apartments or apartments occupied by the owner are once again based on the exposed area of the geographical unit.

Information on integrating your own survey results

Create a contingency table (cross-tabulation) using the owners/lessees and their insurance against natural hazards. Determine the proportion of households insured against natural hazards and, if relevant, the Cramer's V for validating the interrelationship. Use these values in Formula 5.

Visualising the calculated values in map form (see example Figure 4.5) makes it possible to identify differences in the *potential insurance cover* of the households in the individual geographical units. The map enables e. g. the identification of those areas where the financial coping capacity of the households is likely to be particularly low due to the lack of existing *insurance cover* against flood damage.

Calculation of the indicator *flood experience*

In order to estimate the indicator *flood experience*, a process is initially explained that should only be carried out if you are using your own survey results. Alternative processes are subsequently proposed in the event that you have not carried out your own survey.

Question: How many households have already experienced a flood at their place of residence?

Required data:

- Length of occupancy at the place of residence (register of local residents)

Process steps:

Create a logistic regression model using your survey data. The independent variable here is the length of occupancy, while the dependent variable is formed by the flood experience (yes/no). If you are investigating multiple exposure areas at the same time, you should create a regression model for each exposure area separately.

Information about the length of occupancy of households from local government statistics is probably divided into classes (e. g. 0 to 2, 3 to 5 years etc.) and the average values should be taken in this case. Enter these average values into the regression model. This will provide you with the proportion of households with flood experience in each length of occupancy class and each exposure area. These values are then weighted with the corresponding proportions of the length of occupancy classes and, if relevant, the number of households per exposure area.

Before using the regression model, it should of course be checked for its validity (see e. g. information in Appendix 7.4 B).

Integrate this information with the geographical information in the attribute table for the GIS shapefile. Visualise the results in map form (see example Figure 4.6).

The logistic regression model for a binary dependent variable (binary: two possible states, here flood experience/no flood experience) and an independent variable (here: length of occupancy) is[28]:

Formula 6:

$$P(Y=1) = \frac{e^z}{1+e^z}$$

with $z = b_0 + b_1x_1$.

$P(Y=1)$ is the probability of the occurrence of state 1 (here „no flood experience“), it takes values between 0 and 1.
x_1 is the independent variable, here the length of occupancy.
b_i, $i = 0,1$ are the regression coefficients estimated in the modelling (see also estimating the evacuation capability with *Variant 2*).

[28] See. e. g. Backhaus, Klaus; Erichson, Bernd; Plinke, Wulff & Rolf Weiber (2005): Multi-variant Analyses Methods. An Application-Oriented Introduction. Berlin. Heidelberg.

The regression models are estimated separately according to the exposure area (e. g. HQ-100 and EHQ without HQ-100) because it can naturally be assumed that there will be different interrelationships between the length of occupancy and the flood experience.

P(Y=1), or the probability of „no flood experience“ can be interpreted here as the proportion of households in the geographical unit that have not experienced a flood in their place of residence.

Taking concrete regression results from the UNU-EHS Household Survey for estimating the indicator *flood experience* in other communities cannot be supported. The reason is that the information on flood experience is strongly influenced by the location because it is determined by concrete flood events during the past in the relevant city. This means that the interrelationships determined between length of occupancy and flood experience would be completely different in those areas in which flood events occurred in other years and at other intensities. Therefore, the interrelationships must be determined using your own survey results.

An alternative method and an option for making a first basic estimate is to illustrate the average length of occupancy per geographical unit or per exposure area and geographical unit. Although this method does not produce a direct value for flood experience, it does already offer the possibility of comparing geographical units.

In the ideal case, the geographical information on the length of occupancy can be correlated with cartographic representations of previous flood events. This would enable a fairly precise determination of how many households already lived at their place of residence in each area at the time of a particular flood. These results could be used to determine the flood experience per geographical unit. In the course of the current study by UNU-EHS, this information was not available and this possibility was therefore not investigated. Another problem is that the information is based on aerial or satellite images and the precise time the plane or satellite passed over the area has a significant influence on the represented extent of the area affected by the flood.

You need to decide for yourself in your community which flood events should be integrated into the assessment and then ensure that corresponding geographical information is available for each of these events.

Therefore, the indicator *flood experience* can – depending on the availability of data and the possibility of implementing your own survey results – be estimated in a number of different ways.

Visualising the indicator in map form (Figure 4.6 shows the value calculated for flood experience in Cologne using logistic regression) will clearly identify spatial hotspots in which a particularly low proportion of the population have flood experience. It is possible that less preventative measures have been taken in these areas and the population possess less knowledge about how to act correctly in the event of a flood.

4.3 Creating a set of community-specific vulnerability indicators

Alongside the set of standardised core indicators (see Chapter 4.2) for assessing vulnerability, additional community-specific indicators are proposed that are directly based on data collected from your own community i. e. only ascertainable with the help of additional purpose-made surveys or as part of a sample community census.

4.3.1 Calculating community-specific indicators for the susceptibility of the population

Alongside the proposed core indicators for determining susceptibility in Chapter 4.2.3, other community-specific indicators can be used when you complete your own surveys. The two indicators *flood sensitivity* and *level of information on flood hazards* are described in the following section.

Calculation of the indicator flood sensitivity

Flood sensitivity is based on an evaluation of this question: „How probable do you think it is that the house in which you currently live will be affected by a flood in the future?“ In the survey, answers could be selected from a scale from 1 to 8, with 8 standing for „very likely“ and 1 for „very unlikely“. The respondents‘ estimates of their own exposure to floods are then integrated with the actual exposure based on the theoretical flood scenario you selected. In general, the indicator *flood sensitivity* can be understood as the average value (the average values of the classes from class 1 „very likely“ to class 8 „very unlikely“) and thus represents a direct measurement of the subjective flood risk estimated by the surveyed households. Visualising the results in map form (see example Figure 4.7) shows the subjective estimate of flood risk by the surveyed households in comparison to their actual exposure. This method makes it possible to identify those city districts or boroughs in which the *flood sensitivity* is very low (or very high) despite the fact that there is *flood exposure*.

Calculation of the indicator level of information on flood hazards

Data about the level of information held by households on flood hazards in their place of residence can be collected using the following question: „Did you receive or obtain information about the possible flood hazards when selecting your apartment or house?" The following options can used for the answers:

- A) YES, I received the information automatically.
- B) YES, I obtained the information myself.
- C) NO, I have not received or obtained any information.

An evaluation of this question will indicate how high the level of information about the risk of a flood was amongst the population at the time they moved into their apartment or house. The answers are provided independently of the time the people moved into their apartment or house and it thus includes both those who have lived there for a long time and those who have only just moved into the residential area. Furthermore, an evaluation of the possible answers enables a differentiation to be made between those households that actively obtained information on flood hazards themselves and those households which received this information from the city or a third party. This makes it possible to also identify those city districts in which the community or district authorities have quite actively (or even only to a limited extent) made relevant information available.

Irrespective of whether those surveyed have since been informed or become aware of the danger due to a flood event, it is still safe to assume that those households living in an exposed area that didn't have any information about flood hazards when deciding or selecting their place of residence in an exposed location are more vulnerable to flood events than those who were informed (see example Figure 4.8).

4.3.2 Calculating community-specific indicators for the coping capacity of the population

This section describes the indicators *actual insurance cover* and *flood protection measures implemented by private households* as additional community-specific indicators in the area of coping capacity.

Calculation of the indicator actual insurance cover

As well as the question of how many households potentially have insurance against natural disasters (estimated in the core set of indicators based on the survey results and income levels or ratio of owners-lessees), which is covered by the core indicator *potential insurance cover*, it is possible to find out this information with the community-specific indicator *actual insurance cover* using a purpose-made survey. The question used for obtaining the required information when completing the survey is as follows: „Do you have one or more of the following insurance covers for your apartment or your house?" In addition to listing insurance against natural hazards, which is the only insurance policy that covers flood damage, the available answers can include e. g. residential building insurance, personal liability insurance and household contents insurance, as well as the categories „other" and „don't know".

The indicator *actual insurance cover* enables important conclusions to be drawn about the financial coping capacity of households in the event of flood damage. In contrast to the methods used for deriving the level of insurance cover based on household income or alternatively the ratio of owners-lessees in the core set of indicators, the indicator actual insurance cover enables a focus on exceptional local characteristics.

Calculation of the indicator flood protection measures in private households

In order to gain some insight into the actual flood protection measures taken by private households, you should include the question „Have you carried out any measures for providing protection against floods yourself or implemented preventative strategies? If yes, which measures?“ in the survey. While the first part of the question allows for a general assessment, the second part enables further classification based on the individual types of measures taken. These could then be divided e. g. into the following categories: (A) fundamental measures (e. g. moving), (B) financial provisions (e. g. insurance), (C) basic technical/structural measures (e. g. backwater stop), (D) more extensive technical/structural measures (e. g. construction of a wall), (E) organisational measures (e. g. plan for placing possessions up high) (see example Figure 4.9).

4.4 Handling the assessment results

Once the assessment has been carried out, the core indicators have been applied and, if relevant, the community-specific set of indicators has been determined, you are left with a broad set of data for emphasising and spatially distributing certain vulnerability criteria at a community level. The task now is to use the results of the vulnerability assessment to, where possible, bring about an improvement in the current situation. Even when the results within a community turn out to be encouraging, the process for preparing for a future flood, informing or sensitising the population, continuously optimising contingency plans and further developing protective measures is a never-ending one. The significance of the individual indicators and the resulting possibilities for taking action in your community are described directly in the sections on contributions to the vulnerability assessment in Chapters 4.1.4 and 4.1.5.

Author: Kathleen Meisel

V. Chapter

Vulnerability assessment for the environment in the case of a flood event

Objective

These guidelines are designed to assist you in carrying out a small-scale investigation into the vulnerability of the environment to flood events and to evaluate the results in meaningful way. It is not only possible to use the information generated during this process to assess the current level of vulnerability, it can also act as the basis for deriving options for necessary action and offers the possibility of evaluating different planning alternatives.

Prerequisites

A prerequisite for carrying out the process presented in these guidelines to assess the vulnerability of the environment to flood events is the availability of relevant environmental data in a digital form, as well as access to a geographical information system (GIS). The concrete process steps described in these guidelines are based on the software ArcGIS 9.2, although it is of course possible to use an alternative software with a corresponding range of functions. If you do not have access to digital information then it will not be possible to carry out the processes described in the following section of these guidelines to their full extent. It makes sense to use the vulnerability assessment as an opportunity to convert your datasets into a GIS compatible digital data format.

5.1 Vulnerability of the environment

In order to be able to fully understand and implement the steps described in the following assessment process, it is necessary to clarify certain terms and provide an insight into the fundamental decisions that needed to be taken to enable an assessment of vulnerability with respect to the environment. These will be described briefly below.

5.1.1 Definition of the environment

The term environment is defined in these guidelines based on environmental functions or ecosystem services[29]. These include soil genesis, preservation of soil fertility and thus the provision of foodstuffs and clean groundwater for the drinking water supply, safeguarding the gene pool, the production of oxygen, contributions to climate compensation and other functions that serve to protect the basis for human existence. The environment is considered to be vulnerable to a flood event if the listed environmental functions or ecosystem services could be limited as a result. Impairment of these functions or services would then lead either directly or indirectly to the limited provision of those aspects fundamental to human existence.

[29] For more detailed information on this subject, we refer you to the publication described in Chapter 1 from the series of publications „Research into Civil Protection" in which the scientific principles for creating these guidelines are described in detail.

5.1.2 Vulnerability of the environment to contamination in the event of a flood

A flood can generally be described as a natural phenomenon for floodplains. Consequently, there is no environmental vulnerability with respect to the natural process of flooding but rather floods are in reality a necessary prerequisite for the creation of floodplains and make an important contribution to preserving this natural habitat. It is true that there are changes to the composition of biocoenoses or ecosystems after a flood event. The soil can be eroded or material carried by the flood can be deposited, yet these processes are part of the natural dynamics of a floodplain. Environmental functions are not sustainably impaired as a result. A limitation of these environmental functions and thus an increase in the vulnerability of the environment only exists if the flood wave encounters potential contamination sources that have been insufficiently secured and which leads to hazardous materials being released into the environment. Potential contamination sources include installations classified according to Article 19g of the Federal Water Act (Wasserhaushaltsgesetz - WHG) (installations handling substances hazardous to water) and those commercial and industrial establishments according to the 12th Federal Immission Control Act (Bundesimmissionsschutzverordnung -BImSchV) (potential contamination sources), described in the following sections simply as installations/establishments[30], as well as already contaminated sites[31]. In addition, there are other contamination sources that do not fall under these three named cate-gories. For example, agricultural land or railway lines from which chemicals could be flushed can also be considered to be potentially hazardous. However, these contamination sources should not be taken into account initially – on the one hand, to simplify the process for determining the vulnerability of the environment and, on the other hand, because experience from previous flood events has shown that there is a particularly high level of danger posed by the already mentioned installations and sites. This approach also has the advantage that the required information should already be available in local communities.

Therefore, it is only those environmental areas lying within the sphere of influence of potential contamination sources that are considered to be vulnerable. The level of vulnerability in these environmental areas can be derived, on the one hand, from environmental characteristics relevant to vulnerability (see Chapter 5.1.3) and, on the other hand, by the relative harmful impact posed by the potential contamination sources. Therefore, the vulnerability assessment does not focus on the direct impact of the flooding but rather on the chain of events set in motion by the flood (risk of contamination).

[30] Warm, H.-J. & K.-E. Köppke (2007): Schutz von neuen und bestehenden Anlagen und Betriebsbereichen gegen natürliche, umgebungsbedingte Gefahrenquellen, insbesondere Hochwasser (Untersuchung vor- und nachsorgender Maßnahmen) (Protection of new and existing installations and establishments against natural environmental sources of danger, in particular flooding (investigation into preventative and remediation measures)). Berlin.

[31] Publication of the research project: „Auswirkungen des Hochwassers 2002 auf das Grundwasser“, („Effects of the flood of 2002 on groundwater“), e. g. Marre, D., Walther, W. & K. Ullrich (2005): „Einfluss des Hochwassers 2002 auf die Grundwasser – Beschaffenheit in Dresden“ (The influence of the flood of 2002 on the groundwater – the conditions in Dresden), in: Groundwasser (Groundwater), Vol. 10, No. 3, pages 146-156.

5.1.3 Vulnerability criteria

As described in Chapter 5.1.2, the exposure of the environment to contamination plays an important role in determining the vulnerability of the environment. Alongside the geographical proximity to the contamination sources listed in these guidelines, there are also environmental characteristics relevant to vulnerability that make the environment particularly susceptible to the effects of hazardous materials or negatively influence the environment‘s ability to cope with a flood event. These characteristics will be considered together with the possible contamination sources as vulnerability criteria and are described in more detail in the following section.

Exposure (to contamination sources)

This vulnerability criterion is not based, as already indicated, on the whole flood zone because the environment is not considered to be vulnerable to the naturally occurring processes associated with a flood. Instead, the focus is placed on those areas of the flood zone in which the environment is expected to be negatively impacted due to its proximity to possible sources of contamination.

In terms of those hazardous substances already present in contaminated sites, it can be concluded that these substances could be remobilised due to the rising groundwater level in the event of a flood and thus, the soil and, once the groundwater level sinks, possibly also the groundwater could be contaminated. In addition, it is conceivable that leaching processes will be intensified due to increased precipitation (that may have led to the flood), which has the result of washing the hazardous materials into the soil and the groundwater. Plant and animal biocoenoses can also be endangered by the released hazardous materials due to the intake of nutrients and food from the soil. Furthermore, watercourses or other surface waters can be contaminated due to the interflow of water in the soil and groundwater pathways, whereby there is a danger that aquatic biocenoses can be negatively affected. As rapid dilution effects occur in watercourses and no specific differences in vulnerability to contamination can be identified[32], in those watercourses within a comparatively small observation area, such as a community, no conclusions about the effects on watercourses are drawn in the assessment of environmental vulnerability in these guidelines. The dispersal of hazardous materials from contaminated sites into the soil in the event of a flood has been shown to primarily take place vertically and only to a lesser extent horizontally. In the case of the transfer of these hazardous materials from the soil into the groundwater, these materials will be dispersed over decades in the direction of groundwater flow. However, this should not be taken into account in order to simplify the vulnerability assessment. In addition to the information about contaminated sites, data is often also available about suspected contaminated sites. Therefore, it is advisable to also include this data in the vulnerability assessment. Instructions on how to handle these sites is provided in Chapter 5.2 in the description of the 1st Step of the assessment.

[32] If a larger area is being investigated, e. g. a region or the whole of Germany, it is possible to select water quality as a criteria for assessing the vulnerability of watercourses. An examination of those watercourses with a particularly high water quality appears sensible in this context because these watercourses continue to fulfil the environmental functions / ecosystem services such as the provision of an intact aquatic biocoenosis or also the provision of clean water as the basis for drinking water supplies at a good or very good level and thus play a very important role. However, it is difficult to identify any clear differences in the water quality at a community level.

If the flood wave encounters insufficiently safeguarded installations/establishments, this can lead to the discharge of hazardous materials (contamination of the water). Depending on the relative transport capacity of the draining flood water and the characteristics of the released hazardous materials, sediments will occur in the direction of flow. This can directly impact both soil and vegetation. It is possible that the contamination of the soil is passed on to the groundwater through leaching processes, into watercourses through the interflow of water in the soil or to plants and animals through the uptake of nutrients. As the distance to the source of contamination increases, dilution effects take place within the surface water and the potential damaging impact diminishes.

Environmental characteristics relevant to vulnerability

In order to determine the environmental characteristics relevant to vulnerability, the criteria described below have been selected. They have been derived from the considerations made in Chapter 5.1.1 and 5.1.2 that express the vulnerability of the environment based on the impairment of environmental functions or ecosystem services.

- Conservation value of the soil
- Groundwater protection level
- Biotope value

The data available in communities about the conservation value of the soil is used to illustrate vulnerability to the loss of the functional capabilities of the soil in the event of contamination. Soil with a particularly high conservation value is highly vulnerable because there is a danger that those functions of the soil that are currently relatively intact will be subsequently limited or no longer supported after contamination. The vulnerability to a loss of groundwater functions is illustrated by the natural groundwater protection level. A low groundwater protection level is equivalent to a high level of vulnerability because hazardous materials can penetrate into the groundwater with relatively little difficulty in the event of contamination. The biotope value indicates the relative importance of habitats or biocoenoses and thus how well the protective functions for different species and biotopes is being fulfilled. It can be assumed that valuable biotopes are also host to biocoenoses that play a particularly important role in those functions designed to safeguard the gene pool, the production of oxygen, the absorption of CO2, pollination and soil formation etc. Therefore, valuable biotopes are highly vulnerable because a very high loss of functionality can be expected in these cases.

The criteria „conservation value of the soil“, „groundwater protection level“ and „biotope value“ are usually already available in most communities for the creation of landscape plans, environmental areas or an environmental atlas. Although these criteria can also be investigated separately (see Chapter 5.3), they provide a particularly good illustration of those environmental characteristics relevant to vulnerability when examined in combination.

5.2 Assessing the vulnerability of the environment to flood events

After providing you with important preliminary information for carrying out the assessment, this section will describe the individual steps involved in the assessment process and provide instructions on how to interpret the results.

5.2.1 Flow chart

The method presented in these guidelines aims to systemise the previously described data and combine it for the purpose of making vulnerability statements. The flow chart in Figure 5.1 illustrates this process.

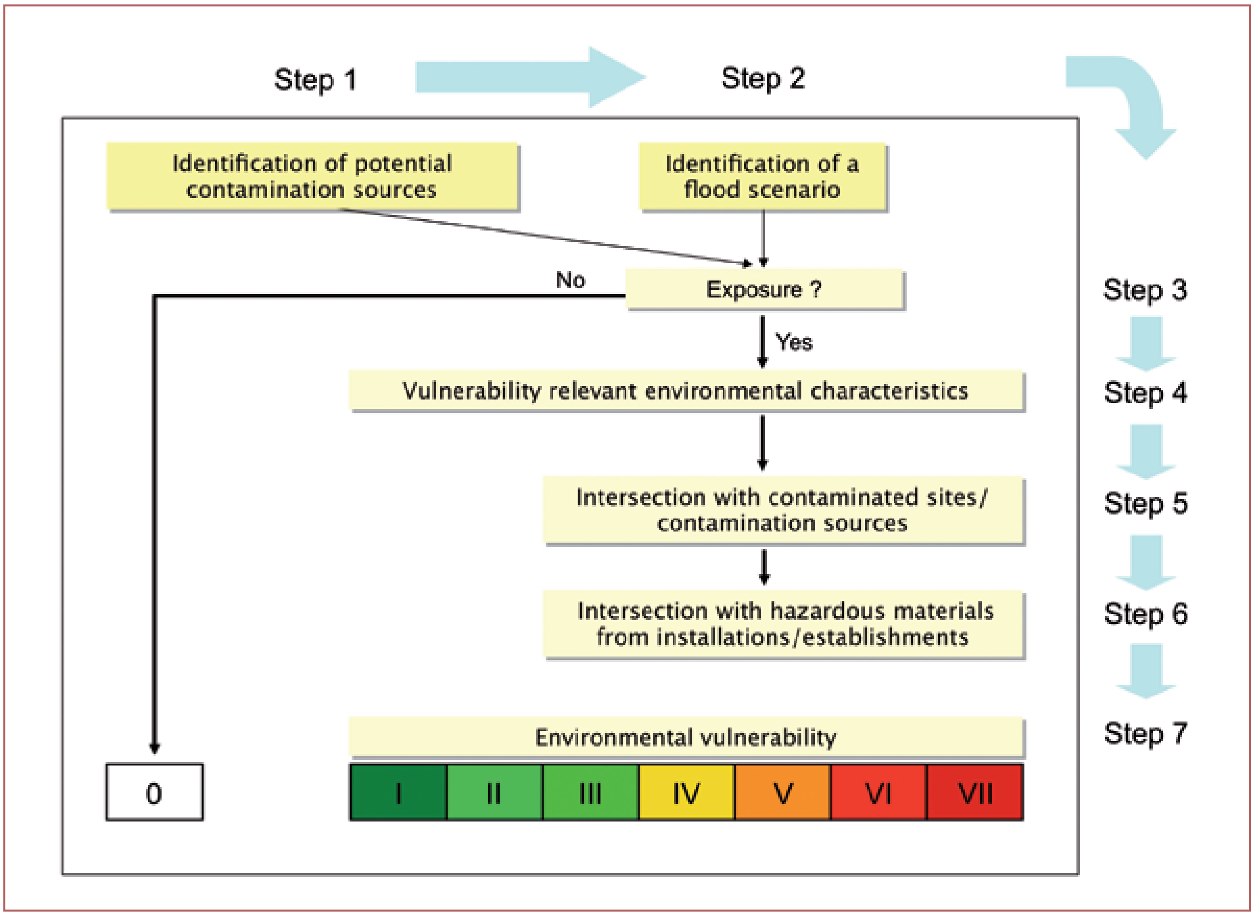


Figure 5.1: Schematic representation of the assessment method (own figure; Kathleen Meisel, MLU)

After checking for the existence of possible contamination sources in the community, it is necessary to firstly define a theoretical flood scenario. This step creates the foundation for the rest of the process – all of the subsequent steps and the assessment results ascertained in the end are always based on the selected flood scenario. In the next step, an exposure analysis of the potential contamination sources in comparison to the flood zone in the scenario is to be carried out. It is only necessary to continue with the assessment process if one of the installations or environmental areas combined in this category is exposed. If this is the case, it is then necessary to consider the environmental characteristics relevant to vulnerability. The information gained up to this point in the assessment process – the exposure of sources of contamination and the environmental characteristics – can subsequently be combined in a two-stage process to determine the vulnerability of the environment. Alongside the determination of the flood-related environmental vulnerability, it may also be useful to carry out individual assessments. For example, the extent to which soil with a high conservation value or valuable biotopes are effected in the event of a flood by the potentially damaging impact of contamination from installations/establishments could be investigated. In addition, it is advisable to investigate in which areas the groundwater or soil with a high conservation value could be especially threatened by a possible release of hazardous materials from contaminated sites. It is also possible to examine whether groundwater threatened by contaminated sites is located within the sphere of influence for protected drinking water catchment areas. These guidelines provide some examples for these individual assessments in Chapter 5.3.

5.2.2 Vulnerability classes

In the course of this assessment, the environmental areas are initially classified according to a 5-level, and later a 7-level, vulnerability scale. This classification process is based on the individual assessment steps, which results in a graded vulnerability rating.

5.2.3 Structure of the individual steps

In the following section, these guidelines will provide step by step instructions for carrying out a vulnerability assessment of the environment at a community level. In the descriptions of the individual assessment steps, there is an attempt to follow a uniform structure (information, process step(s), example(s), information on how to handle gaps in the data).

5.2.4 Step by step process for carrying out the assessment

1st Step: Identifying and locating the contamination sources

At the beginning of the vulnerability assessment, it is necessary to check whether possible sources of contamination (see Chapter 5.1.2) are located within the community under investigation.

***Question:** Are there installations according to Article 19g of the WHG, establishments according to the 12th BImSchV and/or contaminated sites in your community? If yes, are the locations of these possible sources of contamination already known?*

Process steps:
Check whether one or more of the named contamination sources is located in your community. If there are no contamination sources located in the area covered by your community, the following assessment steps become unnecessary and the assessment ends with the best possible result. However, if contamination sources do exist in your community, you should now set up a new GIS by creating a new „View". Alongside the administrative boundaries for your community, the source material for the map should also include some information that makes orientation easier (for example, ground plans of the buildings and transport routes). Add the locations or sites of all potential contamination sources as a new theme in the GIS.

Handling gaps in the data:

If there is no information available about installations/establishments in your community, contact the relevant approval authority (e. g. regional or district government). If the community does not already have a register of contaminated sites, it is generally possible to find the required information at a regional government or state level. When information about installations/establishments is not available as separate datasets, this information can also be applied in combination, saved and used later as the theme „Installations + establishments". If additional information is available about suspected contamination sites, it is possible to handle this data as an additional contamination source and proceed in the same manner as for contaminated sites or to combine the two themes into one common theme called „Contaminated sites and suspected contaminated sites". If in doubt, these sites should be handled as contaminated sites so that all risks are taken into account. This step is carried out in the GIS using the „Union" function.

2nd Step: Defining a hypothetical flood scenario

This step is carried out in accordance with the process described in Chapter 2.1.3.

3rd Step: Determining the exposure of contamination sources to floods

This step decides whether it is necessary to continue with the subsequent steps of the process for determining the vulnerability of the environment to a flood event in your community. If it is established that there are potential contamination sources actually located within the flood zone for the theoretical flood scenario or scenarios defined in Step 2, the assessment should definitely be continued. If this is not the case, the environment has no vulnerability to the assumed flood event. This means that the vulnerability assessment ends at this stage with the best possible result for the community.

Question: *Are potential contamination sources located within the flood zones for your defined flood scenario?*

Process steps:
Create a „View“ in which the flood zone for your theoretical flood scenario is displayed. Add the potential contamination sources as themes. Check whether one or more potential contamination sources is located within the flood zone for the hypothetical flood scenario.

Also overlay the theme „Administrative boundaries“ together with the themes „Flood zone scenario 1 (2, 3…)“, „Contaminated sites“, „Installations” and “Operating areas“. In order to gain an initial overview of the situation, you can simply use the „View“ function to see whether potential contamination sources are located in the flood zone. If this initial evaluation is not sufficient, you can proceed using the GIS „Clip“ function as follows:

Use the theme „Flood zone scenario 1 (2, 3…)“ as a template for the „Clip“ function and use this function to cut out all of the exposed contamination sources from the other themes. The resulting themes can be named „Exposed contaminated sites for scenario 1 (2, 3,...)“, „Exposed installations for scenario 1 (2, 3,...)“ and „Exposed establishments for scenario 1 (2, 3,...)“. The attribute tables for the new themes will contain information about the exposed sources of contamination. If the attribute table is empty, there are no contamination sources located in the flood zone.

If you did not receive separate datasets but have instead worked with the theme „Installations + establishments“, proceed in exactly the same way and create the new theme „Installations + establishments for scenario 1 (2, 3,...)“.

If no contamination source is located in the flood zone for one or more scenarios, the vulnerability assessment for this scenario ends at this stage with the result that no vulnerability exists. In all other cases, the assessment should be continued.

Example:

This step is illustrated based on the example of the city of Cologne with the defined flood scenario HQ-500 (see Figure 5.2). As potential contamination sources are located in the flood zone, the environment is vulnerable to the flood event and the assessment process is continued.

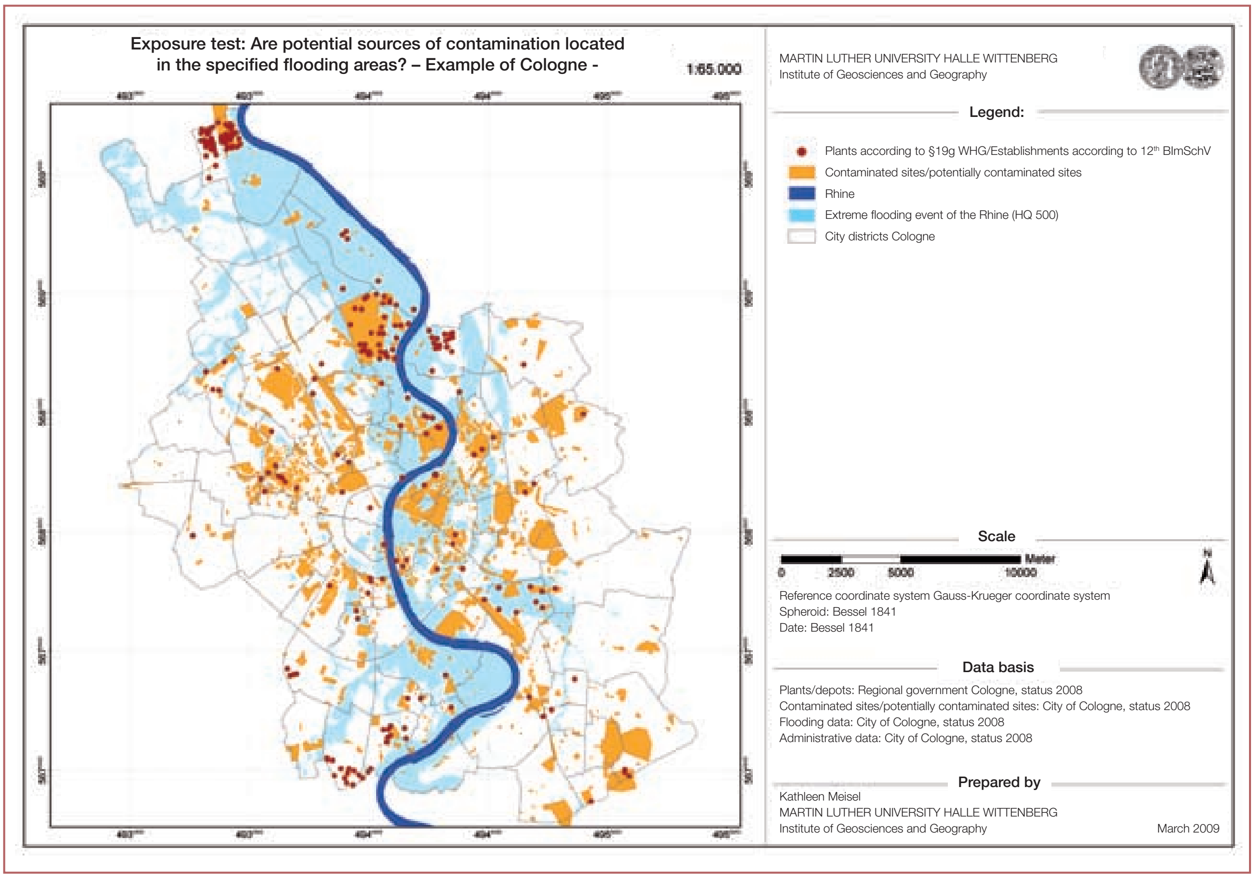


Figure 5.2: Exposure test — testing the exposure of contamination sources

Handling gaps in the data:

No new information is included at this stage but rather already available information is combined. If you have not identified any gaps in the data. The step can be carried out without problems.

4th Step: Determining the environmental information relevant to vulnerability

If during the completion of the 3rd assessment step it was shown that potential sources of contamination are located within the flood zone for the selected scenario (or scenarios), it is necessary in the next step to determine the environmental information relevant to vulnerability. This can be derived from the environmental characteristics relevant to vulnerability (see Chapter 5.1.3). The three criteria „conservation value of the soil“, „groundwater protection level“ and „biotope value“ should already be classified (= ranked) in the respective themes (e. g. very low, low, medium, high and very high groundwater protection level). If it is possible based on the available data, these criteria can be geographically illustrated for the entire area covered by the community in a GIS. If a different flood zone is selected at a later point in time, the areas in which there is data available about the environmental characteristics relevant to vulnerability can then be integrated into the new assessment at any time.

Logical integration of the data – in which each criterion is equally weighted – enables statements to be made in this assessment step about the environmental information relevant to vulnerability. The process of logical data integration using functional relationships and preference matrices (= integration matrices) is usually possible in every GIS – as described in the following assessment step.

In order to be able to better understand the following assessment step, you should read the detailed description of the process of logical data integration in the Appendix to these guidelines (see Appendix 7.5).

Process steps:
Import the environmentally-relevant characteristics „conservation value of the soil", „groundwater protection level" and „biotope value" as themes in a new „View" in the GIS. The criteria can thus be geographically represented based on their rating classes „very low", „low", etc. The next process step requires the preference matrices (see Appendix 7.5 for a description of this process) you created. In the first step of the logical data integration process in your GIS, it is necessary to use the „Merge" or „Union" functions in the toolbox to select the two criteria to be integrated – „conservation value of the soil" and „groundwater protection level". Carrying out this function will automatically create a new theme, which you can name, for example, „Environmental_Information_Intermediate_Results". The datasets for both criteria will appear in the corresponding attribute table for this theme. Add a new column to this table. Now use the query window in the attribute table. It is necessary to query every possible combination of rating classes for both criteria one after another e. g. conservation value = I AND groundwater protection level = II. If the queried datasets are marked, the respective result from the preference matrix needs to be entered in the marked field in the new column. This step has been completed when all fields in the new column have been filled. You can now display the new theme „Environmental_Information_Intermediate_Results" classified according to the new column in „View". Proceed in the same manner in order to integrate this interim result with the third vulnerability criteria „biotope value", i. e. use the „Merge" or „Union" functions in the toolbox to select the two criteria „Environmental_Information_Intermediate_Results" and „biotope value". Now add a new column to the attribute table for this new theme, which you can name „Environmental information relevant to vulnerability". Query every possible combination of rating values for both criteria one after another and enter the corresponding results from the preference matrix in the relevant fields in the new column. Once all of the results have been entered, you can now display the new theme „Environmental Information relevant to vulnerability" classified according to the new column in „View". You can now see the geographical distribution of the rating classes „very low", „low", „medium", „high" and „very high" for the environmental information relevant to vulnerability.

Example:

The characteristics relevant to vulnerability „conservation value of the soil", „groundwater protection level" and „biotope value" are firstly illustrated as themes in the GIS using the example of Cologne (see Figure 5.3). In Cologne, the criteria „groundwater protection level" has five rating classes (I-V), „conservation value of the soil" has four rating classes (I-IV) and „biotope value" has three rating classes (I-III).

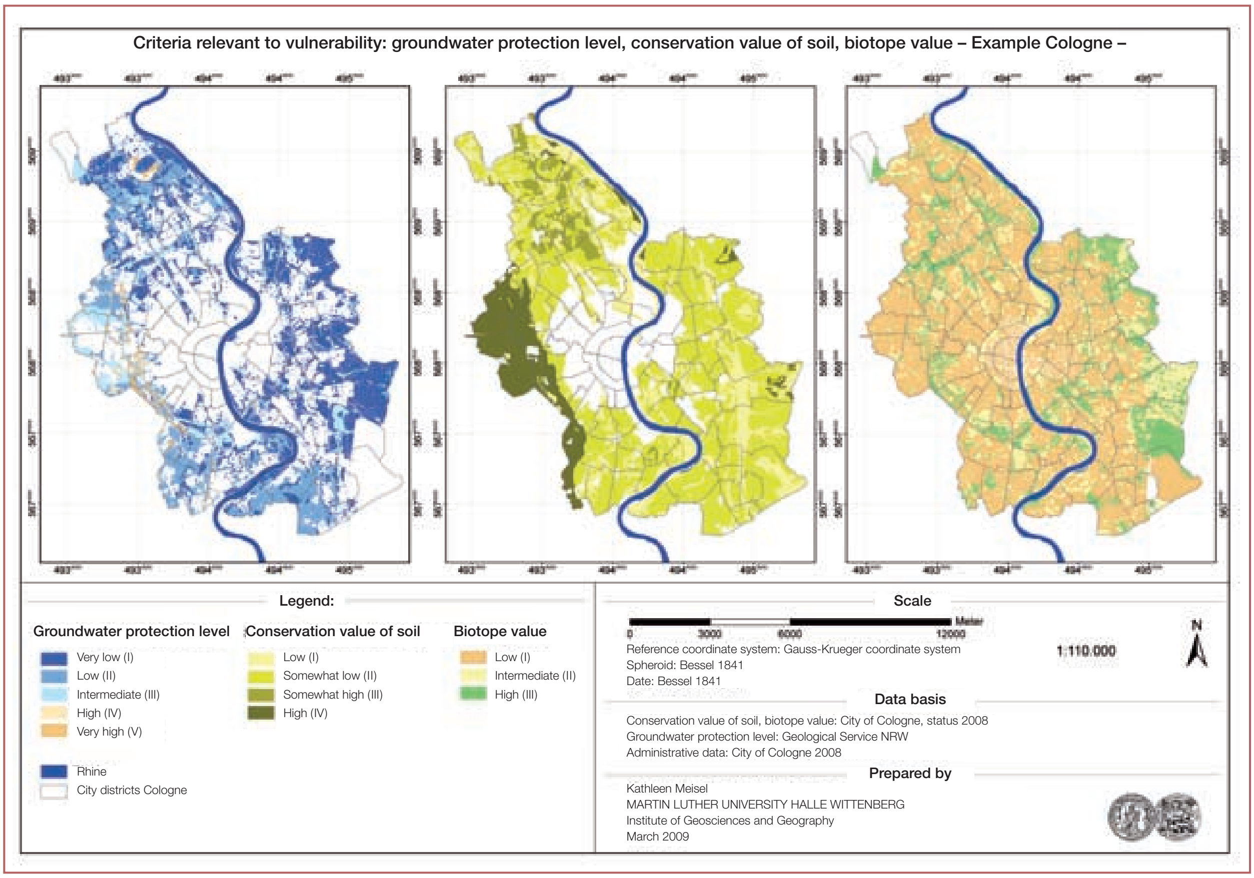


Figure 5.3: Criteria relevant to vulnerability: groundwater protection level, conservation value of the soil and biotope value

The functions that represent the importance of the environmental characteristics relevant to vulnerability and the integration matrices will be described below for the example of Cologne. As the environmental characteristics „conservation value of the soil" and „groundwater protection level" have the same number of rating classes in Cologne as in the example functions described, the functional curve does not need to be either compressed or expanded. They can be used in their current form for reading off the vulnerability ratings (see Figures 5.4, 5.5) (a detailed explanation of this process can be found in Appendix 7.5). In the example for Cologne, the logical data integration of both variables has already been carried out to create the intermediate result „Environmental_Information_Intermediate_Results" so that the preference matrix shown in Figure 5.6 produces a template for the process step in the GIS.

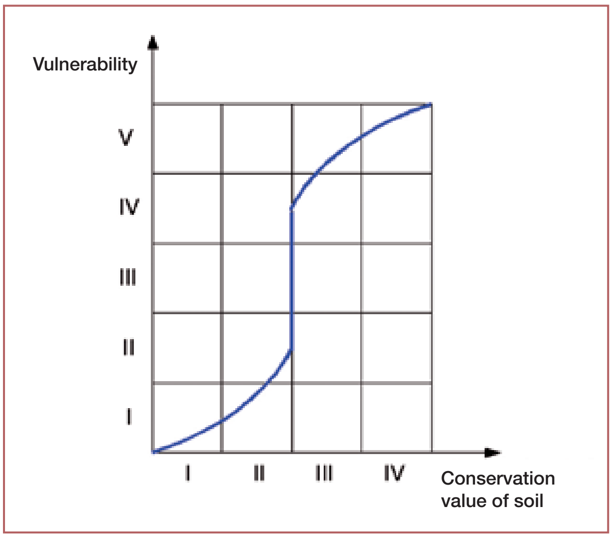


Figure 5.4: Functional relationship between the conservation value of the soil and vulnerability

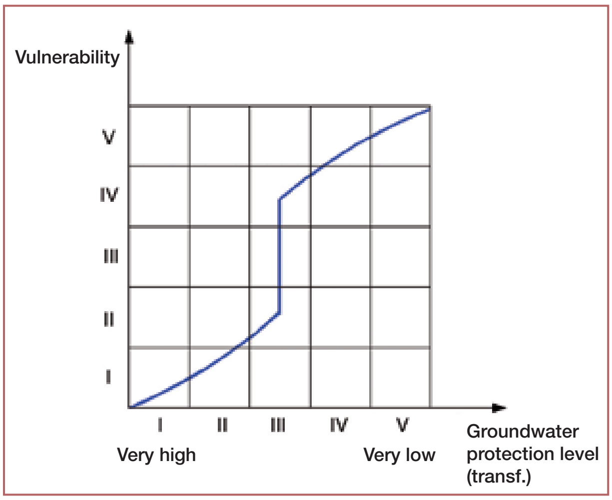


Figure 5.5: Functional relationship between the groundwater protection level and vulnerability

Conservation value of soil

Groundwater protection level	I	II	III	IV
I	I	I	III	III
II	I	I	III	III
III	II	II	IV	IV
IV	III	III	V	V
V	III	III	V	V

Figure 5.6: Preference matrix for the conservation value of the soil and the groundwater protection level

As „biotope value“ only has 3 rating classes in Cologne, the curve needs to be compressed – as illustrated in Figure 5.7. The integration of the two variables „Environmental_Information_Intermediate_Results“ and „biotope value“ has also already been carried out for the example of Cologne (see Figure 5.9).

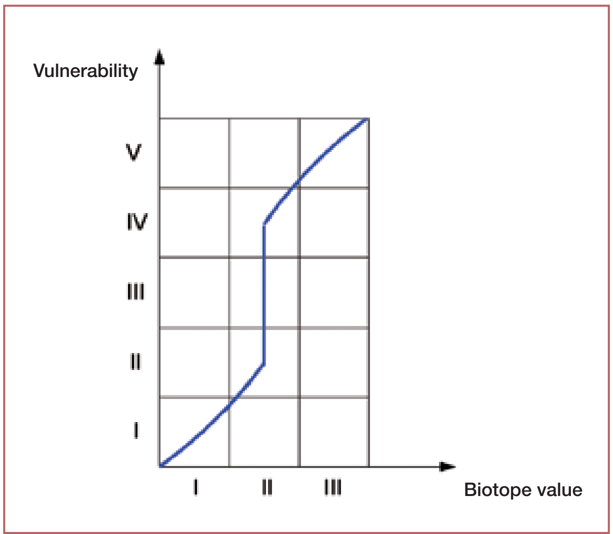


Figure 5.7: Functional relationship between the biotope value and vulnerability

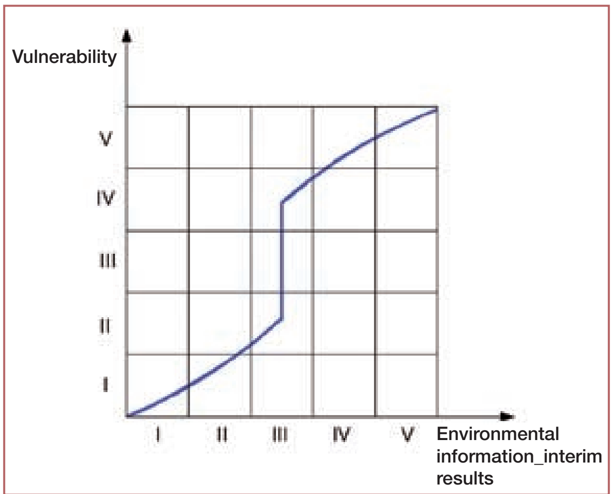


Figure 5.8: Functional relationship between the Environmental_Information_Intermediate_Results and vulnerability

Environmental information_interim results \ Biotope value	I	II	III
I	I	II	III
II	I	II	III
III	II	III	IV
IV	III	IV	V
V	III	IV	V

Figure 5.9: Preference matrix for the biotope value and the Environmental_Information_Intermediate_Results

The result of the integration can be visualised in the form of a map of environmental information relevant to vulnerability, in this case for the example of Cologne (see Figure 5.10).

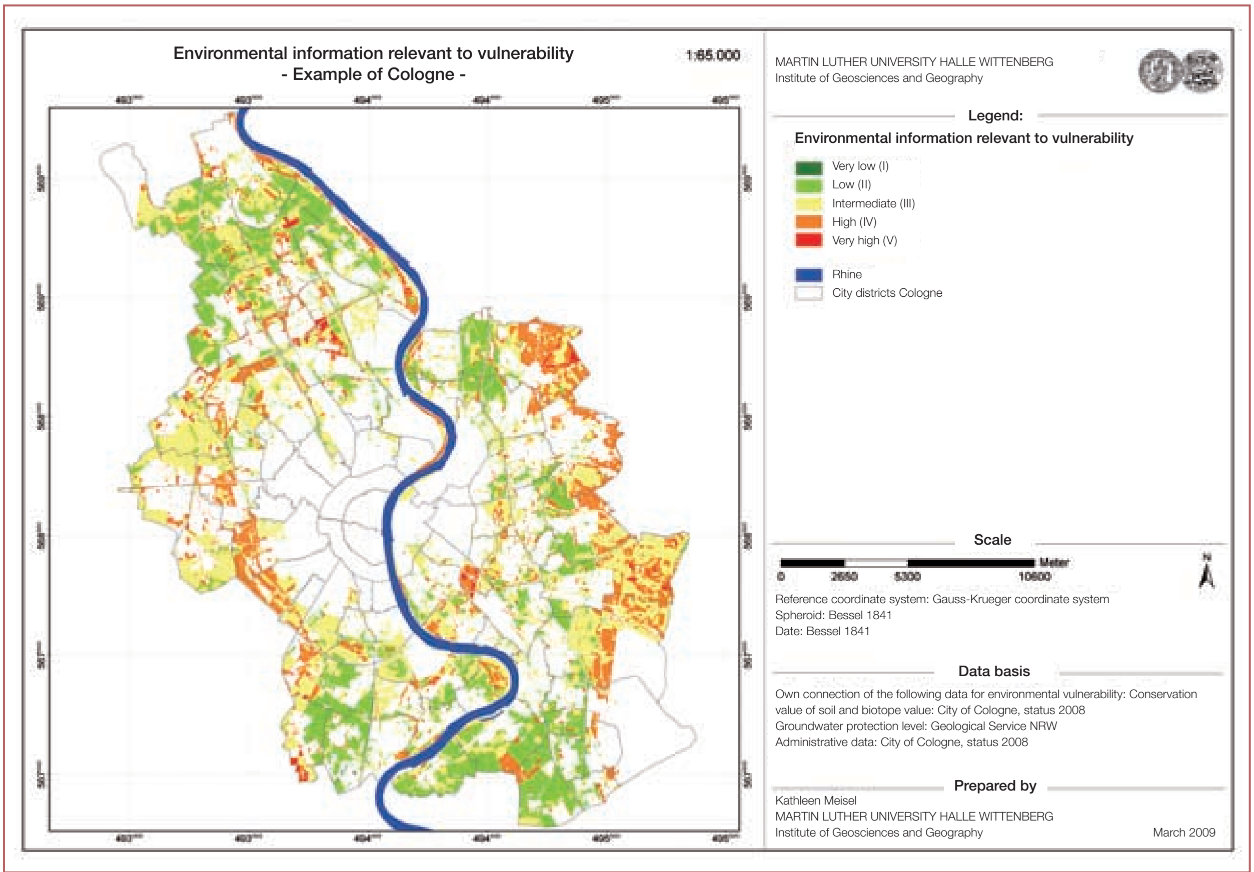


Figure 5.10: Environmental information relevant to vulnerability

Handling gaps in the data:

If it is not already available, information on the conservation value of the soil can be created from a variety of different parameters. If data on the soil‘s „closeness to the natural state“ is collected, other special functions of the soil such as its biosphere function, regulation function and archive function can be used to re-evaluate the rating classes for „closeness to the natural state“. The resulting classifications then form the rating classes for the „conservation value of the soil“. It is also possible to generate rating classes for the „conservation value of the soil“ by estimating the soil‘s fulfilment of the following criteria: „archive function“, „biotope development“ and „fertility/regulation function“. If information about the „groundwater protection level“ is missing, this can also be generated using a range of different procedures described in relevant literature. One possibility is offered by the Hölting method[33] that is based on seepage water calculations. A simpler process is to integrate data about the thickness and permeability of the soil layers above the groundwater. If no data about „biotope values“ is available for the community, this should be

[33] Hölting et al. (1995): Konzept zur Bewertung der Schutzfunktion der Grundwasserüberdeckung, LAWA Arbeitshilfe zur Umsetzung der EG-Wasserrahmenrichtlinie (Concept for the evaluation of the protective function of the groundwater cover, LAWA Guidelines for implementing the EU Water Framework Directive).

generated based on biotype mapping. All three datasets are essential for determining the vulnerability of the environment and should, if not already available, be generated yourself using the processes described above.

It is also possible that the environmental information relevant to vulnerability cannot be represented for the whole area under investigation, as is the case for the example of Cologne, because individual datasets for „conservation value of the soil“, „groundwater protection level“ and „biotope value“ are not available for the entire area covered by the community. It is often the case that the urban soil in inner city areas has not been mapped. Therefore, it is not possible to make any statements about the „conservation value of the soil“. „White spots“ on the map indicate that no information is available about the environmental characteristics in these areas. Nevertheless, it should be noted that these areas could potentially have a high level of vulnerability that remains unidentified due to the lack of available information.

5th Step: Determining the vulnerability of the environment to contaminated sites

Following the identification of the relevant environmental characteristics in the previous assessment step, these characteristics should now be combined with the first source of contamination – the contaminated sites. The vulnerability of the environment to pollution from contaminated sites is determined by overlapping those environmental areas for which environmental information relevant to vulnerability exists with the potential contamination impact of the contaminated sites.

As the dispersion of hazardous materials from contaminated sites into the soil and the risen groundwater during and after the flood event primarily flows vertically as previously described (see Chapter 5.1.2), the assessment of the exposure of the relevant environmental areas exclusively takes into account the biotope, soil or soil layers and groundwater found on or below the contaminated sites. In order to keep the process as simple as possible when dealing with contamination of the groundwater, the direction of flow in the aquifer is not taken into account when looking at the dispersion of hazardous materials.[34] Only those environmental areas located within the contaminated sites are potentially exposed to possible contamination. Therefore, an environmental area is considered very vulnerable if a contaminated site also coincides with a very high rating for the environmental information relevant to vulnerability (from the 4th Step of the assessment).

In the process presented in these guidelines, the potential damage is not differentiated further based on the relevant contaminants because more detailed information on the stock of hazardous materials held at each individual contaminated site or suspected contaminated site is not available for data protection reasons. If you want to more precisely determine the vulnerability of the environment to the damaging impact from contaminated sites, it is possible, for example, to use the detailed investigation process described in the Federal Soil Protection and Contamination Ordinance (BBodSchV) to evaluate the potential risk posed by a contaminated site according to an ordinal scale and to integrate it with the environmental information relevant to vulnerability from the 4th Step of the assessment.

[34] If hazardous materials from contaminated sites penetrate into the groundwater, these materials will be dispersed over decades in the direction of groundwater flow. For the purposes of simplifying the assessment process, no modelling of the direction of flow of the groundwater should be included and as a dilution effect in the water would also need to be calculated, the investigation only focuses on the immediate risk posed at the point of entry.

Question: Which areas are exposed to pollution from contaminated sites or which areas of the environment are vulnerable to contaminated sites?

Process steps:

Import the themes „Environmental information relevant to vulnerability“ and „Contaminated sites“ into a new „View“. Add the information for the flood zone based on the selected flood scenario (theme „Flood zone scenario 1 (2, 3…)“). Use the theme „Contaminated sites“ as a template and cut out the affected environmental areas from the theme „Environmental information relevant to vulnerability“ using the „Cut“ or „Clip“ functions. Save these areas in a new theme and name it „Environmental vulnerability to contaminated sites“. Use the same process to cut out those areas affected by the flood zone from the selected flood scenario from the theme „Environmental vulnerability to contaminated sites“ by using your selected flood zone as a template. The result will indicate those environmental areas that are vulnerable to potential contamination due to the existence of contaminated sites in the case of your selected flood scenario (named “Vulnerability of the environment to contaminated sites”).

Example:

In the map (see Figure 5.11), the environmental information relevant to vulnerability is displayed in combination with the contaminated sites using the example of Cologne. If the contaminated sites are additionally integrated with the flood zone for an extreme flood event (HQ-500 scenario), only those environmental areas vulnerable to pollution from contaminated sites in the case of an extreme flood event will be shown.

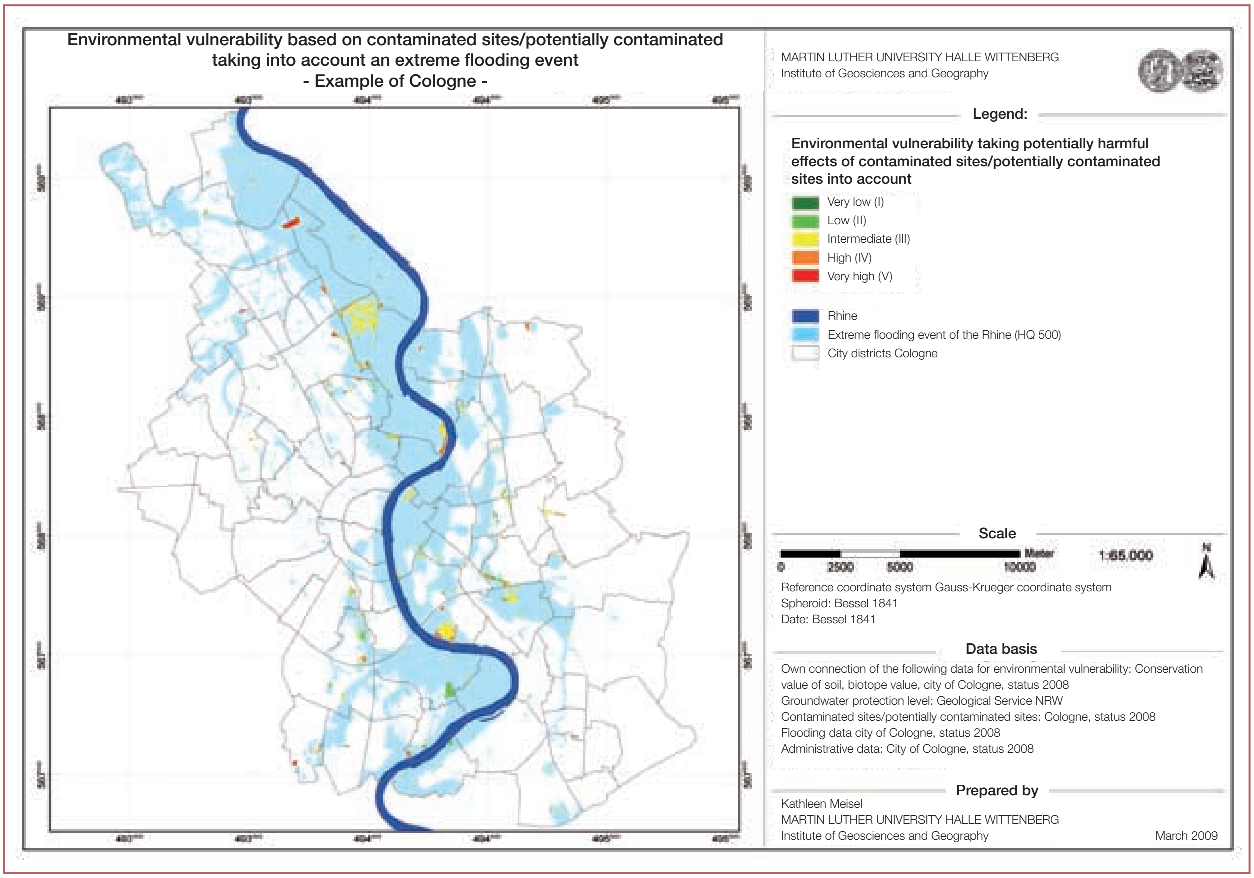


Figure 5.11: Environmental vulnerability based on contaminated sites

Handling gaps in the data:

It is important to note that information on those areas potentially vulnerable to contaminated sites is not necessarily complete. Environmental areas with a high level of environmental vulnerability could be hidden behind „white spots". As a result of inadequate data for the individual criteria, it is not possible to make any statements about the vulnerability in these locations. For example, this is the case in Cologne where the subsoil in the inner city areas has not been comprehensively mapped in order to classify the conservation value of the soil and the groundwater protection level. Consequently, it is not possible to make any statements about the vulnerability of the environment to contaminated sites in these locations. The reliability of any statements about vulnerability are therefore dependent to a large degree on the quality and completeness of the available data.

6th Step: Determining the vulnerability of the environment to hazardous materials from installations/establishments

Following the investigation into contaminated sites, it is now necessary to consider the remaining sources of contamination – the installations/establishments defined in Chapter 5.1.3. In this section of the guidelines, the environmental areas vulnerable to possible contamination are considered to be those that are located within the sphere of influence of a possible release of hazardous materials from these installations and establishments. It is also important to note the decreasing level of damage caused by those hazardous materials dissolved in the flood wave as the distance from the installations and establishments increases. Therefore, those surrounding environmental areas that display, on the one hand, a very high rating for environmental information relevant to vulnerability and, on the other hand, are located in the immediate sphere of influence of an installation/establishment are considered very vulnerable to potential contamination.

***Question:** Which areas are exposed to contamination from hazardous materials from installations/establishments or which areas of the environment are vulnerable to them?*

Process steps:
Import the themes „Environmental information relevant to vulnerability", „Installations" and „Establishments" into your GIS. Add the information for the selected flood scenario (theme „Flood zone scenario 1 (2, 3…)"). If the datasets for the installations and establishments are contained in different themes, link them together using the „Merge" or „Union" functions. This function will automatically create a new theme, which contains both the installations and the establishments. Name this theme „Installations + establishments". If the themes were never available separately, you can continue to use this already existing theme.

Now use the theme „Installations + establishments“ to create a new theme using the „Multiple Ring Buffer“ function, which you can then name „Contamination effects of the installations + establishments“. Create 3 buffer zones at distances of 170 m, 245 m and 300 m[35] from the location of the contamination source. The „Dissolve ALL“ function can be used to combine all buffer zones at the same distance from the contamination source. The areas created in this way should now be allocated to the attribute table for the theme „Damaging effect ratings“. All areas within a distance of 170 m receive a high rating (class III), the areas in the range between 170 m and 245 m a middle rating (class II) and the areas at a distance between 245 m and 300 m a low rating for the damaging effect of the contamination (class I).

It is now necessary to integrate the exposed environmental areas determined in this process with the „Environmental information relevant to vulnerability“. In order to determine the vulnerability of the environment to the damaging effects from installations/ establishments, it is necessary to logically integrate the themes „Contamination effects of the installations + establishments“ and „Environmental information relevant to vulnerability“ (see Appendix 7.5). In this case, it is not necessary to adapt the functional curves according to the specific level of data available (i. e. compress or expand them) because the relationships between environmental information relevant to vulnerability and vulnerability, as well as those between the contamination intensity based on their buffer zone location and vulnerability, are fixed. Therefore, the preference matrix already exists as shown in Figure 5.12. In order to complete the logical data integration in the GIS, it is possible to simply take the values from this matrix.

Environmental information relevant to vulnerability	Damaging effect of installations/ establishments (buffer zones): I	II	III
I	I	II	III
II	I	II	III
III	II	III	IV
IV	III	IV	V
V	III	IV	V

Figure 5.12: Preference matrix for the environmental information relevant to vulnerability and the damaging effect of the installations and establishments (buffer zones)

Integrate the theme „Contamination effects of the installations + establishments“ with the theme „Environmental information relevant to vulnerability“ in your GIS using the „Merge“ or „Union“ functions. A new theme will be automatically created that contains the datasets from both themes (named as „Environmental vulnerability to installations + establishments“). Now continue as described in the 4th Step of the assessment: Add a new column in the attribute table for the new theme. Now query every possible combination of ratings for both criteria and enter the corresponding value from the preference matrix into the new fields for the marked datasets. Once all of

[35] The distances were determined based on a method described in a project publication from the series of publications „Research into Civil Protection“ mentioned in Chapter 1.1. Although the damaging effects of contamination can only occur in the direction of flow, a ring-shaped zone with uniform distances to the source of contamination has been used in order to simplify the assessment process and to take account of the unpredictability of the exact direction of drainage. The actual plume of hazardous materials around the source of contamination cannot be determined without the aid of more complex processes.

the values have been completely entered in the new column, you can now display the new theme classified according to the new column in „View".

The result indicates those environmental areas that are vulnerable to the damaging effects of installations and establishments. However, only those environmental areas within the buffer zones are shown. The resulting theme is named „Vulnerability of the environment to installations + establishments".

Now overlay the flood zone for your selected flood scenario with the vulnerable environmental areas located within the buffer zones using the „Cut" or "Clip" functions. You will obtain the theme „Vulnerability of the environment to installations + establishments scenario 1 (2, 3,…)" as a result.

Example:

The map below (see Figure 5.13) shows the result of linking the environmental information relevant to vulnerability with the potential contamination effects due to installations/establishments and overlapping it with the flood zone for an extreme flood event (HQ-500).

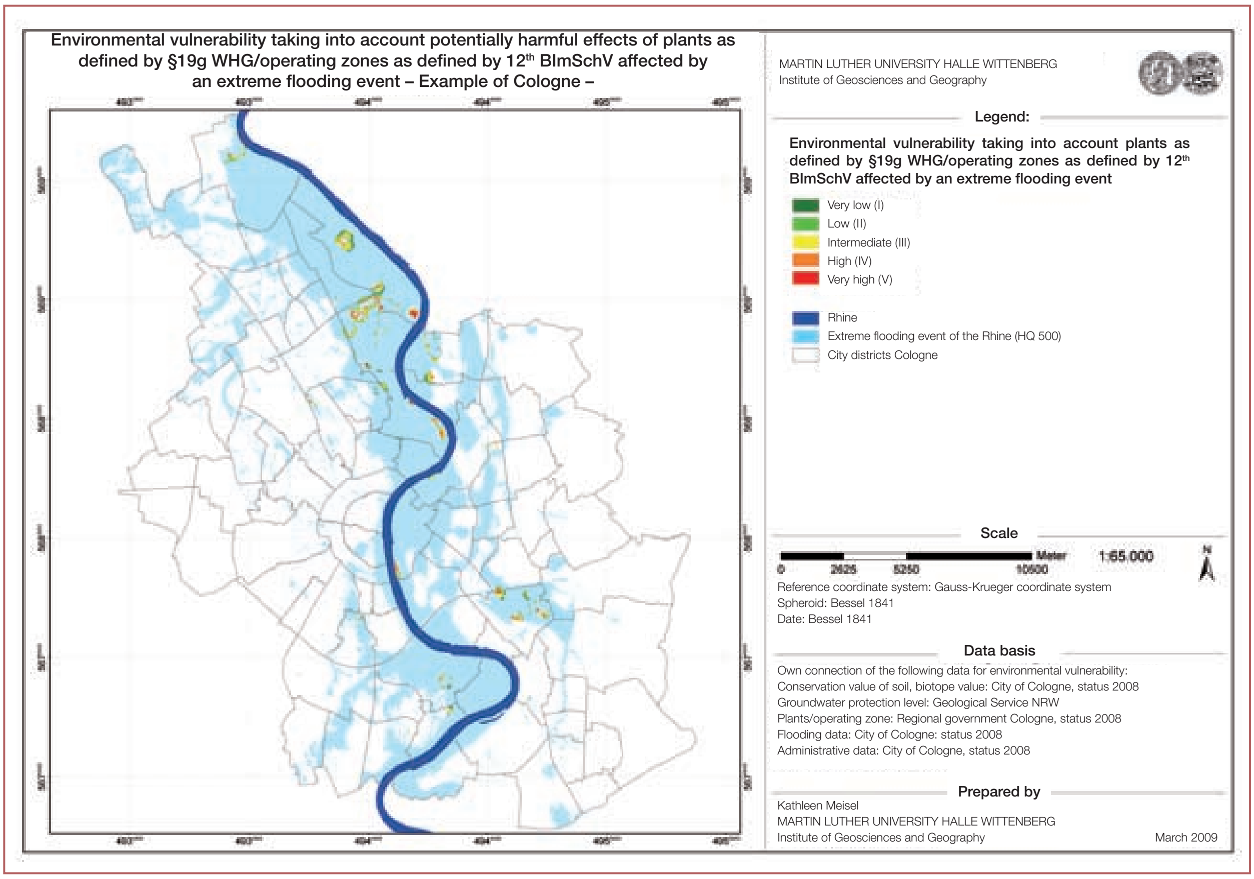


Figure 5.13: Environmental vulnerability due to installations/establishments

Handling gaps in the data:

It is important to note that the information available about those environmental areas potentially vulnerable to contamination due to hazardous materials from installations/establishments is not always complete. In the example shown here for the city of Cologne, the map only displays isolated areas that are considered vulnerable.

7th Step: Determining the vulnerability of the environment to contamination in the event of a flood

It can be assumed that damaging effects and thus the overall flood-related vulnerability of the environment increases due to the cumulative effect of damage caused as a result of the different contamination sources. For example, if the sphere of influence of an installation according to Article 19g of the WHG coincides with a contaminated site then this increases the vulnerability of the environmental area located there.

Question: *Do environmental areas that are vulnerable to potentially damaging effects of contaminated sites overlap with those vulnerable to installations/establishments?*

Process steps:
Import the themes „Vulnerability of the environment to contaminated sites" (result from the 5th Step of the assessment) and „Vulnerability of the environment to installations + establishments" (result from the 6th Step of the assessment) into a new „View" and check whether there is any overlap (see 3rd Step of the assessment).

If you identify any overlapping areas then integrate both themes („Vulnerability of the environment to contaminated sites" and „Vulnerability of the environment to installations + establishments") using the „Merge" or „Union" functions. This will create a new theme that you can name „Vulnerability of the environment to contamination". Create a new column in the attribute table for the theme produced in this process, in which the integration results for all combination possibilities will be entered.

In the attribute table for this theme, two possible cases generally exist. Either the environmental areas that are vulnerable to contamination from contaminated sites or installations/establishments do not overlap but are instead located next to each other (in these cases, the vulnerability rating for both themes is entered as 1:1 in the new field) or they do overlap. If they overlap, the average value of the two vulnerability ratings is increased by two classes and entered in the new field. Therefore, the previous 5-level classification system is now transformed into a 7-level classification system. For example, if the rating I is present in both themes, these datasets are now allocated the rating III in the combined attribute table. The new theme „Vulnerability of the environment to contamination" is now rated according to the new column. The new 7 rating classes for flood-related environmental vulnerability that take into account all potential damaging effects can be verbally described as follows: „particularly low vulnerability"– „very low vulnerability" – „low vulnerability" – „medium vulnerability" – „high vulnerability" – „very high vulnerability" – „particularly high vulnerability". Therefore, the GIS shows those environmental areas located within potentially contaminated sites and buffer zones rated according to their vulnerability. It covers all of those environmental areas that are vulnerable to possible contamination from potential sources of contamination for your selected flood scenario.

Example:

As a result of carrying out this process step, the flood-related vulnerability of the environment to all potential sources of contamination can now be illustrated in a GIS. This is shown here using the example of the city of Cologne for an extreme flood event (HQ-500) (see Figure 5.14).

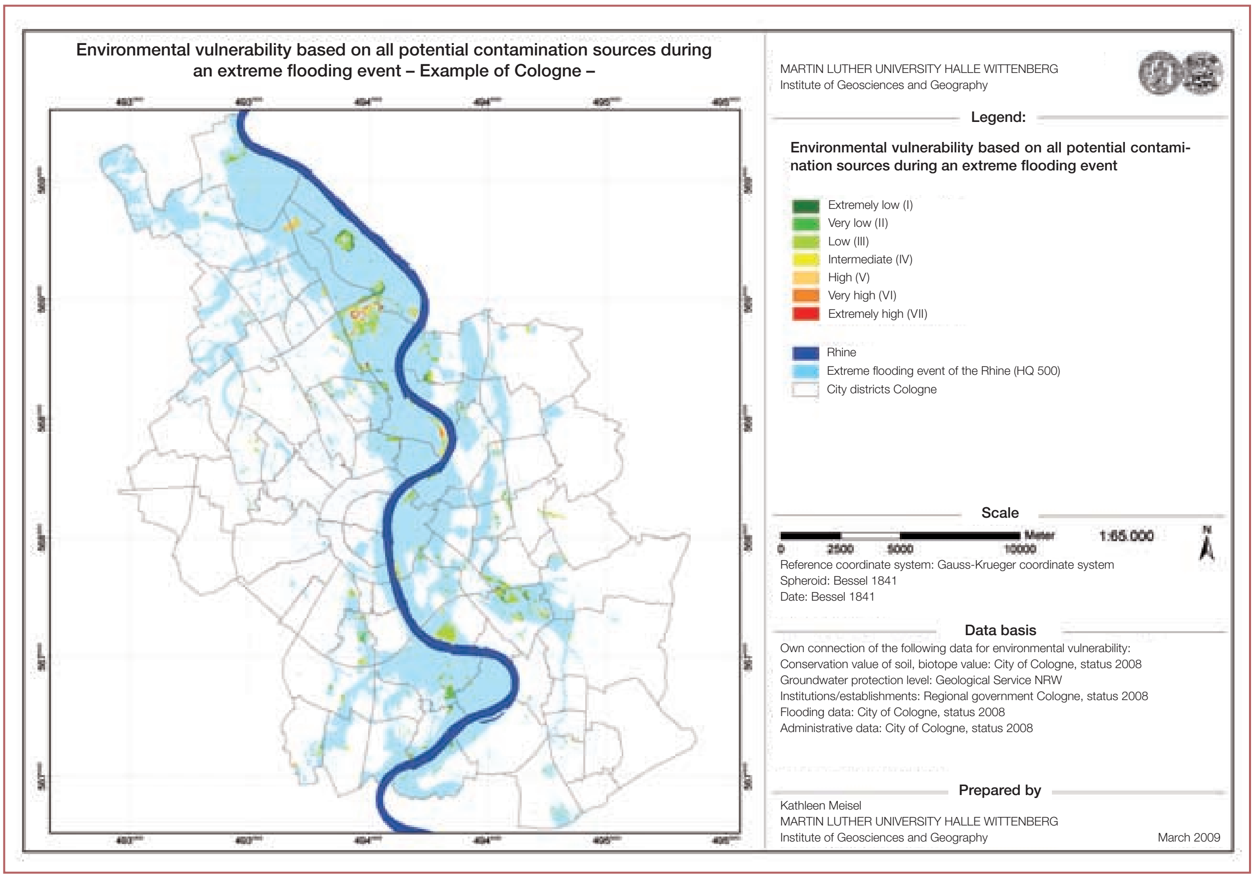


Figure 5.14: Environmental vulnerability based on all potential contamination sources

Handling gaps in the data:

It is also possible here that some areas that are in reality vulnerable to potential contamination cannot be represented due to the lack of available information about the individual themes. This problem must be taken into account in the interpretation of the map.

5.3 Examining the vulnerability of individual environmental areas

Depending on your level of interest, individual assessments of certain environmental areas and sources of contamination can be carried out above and beyond the determination of the flood-related vulnerability of the environment. In the following section of these guidelines, some additional possibilities for using the available themes and, where relevant, sensibly supplementing them with further information will be presented. For example, this could include examining in which locations and to what extent the soil, groundwater or biotope could be negatively influenced by potential contamination from the named sources or determining their relative vulnerability.

As already mentioned in the process for determining the flood-related environmental vulnerability, the vulnerability of the environment is influenced by the environmental characteristics relevant to vulnerability. If the vulnerability of the soil, groundwater and biotope are now to be individually investigated, information about the soil, groundwater and biotope that is relevant to vulnerability and which is derived from the individual characteristics of the soil, groundwater and biotope relevant to vulnerability must be taken into account. The characteristics of the soil relevant to vulnerability are represented by the criterion „conservation value of the soil“, the characteristics of the groundwater relevant to vulnerability by the criterion „groundwater protection level“ and the characteristics of the biotope relevant to vulnerability by the criterion „biotope value“. As described in Chapter 5.1.3, soil with a high conservation value, very valuable biotopes and groundwater with a very poor level of protection can be considered to be very vulnerable.

When overlapping the characteristics of the soil relevant to vulnerability and the characteristics of the groundwater relevant to vulnerability with the potential contamination from contaminated sites, only the ratings for the soil and groundwater data (= ratings for the conservation value of the soil and the groundwater protection level) within the contaminated site are investigated because it is only here that there is an immediate risk of possible contamination. The level of vulnerability is only based in this case on the conservation value of the soil and the groundwater protection level. As described in connection with the 4th Step of the assessment, the community can use the detailed investigation process described in BBodSchV to evaluate the potential risk posed by different contaminated sites and thus determine the level of vulnerability more precisely.

When correlating the contamination effects from installations and establishments, for example, with the information on soil or biotopes relevant to vulnerability, it is not only the ratings for the criteria „conservation value of the soil“ and „biotope value“ within the sphere of influence indicated by the buffer zones that are investigated. Moreover, there is an additional logical data integration to include the graded ratings of the damaging effects around the installations/establishments with the different ratings for the information on soil or biotopes relevant to vulnerability. Therefore, the level of vulnerability is not only dependent on the conservation value of the soil and the biotope value but also the intensity of the damaging impact due to the installations/establishments.

Furthermore, overlapping information about human uses of environmental functions could also prove useful for communities. For example, you could investigate whether contaminated sites are located in drinking water catchment areas and whether in these locations the groundwater only has a poor level of protection – meaning that there is a greater risk to the drinking water supply posed by the contaminated sites.

5.3.1 Determining the vulnerability of the soil and groundwater from contaminated sites

As described in Chapter 5.1.2, contaminated sites represent a potential risk to the soil and groundwater in the event of your selected flood scenario. This contamination could adversely affect the provision of groundwater as the basis for the drinking water supply. A very high level of vulnerability exists in those areas where soil with a very high conservation value and groundwater with a very low protection level geographically overlap with contaminated sites. If the potentially endangered groundwater is located in a protected drinking water catchment area, there is a risk to the supply of clean drinking water to the population.

Vulnerability of the soil from contaminated sites

***Question:** Where and to what extent is the soil vulnerable to contaminated sites in the event of a flood?*

Process steps:
Import the flood zone for your selected theoretical flood scenario („Flood zone scenario 1, 2, 3,...") into your GIS. Supplement this information with the themes „Conservation value of the soil" and „Contaminated sites". Cut out the contaminated sites from the theme „Conservation value of the soil" using the „Cut" or „Clip" functions so that only those soil areas within the contaminated sites are shown with their relevant ratings. Now use the flood zone for your selected flood scenario as a template and cut out all of the areas affected by the flood scenario from the newly created theme. The result indicates those soil areas that are vulnerable to potential contamination from contaminated sites in the case of your selected flood scenario. The theme created in this process can be named „Vulnerability of the soil to contaminated sites scenario 1 (2, 3,…)".

Example:

The following map (see Figure 5.15) illustrates the process step that was just described. It shows the different ratings for the „conservation value of the soil" within the contaminated sites or suspected contaminated sites in the event of an HQ-100 scenario.

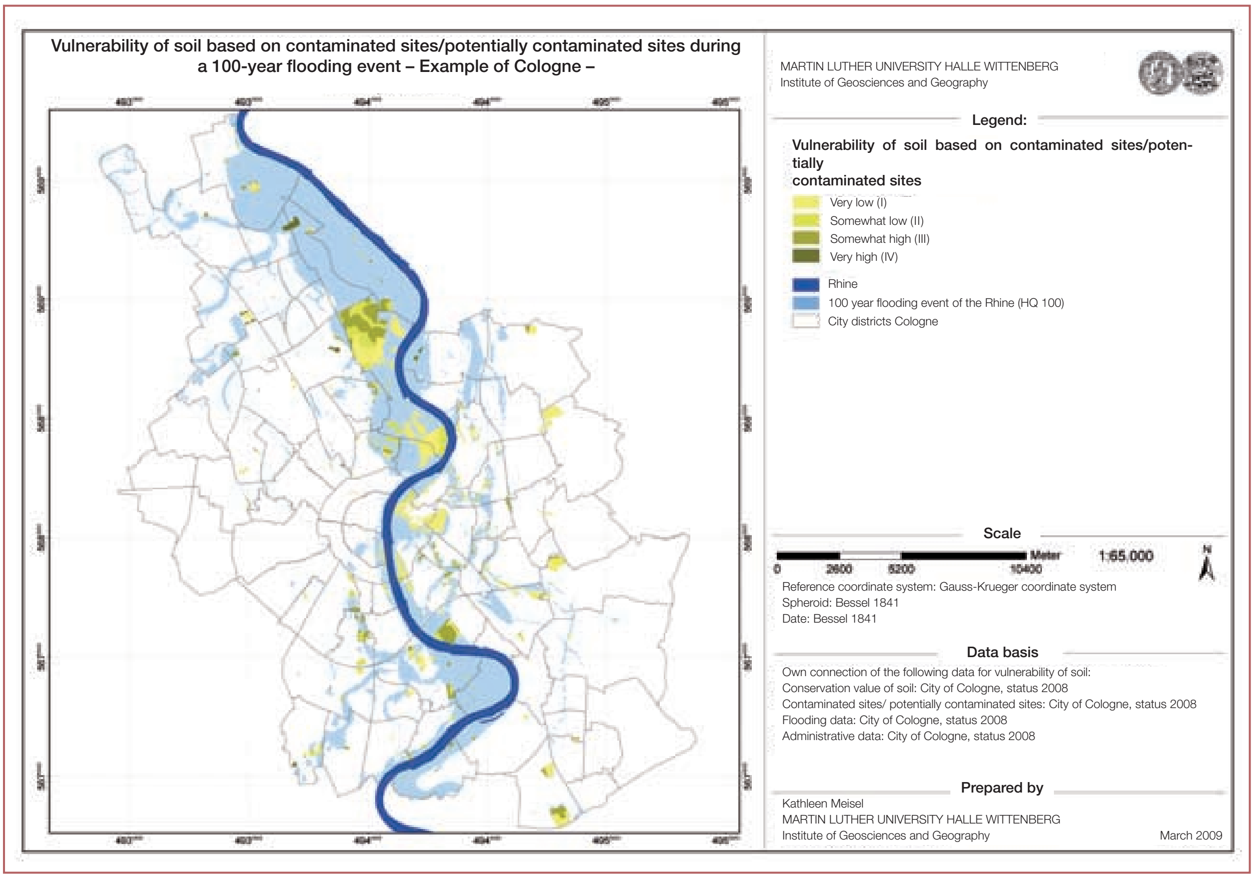


Figure 5.15: Vulnerability of the soil based on contaminated sites

Handling gaps in the data:

It should also be noted here that some soil areas that are in reality vulnerable cannot be represented on the map due to the lack of available information in the theme „Conservation value of the soil“. This is particularly true in the case of the city of Cologne, for example, in the inner city areas. For this reason, it is necessary to be cautious when interpreting the information shown.

Vulnerability of the groundwater to contaminated sites

Question: Where and to what extent is the groundwater vulnerable to contaminated sites in the event of a flood?

Process steps:
Follow the same process used for the theme „Conservation value of the soil“ in the previous step for the theme „Groundwater protection level“. The resulting theme should be named „Vulnerability of the groundwater to contaminated sites scenario 1 (2,3,…)“.

Example:

The map (see Figure 5.16) shows the relevant groundwater protection level in those areas faced with the potential damaging effects of contaminated sites or suspected contaminated sites in the event of a flood with a 100 year recurrence probability (HQ-100) using the example of the city of Cologne.

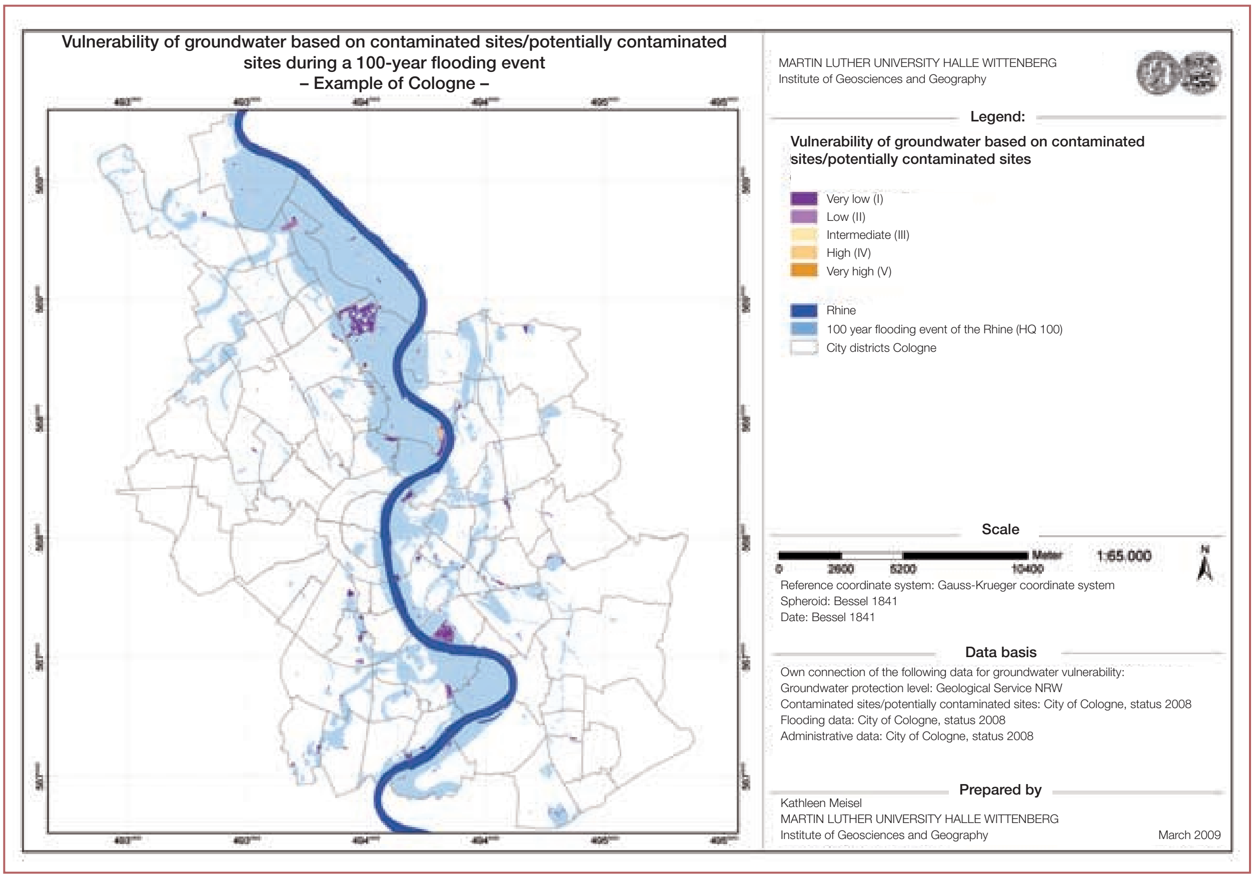


Figure 5.16: Vulnerability of the groundwater based on contaminated sites

Handling gaps in the data:

It is also important to note here that gaps in the available information for the theme „Groundwater protection level“ can lead to an incomplete representation of this topic. This can be observed in the case of the city of Cologne.

Vulnerability of the drinking water to contaminated sites

This process step investigates the extent to which information about the protected drinking water catchment areas can be overlayed onto the contaminated sites. It can be used to find out whether and in what locations the drinking water supply is at risk to contamination from contaminated sites. The vulnerability of drinking water is determined by integrating the already determined vulnerability of the groundwater to contaminated sites from the previous step with the protection zones for the drinking water catchment area. Therefore, you will need to create a new GIS theme, which illustrates the protected drinking water catchment areas, named in the following section „Protected drinking water catchment areas“. The drinking water is considered to be vulnerable when the protected drinking water catchment areas are located within the contaminated sites. The vulnerability of the drinking water is very high in those areas where groundwater with a very low protection level within contaminated sites overlaps with those protection zones for the drinking water catchment area that have the strictest regulations.

Question: *Where and to what extent is the drinking water vulnerable to contaminated sites in the event of a flood?*

Process steps:
Import the themes „Vulnerability of the groundwater to contaminated sites scenario 1 (2, 3,…)“ and „Protected drinking water catchment areas“ in a new „View“. Check whether the protected drinking water catchment areas overlap with the contaminated sites or those areas already classified under groundwater vulnerability (see Step 3). If this is the case, there is a potential risk to the groundwater.

For a more detailed examination, it is necessary to firstly import the theme „Protected drinking water catchment areas“ according to the protective zones I, II, III in a „View“ or carry out a corresponding classification. In order to determine the vulnerability of the drinking water, these classified protected drinking water catchment areas now need to be logically integrated with the groundwater vulnerability to potential damaging effects from contaminated sites according to the principles described in Appendix 7.5. This requires you to use the fixed functional relationship between the protective zones and vulnerability illustrated in Figure 5.17. Adapt the functional curve between the groundwater protection level and vulnerability illustrated in Figure 5.18 to your ratings for the groundwater protection level. This is achieved by either compressing or expanding the curve and then reading off the vulnerability rating from both curves for all ratings for the two variables in order to integrate them and then enter them into the preference matrix for the two variables. In the GIS, carry out the logical data integration in accordance with the same principles described in the 4th Step of the assessment (see Appendix 7.5).

After you have integrated both themes using the „Merge“ or „Union“ functions to create a new theme that you can name „Drinking water vulnerability“, add a new column to the corresponding attribute table. In general, two cases will become clear in the attribute table. On the one hand, if the groundwater areas within the contaminated sites and the protected drinking water catchment areas are located next to one another then there is no overlap. In this case, the drinking water is only vulnerable to a negligible extent because the drinking water supply is not immediately at risk from the potential dangerous effects posed by the contaminated sites. In these datasets, do not enter a value into the new column – these fields remain empty. In all other cases, integrate the ratings for the vulnerability of the groundwater within the contaminated sites with the protected drinking water catchment areas, which will indicate the vulnerability of the drinking water. In the corresponding datasets, the results from the preference matrix you have created are entered in the new column.

The new theme „Drinking water vulnerability“ has now been rated according to the new field. Because no values are allocated when there is no overlap, you only see those groundwater areas significant for the drinking water supply in the event of your selected flood scenario that are also vulnerable to contaminated areas.

Example:

In the following section of these guidelines, the functional curves that illustrate the interrelationships between the individual themes and vulnerability will be presented. The data for the city of Cologne is used as an example. The preference matrix for integrating the themes for the rated drinking water protection zones and the groundwater protection level can be seen in Figure 5.19. The integration results for both themes are entered into the attribute table for the new theme. In „View“, the theme that was created by integrating this data is then rated according to the new column. The results of this integration process are shown in Figure 5.20.

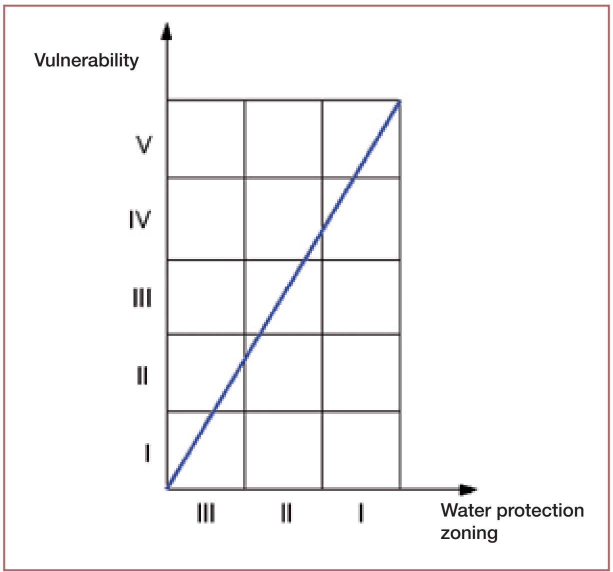


Figure 5.17: Functional relationship between the drinking water protection zones and vulnerability

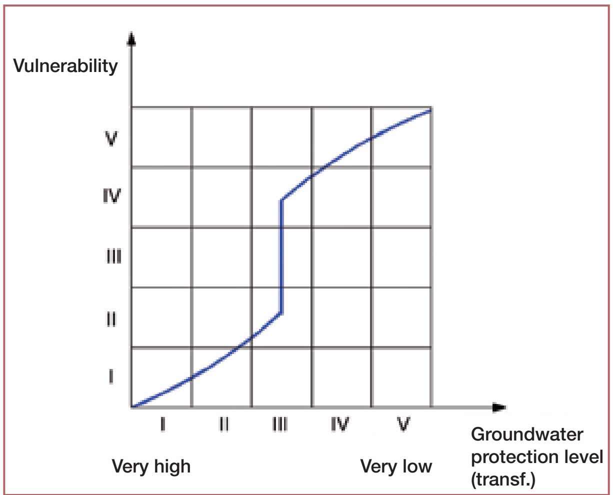


Figure 5.18: Functional relationship between the groundwater protection level and vulnerability

Groundwater protection level (transf.) \ Water protection zoning	III	II	I
I	I	II	III
II	I	II	III
III	II	III	IV
IV	III	IV	V
V	III	IV	V

Figure 5.19: Preference matrix for the drinking water protection zones and the groundwater protection level

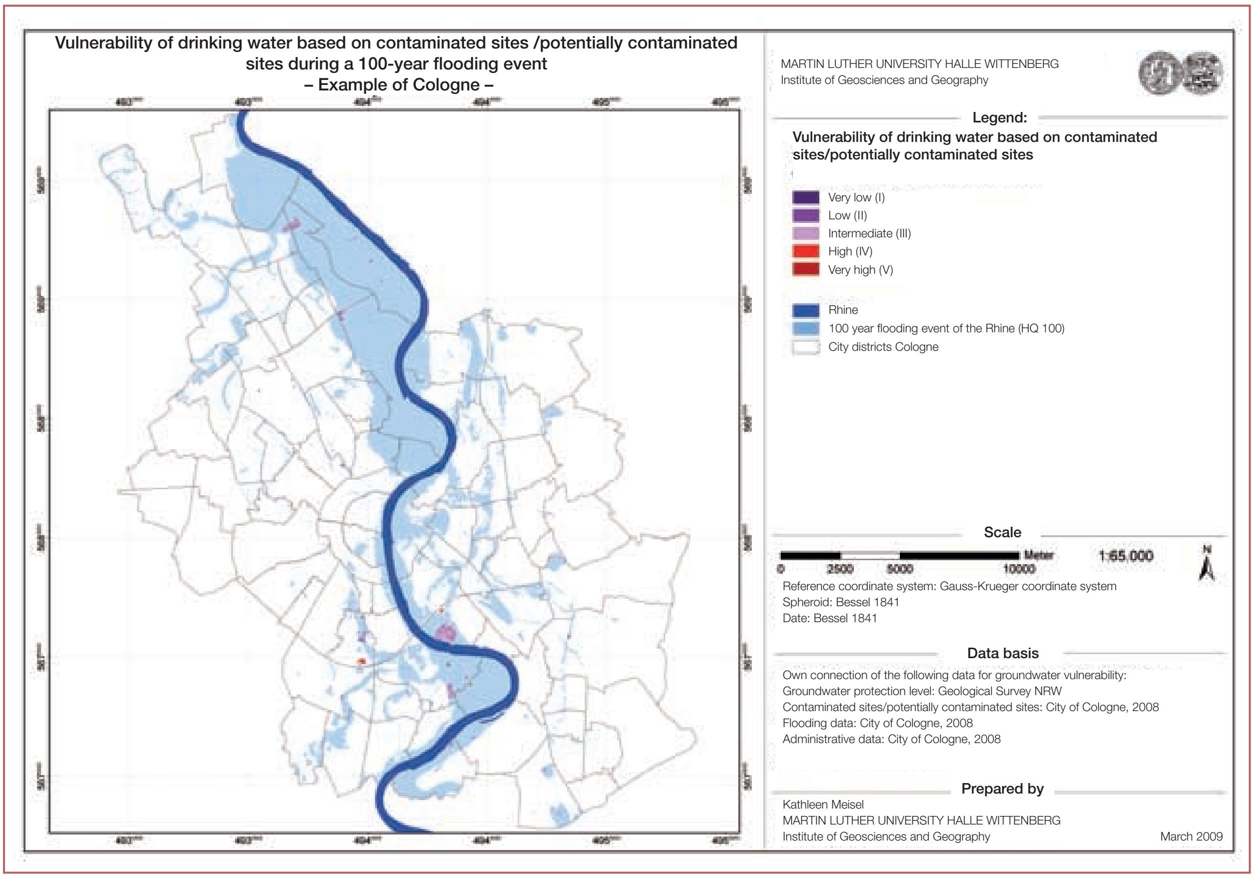


Figure 5.20: Vulnerability of the drinking water based on contaminated sites

Handling gaps in the data:

It is important to note that gaps in the available information on „groundwater protection level“ can lead to an incomplete representation of the vulnerability of the drinking water.

5.3.2 Determining the vulnerability of soil and biotope to contamination from installations/establishments

If hazardous materials are released from installations/establishments as described in Chapter 5.1.2, the surrounding area will be contaminated depending on the transport capacity of the flood and the characteristics of the released hazardous materials. These hazardous materials can directly endanger the soil and plants. The hazardous materials can also be transferred to plants and animal biocoenoses through the intake of nutrients and food from the soil. There is a very high level of vulnerability in those areas where soil with a particularly high conservation value and valuable biotopes are located within the sphere of influence of the named contamination sources (within the buffer zones created in the 6th Step of the assessment).

Vulnerability of the soil to possible contamination from installations/establishments

The vulnerability of the soil to potential damaging effects from installations/establishments is determined by overlapping or integrating the characteristics of the soil relevant to vulnerability, which corresponds to the theme „Conservation value of the soil", with the installations and establishments (theme „Installations + establishments"). The level of vulnerability is determined by the rating for the conservation value of the soil and the intensity of the potential contamination effects (buffer zones).

Question: *Where is the soil vulnerable to contamination from installations/establishments in the event of a flood?*

Process steps:
Import the flood zone based on your selected flood scenario into a new „View" in your GIS. Supplement this information with the themes „Conservation value of the soil" and „Installations + establishments". You have already added the three buffer zones for the different contamination intensities (see Step 6). In order to gain an overview of which areas of the soil are at risk due to the potential damaging effects of the contamination sources, you can display only those soil areas, differentiated according to their conservation value, within the sphere of influence of the installations and establishments. This is achieved by cutting out the sphere of influence of the contamination sources, represented by the buffer zones in the theme „Contamination effects of the installations + establishments" from the theme „Conservation value of the soil" using the „Cut" or Clip" functions. This makes it clear whether and where soil with a very high conservation value is at risk from the damaging effects of the contamination sources in the case of your selected flood scenario (1, 2, 3,…).

If you also want to determine the level of vulnerability of these areas of soil more precisely, carry out a logical data integration of the two themes „Contamination effects of the installations + establishments" and „Conservation value of the soil". This requires you to use the defined functional curve between contamination impact (buffer zones) and vulnerability illustrated in Figure 5.21. Adapt the functional curve between the conservation value of the soil and vulnerability illustrated in Figure 5.22 to your rating classes for the conservation value of the soil. This can be achieved by either compressing or expanding the curve and then reading off the vulnerability rating from both curves for all ratings for the two variables in order to combine and enter them into the preference matrix for the two variables. Now complete the logical data integration in the GIS. After you have integrated both themes using the „Merge" or „Union" functions to create a new theme, add a new column to the corresponding attribute table. Now query all possible combinations of rating classes again from both themes in the attribute table and enter the corresponding values from your preference matrix into the new column for the queried and marked datasets. You can now use the „View" function to display the different levels of vulnerability of the soil to the damaging effects from installations/establishments using the rating classes in the new column for the integrated theme.

Now overlap the flood zone with the vulnerable soil areas located within the buffer zones using the „Cut" or „Clip" functions. The result indicates those soil areas that are vulnerable to potential contamination due to installations and establishments in the case of your selected flood scenario.

Example:

The functional curves for illustrating vulnerability compared to, on the one hand, the intensity of the contamination impact (buffer zones) and, on the other hand, the conservation value of the soil are initially shown using the example of the city of Cologne (see Figures 5.21, 5.22). The preference matrix for both variables has already been created (see Figure 5.23). The visualisation in map form can be found in Figures 5.24 and 5.25.

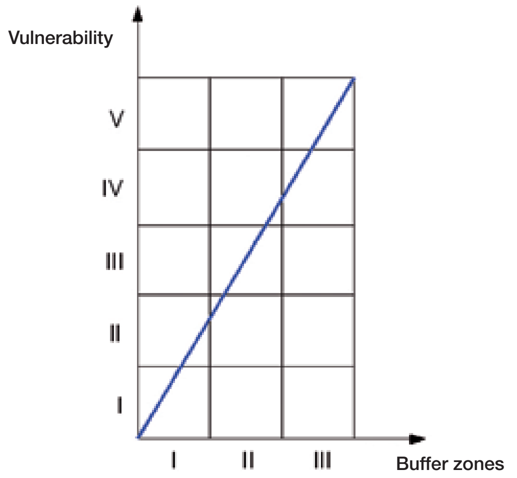


Figure 5.21: Functional relationship between the buffer zones and vulnerability

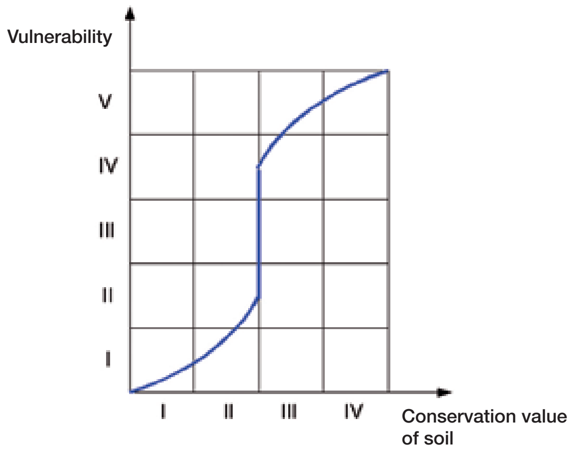


Figure 5.22: Functional relationship between the conservation value of the soil and vulnerability

Damaging effects of installations establishments (buffer zones)

Conservation value of soil	I	II	III
I	I	II	III
II	I	II	III
III	III	IV	V
IV	III	IV	V

Figure 5.23: Preference matrix for the damaging effect of installations/establishments (buffer zones) and the conservation value of the soil

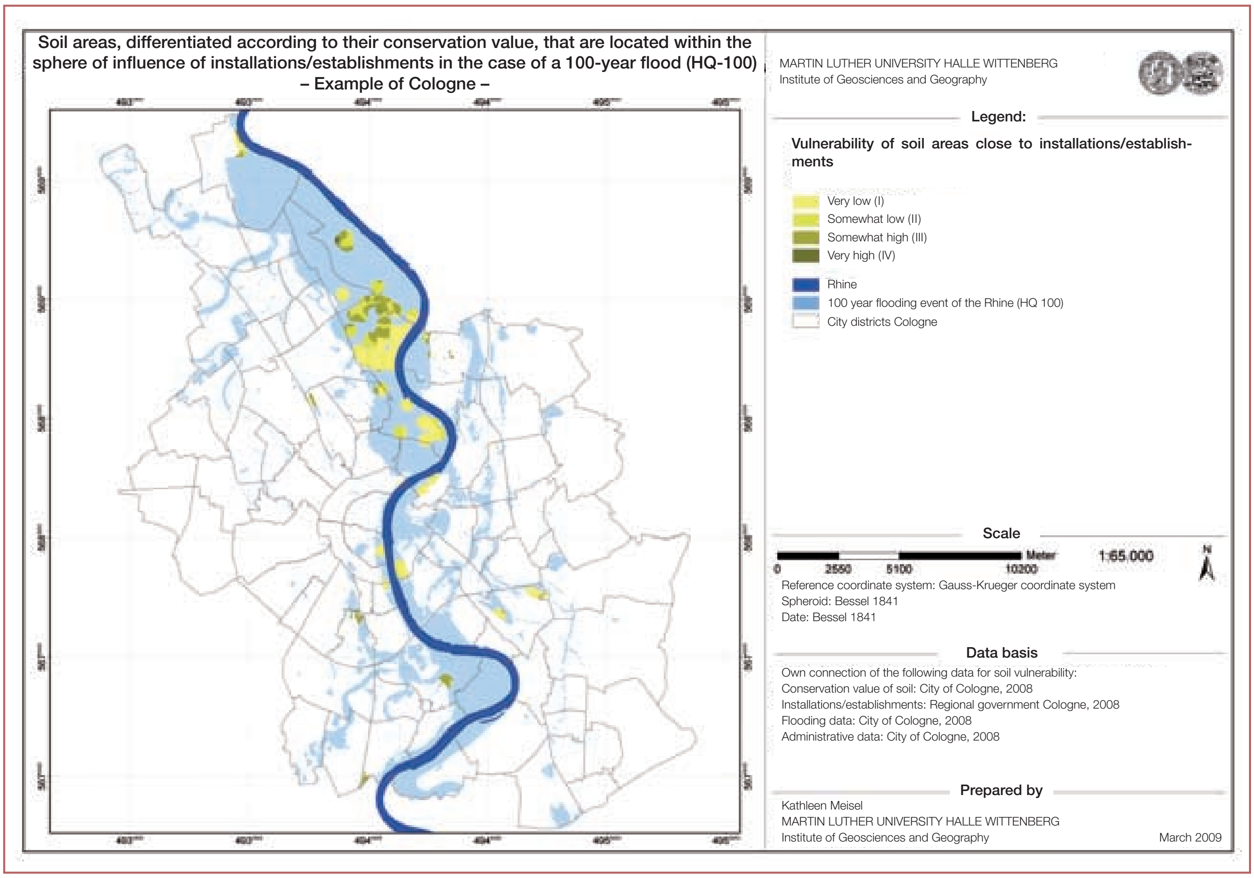


Figure 5.24: Soil areas, differentiated according to their conservation value, that are located within the sphere of influence of installations/establishments in the case of a 100-year flood (HQ-100)

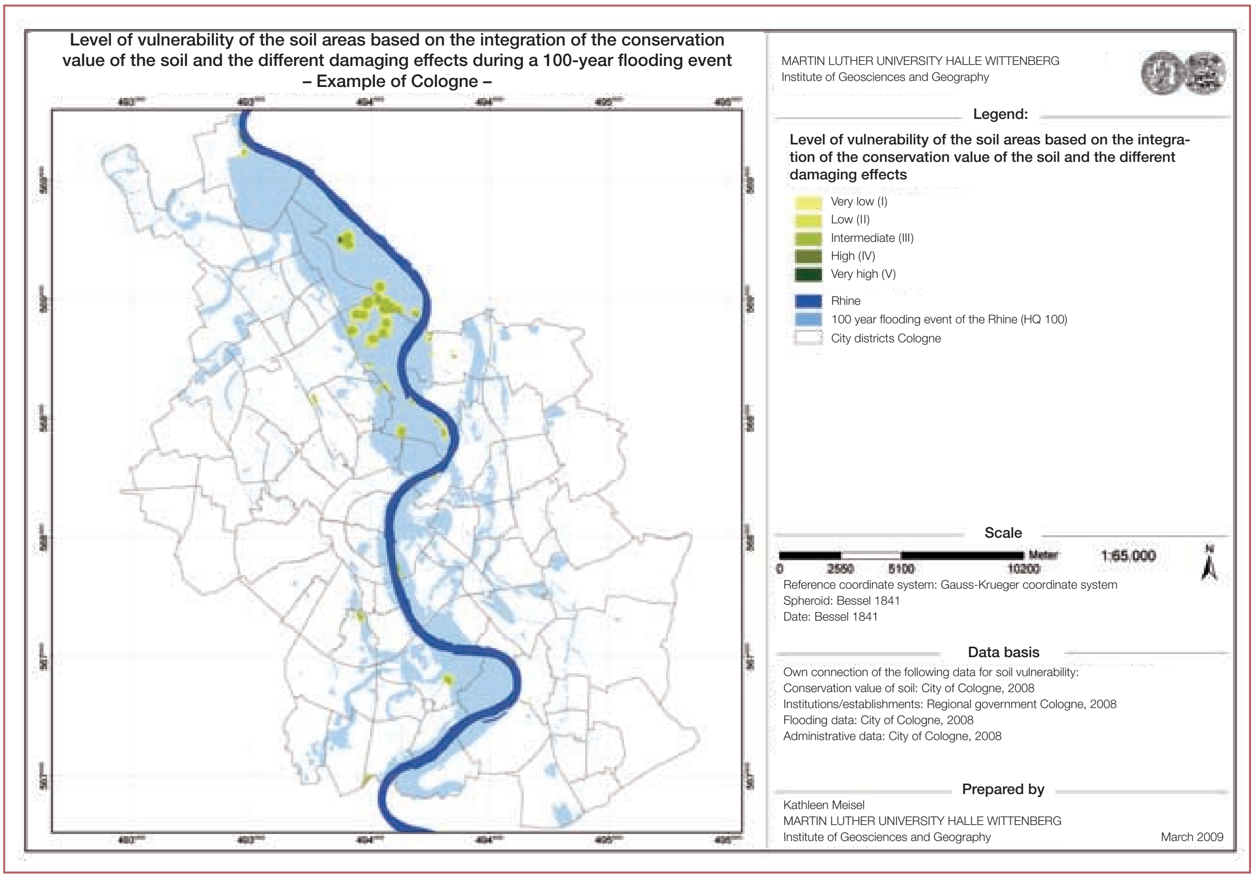


Figure 5.25: Level of vulnerability of the soil areas based on the integration of the conservation value of the soil and the different damaging effects

Handling gaps in the data:

It is important to note that any gaps in the information available about the theme „Conservation value of the soil“ will lead to an incomplete representation of the vulnerability of the soil within the sphere of influence of potential sources of contamination.

Vulnerability of the biotope to possible contamination from installations/establishments

The vulnerability of the biotope to the potential damaging impact from installations/establishments is determined by overlapping or integrating the characteristics of the biotope relevant to vulnerability, which corresponds to the theme „Biotope value“, with the installations and establishments (theme „Installations + establishments“).

Question: Where are biotopes vulnerable to contamination from installations/establishments in the event of a flood?

Process steps:

Import the flood zone for your selected theoretical flood scenario („Flood zone (scenario 1, 2, 3,...“) into your GIS. Import the theme „Biotope value“ and the already combined theme for the installations and establishments and the spheres of influence illustrated in the three buffer zones (the theme „Contamination effects of the installations + establishments).

You can gain an overview about whether and in what locations the biotopes, including the biocoenoses found within them, are potentially at risk due to contamination from installations/establishments by displaying the biotopes, differentiated according to their biotope value, within the sphere of influence of the installations and establishments. This can be achieved by cutting out the spheres of influence, represented by the buffer zones, from the theme „Biotope value“ using the „Cut“ or „Clip“ functions.

When you then subsequently integrate the result with your defined flood zone using the „Cut“ or „Clip“ functions, you can see the biotopes, including their biocoenoses, within the flood zones that are vulnerable to potential contamination from installations and establishments. This makes it possible to identify where very valuable biotopes are at risk from the potentially damaging effects.

In a similar process to the one described in the previous chapter for the vulnerability of the soil, you can now also determine different levels of contamination to refine the vulnerability statements by linking the information about the different intensities of the contamination, represented by the buffer zones, around the installations/establishments with the biotope values.

Example:

The following map (see Figure 5.26) shows the biotopes, including their biocoenoses, differentiated according to their biotope value that are located within the sphere of influence of the installations and establishments in the event of a 100-year flood (HQ-100). This corresponds to the vulnerability of the biotope to contaminations from installations according to Article 19g of the WHG and establishments according to the 12^{th} BImSchV.

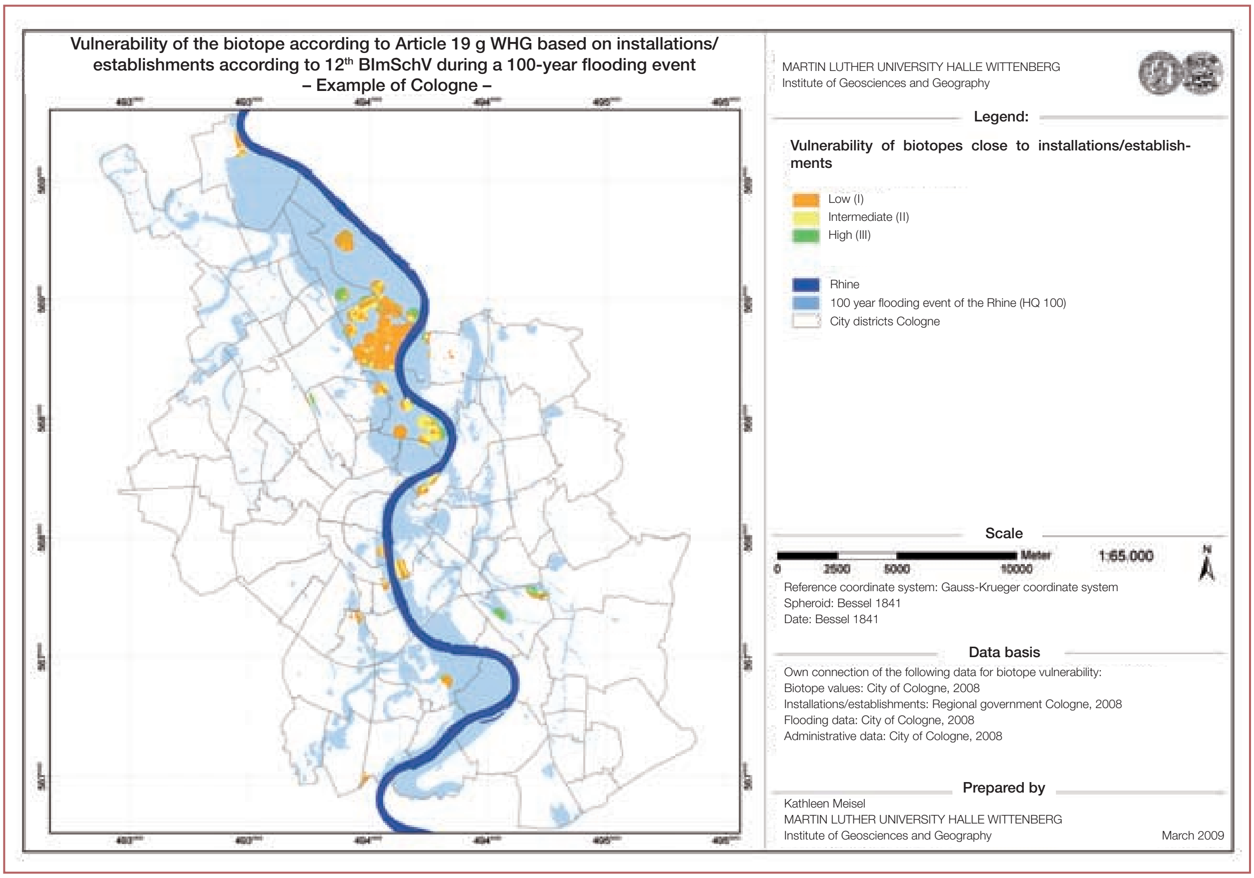


Figure 5.26: Vulnerability of the biotope based on installations/establishments

Handling gaps in the data:

It is necessary to be cautious when interpreting the information if the biotope values are not available for the entire community due to incomplete biotope mapping.

5.4 Handling the assessment results

5.4.1 Dealing with the problem of community boundaries

It is strongly recommended that communities work together or consult with neighbouring communities when carrying out the vulnerability analysis because contamination sources, which are a prerequisite for representing the vulnerability of the environment to flood events, may also be located outside of the local government boundaries. Therefore, it is possible that contamination sources upstream can affect your community and those contamination sources in your community can also have negative consequences for other communities downstream. In addition to determining the relative level of vulnerability, this cooperation should also focus on the possibilities available for handling the assessment results and, if relevant, for reducing the vulnerability of the environment.

5.4.2 Use of the assessment results as the basis for planning measures

The information on the vulnerability of the environment can be used as the basis for making future regional planning decisions and for realising precautionary civil protection measures in a broader sense. Independently of the actual impact experienced in the event of a flood, this data can be used to identify those sites (e. g. close to particularly vulnerable environmental areas) that should no longer be home to certain uses. Therefore, the vulnerability analysis and the resulting maps can be used, for example, as the basis for making statements about planning processes. Furthermore, the results could also be used to update landscape plans or environmental reports.

It is also conceivable and recommended in the investigation, evaluation and remediation of contaminated sites or suspected contaminated sites to also take into account the areas where contaminated sites coincide with vulnerable environmental areas i. e. those areas in which the contaminated sites can cause particularly great damage to the environment in the event of a flood. If the individual assessments described in these guidelines are carried out by the community, it is also possible to identify those areas in which the soil or groundwater and drinking water could be at risk due to the damaging effects of contaminated sites.

The process for determining the vulnerability of the environment or for determining the vulnerability of the soil, groundwater or biotope (including their biocoenoses) could also be used, for example, to prioritise the relocation or dismantling of existing installations according to Article 19g of the WHG and establishments according to the 12th BImSchV that are currently located in flood zones, flood endangered zones or groundwater sensitive areas. If relocating or dismantling these facilities is not possible, the local authority could nevertheless incorporate the information on the vulnerability of the environment into the safety requirements considered during planning or refitting approvals.

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VI. Chapter

Assessing vulnerability to flood events using remote sensing

In contrast to the previous sections of these guidelines that advocate an independent assessment of vulnerability by the relevant community, the following section presents remote sensing methods for assessing vulnerability to flood hazards. These methods can only be applied using specialist software and corresponding expertise. The main focus is placed here on the assessment of physical vulnerability (e. g. in terms of buildings and structures) in cities.

6.1 Basic terms and definitions

Remote sensing in its broadest sense can be defined as recording or measuring objects without coming into physical contact with them. Furthermore, the evaluation of data or images obtained in this way is highly important for acquiring quantitative and qualitative information on the appearance, state or change of state of objects, as well as for determining, where relevant, their natural or social relationship with one another. The most common systems are aircraft or satellite-based sensors, which provide data for making geographical statements about the land surface. Flood events are especially characterised by their large-scale, spatial components. Remote sensing can thus provide a particularly broad information base for stakeholders, decision-makers and politicians.

The greatest advantage offered by remote sensing is that it quickly delivers up-to-date and extensive information relevant to geographical issues. Data from a number of different systems and sensors are available for this purpose, each with their own special features yielding specific characteristics and information.

The interpretation of the respective datasets – or the methods used to extract the desired information – must be carried out based on the individual characteristics of each individual dataset. This evaluation can be carried out in a traditional, manual interpretation process. However, this process requires a lot of time. Automated procedures involving digital image processing mean that the evaluation process is significantly accelerated and it delivers objective and thus comparable results.

The following chapter is designed to provide an overview of the diverse range of remote sensing datasets, as well as their technical features, availability and costs. In addition, the possibilities offered by multisensoral remote sensing data for the assessment of exposure, risk management and operations management will be presented using specific flood-related results – based on these different datasets. In this way, the potential offered by remote sensing for supporting decision-makers *before, during* and *after* an event will be discussed.

6.1. Remote sensing data as the basis for assessing exposure and physical vulnerability in the event of a flood

Remote sensing data from satellites have – at least since the launch of the first commercial satellites for the Landsat missions in 1972 – provided an important information base for the extensive observation of the earth and thus also for exposure and vulnerability analyses. The technical evolution of these systems has led to an improvement in all characteristics of data structures. As a result, a wide range of up-to-date information is available at a consistently higher level of quality.

On the one hand, long-term processes over the last 35 years – for example spatiotemporal changes to urban areas – can be extensively represented and analysed using timelines. While on the other hand, the steadily improving geometric resolution of imaging data enables detailed analysis at the level of a section of road or a house (for an overview see Table 6.1).

Spontaneous and rapid changes to the earth's surface, which can result from natural events like a flood for example, can be recorded using systems with a very high temporal resolution. Active systems, which are not affected by weather conditions and can thus very quickly log the flood zone for mapping purposes, are particularly suitable for use in this area.

Geometric resolution (*m*) Edge length of the image elements	0.4 – 79 m
Temporal resolution (*d*) Temporal coverage between two images	1 – 16 days
Spatial resolution (*km*) Coverage / extent of the imaging	11 – 185 km
Spectral resolution (*bands*) Number of bands	3 – 8
Radiometric resolution (*bit*) Depth of information offered by the data (number of grey tones)	8 – 11 bit (256 – 2,048 grey tones)

Table 6.1: Bandwidths for the different characteristics of the remote sensing data presented

6.1.2 Fundamental remote sensing data from passive imaging systems

Passive earth imaging systems record electromagnetic radiation that has been emitted by the sun and reflected by the earth and then transfer the collected data to a receiving station on the ground, where it is prepared for users and converted into standard data formats. However, the remote sensing data acquired by these optical sensors are reliant on sufficient natural lighting of the areas under investigation: Weather conditions (cloud cover) and shadows – particularly at very high geometric resolutions – can negatively influence the quality of the data. The Landsat series – consisting to date of 6 satellites sent into the earth's orbit – described in more detail in Table 6.2, has delivered the longest continuous series of images of the earth's surface. As a result of its medium level geometric resolution, the data can be processed and classified at relatively low expense, enabling statements to be made about the temporal development of the area under investigation.

Sensor	Landsat MSS	Landsat TM	Landsat ETM+
Mission time	1972 - 1983	Since 1982	Since 1999
Orbit height	705 km	705 km	705 km
Repeat cycle	16 days	16 days	16 days
Strip width	185 km	185 km	185 km
Geometric resolution	79*79 m	30*30 m	30*30 m or 15*15 m (pan.)
Spectral resolution	4 bands	6 + 1 (thermal)	6 + 1 (thermal) + 1 (pan.)
Processing expense	low	low	low
Data costs	free of charge	free of charge	free of charge

Table 6.2: The Landsat Mission Satellites

These changes can be observed using the example of the city borough of Rondorf in the Rodenkirchen district (Cologne). Figure 6.1 shows a series of Landsat images with false colour infrared representations for the time period between 1975 and 2001. It is possible to clearly identify details (e. g. roads) due to the improved geometric resolution over the time period, as well as the change in the settlement structure between 1989 and 2001. Alongside 6 bands for multispectral (multiple bands for sections of the electromagnetic spectrum) evaluation, Landsat ETM+ (Enhanced Thematic Mapper Plus) also offers a panchromatic band (a band for the entire range of visible light in the electromagnetic spectrum) with double the geometric resolution.

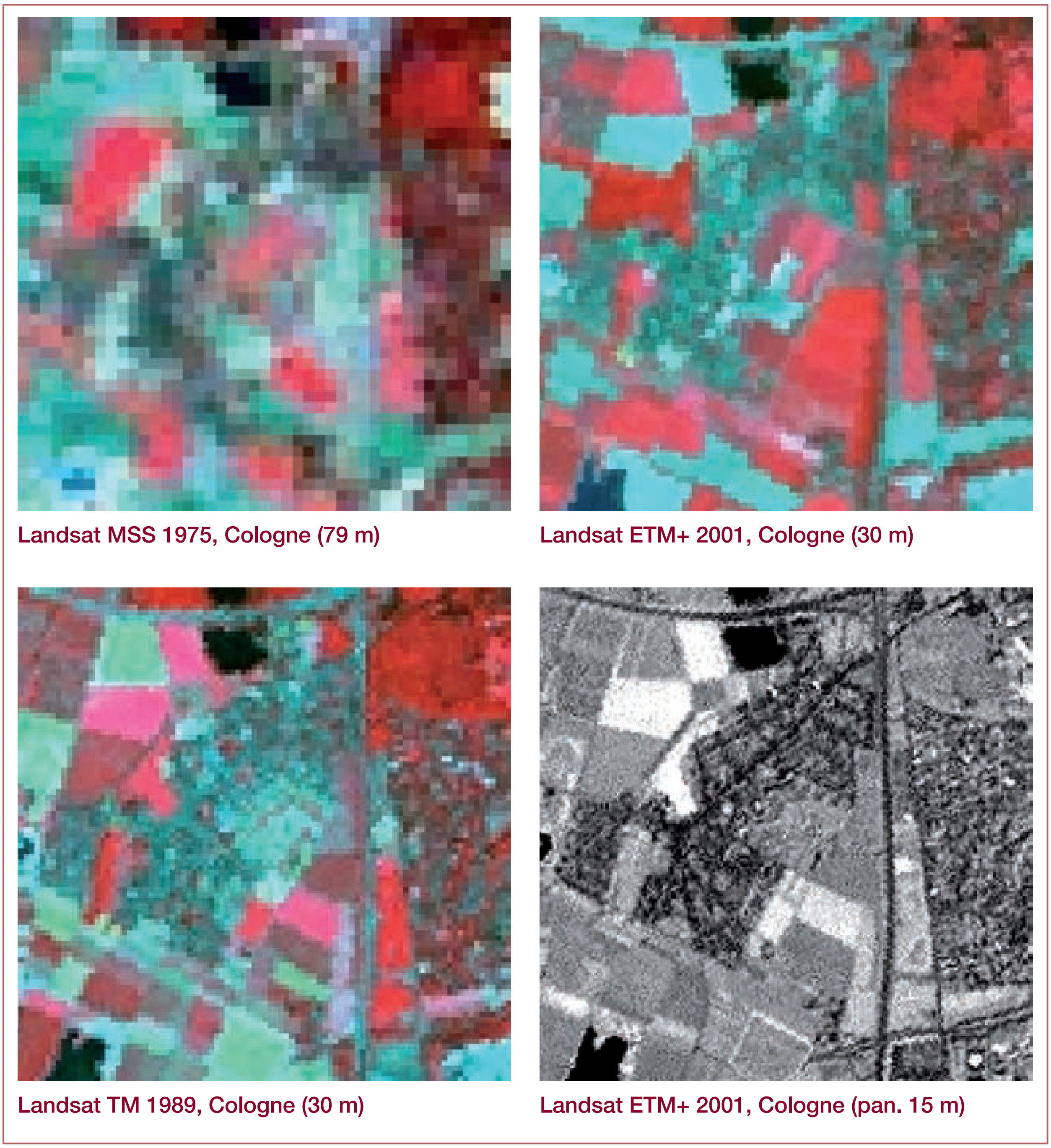


Figure 6.1: Landsat time series using the example of Rondorf, Cologne

Since the RapidEye satellite system was brought into operation at the end of 2008 (see Figure 6.2), there has been another source of data available for acquiring images on a daily basis at a higher geometric resolution and with greater geographical coverage. A total of 5 satellites provide a high temporal resolution (daily images) and thus offer a very good dataset for extensively mapping and observing short-term changes to the earth. This is extremely beneficial particularly in the case of applications based on natural hazards.

	RapidEye	
Mission time period	Since 2008	
Flight altitude	630 km	
Repetition rate	daily	
Strip width	77 km	
Geometric resolution	5 m	
Spectral resolution	5 bands	
Processing effort	medium	
Data costs	low (1,5 €/km²)	
		RapidEye 2009, Cologne (5 m) www.rapideye.de (data made available from the project Urbane Struktur Analyse (USARE), DLR)

Figure 6.2: RapidEye extract for Cologne

	Ikonos	
Mission time period	Since 1999	
Flight altitude	681 km	
Repetition rate	3-5 days	
Strip width	11 km	
Geometric resolution	4 m or 1 m	
Spectral resolution	4 bands + 1 (pan.)	
Processing effort	high	
Data costs	medium (~20 $/km²)	
		Ikonos 2007, Cologne (1 m)

Figure 6.3: Ikonos false colour infrared representation of Rondorf, Cologne

With the launch of Ikonos in 1999 (see Figure 6.3), commercial satellite remote sensing entered a new phase. This satellite offered a previously unachievable geometric resolution of down to one metre in the panchromatic band, which enables, in particular, applications in highly structured urban areas with their complex arrangements of buildings, roads and open spaces. Other high-resolution sensors are now available with Quickbird, GeoEye-1 and WorldView-1. The high geometric resolution of the data places greater challenges on automated imaging analyses due to their increased complexity and structure. This is reflected in higher processing costs. As can be seen in Figure 6.3, it is possible to differentiate between different types of objects on the earth's surface such as roads, individual buildings, agricultural areas, water systems, meadows and forested areas.

	Aerial image	
Mission time period	For approx. 60 years	
Flight altitude	variable (approx. 500 m)	
Repetition rate	variable	
Strip width	variable (area being analyzed)	
Geometric resolution	variable (0,05~1 m)	
Spectral resolution	4 bands + 1 (pan.)	
Processing effort	high	
Data costs	high	Orthophoto 2002, Cologne (0.5 m)

Figure 6.4: Aerial image of Rondorf, Cologne (© Stadt Köln)

Aerial images (see Figure 6.4) have usually been available over the longest period of time for an area under investigation. Data is often available as far back as the 1950s and therefore represents a very valuable source of documentation about urban developments. The effort and expense involved in processing and evaluating this data varies according to the respective dataset (analogue, digital). Because it is necessary to organise an independent flight mission of the area under investigation for every data acquisition, increased costs and less up-to-date data usually have to be taken into account.

6.1.3 Fundamental remote sensing data from active imaging systems

Active imaging systems are fundamentally different from the optical processes described above. These systems do not depend on reflected, electromagnetic radiation from the sun but are instead characterised by the fact that they actively send out signals themselves (microwaves or laser impulses), which are then reflected by objects on the earth, bounced back to the sensor and recorded there.

Radar systems (**RA**dio **D**etection **A**nd **R**anging) create the electromagnetic radiation used for illuminating the section of the earth's surface under investigation and are thus not reliant on weather conditions, cloud cover and daylight. This is a significant advantage particularly for use during and after natural events or for the quick detection of damage (Rapid Mapping). Particularly in the event of flooding, which is often accompanied by heavy cloud cover and precipitation, it is possible to quickly map the extent of the flood event irrespective of the weather conditions.

The way the earth's surface is represented using radar data is dependent on many factors: different wave lengths, polarisation, surface roughness, dielectric constants, surface features and interference need to be taken into account in the evaluation.

Since the German SAR (**S**ynthetic **A**perture **R**adar) satellite TerraSAR-X began operating at the beginning of January 2008, images of the same sections of the earth's surface can be taken every 2-4 days using a pivoting radar beam. As a result of the different imaging modes (High Resolution, SpotLight, StripMap, ScanSAR), the geometric resolution and the strip width can be adapted to individual requirements (see Figure 6.5).

	TerraSAR-X	
Mission time period	since 2007	
Flight altitude	514 km	
Repetition rate	2-4 days (Germany)	
Strip width	10 km (HR-/SpotLight), 30 km (Stripmap) 100 km (ScanSAR)	
Geometric resolution	Up to 1 m (2 m) Up to 3 m Up to 18 m	
Spectral resolution	1 band	
Processing effort	very high	TerraSAR-X 2009, Cologne (1 m)
Data costs	135 €/km^2 HR-SpotLight 67,5 €/km^2 SpotLight 25 €/km^2 Stripmap 0,18 €/km^2 ScanSAR	

Figure 6.5: TerraSAR-X StripMap image of Rondorf, Cologne (© DLR)

Airborne Laser scanning or LiDAR (Light Detection And Ranging, see Figure 6.6) is – similar to standard aerial photography – used in aircraft-based platforms above the area under investigation. The decisive advantage offered by this source of data is the possibility of integrating a third dimension into the analysis. Using GPS (Global Positioning System) and INS (Inertial Navigation System) data, it is possible to precisely define and locate the position of the sensor – and thus the emitted laser beams. By measuring the time delay between sending and receiving the laser beam, the exact position of objects on the earth‘s surface and also their absolute height can be determined. Depending on the pulse density per square metre (p/m^2), it is possible to describe the scanned surface at different levels of precision and thus adapt it for different applications. This enables different structures to be identified and other results to be derived – particularly in urban areas (see example in Figure 6.6). As a result, it also proves a particularly important source of information for the extensive evaluation of building structures and the earth‘s topography. At an especially high point density, which enables demarcation down to the level of single buildings, it is possible to capture data on the height and form of individual buildings. Digital surface models derived from these types of datasets provide important information for an analysis of physical vulnerability – providing appropriate detail down to the level of an individual house or block. This is crucially important, particularly when determining the exposure of individual buildings, the potential for vertical evacuation or estimating population levels.

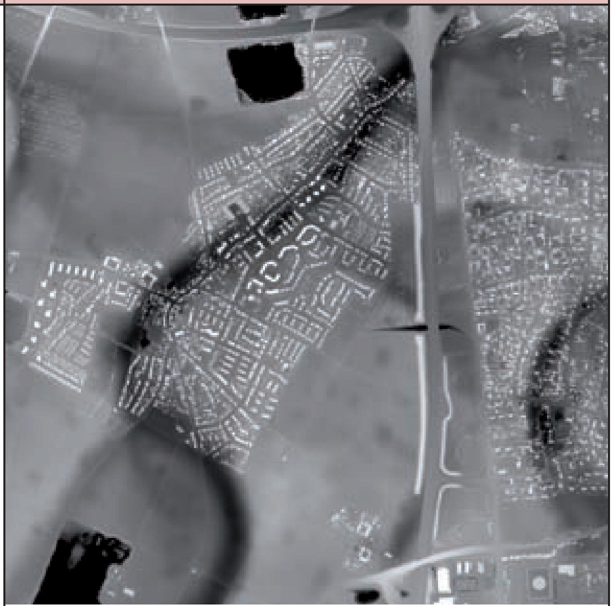
	LiDAR	
Mission time period	variable	
Flight altitude	variable	
Repetition rate	variable	
Strip width	variable	
Geometric resolution	variable (approx. 1 m)	
Spectral resolution	1 band (height)	
Processing effort	high	
Data costs	high	
		LiDAR 2007, Cologne (1 m)

Figure 6.6: LiDAR image of Rondorf, Cologne (© Stadt Köln)

For large-scale applications, height data for almost the whole of the land surface of the earth – between 60°N and 58°S – was recorded and prepared in the form of a Digital Terrain Model (DTM) during the course of a campaign by the SRTM (Shuttle Radar Topography Mission) in 2000. The spatial resolution down to 30 m makes it possible to record large-scale features of the landscape and analyse the topography (see Figure 6.7).

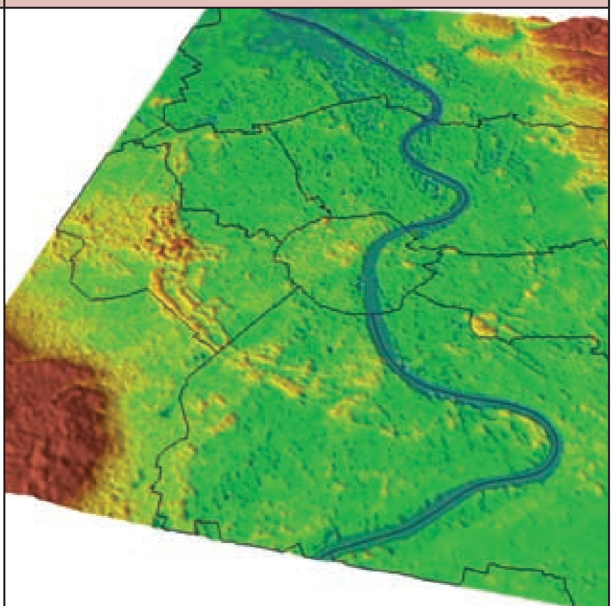
	SRTM	
Mission time period	2000	
Flight altitude	233 km	
Repetition rate	none	
Strip width	variable	
Geometric resolution	30 m or 90 m	
Spectral resolution	1 band (altitude)	
Processing effort	low	
Data costs	free of charge	
		SRTM 2000, Cologne (30 m)

Figure 6.7: Perspective view of the city of Cologne (overlayed with district boundaries and the Rhine) (© DLR)

6.2 Areas of application for remote sensing in vulnerability assessments

The flood events that have occurred over the last few years in Germany have made people more aware of this type of natural hazard and also demonstrated the vulnerability of the affected areas. There is a high structural, financial and not least human risk posed by flooding, which is often underestimated in Germany. Strategic management with the goal of reducing this risk through preventative measures, or for quickly and strategically making the right decisions when coordinating relief efforts during or after the event, often fails due to insufficient data. In the following section of the guidelines, the potential offered by the diverse range of remote sensing datasets and evaluation methods for filling these gaps in the provision of up-to-date and comprehensive information will be discussed.

6.2.1 Areas of application for remote sensing before a flood event

Strategic management for reducing flood risk to an acceptable degree through the optimal selection of protective measures requires answers to the following key questions:

1) **Where** are the endangered areas?
2) **Which buildings/objects** would be potentially affected?
3) **How many people** would be potentially affected?
4) **How high** would the damage be?
5) **Which** concrete **measures** could be taken to reduce vulnerability?

The large number and diverse variety of remote sensing datasets (see Chapters 6.1.2 and 6.1.3) enables the preparation of very different information for answering these questions and thus for assessing the relevant flood risk as the basis for making meaningful decisions about protective measures.

1) Where are the endangered areas?

It is possible to very precisely visualise the geographical extent of a flood event and thus map the affected area with the help of earth observation systems. However, it is not only the extent of the geographical area covered by the flood but also important parameters such as the depth of the flood that are relevant for many applications (e. g. risk assessments and damage assessments). These parameters can be determined by combining flood templates derived from satellite data with a digital terrain model. The flood template is adapted to the landscape topography using cross-sectional profiles and the water level is then derived for each profile. As shown in the following illustration (Figure 6.8), this can be used to calculate the flood depths for the affected sections of the river. Conversely, an analysis of the flood scenario also enables safe areas to be identified and thus makes it possible to coordinate and organise rescue measures with the aid of the available information on open spaces, infrastructures etc. in an effective and targeted way.

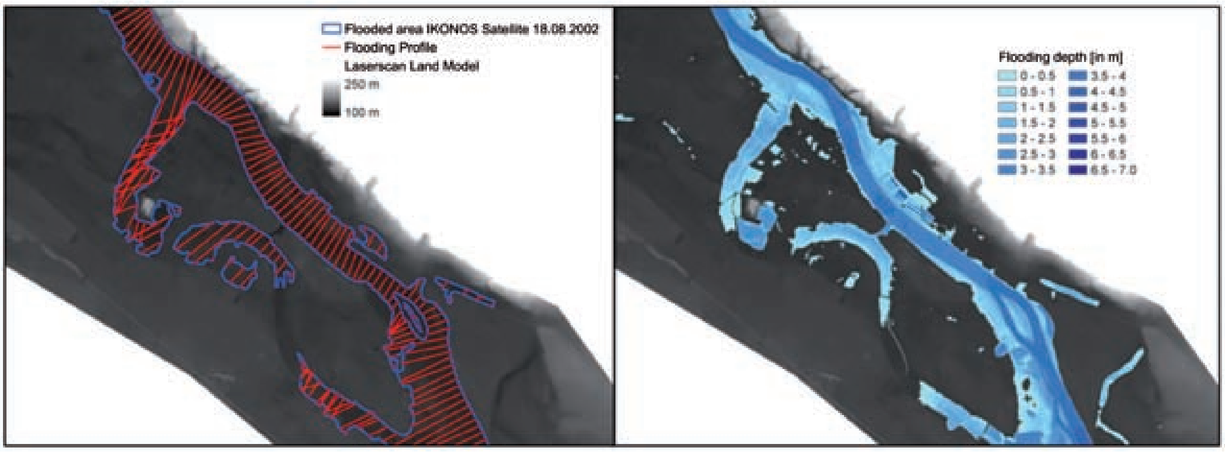


Figure 6.8: Geographical extent of the flood zone for Dresden and an analysis of the flood depths

The image data created shows the absolute height of the objects and thus provides a realistic representation of the shape of the earth's surface. Digital image processing software can be used to derive object-based parameters such as the absolute and relative heights, gradients, exposure or surface roughness.

2) Which buildings/objects would be potentially affected?

The datasets listed in Chapters 6.1.2 and 6.1.3 enable a variety of perspectives to be investigated for answering the question about potentially affected objects. In general, it is possible to derive „urban footprints" – or the impervious surfaces of the landscape – for determining geographical information from large-scale remote sensing data. Datasets have been available at this geometric level since the beginning of the 1970s and this enables changes in urban areas to be understood and quantified over time. Multisensoral approaches, such as our example, demonstrate that remote sensing generates a consistent, extensive and permanently up-to-date source of information about urban areas, while at the same time allowing spatiotemporal changes to urban areas to be observed and analysed over the decades.

Figure 6.9 shows the urban footprint of the city of Dresden using multisensoral data from the Landsat and TerraSAR-X satellites. It is thus possible to quickly carry out a change analysis or derive the current geographical extent of the urban area, as well as the location and size of potentially affected city districts.

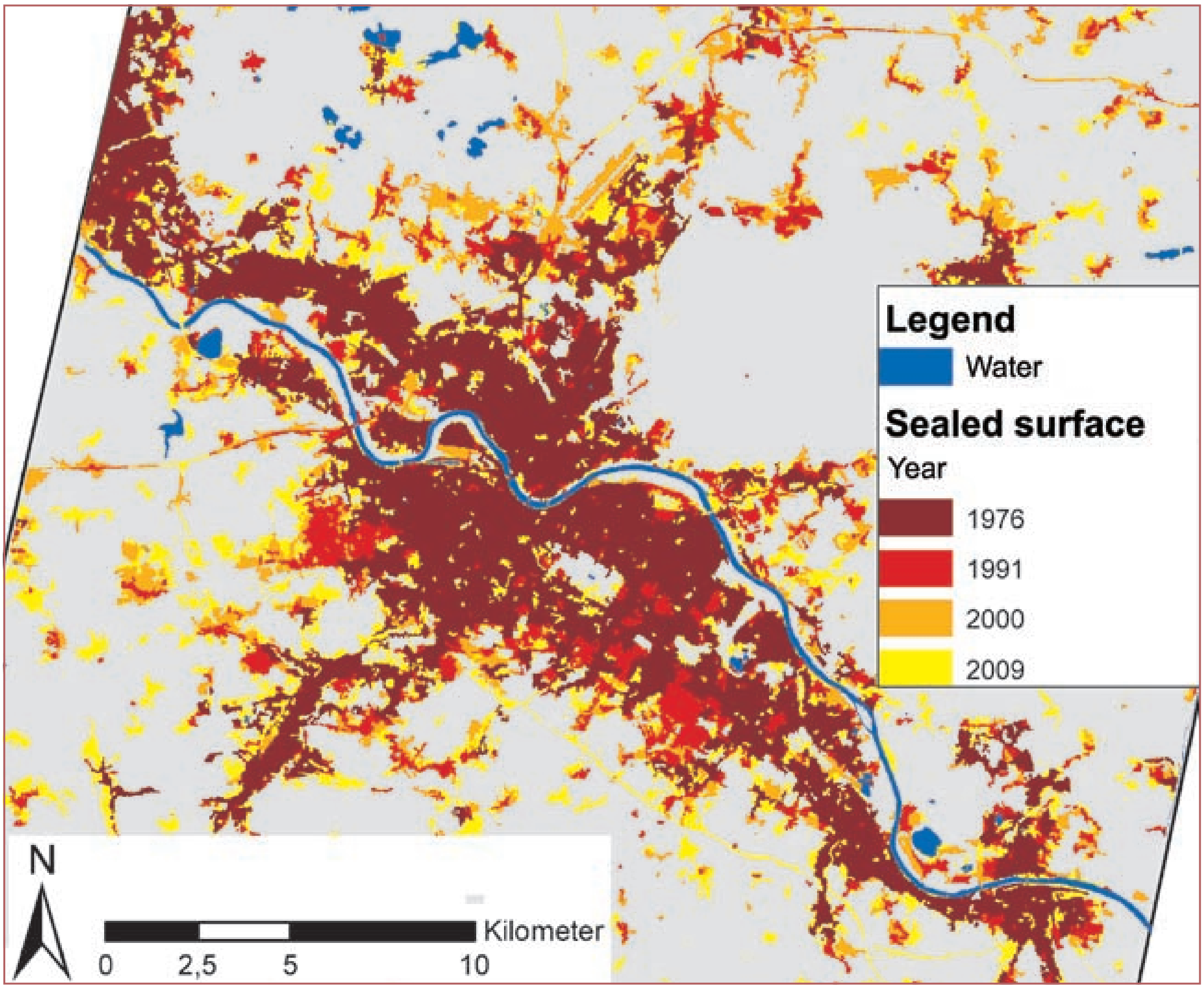


Figure 6.9: Analysis of the changes to the urban area from 1976 to 2009 for the city of Dresden

However, the complex interaction between flooding and the affected areas mostly requires a higher geometric and thematic level of detail. Using those datasets with a high resolution listed above e. g. Ikonos, it is possible to collect more thematically detailed and significantly more precise geographical information about urban areas. Modern image analysis processes enable the automatic extraction of image data to a very high level of precision. The following results can thus be displayed at a geometric resolution down to the level of an individual house. The thematic differentiation of the area can also be shown in significantly more depth with the classifications „buildings“, „roads“, „meadows/grasslands“, „forests/trees“ and „water“. On this basis, the urban area can be subdivided into homogeneous geographical units or so-called urban structure types using physical parameters such as the collected building structures, spatial arrangements, the level of impervious cover, the proportion of green spaces or the location. This process of differentiation can enable quick and clear visual observation of the urban landscape, as well as a quantitative and qualitative assessment of the affected structures.

Furthermore, this type of structural differentiation enables the functions of buildings to be indirectly derived – from residential areas to industrial locations. Figure 6.10 shows the land cover classifications and the classifications according to urban structure type.

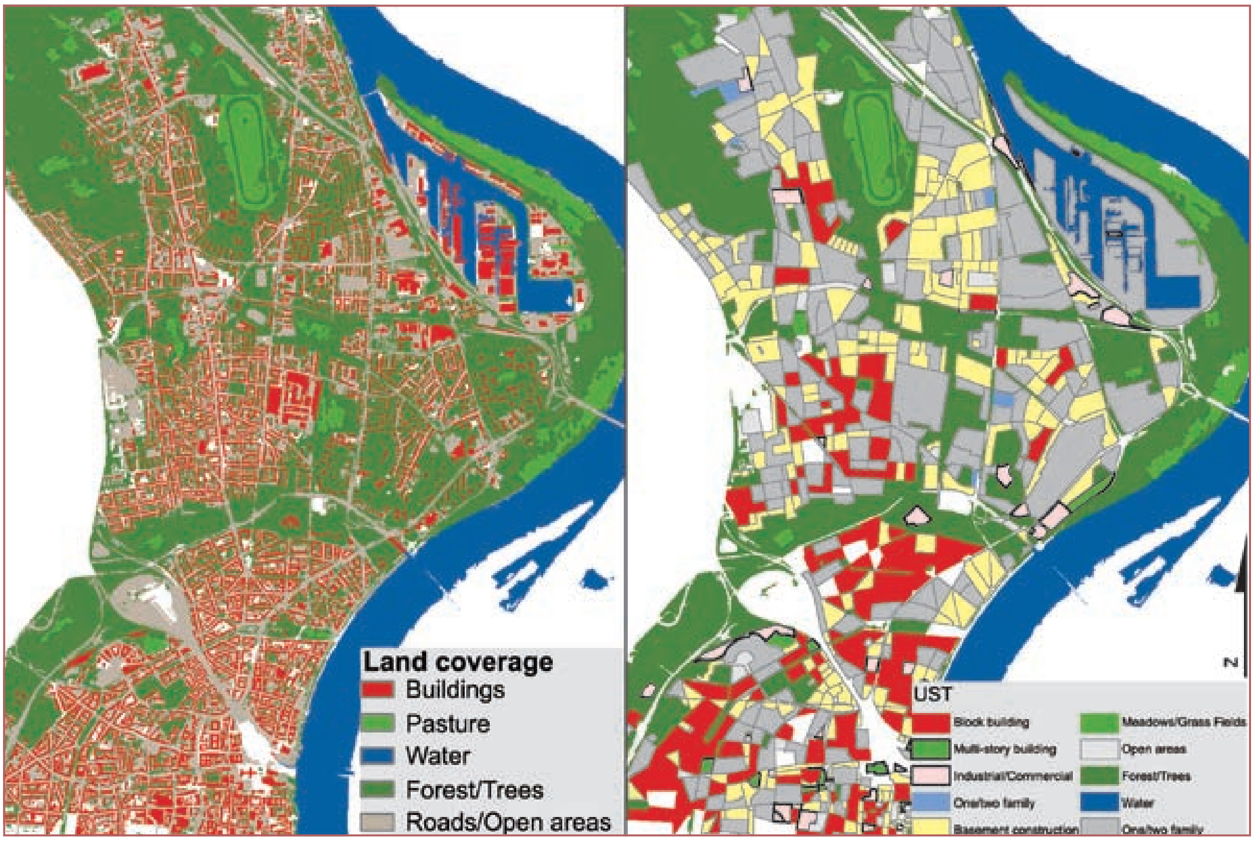


Figure 6.10: Land cover classification and urban structure type (UST) classification – borough of Nippes in Cologne

The third dimension can be integrated into the urban data using high resolution Digital Surface Models (DSM). The DSM allows the exact topography of the urban areas to be illustrated in detail. In addition, individual buildings can be extracted and issued as building templates. Based on these building templates and the relevant height information, it is possible to create a highly accurate three-dimensional model of the city. Figure 6.11 shows a representation of the city model for the centre of Cologne. This geographical knowledge enables, on the one hand, the identification of suitable buildings for vertical evacuation, while on the other hand, information on the size of the buildings and the relevant number of floors can be used to indicate population distribution. The information gained using this method sheds light on the physical vulnerability of the buildings and enables statements to be made about the susceptibility and coping capacity of the population living in those areas under investigation. This information is highly relevant for the purposes of evacuation planning.

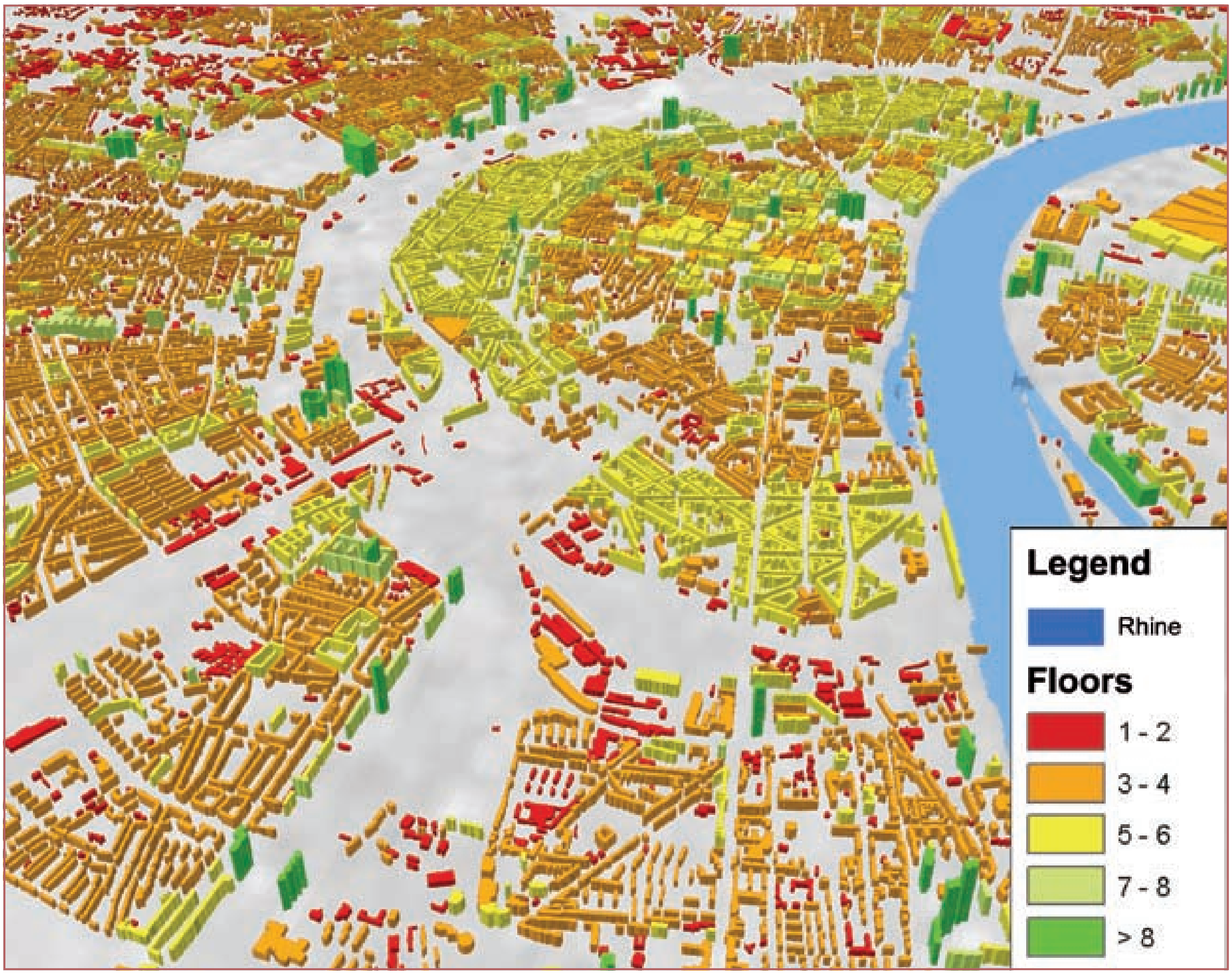


Figure 6.11: Three-dimensional city model of the old town of Cologne with an estimate of the number of floors

3) How many people will be potentially affected?

The highly precise three-dimensional city model shows an immediate correlation with parameters that cannot be directly derived from remote sensing data. For example, knowledge about the number of floors, footprint and principle use of the building can be used as the basis for calculating the geographical distribution of the population – also in combination with the time of day. It is often only possible in many cases to access population data for a city or a community in aggregated form for an administrative or statistical geographical unit (e. g. city borough). This generalised knowledge can now be projected onto the three-dimensional city model by geographically linking it in linear form, as illustrated in Figure 6.12. The result is an estimate of the population distribution down to the level of individual buildings. Naturally, the level of precision cannot be compared to that of data from land registers but the results have shown that this method is between 80% and 90% accurate. Therefore, it provides a sufficient basis for making substantial decisions because no exact figures are required for coordinating and managing relief efforts or calculating risk – the important factor is being aware of the correct dimensions. Linking the information from the detailed descriptions of the individual buildings, according to their size and the population estimates for each building, reveals particularly relevant geographical aspects in the event of a crisis. This information is greatly important in the planning and coordination of evacuations from affected areas and for quantitative estimates dealing with evacuating the population from higher floors.

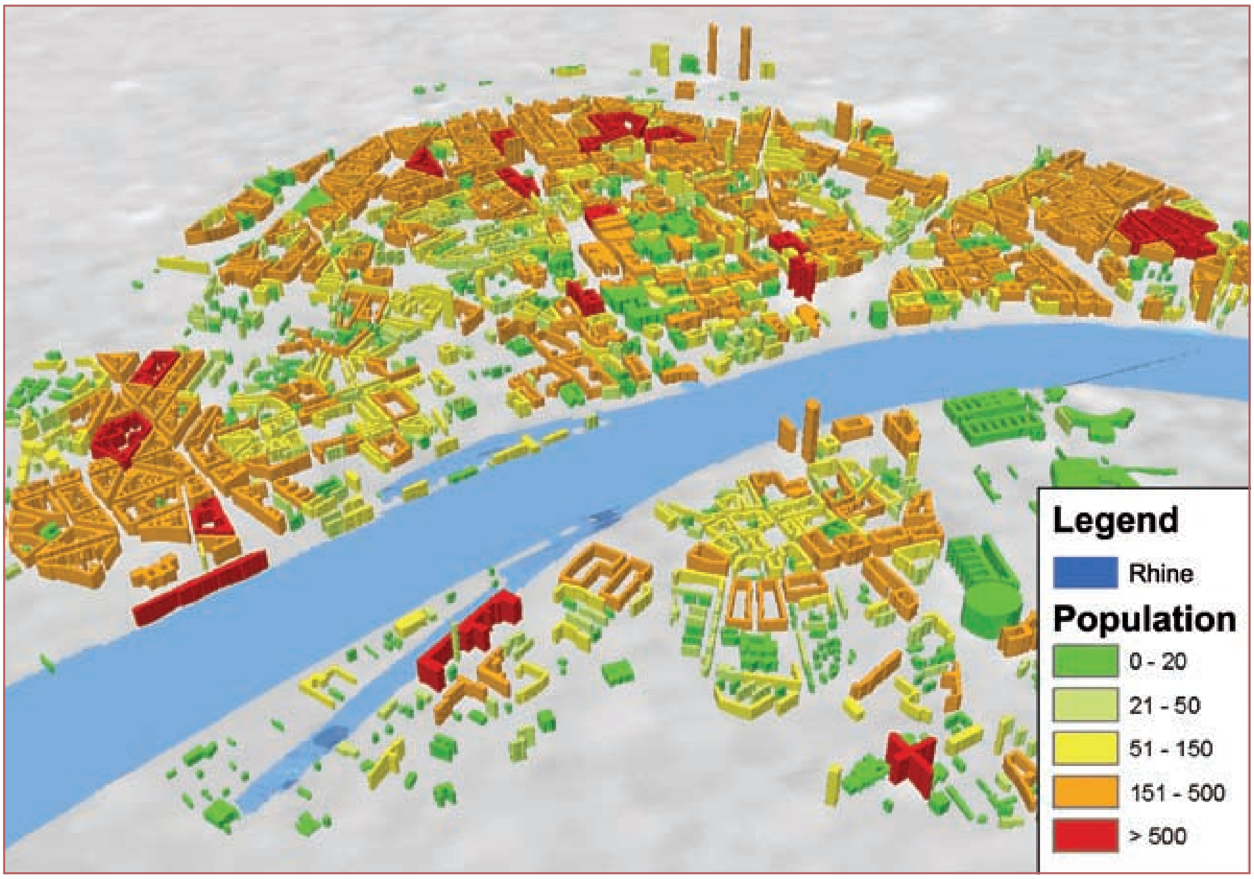


Figure 6.12: Projection of the population distribution onto the three-dimensional city model for the city centre of Cologne

4) How high would the damage be?

The results described so far show the potential benefits offered by remote sensing for visualising the urban landscape, as well as for very precisely and geographically quantifying, for example, physical structures or the population in a city. Knowledge about the number of affected buildings or infrastructures, as well as the affected population, flood depths etc., is closely associated to the level of economic damage. Further knowledge about the building types or the urban structure types enables additional information to be linked in or calculated, which can be used to estimate the potential economic damage. The geographical location or exposure enables affected infrastructures, industrial or commercial sites, transport facilities and private households to be identified and quantified. If interested, further information can be found in the information system for the flood damage database – HOWAS 21: (http://nadine-ws.gfz-potsdam.de:8080/howasPortal/client/start).

5) Which concrete measures could be taken to reduce vulnerability?

With the help of a geographical information system (GIS), it is possible to arbitrarily overlay sets of results with one another and combine them for the purposes of quantitative analyses. This offers an essential benefit for risk assessments and as a result for the targeted strategic planning and development of disaster relief plans. The potential for combining diverse layers of information based on individual requirements highlights location-specific issues and enables an assessment of the concrete measures required. This is especially true when evaluating those measures associated with a reduction in physical vulnerability (for example, measures relating to building or urban structures, comprehensive protective measures and the protection of buildings or assets).

In the following example, the flood zone for an extreme flood scenario (EHQ) on the Elbe affecting the city of Dresden is overlayed onto a three-dimensional city model and an estimate of the population distribution. In advance of an expected flood, this makes it possible for decision-makers to estimate how many people will be affected in this scenario, where they reside, how accessible these areas will be, how many buildings or structures will be flooded and who will actually need to be directly evacuated. Figure 6.13 visualises how a possible information system of this type could provide decision-makers with essential information. The goal here is to provide information for long-term sustainable planning for minimising the effects of a natural hazard in advance of an expected flood and also to deliver information for making decisions rapidly when the flood event occurs – such as the number of protective areas required or an assessment of the need for humanitarian aid.

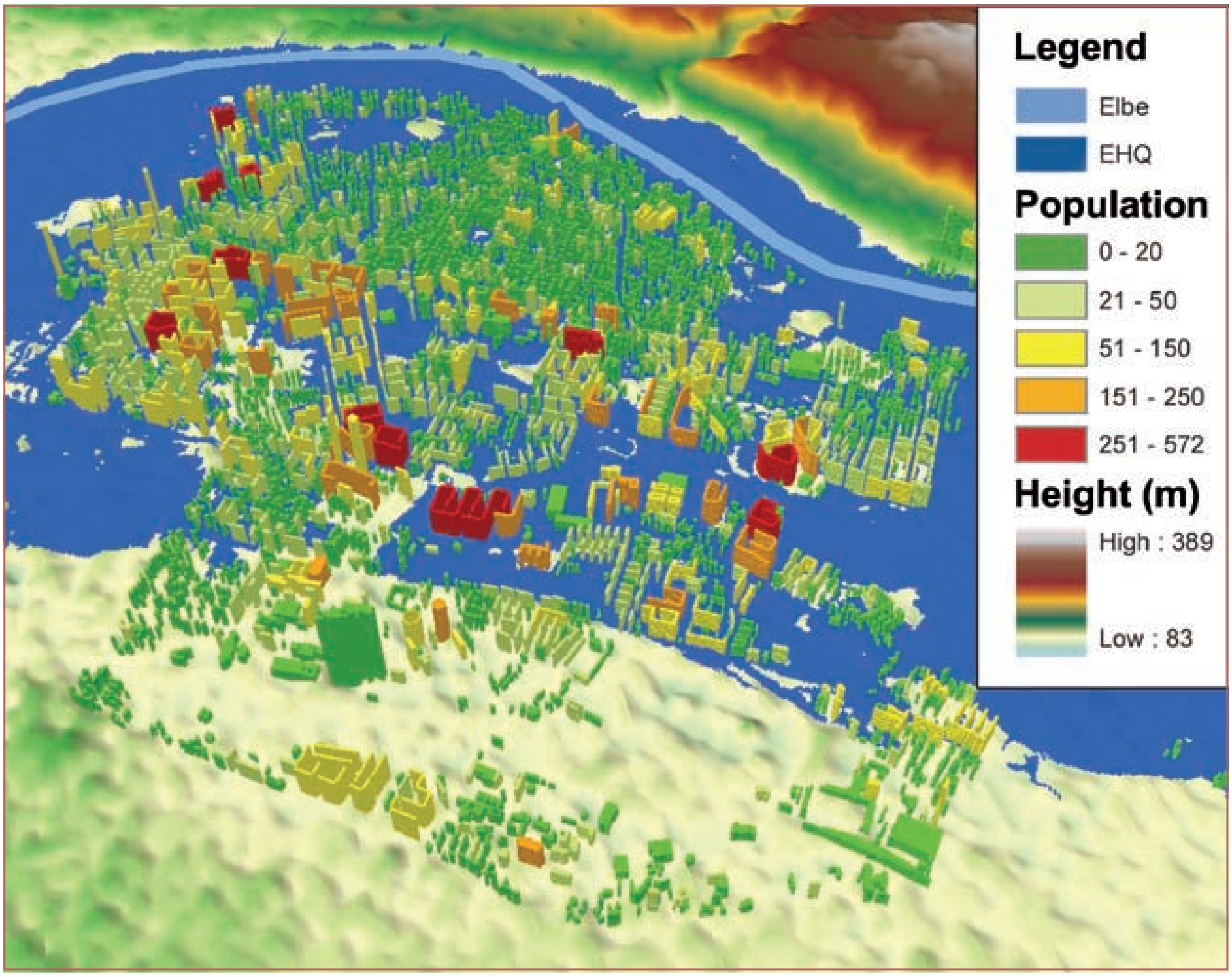


Figure 6.13: Crisis information system for the example of Blasewitz/Dresden

Information on the city district	Szenario EHQ
Name: Blasewitz **Location:** Distance to the city centre approx. 4.5 km Distance to the airport approx. 13.4 km Distance to the main railway station approx. 5.5 km 1 bridge over the Elbe **Transport connections:** 2 main transportation routes **Land coverage:** Number of buildings: 2,989 Number of buildings < 3 floors: 380 Primary use: Residential area Open spaces: Yes **Population:** 80,215	**Flooded buildings:** Number of buildings: 2,564 Number of buildings < 3 floors: 285 **Population affected:** Total: 69,628 Population in buildings < 3 floors: 2,795 **Situation:** Roads fit for traffic, distance to emergency facilities such as fire department, hospitals, police, public buildings for potential evacuation, open spaces, etc.

6.2.2 Areas of application for remote sensing during and after a flood event

As soon as a flood event occurs, the initial task is to identify the extent of the hazard as quickly as possible in order to obtain up-to-date, precise and extensive geographical information. This information can be provided through the evaluation of satellite remote sensing data.

Commercial and research-based earth observation satellites have achieved a level of quality in terms of their availability and precision over the last ten years that enables them to be routinely utilised for obtaining up-to-date information in a crisis situation. It is thus possible to collect satellite imaging data on a daily basis with a geometric resolution that enables structures down to the size of individual buildings to be recognised.

In order to implement the collection and preparation of this satellite data in the event of a crisis, it requires suitable structures and capacities that guarantee the fast procurement, preparation and analysis of the satellite imaging data. In this context, the German Aerospace Centre (DLR) has set up the Center for Satellite Based Crisis Information (ZKI) as a service from the German Remote Sensing Data Center (DFD). It operates in a national, European and international context and is closely linked with various partners at an EU, federal and state level (crisis response centres, civil and environmental protection), non-government organisations (humanitarian aid organisations) and satellite operators, as well as space agencies. In the case of emergency mapping directly after a disaster, a 24 hour/7 day a week service is available for primarily creating overview maps and damage maps. The evaluations are carried out in accordance with the specific requirements of national and international public agencies and aid organisations.

Figure 6.14 shows the process chain for an emergency mapping process carried out in the event of a crisis. The process for acquiring data coordinates the use of both new image data from satellites and also archived data documenting the situation before the crisis situation. The damage potential and the current situation are then analysed using the archived data and the new images. After a diverse range of preprocessing steps and an analysis of the data, results for coordinating and managing aid relief measures and emergency services are provided.

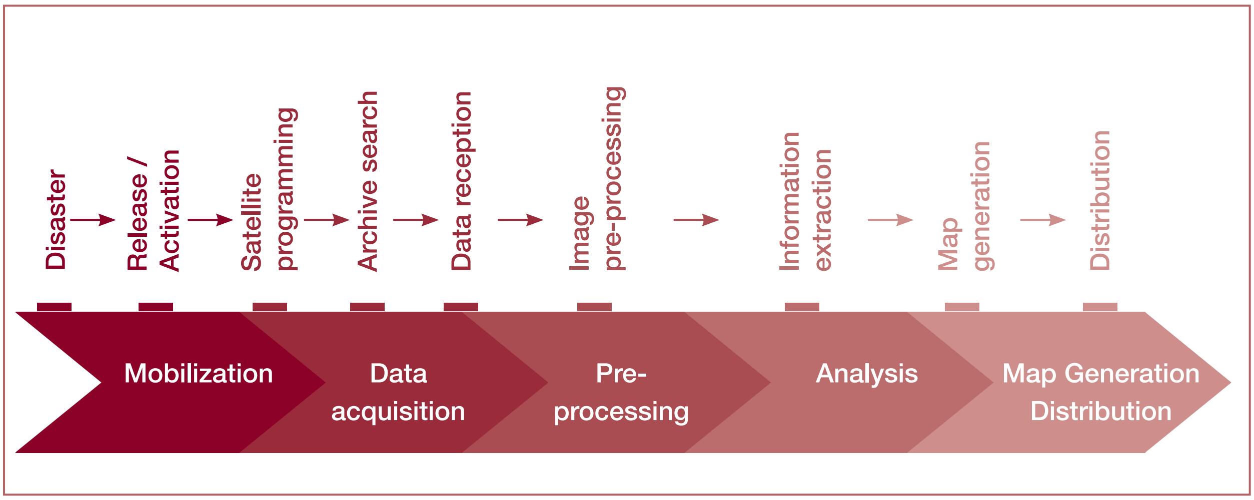


Figure 6.14: From remote sensing data to a process chain for crisis information in the form of an emergency map (Rapid Mapping)

Figure 6.15 shows an example crisis management analysis for the Elbe flood in the area of Dresden using remote sensing data. Different satellite imaging data from before and after the disaster was processed and combined with additional geodata – such as topographic maps. The map shows the flood areas derived from the remote sensing data and illustrates the normal water level and the flood zones.

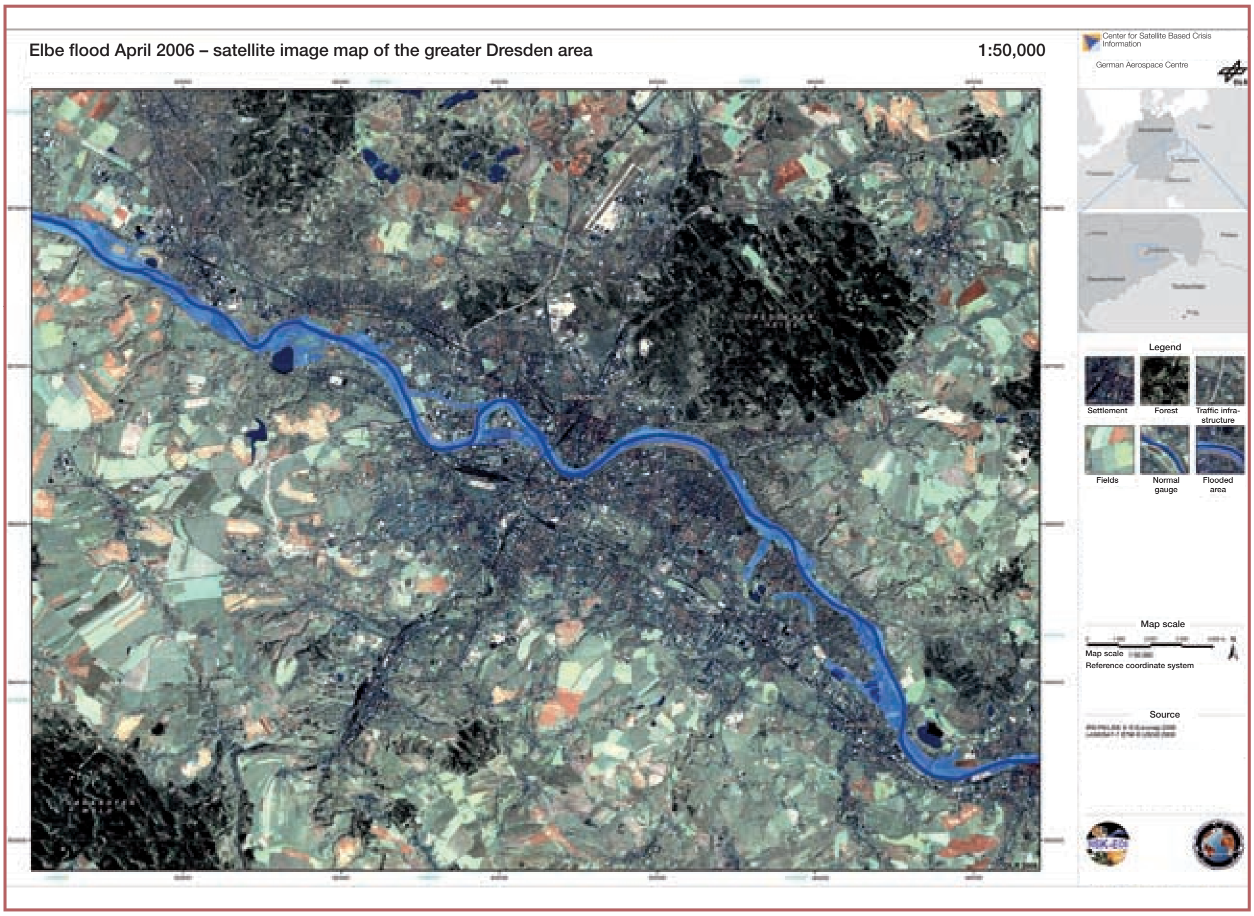


Figure 6.15: Elbe flood 2006 – detection of flood zones in the area of Dresden – derived from IRS-P6/ LISS III and visualised on Landsat-7 ETM.

6.3 Summary

An assessment of the vulnerability and risk *before* and the management *during* and *after* a flood event requires a wide range of information and decision-making structures. These allow an analysis of the effects of a natural hazard according to physical, economic, demographic, social, ecological and not least political aspects. Remote sensing makes it possible, within this complex interplay of different factors, to provide specific geographical information for stakeholders, decision-makers and politicians. The possibilities offered by remote sensing are particularly important when making event-based assessments of exposure, contributions to the determination of social vulnerability and detailed, comprehensive statements on the physical vulnerability of urban areas. The diverse range of remote sensing datasets exhibit different levels of potential in terms of the geometric or thematic depth of the results. This varies from the derivation of urban areas and an estimation of the flood zones through to detailed knowledge about buildings or structures and population distribution down to the level of individual houses. The cost of data or data processing also varies accordingly. The resulting comprehensive geographical information serves as the basis for sustainable development and associated planning decisions *before* an expected flood event, as well as for strategic coordination and comprehensive management decisions based on quantifiable statements about the flood *during* and *after* an event.

VII. Chapter

Appendix

7.1 Checklist 1: Emergency power supply in a flooding event

The following checklist serves to assist in examining the flood protection afforded to an emergency power supply. It is advisable to use it when it has been demonstrated that, within the scope of the vulnerability assessment and your municipality, and under the assumption of a certain flooding scenario, there are facilities of special significance whose power supply must be guaranteed should there be a power failure. Examples are hospitals, homes for the aged or components of other infrastructures such as water supply or waste-water disposal.

The checklist allows for the examination of the emergency power supply under the assumption that this emergency supply has been installed according to current, valid technical requirements and electrical wiring regulations. This checklist refers only to problems and questions specific to flooding – general advice on setting up emergency power systems (different types of emergency power generators, calculations, maintenance, crisis management, etc.) has been omitted intentionally. (For more detailed information, see the "Sources of further information" section at the end of the checklist.) The checklist therefore should be viewed as a supplementary document regarding floods, to be used during and in addition to a general inspection of emergency power supply. At the end of the checklist, you can find information on the implications of the checklist results for the vulnerability assessment.

Basically, two forms of emergency power supply exist. Emergency power systems (EPSs) generally consist of diesel generators; they may provide energy over a fairly long time period but usually only start running after a certain delay. Interruption-free power supply systems (UPS – uninterruptible power supply) work differently; they make power available from batteries for only a short period of time but offer an uninterrupted emergency power supply. UPSs frequently serve primarily to bridge the time period before an EPS starts up. Whether a facility utilizes an EPS, a UPS or a combination of both is dependent on its particular requirements. To allow for these different requirements, the checklist is divided into the following subtopics: "Technical requirements and location", "Preparedness of staff" and "Fuel reserves and logistics" (which either refer to both UPS and EPS or explicitly to one of the two types of supply).

The answers that are marked in bold print indicate a problem that increases the risk of a failure of the emergency power supply in the event of flooding. These are classified using symbols. Alternative answers that are labeled **(!!!)** involve an immediate failure or outage of the emergency power supply or point to a significant safety risk. The label **(!!)** indicates that the risk is substantially increased – the emergency generating plant could fail, but not necessarily so. In every such case, the problems thus identified must be dealt with because the actual impacts are not foreseeable. An overall positive evaluation of the emergency power supply in the event of flooding can only be given when every question on the checklist has been answered affirmatively. (Please note that some questions are meant to navigate you through the checklist – they just refer to a follow-up question and they are not marked in bold print. A negative answer does not point to a problem in these cases.)

1. Technical requirements and location

QUESTION 1: Does the component have an emergency power supply or an uninterruptible power supply (EPS or UPS)?

A) No	> There is no emergency power supply in this case. You can find general advice on the planning and installation of an emergency power supply in the guideline referred to at the end of this checklist. (!!!)
B) Yes	> go to Question 2.

QUESTION 2: Are the components of the emergency power system in a location unaffected by flooding (not in a basement or underground garage) or are they protected by flood protection measures (e. g. batteries in heavy-duty watertight containers)?

A) No	> The emergency power supply cannot be expected to function in a flooding event. (!!!)
B) Yes	> go to Question 3.

QUESTION 3: Are all emergency power supply connections installed in a location unaffected by flooding (below the ceiling, on the first floor, etc.) or can they be separately switched off in a flooding event (separate power circuits or power circuits that can be disconnected)?

A) No	> The emergency power supply cannot be expected to function properly in a flooding event. In addition, connections that are underwater may pose a major risk for employees. (!!!)
B) Yes	> go to Question 4

QUESTION 4: In order to be able to make disconnections when and where necessary, are all connections and electrical equipment that are supplied with emergency power as well as all switches in the power distribution systems labeled clearly and visibly and are employees aware of their meaning?

A) No	> All outlets, switches and electrical equipment supplied with emergency power should be labeled in color and employees should be informed of their special meaning so that no unnecessary devices are connected and, vice versa, all important devices can be connected. Otherwise, the size of the EPS may not be adequate in an emergency. Moreover, in a flooding event it must be possible to switch off the power supply quickly and safely to avoid risks to employees and damage to installed equipment. (!!) > go to Question 5
B) Yes	> go to Question 5

QUESTION 5: Is the system equipped with an EPS that requires a start-up power source?

A) No	> go to Question 7.
B) Yes	> go to Question 6

QUESTION 6: Is the EPS start-up power source safely located and operational (e. g. battery is located in a location unaffected by flooding and is regularly tested; the manual starter or crank is accessible)?

A) No	> The EPS is not expected to function properly in a flooding event. (!!!)
B) Yes	> go to Question 7

2. Preparedness of staff

QUESTION 7: Does the system have a UPS?

A) No	> go to Question 15
B) Yes	> go to Question 8

QUESTION 8: Will employees know when the UPS has turned on (e. g. alarm)?

A) No	> You should make sure that employees know that the UPS has turned on. If they do not, necessary measures will not be taken and the valuable and limited time during which the UPS can maintain the power supply will be wasted. (!!) > go to Question 9
B) Yes	> go to Question 9

QUESTION 9: Do you know how long the UPS can ensure power supply to the component(s)?

A) No	> It is important to know how long the UPS can maintain its supply of power in order to be able to coordinate plans for measures to be taken after the UPS has turned on. (!!) > go to Question10
B) Yes	> go to Question 10

QUESTION 10: Have plans been drawn up specifying which measures are to be taken in an emergency after the UPS has turned on (warning employees, orderly shutdown of systems, etc.)?

A) No	**> You must determine whether or not certain measures are to be taken after the UPS has turned on. This is the only way to use the often limited time provided by the UPS efficiently. (!!)** **> go to Question 11**
B) Yes	> go to Question 11

QUESTION 11: Do employees know these plans and are they aware of what they have to do?

A) No	**> You must ensure that employees are informed of their personal responsibilities and of the routine actions to be taken by everybody once the UPS has turned on. Otherwise misunderstandings could arise during a flooding event. (!!)** **> go to Question 12**
B) Yes	> go to Question 12

QUESTION 12: Are the necessary emergency measures resulting from the power supply switching to the UPS regularly practiced with the employees involved?

A) No	**> You must ensure that the employees involved not only know the measures necessary once the UPS is in operation in theory, but that they can also put them into practice. (!!)** **> go to Question 13**
B) Yes	> go to Question 13

QUESTION 13: Are these emergency drills evaluated to continually improve the procedure?

A) No	**> It is advisable to use the results of the practices to optimize the procedure.** **> go to Question 14**
B) Yes	> go to Question 14

QUESTION 14: Is the operation of an emergency power system planned in addition to the UPS?

A) No	> go to Question 31
B) Yes	> go to Question 15

QUESTION 15: Does the emergency power generator need to be switched on manually?

A) No	> go to Question 25
B) Yes	> go to Question 16

QUESTION 16: Have you ensured that the emergency power generator, as well as all other systems necessary for supplying emergency power (e. g. switch and control gear), are accessible during a flooding event? (Routes are accessible, electrical doors/gates are open, no risks/hazards for employees, etc.)

A) No	> The emergency power system cannot be expected to function under these conditions. (!!!)
B) Yes	> go to Question 17

QUESTION 17: Is there a plan for who is responsible for switching on the emergency power generator?

A) No	> You must ensure that someone is explicitly responsible for switching on the emergency power generator. Otherwise misunderstandings could arise during a flooding event. (!!) > go to Question 19
B) Yes	> go to Question 18

QUESTION 18: Do the employees know the plans and are they aware of what they have to do?

A) No	> You must ensure that the person responsible for switching on the emergency power generator is aware of his/her responsibility. Otherwise misunderstandings could arise during a flooding event. (!!) > go to Question 19
B) Yes	> go to Question 19

QUESTION 19 Have preparations been made for a stand-by duty plan to be drawn up so that there is always at least one of the employees responsible on-site during a flooding event?

A) No	> As it is impossible to predict whether the emergency power generator must be switched on during normal working hours or not, an emergency team should be put on stand-by to take over this responsibility in a flooding event. (!!) > go to Question 20
B) Yes	> go to Question 20

QUESTION 20: Have the employees responsible been trained on how to decide when the emergency power generator should be switched on?

A) No	> You must be certain that the employees involved are able to make this decision. This also includes the decision not to switch on the EPS if the situation demands this; for example, if safety concerns come into play because of quickly rising water or of water unexpectedly inundating the building. Otherwise, the safety of employees is at risk and the emergency power generator cannot function in an emergency. (!!!) > go to Question 21
B) Yes	> go to Question 21

QUESTION 21: Do the employees have the technical competence to switch on the emergency power generator or to instruct someone else how to do it?

A) No	> You must be certain that the persons responsible are able to take the necessary steps. Otherwise the emergency power generator may not function in an emergency. (!!!)
B) Yes	> go to Question 22

QUESTION 22: Are emergency situations that involve switching on the emergency power generator regularly practiced with the employees involved?

A) No	> You must ensure that the persons responsible not only know the steps to be taken to switch on the emergency power generator in theory, but can also put them into practice. Otherwise problems can arise in unusual and, to a certain degree, unforeseeable situations such as a flood. (!!) > go to Question 25
B) Yes	> go to Question 23

QUESTION 23: Are specific details which may have to be borne in mind in a flooding event part of these drills (e. g., finding and donning protective clothing, safely shutting down the normal power circuit to prevent accidents and short circuits, etc.)?

A) No	> It is advisable to include flood-specific approaches in the drills. Otherwise unforeseeable problems could occur in a flooding event. (!!) > go to Question 24
B) Yes	> go to Question 24

QUESTION 24: Are these drills evaluated to continually improve the procedure?

A) No	> It is advisable to use the results of the exercises to optimize the procedures. > go to Question 25
B) Yes	> go to Question 25

QUESTION 25: Have plans been drawn up about which measures are to be taken after switching on the EPS in an emergency situation (warning employees, orderly shutdown of systems, making sure of fuel being available, etc.)?

A) No	> It must be determined whether or not certain measures are to be taken after activating the emergency power system. Only in this way can the often limited running time of the emergency power system be used efficiently in a flooding event. (!!) > go to Question 27
B) Yes	> go to Question 26

QUESTION 26: Do the employees know these plans and are they aware of what they have to do?

A) No	> You must ensure that employees are informed of their personal responsibilities and of the routine actions to be taken by everybody while the EPS is operating. Otherwise misunderstandings could arise during a flooding event. (!!) > go to Question 27
B) Yes	> go to Question 27

QUESTION 27: Are emergency situations that involve the operation of the emergency power supply the subject of regular drills for the employees responsible?

A) No	> You must ensure that the employees involved not only know the measures that are necessary for operating the emergency power system in theory, but can also put them into practice. (!!) > go to Question 29
B) Yes	> go to Question 28

QUESTION 28: Are these drills evaluated to continually improve the procedure?

A) No	> It is advisable to use the results of the drills to optimize the procedure. > go to Question 29
B) Yes	> go to Question 29

QUESTION 29: Do the employees know how long the emergency power system can or should be operated? Has a plan been drawn up that regulates what is to be done when this time period is over?

A) No	> You should also consider how long it is sensible to operate the emergency power system in a flooding event. > go to Question 30
B) Yes	> go to Question 30

QUESTION 30: Have employees been assigned to monitoring the operation of the EPS (reliable performance of the cooling, ventilation, exhaust, etc.)?

A) No	> If the emergency power system is operated for more than just a brief period, the reliable performance of the plant should be checked regularly. Flood-specific problems could crop up (e. g. with regard to ventilation and exhaust gases), which would make the operation of the emergency power supply difficult or impossible. (!!) > go to Question 31
B) Yes	> go to Question 31

QUESTION 31: Do you know at which water level the emergency power from the EPS or UPS will fail or will have to be switched off (at what point the first electrical connection or the plant itself will be flooded)?

A) No	> If the flood waters rise higher than what was assumed during the planning of the emergency power supply, the emergency power itself may also fail due to flooding. This eventuality should be taken into account in the interest of the safety of staff and equipment. (!!!) > go to Question 32
B) Yes	> go to Question 32

QUESTION 32: Do plans specify when (at which water level) the shutdown of the emergency power supply and, if necessary, the removal of certain items of equipment must be considered?

A) No	> In order to avoid misunderstandings, employees should be able to have recourse to plans drawn up for dealing with this situation. > go to Question 36
B) Yes	> go to Question 33

QUESTION 33: Do the employees know these plans and are they aware of possible dangers?

A) No	> You must be certain that the employees are aware of their responsibilities and of the dangers that may arise in a flooding event. > go to Question 34
B) Yes	> go to Question 34

QUESTION 34: Have measures been taken to ensure that the employees know the prevailing water level (display panel, alarm, etc.)?

A) No	> Plans cannot be carried out if the staff do not have this essential information on which the plans are based. (!!!) > go to Question 35
B) Yes	> go to Question 35

QUESTION 35: Is it guaranteed that employees can still carry out the shutdown at this point in time (e. g. safe, risk-free access to the relevant elements of the system)?

A) No	> If on reaching a certain water level the emergency power system can no longer be shut down, the flood water may reach connections supplied with emergency power and other electrical equipment. This may mean a dangerous situation for both staff and equipment. (!!!) > go to Question 36
B) Yes	> go to Question 36

QUESTION 36: If the emergency power supply should unexpectedly not function in a flooding event, is it certain that technical support is available and that the employees know who to contact?

A) No	**> If the emergency power supply should unexpectedly not function, it is helpful if plans have been drawn up in advance identifying whom employees can contact (maintenance service personnel, technicians on site, manufacturer, etc.). Once flooding has occurred, there might no longer be time or opportunity to search for telephone numbers.** **> go to Question 37**
B) Yes	> go to Question 37

If you have an emergency power generator please proceed with QUESTION 37. If there is only a UPS available, the checklist ends at this point (all following questions are only concerned with the operation of an emergency power generator). In this case, you can ignore all remaining questions and go directly to the remarks at the end of the checklist.

3. Fuel reserves and logistics

QUESTION 37: Do you know how long existing fuel supplies will last to guarantee the emergency power supply you require? Do you know the fuel consumption of the emergency power generator under full load?

A) No	**> It is important to know for how long the EPS can be supplied with fuel in order to accordingly adjust the measures to be taken after starting it up. (!!)** **> go to Question 38**
B) Yes	> go to Question 38

QUESTION 38: Have you made sure that fuel tanks of the generator are always full (refueling after the plant has been in use)?

A) No	**> If the tanks are not completely full, the calculations on the length of time that the emergency power system will function may not be accurate. (!!)** **> go to Question 39**
B) Yes	> go to Question 39

QUESTION 39: Do you plan to run the emergency power generator longer than the time expected for one full tank, i. e. is it possible that the generator's tank must be refilled?

A) No	> End of checklist. No more relevant questions to answer.
B) Yes	> go to Question 40

QUESTION 40: Is refuelling to be carried out by staff or by an external service provider?

A) By staff	> go to Question 41
B) By an external service provider	> go to Question 46

QUESTION 41: Is the fuel necessary for refilling the generator's tank stored on site?

A) No	> go to Question 43
B) Yes	> go to Question 42

QUESTION 42: Is the fuel stored so that it cannot be affected by flooding and can refueling also take place during a flooding event (access to the tanks, no risk to employees and the environment, etc.)?

A) No	> There is a risk that either the refueling cannot be carried out during a flooding event or the fuel presents a hazard to staff or the environment. (!!) > go to Question 43
B) Yes	> go to Question 43

QUESTION 43: Are there plans for who is responsible for refueling the EPS in an emergency?

A) No	> You should ensure that someone is explicitly responsible for refueling the EPS. Otherwise misunderstandings may arise during a flooding event. (!!) > go to Question 44
B) Yes	> go to Question 44

QUESTION 44: Do the employees know the plans and do they know what they have to do?

A) No	> You should ensure that the people responsible for refueling the emergency power generator are informed of their responsibility. Otherwise misunderstandings may arise during a flooding event. (!!) > go to Question 45
B) Yes	> go to Question 45

QUESTION 45: Have preparations been made for a stand-by duty plan to be drawn up so that there is always someone responsible for carrying out this task during a flooding event?

A) No	> As it is impossible to predict whether or not the emergency power generator must be refueled during normal working hours, an emergency team should be put on stand-by to take over this responsibility in a flooding event. (!!) > go to Question 46
B) Yes	> go to Question 46

QUESTION 46: Are there plans for and contracts with external service providers who will supply fuel during a flooding event?

A) No	> You should ensure that contracts or agreements with a service provider who will take over refueling in a flooding event have been made in advance. (!!) > go to Question 47
B) Yes	> go to Question 47

QUESTION 47: Is it certain that external service providers can reach the building/premises in the event of a flood (electric gates/doors open, road accessible, etc.)?

A) No	You must ensure that service providers can gain access to the premises. Otherwise it may not be possible to carry out refueling as planned. (!!) > go to Question 48
B) Yes	> go to Question 48

QUESTION 48: Are there plans regarding who arranges for delivery in an emergency (calling the service provider, ensuring access to premises, etc.)?

A) No	> You should ensure that someone is explicitly responsible for arranging for delivery. Otherwise misunderstandings could arise during a flooding event. (!!) > End of check list
B) Yes	> End of check list

Results:

If all questions have been answered positively, it appears that not only the technical requirements and the location of the emergency power system but also the preparedness of the personnel, the fuel reserves and logistics constitute good prerequisites for the functioning of the emergency power supply and an efficient use of the operational time available. If problems have arisen when answering the questions, the checklist should be used as a diagnostic instrument and the problems should be addressed. Nevertheless, despite all the precautionary measures, you should still think about how the emergency plans would function in the case of a possible power failure. Flooding involves unpredictable eventualities and is accompanied by many problems.

Significance of the checklist results for vulnerability assessment

With the help of this checklist for examining the technical requirements, the preparedness of staff and, in the case of the EPS, the logistics and the fuel reserves, you have been able to obtain an overview of how good your preparations are regarding emergency power supply during a flooding event. The results should be incorporated into the vulnerability assessment so that they help to determine the functional susceptibility of certain components more exactly. If across-the-board function failure during the supposed exposure is too much of a generalisation and the emergency power supply can be positively assessed after finishing the checklist, a reassessment can take place on this basis. It should be noted that only if the checklist has been answered completely and all the problems have been eliminated, can a truly meaningful result be obtained.

Sources of further information (in German)

Arbeitskreis Maschinen- und Elektrotechnik staatlicher und kommunaler Verwaltungen (Working Group Machines and Electrotechnology of State and Municipal Administration Departments) (AMEV) (2006). *Hinweise zur Ausführung von Ersatzstromanlagen in öffentlichen Gebäuden (Advice on the Implementation of Emergency Power Systems in Public Buildings). Berlin*. Available from www.amev-online.de.

Bundesamt für Bevölkerungsschutz und Katastrophenhilfe (Federal Office for Civil Protection and Disaster Assistance) (BBK) (2006). *Leitfaden für die Einrichtung und den Betrieb einer Notstromversorgung in Behörden und anderen öffentlichen Einrichtungen (Guideline for Setting Up and Operating an Emergency Power Supply in Public Agencies and Other Public Facilities)*. Available from www.bbk.bund.de.

Verein Deutscher Ingenieure (The Association of German Engineers) (VDI) (2006). *Schutz der Technischen Gebäudeausrüstung. Hochwasser. Gebäude, Anlagen, Einrichtungen. (=VDI Richtlinie 6004) (Protection of Technical Building Services: Flooding, Buildings, Plants, Facilities (=VDI Guideline 6004)).*

7.2 Checklist 2: Organizational requirements for replaceability of failed services

This checklist is used for determining organizational requirements for replaceability of failed services. It is useful either to get together with the utility operators to talk through the checklist, or to give the list to the operators and request them to be guided by the checklist when answering the assessment questions. It should be explicitly stated that the checklist cannot be used as a set of instructions for drawing up a crisis management plan and that it only applies to the replaceability of various components in a flooding event. The flooding event can only be mastered if there is effective planning which goes beyond this checklist and which is carried out within the scope of general crisis management, such as setting up a 24-hour service. If you want more information on developing comprehensive risk and crisis management, you can find references to additional literature at the end of this checklist.

When preparing the checklist, quantification was consciously omitted because the answers cannot be used to assess whether measures can be fully or only partially implemented. The implementation will indeed lead to a complete, partial or in the worst case no replacement of the failed service. However, these assessments can only be made by the utility operators after considering all of the aspects addressed in the checklist. The answers in bold print indicate a problem, which, in a flooding event, will increase the risk that replaceability measures cannot be carried out.

In addition to its contribution to making an assessment, the checklist can be seen as a diagnostic tool that can uncover weaknesses in crisis management as regards implementing replaceability measures for failed services. To improve the situation, those problems should be addressed which become apparent when questions are answered in the negative.

QUESTION 1: Have the employees been informed of the risk to the component in the event of a flood?

A) No	**> The employees should be informed of the possible risks from flooding.** **> go to Question 2**
B) Yes	> go to Question 2

QUESTION 2: Have the employees been informed that, in a flooding event, the component is threatened by function failure?

A) No	**> The employees should be informed of the possible function failure caused by the impact of the flooding.** **> go to Question 3**
B) Yes	> go to Question 3

QUESTION 3: Have plans been drawn up specifying which measures to take to replace the failed service in case of function failure?

A) No > The replacement of failed service is frequently based on complicated calculations involving the capacity and load of other components and of the network as a whole. If these calculations are made in advance, preparations for an actual function failure can be significantly improved. (!!!)
> go to Question14

B) Yes > go to Question 4

QUESTION 4: Do these plans provide for the function failure of other components affected by the flooding?

A) No > If the plans have only been made for the failure of an individual component, it may not be possible to use them in a flooding event. It may be the case that components in these plans which are classified as functioning have in fact already been switched off. It is thus crucial to include all potentially affected components in the plans. (!!)
> go to Question 5

B) Yes > go to Question 5

QUESTION 5: Do these plans clearly lay down who is responsible for implementing these measures?

A) No > You should determine whose responsibility it is to implement the measures. Otherwise, misunderstandings could arise in a flooding event.
> go to Question 6

B) Yes > go to Question 6

QUESTION 6: Are the employees familiar with these plans and are they aware of their responsibilities?

A) No > You should make sure that the employees are aware of their responsibilities. Otherwise misunderstandings could arise in a flooding event.
> go to Question 7

B) Yes > go to Question 7

QUESTION 7: Have the employees been trained in carrying out these measures or are they capable of instructing others in this matter?

A) No	> You must ensure that the employees involved are able to take the necessary measures. Otherwise replacement in an emergency is not possible. > go to Question 8
B) Yes	> go to Question 8

QUESTION 8: Are there plans specifying when to take these measures (e. g. depending on the water level)?

A) No	> You must be certain that the people responsible know when certain measures are to be taken. Otherwise replacement may not be possible in an emergency. > go to Question 9
B) Yes	> go to Question 14

QUESTION 9: Do the employees know these plans?

A) No	> You should ensure that the employees know the plans and the schedules, measures and actions they lay down. Otherwise misunderstandings could arise in a flooding event. > go to Question 10
B) Yes	> go to Question 10

QUESTION 10: Are the employees continuously informed of the water level in a flooding event?

A) No	> If employees have no way of finding out about the prevailing water level, they cannot carry out measures dependent on this water level. (!!) > go to Question 11
B) Yes	> go to Question 11

QUESTION 11: Are the measures that must be taken when a particular component fails regularly practiced with the employees responsible?

A) No	> You should be certain that the employees involved not only know the measures that are needed to replace components in theory; they must also be able to put them into practice. > go to Question 14
B) Yes	> go to Question 12

QUESTION 12: Are flood-specific issues taken into account in these emergency drills (e. g. locating and donning protective clothing)?

A) No	> In such drills it is also advisable to practice challenging situations that may play a role in a flooding event. Otherwise unforeseen problems could arise when a flood occurs. > go to Question 13
B) Yes	> go to Question 13

QUESTION 13: Are these exercises continually evaluated to see if the procedures can be improved?

A) No	> It is advisable to use the results of the exercises to optimize the procedures. > go to Question 14
B) Yes	> go to Question 14

QUESTION 14: Can the measures that must be taken in the case of a (an impending) function failure be implemented using automated or telecontrol technology?

A) No	> go to Question 18
B) Yes	> go to Question 15

QUESTION 15: Is the telecontrol equipment regularly maintained and, if necessary, repaired?

A) No	> You should ensure that the telecontrol equipment is regularly maintained and, if necessary, updated or modernized. > go to Question 16
B) Yes	> go to Question 16

QUESTION 16: Is it certain that all connections of the automated or telecontrol equipment remain intact under the conditions of a flooding event (dependent on a power supply? sensitive to water?)?

A) No	> There is no guarantee that the measures for replacing failed components can be carried out in a flooding event. (!!!) > go to Question 17
B) Yes	> go to Question 17

QUESTION 17: Can the measures also be carried out directly on the component itself (i. e. independent of the telecontrol technology)?

A) No	> End of checklist.
B) Yes	> go to Question 18

QUESTION 18: Are you certain that the employee(s) responsible can reach the component (vehicle available, access road still passable, no risk for employees) under flooding conditions and at the time point when the measures must be taken?

A) No	**> If the employee(s) cannot reach the component safely in a flooding event, there is the risk that the measures needed to replace the component cannot be carried out.** **> End of checklist.**
B) Yes	> End of checklist.

Significance of the checklist results for the vulnerability assessment

With the aid of the above checklist for the examination of organizational requirements for the replaceability of failed service in a flooding event, you have been able to gain an overview of how good your organizational and logistical preparations are. The results should be included in the vulnerability assessment in order to help in answering the question: To what extent are personnel able to make use of the technical options for replaceability? If large gaps are found, it can be assumed that the implementation of the measures will not function smoothly. If the questions in the checklist are answered positively throughout, this can be a sign that the employees are able to fully implement the technical options available. It should be noted that only if the checklist has been answered completely and all problems have been eliminated can a really meaningful result be obtained. Remember, however, that flooding can always involve unforeseen eventualities.

Source of further information

German Federal Ministry of the Interior (BMI) (2008): *Protecting Critical Infrastructures – Risk and crisis management. A Guide for companies and government authorities. Berlin.*

7.3 Examples of the vulnerability assessment of power supply

The following sections illustrate the individual steps in a vulnerability assessment of the power and drinking water supply and ways of dealing with the results by means of imaginary examples. The examples are not absolutely necessary for the use of the guideline, but they facilitate understanding.

Cross-references to the corresponding sections in the guideline are provided throughout. The examples are divided into two sections:

A. Examples of individual assessment steps
B. Examples of dealing with assessment results

Please note that all the examples given are imaginary and to some extent idealized for better understanding and illustrative value. Reality will certainly prove to be more complicated!

This step corresponds to the "First assessment phase: vulnerability assessment of sub processes/components" in Chapter 3.

Step 1: Specifying a flooding scenario

This step is described in the "Use of the scenario-based approach" section in Chapter 2.

Step 2: Determination of the sub-processes and components

Example 1

For fictional municipality A, the list in Figure 7.1 is the result of analyzing the power supply.

Sub-processes and components of the power supply in municipality A

Power station(s)	Grid substation(s) (extra-high voltage > high voltage)	Grid substation(s) (high voltage > medium voltage)	Network control center	Network substations (medium voltage > low voltage)
0	1) Substation 'Meadow Lane (I)'	1) Substation 'Meadow Lane (II)' 2) Substation 'Forest'	0	Total 100

Fig 7.1: Determination of the sub-processes and components in A

Note: The number of network substations becomes increasingly larger as the size of the municipality increases, and so in this case they have not all been entered separately into the list. Doing so can, however, be appropriate for smaller municipalities. Depending on whether the data allows it, the cable distributor boxes can also be included in the list. In A, there is no "power station" and no "network control center" – accordingly, these components do not have to be taken into account in A. However, the vulnerability of the sub-processes they perform is important for the functioning of the system as a whole and it would be advisable to contact the provider to obtain this information.

Example 2

In fictional municipality B, the list in Figure 7.2 is the result of analyzing the power supply.

Sub-processes and components of the power supply in municipality B

Power station(s)	Grid substation(s) (extra-high voltage > high voltage)	Grid substation(s) (high voltage > medium voltage)	Network control center	Network substations (medium voltage > low voltage)
1) Power station 'Mill Street'	1) Substation 'Lake View'	1) Substation 'Main Street' 2) Substation 'Baker Street' 3) Substation 'City Center' 4) Substation 'Stadium'	1) Headquarters	Total 500

Fig 7.2: Determination of the sub-processes and components in B

Note: In municipality B all the listed sub-processes/components must be considered.

Step 3: Determining the degree of exposure

Example 1

In case A, Figure 7.3 is the result of completing this step in the assessment of the power supply.

Sub-processes and components of the power supply in municipality A

Power station(s)	Grid substation(s) (extra-high voltage > high voltage)	Grid substation(s) (high voltage > medium voltage)	Network control center	Network substations (medium voltage > low voltage)
1) Power station 'Mill Street'	1) Substation 'Meadow Lane (I)'	1) Substation 'Meadow Lane (II)' ~~2) Substation 'Forest'~~	0	~~Total 100~~ Total 25

Fig 7.3: Determining the degree of exposure in A

Note: One of the substations is not exposed. As, however, another one is exposed, the sub-process as a whole must be checked further. The same applies to the sub-process "Transforming to low voltage"; although many of the individual network substations are taken to be not exposed, the sub-process as a whole must be further considered. All other components and sub-processes are subject to the next steps in the assessment.

Example 2

In city B, the situation illustrated in Figure 7.4 is the result of this step in the assessment of the power supply.

Sub-processes and components of the power supply in municipality B

Power station(s)	Grid substation(s) (extra-high voltage > high voltage)	Grid substation(s) (high voltage > medium voltage)	Network control center	Network substations (medium voltage > low voltage)
~~1) Power station 'Mill Street'~~ → Class I	1) Substation 'Lake View'	1) Substation 'Main Street' 2) Substation 'Baker Street' 3) Substation 'City Center' ~~4) Substation 'Stadium'~~	~~1) Headquarters~~ → Class I	~~Total 500~~ Total 60

Fig 7.4: Determining the degree of exposure in B

Note: From this list it emerges that the power station and the network control center no longer need to be included in the following assessment steps; rather, these two sub-processes as a whole belong to vulnerability Class I.

Step 4: Determining the functional susceptibility of exposed components

Example 1

For municipality A, Figure 7.5 is the result of carrying out this step of the assessment.

Sub-processes and components of the power supply in municipality A

Power station(s)	Grid substation(s) (extra-high voltage > high voltage)	Grid substation(s) (high voltage > medium voltage)	Network control center	Network substations (medium voltage > low voltage)
0	1) Substation 'Meadow Lane (I)'	1) Substation 'Meadow Lane (II)' ~~2) Substation 'Forest'~~	0	~~Total 100~~ Total 25

Fig 7.5: Determining the functional reliability of exposed components in A

Note: Unfortunately, A cannot cross off any components of the power supply from the list – some components of all sub-processes are threatened by function failure.

Example 2

As a result of this assessment step, in municipality B a further sub-process can be crossed off the list, as can be seen in Figure 7.6.

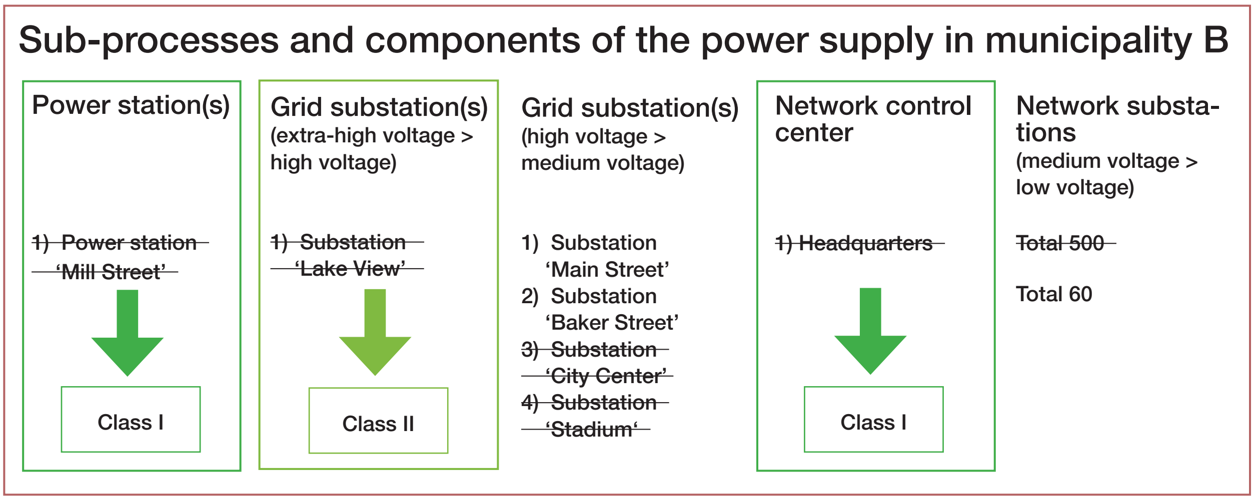


Fig 7.6: Determining the functional reliability of exposed components in B

Note: In B, two of the exposed substations have been protected through measures to protect the sites from flooding. They will not fail under the conditions assumed in the specified scenarios and can therefore be crossed off the list. The sub-process "Transforming from extra-high to high voltage" can therefore be assigned to Class II. The sub-process "Transforming from high to medium voltage" must, however, continue to be considered in the assessment because two of its components may be affected by a failure.

Step 5: Determining replaceability (I) – technical requirements

Example 1

With regard to the technical feasibility of replacing failed services, the situation in municipality A is shown in Figure 7.7.

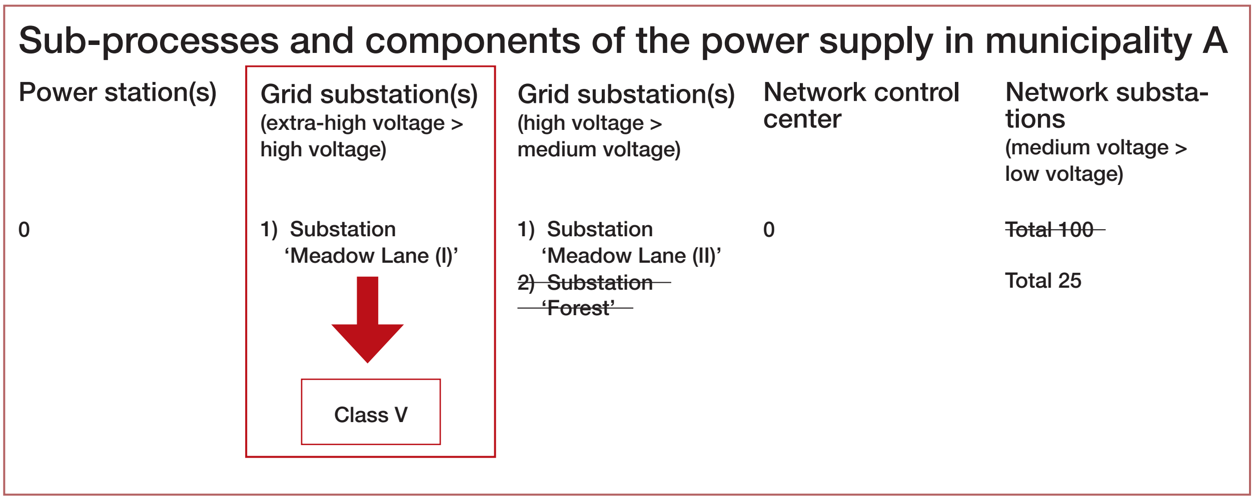


Fig 7.7: Determining replaceability (I) – technical requirements in A

Note: In A, a problem has appeared with regard to the power supply: both substations 'Meadow Lane' I and II, which are located next to each other, are exposed and functionally vulnerable. Additionally, substation 'Meadow Lane I' is not replaceable, while substation 'Meadow Lane II' is partially replaceable. Some of the 25 network substations are partially replaceable and some can be expected to fail.

Example 2

In B, Figure 7.8 is the result after carrying out Step 5.

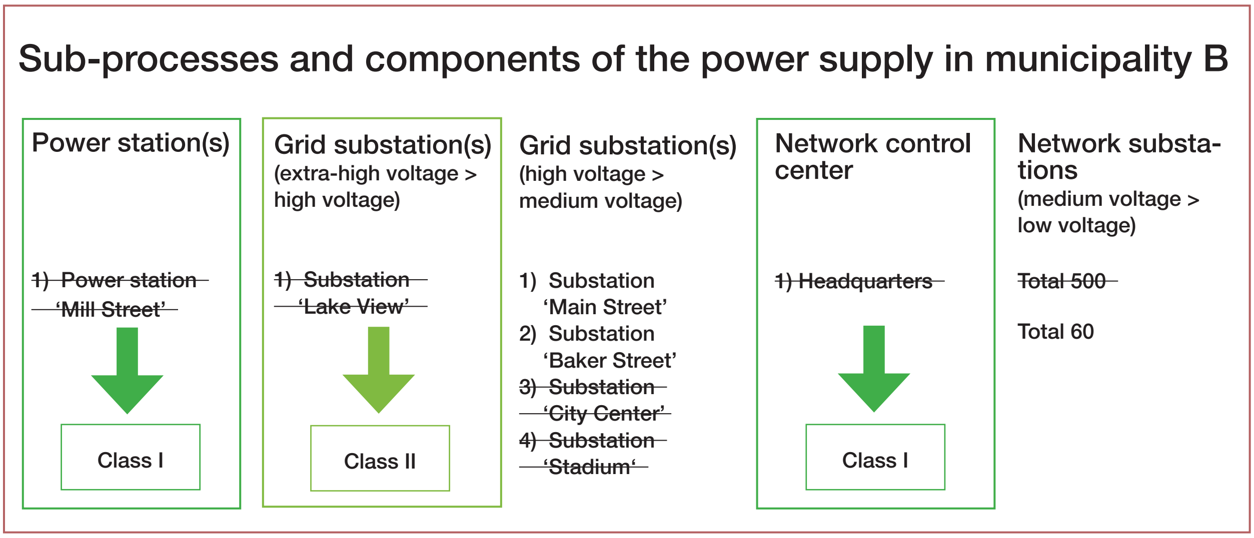


Fig 7.8: Determining replaceability (I) – technical requirements in B

Note: In B, the situation as regards the power supply looks better. Substations 'Main Street' and 'Baker Lane' can, in technical terms, be completely replaced because the network configuration and the load of the two remaining substations make redundant operation possible according to information from the utility operator. The network substations can be partially replaced; in part, however, network configuration and capacity do not allow for any redundancy. Therefore, no class assignments can yet be made for the sub-processes as a whole.

Step 6: Determining replaceability (II) – organizational requirements

Example 1

Figure 7.9 shows the situation in municipality A after completion of the last step in the assessment.

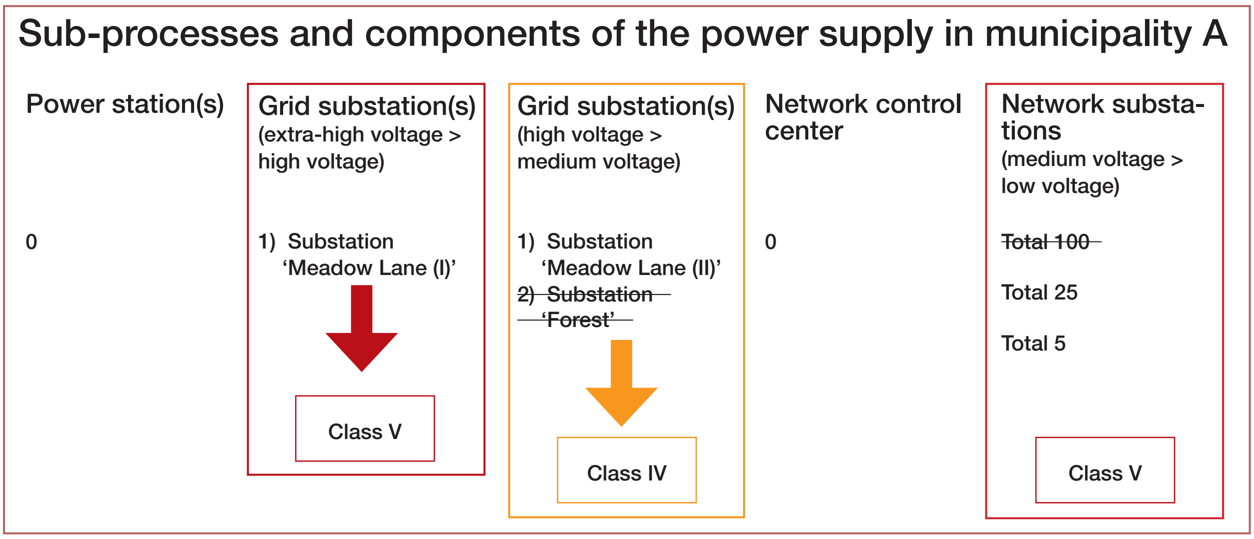


Fig 7.9: Determining replaceability (II) – organizational requirements in A

Note: In A, five of the network substations are not fully replaceable. They will fail in the event of a flood and therefore the sub-process as a whole must be assigned to vulnerability Class V. Neither can the full performance provided by the sub-process "Transforming to medium voltage" be fully replaced. Here, a partial failure is to be expected.

Example 2

Figure 7.10 shows the results in municipality B after completion of the assessment phase.

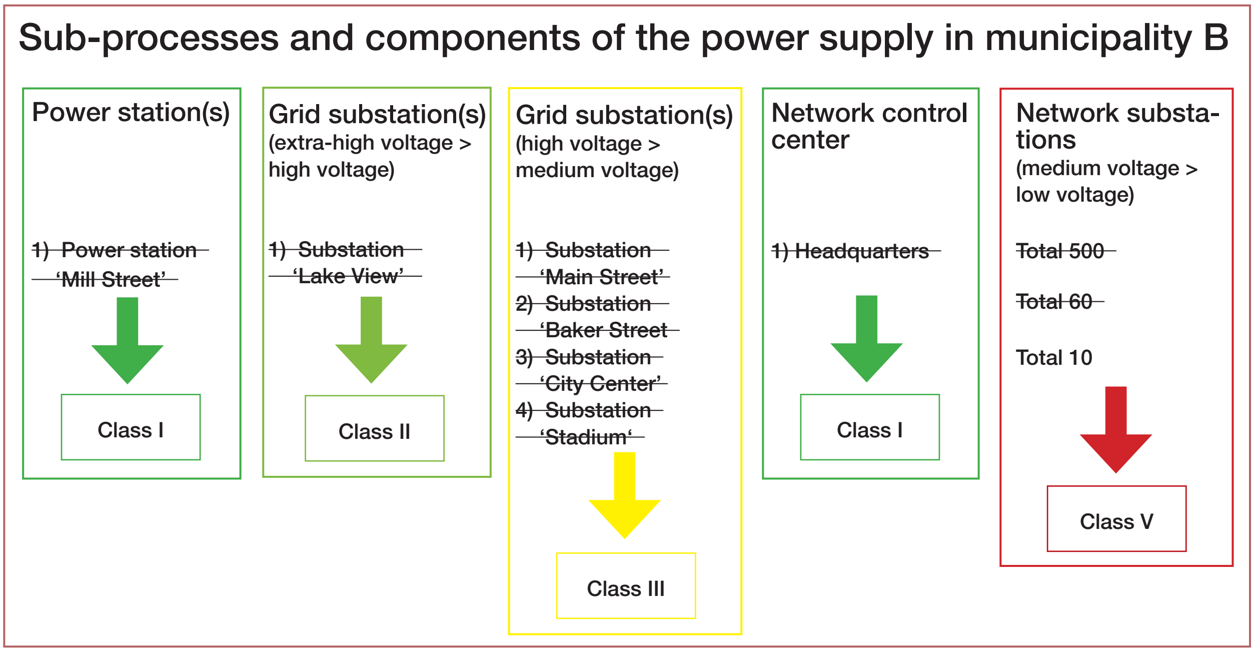


Fig 7.10: Determining replaceability (II) – organizational requirements in B

Note: In B, the services provided by the two substations can be completely replaced. They are therefore assigned to Class III. Some of the network substations cannot be replaced. Being assigned to Class V is the result for 10 of the components and thus for the entire subprocess.

7.4 Results of the UNU-EHS Household Survey

In order to assess the vulnerability of the population to flood events, formulas for calculating the core indicators were presented in Chapter 4.2. The corresponding parameters are defined with the help of data from a household survey. In the event that no purpose-made independent survey has been carried out, some of the results and parameters from the UNU-EHS Household Survey are presented here. While assuming that the same interrelationships exist, these parameters can be used as substitutes in the corresponding formulas.

7.4.1 Evacuation capability according to household type

		Would you manage to get yourself and your dependants in the household to safety in the event of an evacuation ?	
		Yes	No
Household type	1) Households with children younger than 6 years	91.7 per cent	8.3 per cent
	2) Households with members between 6 and 59 years	95.3 per cent	4.7 per cent
	3) Households with people 60 years or older (at least 2 people)	88.2 per cent	11.8 per cent
	4) One-person-households 60 years or older	60.5 per cent	39.5 per cent
Total		89.0 per cent	11.0 per cent

	Value	p-value
Cramer's V	0.352	< 0.001

Table 7.1: Overall evacuation capabilities of the different household types in the HQ-100 areas of Cologne and Dresden (Data source: UNU-EHS Household Survey)

Cramer's V is a measure of association that can take values between 0 and 1, whereby the interrelationship is greater the larger the value of the Cramer's V. The p-value represents the result of a significance test. In significance tests, a null hypothesis (e. g. „there is no relationship“) is always tested against an alternative hypothesis (e. g. „there is a relationship“). The p-value also describes the likelihood of error, i. e. the probability that you decide incorrectly when you reject the null hypothesis and accept the alternative hypothesis[36]. In common parlance, we speak of a significant result for p-values under 0.05, i. e. the null hypothesis will be rejected in these cases. The significant Cramer's V value here of almost 0.4 thus indicates a relationship that can be considered to be more than just trivial.

Therefore, the indicator „evacuation capability“ (according to Variant 1) is calculated as follows using the values from the UNU-EHS Household Survey in the HQ-100 zone for Cologne and Dresden:

Number of HH capable of evacuating themselves unaided =
(Number of HHtype 1 * 0.917) + (Number of HHtype 2 * 0.953) + (Number of HHtype 3 * 0.882) + (Number of HHtype 4 * 0.605).

[36] See e. g. Bühl, A. (2008): SPSS 16. Einführung in die moderne Datenanalyse (Introduction to Modern Data Analysis). 11th, Updated Edition. Munich.

7.4.2 Estimating the evacuation capability using a logistic regression model

Formula 2 for the model calculated using the values from the UNU-EHS Household Survey for the HQ-100 zone (see Table 7.2) is:

$$P(Y=1) = \frac{e^z}{1+e^z}$$

with $z = 1{,}394 + (2{,}606 * x_1) + (2{,}042 * x_2) + (1{,}285 * x_3) + (-2{,}032 * x_4)$

	b	p-value[37]	Exp(b)[38]
Constant Term	1.394	0.001	
HHtype=1	2.606	0.002	13.542
HHtype=2	2.042	0.000	7.710
HHtype=3	1.285	0.009	3.614
HHtype=4	0[39]		
Run	-2.032	0.000	0.131

Table 7.2: Table of parameter estimates from the UNU-EHS Household Survey

Dependent variable: "Would you manage to get yourself and your dependants in the household to safety in the event of an evacuation without external assistance?" Reference category: No.
The variable "Run" shows the presence of "people in the household who cannot leave the house on their own or cannot walk any longer distance (2 km)".

[37] See explanations in Appendix 7.4.1

[38] For an interpretation of Exp(b) see e. g. Backhaus, K., Erichson, B., Plinke, W. & R. Weiber (2005): Multivariate Analysemethoden. Eine anwendungsorientierte Einführung (Multi-variant Analyses Methods. An Application-Oriented Introduction). Berlin. Heidelberg.

[39] This parameter is set to zero because it is redundant.

Example:

Data for the „Old Town South“ district of the city of Cologne has been used as an example for calculating the indicator „evacuation capability“ in accordance with Variant 2: This district has 7% of households rated as household type 1, 74% as type 2, 5% as type 3 and 13% as type 4. According to the micro community census, 5% of the households contain people that cannot walk long distances. The proportion of households capable of evacuation is then calculated as follows:

$$z = 1{,}394 + (2{,}606 * 0{,}07) + (2{,}042 * 0{,}74) + (1{,}285 * 0{,}05) + (-2{,}032 * 0{,}05) \text{ and thus}$$

$$P(Y=1) = \frac{e^z}{1+e^z} = 0{,}95.$$

According to this logistic regression model, 95% of households in the „Old Town South“ district of the city of Cologne contain people who are able to get themselves to safety unaided.

Notes:

Selected statistical information on the validity of the logistic regression model:

- The likelihood ratio test was significant → it can be assumed that the regression coefficient will not be equal to zero.

- The Pseudo R^2 according to Nagelkerke is 0.31. The measurement of Pseudo R^2 attempts to quantify the „variation“ of a logistic regression model. Values close to 0 indicate a low explanatory power, while values close to 1 point to a high explanatory power[40].

- The Wald test checks the significance of every individual independent variable („p-value“). It proved significant in every case, which confirms the influence of every single household type and of the walking capability.

- In the regression model, it was possible to correctly predict 90.3% of all cases in the survey data.

In general, this indicates an altogether acceptable model adjustment, which enables an estimate of the evacuation capability to be made.

[40] See e. g. Backhaus, K., Erichson, B., Plinke, W. & R. Weiber (2005): Multivariate Analysemethoden. Eine anwendungsorientierte Einführung (Multi-variant Analyses Methods. An Application-Oriented Introduction). Berlin. Heidelberg.

7.4.3 Medians of the evacuation time according to household type

The UNU-EHS Household Survey for Cologne and Dresden produced the following values (in minutes) for the evacuation time in the HQ-100 zone:

	HHtype 1	HHtype 2	HHtype 3
Median:	30	20	30

Therefore, the indicator „evacuation time“ is calculated as follows using the values from the UNU-EHS Household Survey in the HQ-100 zone for Cologne and Dresden:

Median time =
(Proportion of HHtype 1 * 30) + (Proportion of HHtype 2 * 20) + (Proportion of HHtype 3 * 30).

The calculation of the average evacuation time (median) for households in the different household groups indicates that those households exclusively containing people capable of working (HHtype 2) can evacuate themselves quicker than those households with children (HHtype 1) or those households with people of retirement age (HHtype 3).

Using a statistical variance test, it was demonstrated that it is possible to easily differentiate between the evacuation times for the relevant household types (HHtypes 1, 2, 3), even if the median values sometimes concur or are very close to one another. Consequently, it is possible to use the household types to derive information about the evacuation time for the whole borough or the whole city district.

The validation of the interrelationship between evacuation time in minutes and the household type was carried out using a variance analysis without a constant term. It evaluated what proportion of the variance in the evacuation time can be explained by the household types. This proportion is expressed by the partial eta-squared value, which in this case is 0.27. In addition, it was tested whether the evacuation time for all household types was the same (null hypothesis). If this assumption is rejected (unequivocally in this case with a p-value < 0.01), this means that the household type has a significant influence on evacuation time.

7.4.4 Estimating insurance cover using income data

The following regression model for insurance cover was produced for the UNU-EHS Household Survey carried out in Cologne and Dresden based on the HQ-100 zone:

$$y = 0{,}25 + 0{,}00006x_1$$

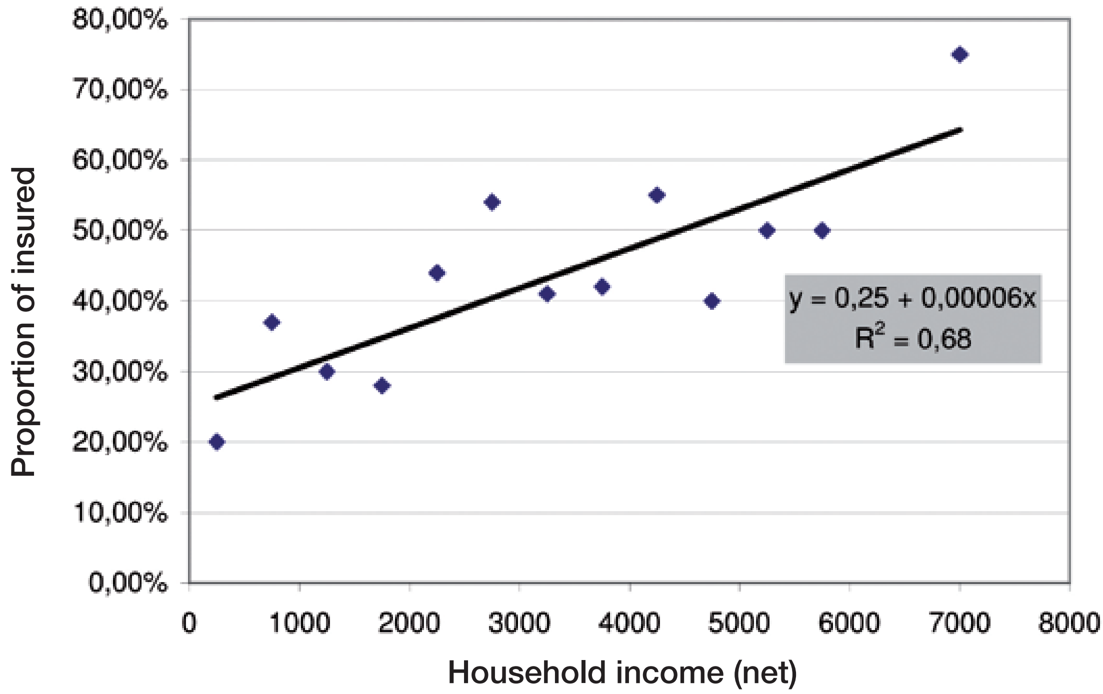


Figure 7.11: Linear regression between household income and the proportion of households insured against flood damage (insurance against natural hazards) (Data source: UNU-EHS Household Survey)

In order to estimate the proportion of insured households within a certain income class, you simply need to insert the average income value for this income class into the regression model.

Note:

Selected statistical information on the validity of the linear regression model:

- The coefficient of determination R^2 is almost 0.7. The coefficient of determination is a measurement of the explained level of variance in the linear regression model. The value range lies between 0 and 1; the higher the level of explained variance, the larger the value of R^2.

- The F-test proved significant. In F-statistics, the estimated regression model is also tested for validity using the overall population beyond the sample. This involves including the size of the sample in the calculations. The null hypothesis states that there is no interrelationship in the overall population and all regression coefficients are zero. If this null hypothesis is rejected (small p-value), it can be assumed that an interrelationship exists.

- The standard error in the estimate, i. e. the mean error that is calculated in the use of the regression function, is 8 %[41].

Therefore, this indicates a good model fit in a statistical sense.

[41] See e. g. Backhaus, K., Erichson, B., Plinke, W. & R. Weiber (2005): Multivariate Analysemethoden. Eine anwendungsorientierte Einführung (Multi-variant Analyses Methods. An Application-Oriented Introduction). Berlin. Heidelberg.

7.4.5 Estimating insurance cover using data about the ratio of owners-lessees

			Natural hazards damage insurance	
			No	Yes
Lessee			80.5 per cent	19.5 per cent
Owner			36.9 per cent	63.1 per cent
Total			62.1 per cent	37.9 per cent
	Value	p-value		
Cramer's V	0.44	< 0.001		

Table 7.3: Overall ownership status (lessee / property owner) of the apartments and insurance cover in the HQ-100 zone for Cologne and Dresden (Data source: UNU-EHS Household Survey)

Cramer's V is a measure of association that can take values between 0 and 1, whereby the interrelationship is greater the larger the value of the Cramer's V. The p-value represents the result of a significance test. In significance tests, a null hypothesis (e. g. „there is no relationship") is always tested against an alternative hypothesis (e. g. „there is a relationship"). The p-value also describes the likelihood of error, i. e. the probability that you decide incorrectly when you reject the null hypothesis and accept the alternative hypothesis[42]. In common parlance, we speak of a significant result for p-values under 0.05, i. e. the null hypothesis will be rejected in these cases. The significant Cramer's V value here of over 0.4 thus indicates a relationship that can be considered to be significantly more than just trivial.

Using the weighting factors from the UNU-EHS Household Survey, Formula 5 is as follows:

Proportion of insured households =
(proportion of rented apartments * 0.195) + (proportion of apartments occupied by their owner * 0.631).

[42] See e. g. Bühl, A. (2008): SPSS 16. Einführung in die moderne Datenanalyse (Introduction to Modern Data Analysis). 11th, Updated Edition. Munich.

7.5 Digression: The process of logical data integration in the area of „environmental vulnerability“

The process of logical data integration is used when multiple – at least two – ordinal scale variables need to be joined together to produce a combined result[43]. In the case of ordinal scale variables, values represent rating classes in a ranked order e. g. very low biotope value, low biotope value, medium biotope value, high biotope value and very high biotope value. These verbally defined rating classes are usually allocated the Roman numerals I, II, III, IV, V. However, it is not permitted for them to be arithmetically joined together into a combined result through addition or subtraction. It is only permitted to „logically integrate“ them[44]. In order to carry out a logical data integration, the use of preference matrices is one method proposed in the relevant literature. This involves comparing the two variables to be integrated using their ranked values (see Figure 7.12).

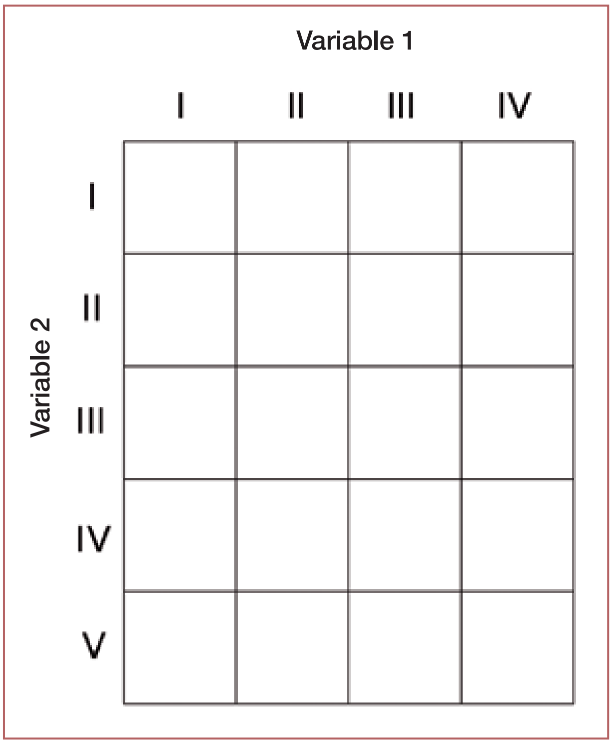


Figure 7.12: Example of an empty preference matrix

Logically integrating the respective values, or in other words the rating classes of the variables, means using logical principles to determine the combined result of joining together e. g. the rating „low“ (I) for one variable with the rating „medium“ (III) for another variable. In this specific case, the purpose is to find an intermediate result for environmental information relevant to vulnerability from e. g. „soil with a low conservation value“ and „groundwater with a medium protection level“.

There is no uniform or standardised process for integrating two variables based on logical principles. It is left to the judgement of the person processing the data to make decisions in a logical and understandable way. In order to simplify the decision-making process when joining together criteria for the desired combined result describing „environmental information relevant to vulnerability“, a new method using preference matrices was developed. Here, each of the existing ordinal values for those criteria relevant to vulnerability are allocated a vulnerability rating using expert knowledge and with the aid of a functional diagram. Integrating the three vulnerability ratings produces the environmental information relevant to vulnerability. In the function, the relative importance of the respective criterion for assessing vulnerability is represented. Therefore, it describes how the level of vulnerability changes with respect to increasing value of the relevant criterion.

[43] Bachfischer, R. (1978): Die ökologische Risikoanalyse – eine Methode zur Integration natürlicher Umweltfaktoren in der Raumplanung (Ecological risk analysis – a method for integrating natural environmental factors into regional planning). Diss. Munich.

[44] F. Scholles (2008): Bewertungsmethoden: Der Relevanzbaum (Evaluation methods: The relevance tree). In: Fürst, D. u. F. Scholles (Ed.): Handbuch, Theorien und Methoden der Raum- und Umweltplanung (Manual, theories and methods for regional and environmental planning). Dortmund.

In order to create the functional diagram, it is firstly necessary to define how many rating classes should be used to describe the environmental information relevant to vulnerability as this will define the number of rating classes used for vulnerability in the functional diagram. A 5-level classification system is recommended. Consequently, the functional diagram describes the environmental vulnerability based on five rating classes. The number of values for each respective criterion is based on the rating classes available in your datasets. The illustrated interrelationship – corresponding to the curve of the function – between the individual criterion and vulnerability is defined in the functional diagram. Because each community has a different number of values for these criteria, it is necessary for the functional curve to be compressed (less values than in the example curve, see Figures 7.13, 7.14, 7.15) or expanded (more values than in the example curve). In the following example, the relationship between the biotope value and vulnerability will be demonstrated (see Figure 7.13).

In this example, the biotope value has five rating classes (I-V). The curve indicates that a very low or low biotope value (rating classes I and II) primarily indicates a very low level of vulnerability (primarily rating class I), while a high or very high biotope value (rating classes IV and V) indicates a very high level of vulnerability (primarily rating class V). Therefore, the functional curve is not linear. Linearity would have meant that the vulnerability level increases with respect to increasing ranked values for the criterion. This would mean that the rating class „very low" represents a very low level of vulnerability and the rating class „low" represents a low level of vulnerability. However, the transition of the function from low to high vulnerability (rating class II to rating class IV) is actually characterised by a jump.

The other criteria „conservation value of the soil" and „groundwater protection level" also display this already outlined non-linear curve (see Figures 7.14 and 7.15).

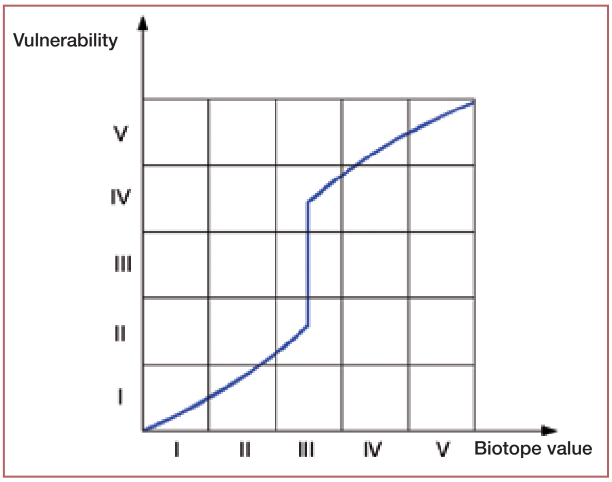


Figure 7.13: Example of a functional relationship between the biotope value and vulnerability

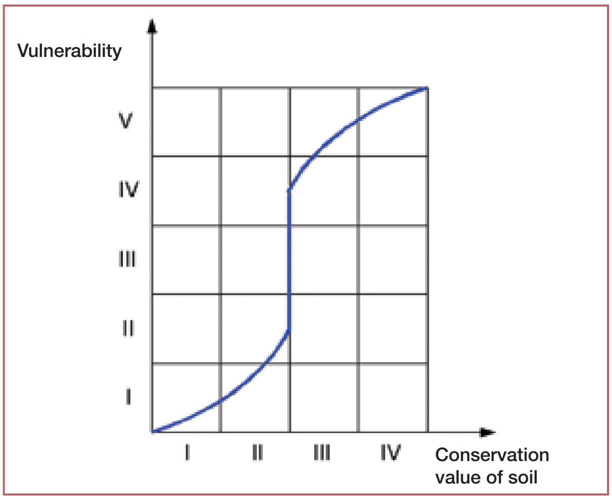


Figure 7.14: Example of a functional relationship between the conservation value of the soil and vulnerability

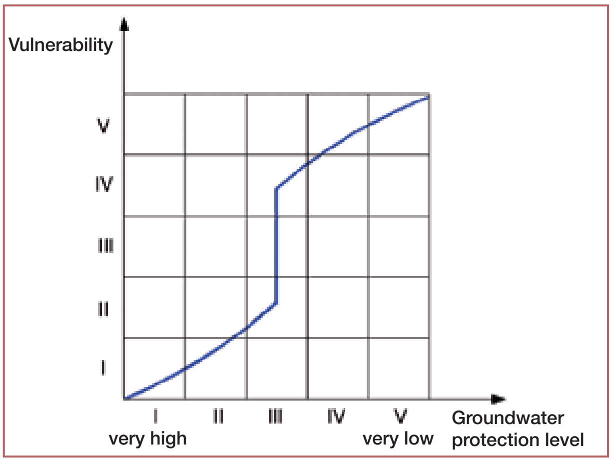


Figure 7.15: Example of a functional relationship between the groundwater pro-tection level and vulnerability

In the case of every rating class for the criteria relevant to vulnerability, the level of vulnerability (= vulnerability rating) can be read off the functional curve. In order to carry out the logical data integration in the preference matrix, you now need to determine the result from reading off the two vulnerability ratings. A low vulnerability rating (class II) and a high vulnerability rating (class IV) will result in a medium vulnerability rating (class III) if both criteria are equally weighted. The result is entered into the relevant field in the preference matrix. However, it is also possible that the functional curve intersects two vulnerability ratings. For example, the ratings „very low vulnerability“ and „low vulnerability“ (classes I and II) can be read for the rating „low biotope value“ (class II) in Figure 7.16. However, as the functional curve tends to be primarily located in the rating „very low vulnerability“ (class I), you would read off I/II, i. e. for the integration process you would evaluate the rating as „very low vulnerability“ rather than „low vulnerability“.

The logical data integration of two criteria in the preference matrix is complete when a result has been entered in the preference matrix for every possible combination of values for both criteria. In the logical data integration of the vulnerability criteria „conservation value of the soil“, „groundwater protection level“ and „biotope value“ to generate the environmental information relevant to vulnerability, it is only possible at first to evaluate and integrate two criteria in the preference matrix e. g. „conservation value of the soil“ and „groundwater protection level“ (it is also only possible to integrate a maximum of two criteria when visualising the data in the GIS).

For the intermediate result of integrating the „conservation value of the soil“ and „groundwater pro-tec-tion level“, the importance for vulnerability must also be represented in the form of a function. As the intermediate result is taken from both individual criteria, the same functional relationship exists between the intermediate result and vulnerability as between the individual criterion and vulnerability (see Figures 7.13, 7.14, 7.15). The same principles already described above are also valid for integrating the remaining criterion „biotope value“. When integrating the rating classes for the intermediate result and the biotope value in the preference matrix, the vulnerability ratings should be read off both functional curves and logically integrated according to your judgement. The vulnerability ratings entered into this preference matrix provide us with the ratings for the environmental information relevant to vulnerability i. e. the ratings in the preference matrix for the two variables „intermediate result“ and „biotope value“ correspond to the ratings for environmental information relevant to vulnerability.

Abbreviations

A

AMEV	Arbeitskreis Maschinen- und Elektrotechnik staatlicher und kommunaler Verwaltungen [Working group Machines and Electrotechnology of State and Municipal Administration]

B

BBK	Bundesamt für Bevölkerungsschutz und Katastrophenhilfe [Federal Office of Civil Protection and Disaster Assistance]
BBodSchV	Bundes-Bodenschutz- und Altlastenverordnung [Federal Soil Protection and Contaminated Sites Ordinance]
BBR	Bundesamt für Bauwesen und Raumordnung [Federal Office for Building and Regional Planning]
BfLR	Bundesanstalt für Landeskunde and Raumordnung (today BBR, see above)
Bit	Binary digit
BImSchV	Bundesimmissionsschutzverordnung [Federal Emission Control Act]
BMI	Bundesministerium des Inneren [German Ministry of the Interior]

D

d	day
DFD	Deutsches Fernerkundungsdatenzentrum [German Remote Sensing Data Centre]
DTM	Digital Terrain Model
DLR	Deutsches Zentrum für Luft- und Raumfahrt [German Aerospace Center]
DSM	Digital Surface Model

E

EHQ	Extremhochwasserszenario [extreme flood scenario]
EPS	Emergency Power System
ETM+	Enhanced Thematic Mapper Plus
EU	European Union

G

GIS	Geographic Information System
GPS	Global Positioning System

Abbreviations

H

HHGen	Haushaltegenerierungsverfahren [household generation procedure]
HHType	Household type
HQ-100	Hochwasserszenario mit einem statistischen Wiederkehrintervall von 100 Jahren [flooding scenario with a statistical reoccurrence interval of 100 years]
HQ-500	Hochwasserszenario mit einem statistischen Wiederkehrintervall von 500 Jahren [flooding scenario with a statistical reoccurrence interval of 500 years]

I

IKSR	Internationale Kommission zum Schutz of the Rheins [International Commission on the Protection of the Rhine]
INS	Inert Navigation System
IRS-P6/LISS-3	Indian remote sensing satellite

K

km	Kilometer
KOSIS	Verbund Kommunales Statistisches Informationssystem [Group of Municipal Statistic Information System]
kV	Kilovolt

L

LAWA	Bund/Länder Arbeitsgemeinschaft Wasser [Federal/State Working Group on Water]
LiDAR	Light Detection And Ranging

M

m	Meter
MLU	Martin Luther University Halle-Wittenberg
MSS	Multispectral scanner

N

NRW	North Rhine-Westphalia

P

P	Probability
pan.	panchromatic

R

Radar	Radio Detection And Ranging

S

SAR	Synthetic Aperture Radar
SRTM	Shuttle Radar Topography Mission

T

therm.	thermal
TM	Thematic Mapper

U

UNU-EHS	United Nations University Institute for Environment and Human Security
UPS	Uninterruptible power supply
UST	Urban Structure Type

V

V	Volt
VDI	Verein Deutscher Ingenieure e.V. [Association of German Engineers]

W

WHG	Wasserhaushaltsgesetz [Federal Water Act]

Z

ZKI	Zentrum für Satellitengestützte Kriseninformtion [Centre for Satellite-based Crisis Information]

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