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IHP/HWRP-BERICHTE

Heft 9

Koblenz 2009

Managing Extreme Flood Events

Analysing, forecasting, warning, protecting and informing

IHP – International Hydrological Programme of UNESCO

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Managing Extreme Flood Events

Analysing, forecasting, warning, protecting and informing – case studies from the RIMAX projects

Georg Petersen

Koblenz, 2009

Deutsches IHP/HWRP National Committee

BfG – Federal Institute of Hydrology, Koblenz

HWRP – Hydrology and Water Resource Programme of WMO

United Nations
Educational, Scientific and
Cultural Organization

International
Hydrological
Programme

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Hydrology and Water Resources Programme (HWRP) of WMO
Koblenz 2009

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Foreword

Extreme floods have always been an integral part of our environment. They feature amongst the most destructive natural hazards in many countries around the world. Damage resulting from the natural destructive power of floods is aggravated by increasing vulnerability of growing populations in river flood-plains. This is paired with a perception that floods nowadays impact the societies more frequently than in the past.

There is international consensus on the importance of understanding the flood generating processes as well as of the need for their integrated management. Integrated flood risk management is a process that promotes flood risk modelling, taking into account changing boundary conditions and driving forces. It incorporates vulnerability issues through land use and water resources development in river basins while considering climate change impacts. The synergy between risk assessment and effective communication is indispensable for developing suitable flood mitigation and response measures.

The German Federal Ministry of Education and Research (BMBF) has funded the inter-disciplinary programme "Risk Management of Extreme Flood Events (RIMAX)" with the aim to develop and evaluate scientifically relevant methods and instruments for modern flood risk management. Within the scope of this research programme, 36 projects have been addressing three key areas since 2005: "Analysing, Forecasting and Warning", "Protecting and Controlling" and "Informing and Communicating".

The geographical research focus of the RIMAX programme is on Central Europe. However, the tools, procedures and strategies are universally applicable and may provide assistance to operational hydrological services worldwide.

This publication is a contribution to the VIIth Phase of the International Hydrological Programme (IHP) of UNESCO with emphasis on hydro-hazards, hydrological extremes and water-related disasters in the context of the topic: "Adapting to the Impacts of Global Changes on River Basins and Aquifer Systems". The Hydrology and Water Resources Programme (HWRP) of WMO is supporting national hydrological services in water resources management. This work is intended to assist in evaluating national capacities and to develop adequate strategies for strengthening effective national services and warning centres.

This résumé of the research results obtained within the scope of RIMAX was compiled and edited by Dr. Georg Petersen, whose work is highly appreciated.

We hope that these guidelines will help hydrological services to enhance managing extreme floods in the future and will assist in mitigating the consequences of floods, thus improving the protection of the population against flood damage.

Dr. Johannes Cullmann
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Contents

Introduction

Flood events are the world's most dangerous natural hazards. They cause immense damage and account for a large number of casualties world-wide.

Developing as much as developed countries are affected by flood events. Within the scope of the "RIMAX – Risk Management for Extreme Flood Events" research programme, the German Federal Ministry of Education and Research has invested 24 million Euros since 2005 in developing strategies and instruments for flood prediction as well as improving flood protection and management solutions during extreme events. The programme integrates different disciplines and several participants. RIMAX concentrates on extreme flood events with a highly destructive potential occurring once in a hundred years or even less often. A significant feature of the programme is the close interaction between research and practice.

The RIMAX research programme with its projects as briefly described in Section 8 focuses on three main areas:

1. Analysis, Forecasting, Warning

- Operational flood management
- Forecasting and early warning
- Analysis of historical floods
- Trans-disciplinary analysis of extreme flood events and their consequences
- Risk-based approaches to flood mitigation

2. Information and Communication

- Education
- Networking
- Flood awareness
- Risk communication

3. Protection and Control

- Dike safety, monitoring and dike protection
- Management of dams and retention systems
- Management of urban infrastructure (water supply, sewage etc.) during floods
- Risk-based reliability analysis of flood defence system

The results of the RIMAX projects relate to Central Europe. The general strategies and methods are universally applicable and can be used by operational service providers, water authorities, interested agencies and NGO's in developing countries to improve strategic planning tasks. This can make a major contribution towards reducing the impacts of flood disasters in these countries in the future. A timely knowledge transfer to developing countries can be of vital importance with regard to climate change scenarios with an expected increased probability for the occurrence of extreme events.

This guideline puts German research results into practice by presenting the aspects, strategies and methods for application while considering potentially different conditions in developing countries and maintaining the core principles. Methodologies and approaches are explained and adaptation strategies and concepts highlighted. Based on relevant projects, four thematic areas are explained in detail:

- Forecast and warning
- Preparedness of defences
- Disaster management
- Damage assessment and social impact

The general structure of this publication reflects these thematic priorities. Each chapter starts with a description of the methodologies.

Adaptation strategies are formulated for each of the projects addressed in separate sections of the chapters.

Flood forecasting and warning is an important mechanism for protecting of populations against flood hazards. Flood forecasting systems have advanced through new techniques and methods and have developed in different fields covering whole river catchments with longer reaction times as well as head catchments and highly vulnerable urban areas where short lead times can be expected. Matured systems include flood forecast and flood warning elements as well as decision support tools, information and monitoring elements. Subject to the location of the target area to be protected, lead- and reaction times depending on the nature of the upstream catchment and meteorological conditions may vary. This factor needs to be taken into account when deciding on suitable forecast and warning systems as well as related preparedness and mitigation measures.

Over time, the abilities of flood forecasting systems have developed from simple indications of the likelihood of a flood event to an accurate prediction of its magnitude and timing. The forecasting systems provide a basis for warning local authorities and the affected population of the expected flood levels and extent of inundation in defined areas. These systems provide major cost-effective benefits for many people and the national economy. More information on this topic is provided in Section 2.

Preparedness of defences advocates long-term planning to prepare communities and crucial infrastructure for floods with the primary objective of finding permanent structural solutions to flood problems. While flood defences exist in many locations, their structural standard and level of protection is often inadequate or unknown. As a consequence, there is a high risk of failure and/or a low degree of protection. Upgrading defences may be expensive. Therefore, the state of the defence systems, their prioritization as well as improvement options require careful and detailed assessment. While a range of best practice improvement methods is available, the timing of maintenance, improvement and/or upgrading works as well as monitoring aspects represent tools that can be used to optimize the cost-benefit ratio and to implement a long term defence system upgrading programme. Experience shows that a thorough assessment of system specific parameters needs to be combined with an assessment of the external loading conditions as well as passive excitation factors to obtain an optimised programme and design solution. This topic is covered in detail in Section 3.

Disaster management aims at mitigating effects of floods that cause the largest share of mortality and economic losses of all natural hazards worldwide. Types of flood disasters range from inundations of large relatively flat areas to rapid flash floods and debris flows in steep catchments. The latter, while mostly being smaller scale events, often cause high mortality rates.

Practical management of flood disasters is therefore an important issue to avoid losses of life and minimize economic damage. The topic covers both pre and post event tasks including e.g. awareness raising and emergency planning for rescue and relief operations. The role of local communities and organizations is particularly important here. Section 4 discusses the topic in detail.

Damage assessment and social impact deals with the estimation of direct and indirect economic damage caused by flood events to support management decisions based on cost-benefit calculations, aiming at providing cost efficient flood management. These assessments cover damages to agricultural land, residential property, businesses and public infrastructure. They also look into the socioeconomic aspect of disruption of daily life and loss of production. Section 5 provides information about this topic.

1. Background

As climate change advances, extreme flood events become an increasingly threatening hazard in view of the risks involved and the inherent damage potential. In recent years, recognition has grown that flood risk management rather than full flood protection is the right track towards coping with these extreme events. This is largely due to the fact that forecasts still include a certain level of uncertainty, protection systems are subject to technical and financial limits and the implementation of projects depends on social acceptance. While much progress has been made with regard to flood forecasting, calculation of flood mitigation, flood protection systems as well as operational strategies, it has been acknowledged that extreme events cannot be prevented but need to be controlled and managed.

Managing flood events means considering the whole string of events from forecasting precipitation scenarios, calculating or modelling runoff events, installing and operating technical retention and protection units as well as taking account of social and financial impacts and providing for emergencies. Ideally, decision-making in terms of future strategies and extreme events should be based on optimum information availability and information evaluation, i.e. a combination of knowledge and forecast systems.

The exemplary RIMAX projects presented in this guide are meant to provide a base for establishing good practice examples and guidelines for tackling problems. To give a better overview, four thematic blocks have been identified that have been assessed as to the following criteria: forecasting and warning, provision of defences, disaster management, damage assessment and social impact. These criteria are described in detail in the introduction and project descriptions in the following chapters of this guide.

When managing extreme flood events it is important to address related actions and risks in an integrated and sustainable manner while considering various aspects. On the technical side, various cause-consequence chains have to be taken into account. When considering changes to improve flood security in one location, possible negative effects on other locations have to be envisaged to prevent an aggravation of the situation. Furthermore, all elements that might lead to a potentially catastrophic flood event have to be taken in mind. On the socioeconomic level, varying and possibly conflicting stakeholder interests need to be incorporated for the sake of a fair distribution of risk and safety levels. This approach is to achieve the best possible overall reduction of flood risk under the prevailing natural, socio-cultural and financial conditions. Some factors that are relevant for the appraisal of flood risks and mitigation options are described in the following paragraphs.

A flood situation is an event triggered by a cause-consequence chain with many interrelated layers. Static and dynamic upstream catchment factors have an influence on possible flooding scenarios. Static factors provide data such as the typical magnitude of precipitation events and slope gradients, while dynamic factors provide information such as land use change, vegetation cover change, seasonal variations and the state of soil saturation. The elements of a cause-consequence chain are interrelated in the downstream and upstream parts of a river network. Actions taken and events happening in an upstream part of a river have a strong impact on downstream river sections. Downstream relations, for instance, exist in places where flood protection systems have been built or flood retention areas reduced, causing more water to be discharged and creating a flood wave with multiple peaks. Upstream relations emerge when upstream flood control installations are used to reduce discharge in order to protect a downstream location, resulting in rising water levels in the upstream area.

When making decisions in the fields of flood protection, mitigation of flood effects and flood control, a selection has to be made as to which of the multiple and conflicting stakeholder interests should be taken into consideration. Pre-planning may help in taking decisions at an early stage, communicating the residual risk and preparing stakeholders in regions that will receive less support than others during flood events. When operating flood retention facilities under non-flood conditions, numerous stakeholder concerns need to be integrated as dams, for instance, perform many tasks such as providing irrigation and drinking water in addition to their flood retention function.

Changing conditions can be monitored in catchments due to long-term climate change scenarios. As land use change, population pressure or other factors become more pressing, the development of adaptation strategies plays an increasingly important role. Planning, prevention, mitigation or coping approaches are choice tools in this respect while the ideal solution depends on the individual conditions in a setting that must also allow for the inclusion of potential future changes.

A flood risk management strategy as well as a holistic assessment are imperative in appraising flood risks and deliberating mitigation options. Natural and socioeconomic conditions in a catchment are subject to changes over time that need to be incorporated into planning approaches if one is to reduce flood risks efficiently and sustainably.

An important issue, sometimes overseen due to limited knowledge or unawareness of interactions, is the interdependence of different factors within a river system that, if changed, have an impact on flood risks elsewhere. A first level assessment may lead to the result that changing a local dam operation schedule, for instance, will reduce the downstream flood risk but may have severe impacts on flooding in the reservoir area itself. In the same way, the construction of flood protection systems may increase flood risks elsewhere. Such issues need to be assessed in detail before making decisions to change the system, while including other secondary stakeholder aspects regarding the use of resources that may involve plans and practices contrary to those beneficial for flood risk reduction. An example for this is the tendency to keep dams filled for water supply purposes while it should provide as much free storage capacity as possible for flood retention. An assessment procedure as described above would allow to decide on the most beneficial approach to reduce the flood risk. Such a decision may include the acceptance of a local increase in flood risks to protect higher valued areas. Such an approach should consider the vulnerability of certain areas. Population density, population vulnerability, structure fragility, property value, property type, importance of affected infrastructure, sources of pollution and hazards could be some factors to be taken into account, aiming at an assessment of the overall flood damage potential.

While the assessment of flood risk based on the above mentioned hard facts is important for certain decisions, other decisions can be made on the basis of adapted management plans that can be remodelled to mitigate flood risks or serve as a substitute for a physical flood risk reduction. Preparation and warning strategies as well as strategic planning aspects with regard to the type of developments allowed in certain flood risk areas should be considered when conducting flood risk reduction and flood mitigation strategy assessments. The preparation strategy requires active education and involvement of the affected stakeholders such as industries and communities and can only be implemented if certain circumstances such as building fragility and the possibility of safe havens are given. Warning strategies would have to be set up in line with a functioning flood forecasting and warning strategy, including the necessary monitoring facilities, modelling tools and validated systems as well as suitable and tested communication channels for timely warnings. Strategic planning would be a way forward to control new developments. Decisions would need to be based on the establishment of flood risk maps, showing the risk of flooding under different probability events. Types of use and types of property could then be allowed in the different zones depending on their fragility and risk potential.

The following chapters will give a broad overview of methodologies that have been developed, applied and tested under RIMAX. Although not being comprehensive presentations, the methodologies and respective adaptation strategies can be used as suggestions how to tackle flood risk problems. More detailed information can be found via the respective project references given in Section 7.

2. Forecasting and warning

2.1 Projects

Flood forecasting and warning systems are important tools for the protection of our societies against flood hazards. Flood forecasting systems have advanced through new techniques and methods and have developed in different fields covering whole river catchments with longer reaction times as well as head catchments and highly vulnerable urban areas where short lead times must be considered. Depending on the degree of sophistication, systems may include linked elements for flood forecasting and flood warning as well as decision support, information and monitoring tools. Depending on the location of the target area to be protected, lead- and reaction times, which depend on the nature of the upstream catchment and meteorological conditions, may vary. This factor as well as the vulnerability of the target area needs to be taken into account. Over time, the functionality of flood forecasting systems has developed from simple indications of the likelihood of a flood event into an accurate prediction of its magnitude and timing. The forecasting system provides a basis for warning local authorities and the affected population of the expected flood levels and extent of flood inundation.

An integrated functional flood warning system can be divided into five stages, namely:

- Data collection
- Data processing and evaluation
- Warning decisions
- Warning distribution
- Receipt and response

To run a flood forecasting and warning system, a network of monitoring stations should exist that collect and supply data to a forecasting centre. These data then serve as a basis to calculate a predicted runoff event allowing for decisions to be made depending on the severity of the forecasted event. Communication is then necessary between the forecasting centre and the respective flood defence and disaster management units to effectively respond to the potential threat.

The forecasting procedure typically includes a series of hydrological and hydraulic models (rainfall-runoff, flood wave propagation, inundation) capturing flood extent, depth of inundation and specific timing of the event. The decision-making actions generally include all formal decision-making elements such as the type of response, type of protection and allocation of resources to various protection activities and areas.

Three projects out of the RIMAX work have been selected to highlight forecasting and warning strategies as well as methodologies and to describe their adaptation to a wider range of situations and settings.

- MULDE – Ensemble forecasts in operational flood risk management of the Mulde river basin
- OPAQUE – Operational discharge and flooding predictions in head catchments
- URBAS – Prediction and management of flash floods in urban areas

The projects describe forecast, prediction and management methods for a range of different catchment types, covering basin-wide approaches, head catchments and urban areas.

MULDE utilizes ensemble flood forecasts as a means of describing the uncertainty of the potential future development of the hydro-meteorological situation. The meteorological ensemble forecasts are then transformed into discharge ensembles using hydrological models. The project has developed a methodology and optimized algorithms that allow the evaluation and tracking of forecast uncertainty based on meteorological ensemble predictions, ensembles of model parameters and integration of measurements for updating probabilistic assessments of ensemble members. A flood information and management system was designed which supports decision makers in issuing alerts based on a probabilistic evaluation of the ensembles, scenarios of future developments and the likely resulting damage. The project has integrated different aspects to form an overall picture including precipitation forecasting, hydrologic flood forecast model development, technical aspects of flood management, data management and information systems as well as decision support and flood management systems.

In addition, the project evaluates the flood protection capability of existing technical structures while considering different flood protection goals downstream, and assesses the advantages of event-based and flexible controls of dams and reservoirs. The overall information is processed in an information system, developed to utilize risk analysis approaches. Based on results, recommendations for issuing alerts considering multiple criteria regarding the current hydrological situation, scenarios of future developments and the resulting likely damage are made available.

OPAQUE deals with the large uncertainty inherent in the operational prediction of intense flood events in headwaters of large rivers. These areas are not only of interest due to their potential for flood generation in the large downstream rivers but also because of their own significant damage risk. Thin soil with little retention capacity, steep slopes and often extremely intense precipitation events result in quick runoff response in these areas. Warning lead times are therefore short, posing an increased risk to local and downstream communities.

An improved operational method to estimate strong precipitation fields for simulation and forecast has been established by combining precipitation observations in the catchment area and precipitation radar. The use of new technologies permits the improved recording of baseline conditions at the beginning of a possible flood event (soil moisture, snow cover). The integration of this new information into operational models leads to improved forecasting of discharge formation and distribution.

Another aspect OPAQUE looks into is the optimized flood regulation of dams for headwater flood management. Based on an improved long-term prediction of precipitation and discharge, the possibility of reducing flood risk downstream from the dams through optimum control mechanisms, has been analyzed. The likely ensuing damage is then quantified for downstream communities and different stakeholders such as water suppliers, tourism, energy production and flood protection systems to establish a control mechanism keeping the damage to a minimum.

URBAS deals with flash floods, a topic of growing importance considering recent studies about climate change which indicate a growing frequency and intensity of extreme precipitation events that partly exceed extreme values of design storms used for the design of hydraulic structures. Such heavy rainfall may trigger flash flooding in urban areas.

Knowledge about the distribution, frequency and typical damage of flash floods is scarce. Within URBAS, these parameters including meteorological conditions, have been investigated and innovative actions and precautionary measures have been developed with a reasonable cost-value-ratio. Typical case studies have been analyzed for 15 municipalities using modern technologies for the investigation of precipitation and runoff. Based on these studies, forecast tools have been improved and recommendations regarding information management, early warning, precautionary measures and disaster control have been given.

2.2 Methodologies

While the general approach to produce reliable flood forecasts is similar in most cases, methods can be adapted and fine-tuned in line with the conditions they are applied to for generating optimal results. In a standard approach starting from a prediction of meteorological conditions, rainfall-runoff models are applied while considering catchment conditions influencing runoff. Subsequently, distance and hydraulic processes between runoff area and affected area need to be taken into account for local impact predictions and estimation of lead times.

The methodologies employed in MULDE, OPAQUE and URBAS are described in the following sections. The methodologies have been developed and tailored to the specific areas of application considering their specific needs and requirements.

2.2.1 MULDE – Ensemble flood forecasts

Overview

Uncertainties in flood forecasting mainly result from incomplete knowledge of the further meteorological development and from uncertainties of hydrological and hydraulic modelling. Known and knowable sources of uncertainty are the availability and quality of input data, respective initial and boundary conditions for the models, as well as model parameters and model structure. Inaccurate human interaction and technical problems may also affect the output of a flood prediction chain. The highly nonlinear behaviour of the atmospheric system and the land-atmosphere interaction adds unknowable sources of uncertainty. Resulting from these uncertainties it is not possible to issue a perfect weather forecast and respectively a perfect flood forecast.

During the last decades modelling and forecasting techniques evolved from a deterministic towards a probabilistic paradigm. Uncertainty estimation in forecasting aims at framing the possible future development, admitting and communicating the imperfection of the forecast. Exceedance probabilities for threshold values (e.g. critical discharge levels causing inundation) can be provided to flood managers and decision makers. Ensemble techniques were developed to deal with these problems.

In the context of flood management, ensembles are a group of alternative scenarios of possible future development of the hydro-meteorological situation. Different types of ensembles can be classified according to the generating mechanisms (for meteorological as well as for hydrological applications):

- Single system ensembles: perturbation of initial and boundary conditions, different convection schemes (physically based ensembles), perturbation of model parameters
- Multiple systems or multi-model ensembles ("poor man ensembles"): combination of simulations from different models
- Lagged average ensembles: combination of current forecasts with forecasts from earlier model runs

Probabilistic forecast systems like meteorological ensemble prediction systems require the computation of a large number of model runs within a time frame of a few hours. Here computational resources still constrain the possibilities of probabilistic forecasts in an operational real-time environment. However the application of numerical models on personal computers can profit from recent developments in parallelization. Flood forecasts for large river basins can now be simulated on workstations, which can be operated by local water management authorities.

Project description

The MULDE project includes interdisciplinary links of meteorological, hydrological and water management facilities combined with decision theories based on an information technology platform. The specific require-ments of flood management projects demand a high

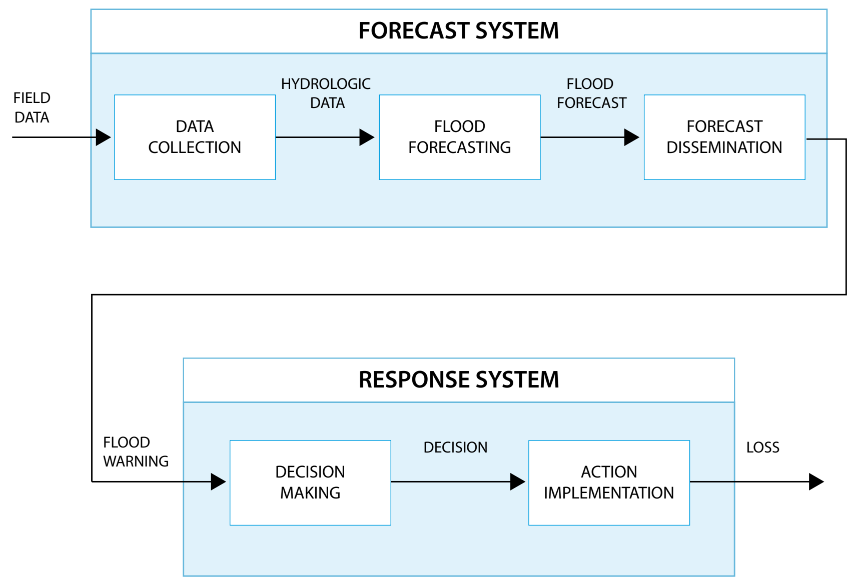


Figure 1
Elements of flood management (after Krzysztofowicz and Davis, 1983)

degree of interdisciplinary cooperation in coordinating the methodological approaches and their interlinking in a uniform spatial and temporal environment. Against this background, MULDE aimed at providing a base for timely and reliable flood warning and prediction. The prediction of a flood event serves as a basis for warnings, constituting an essential element of efficient flood management. An overview of the elements involved is shown in Figure 1; MULDE focuses on forecast system elements, whereas response system elements have not been dealt with in this project.

It needs to be considered that there may be problematic dependencies of the future meteorological developments and the extremely dynamic and non-linear interrelations of meteorological and hydrological processes. Short reaction times result in short forecasting periods if based on measured precipitation data only. In mountainous regions meteorological forecasts are uncertain with regard to characteristics which are most important for the hydrological response: the spatial and temporal distribution of precipitation within the scales of space (some kilometres) and time (hours). Considering the necessity to improve flood forecasting and warning in headwaters, a decision support system as part of a flood management system has been developed that includes the uncertainties in predictions as well as the consequences of a predicted runoff event in form of a spatially and timely varying hazard analysis. The predictions are displayed with a degree of uncertainty resulting from uncertainties of the utilized hydrological model, uncertainties in parameterization and uncertainties of input parameters. The uncertainty band widens with the length of the forecast period (Figure 2).

The quality of the forecasts, their spatial and temporal resolution as well as the prediction period is dependent on the respective modelling system and the area-specific conditions and limitations of the modelling process. Ensemble forecasts are a means to determine the limits of the forecasts based on uncertainties. Precipitation forecasts based on ensembles have been successfully used worldwide. In the same way, the MULDE project has used ensemble forecasts for hydrological predictions considering the following problems:

- The precipitation events need to be spatially specified as a deviation can lead to a flood prediction for the wrong subcatchment
- The temporal occurrence of a precipitation event needs to be clearly identified as the reaction and runoff processes in the catchment depend on the distance in time to any previous event
- The precipitation intensity is important

In the MULDE project, ensemble precipitation forecasts are deduced from different meteorological ensemble systems like the European COSMO-LEPS, SRNWP-PEPS and COSMO-DE prediction systems. Additionally a multi-model lagged average super-ensemble was generated by recombining members from different runs of these meteorological forecast systems. Instead of runoff predictions, ensembles of the possible future runoff development are generated (Figure 3).

To this end, a hydrological modelling system was required that has been specifically adapted to the Mulde study area. The spread of the ensemble forecasts provided with the "Limited-Area Ensemble Prediction System" of the Consortium for Small-Scale Modelling (COSMO) is shown by an example in Figure 4.

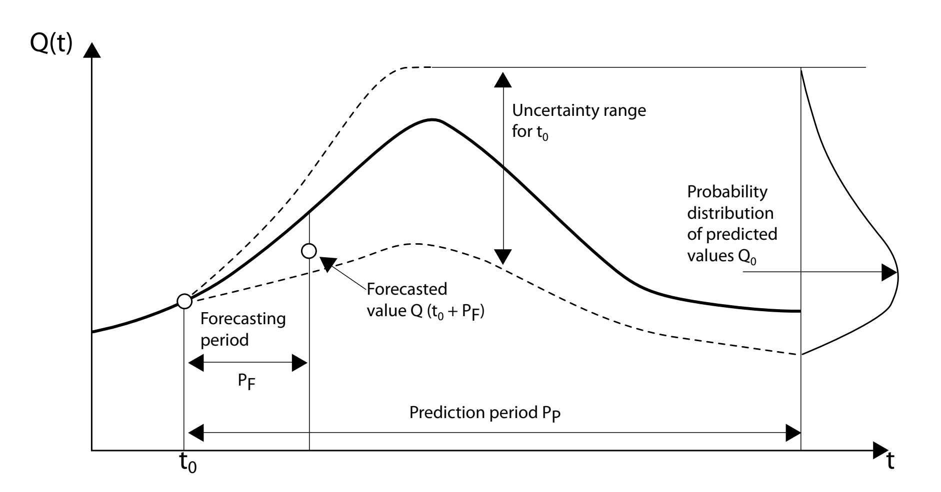


Figure 2
Flood forecast and prediction (MULDE, 2008)

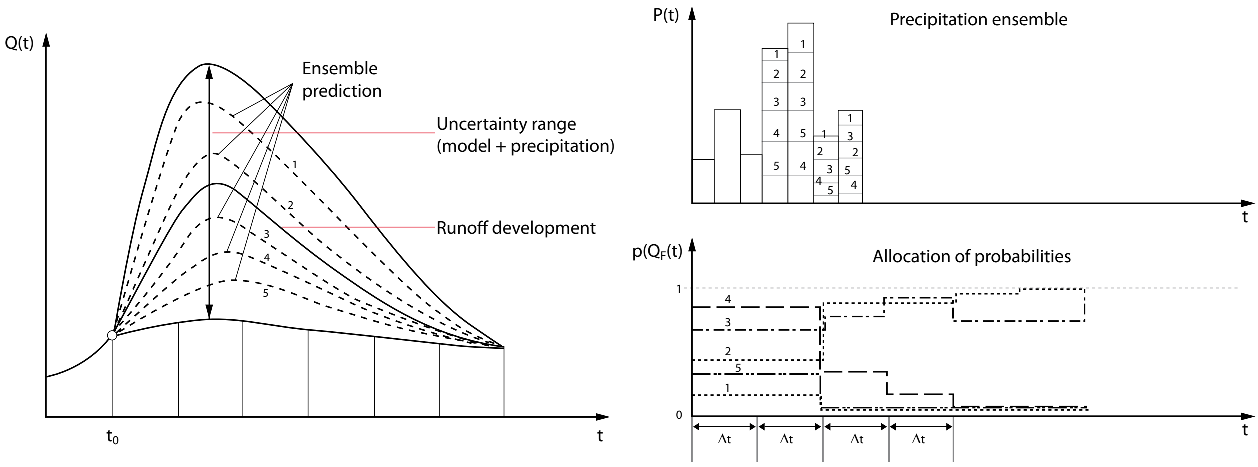


Figure 3 *Schematic display of runoff ensemble forecast including probabilistic assessment of calculated runoff scenarios (MULDE, 2008)*

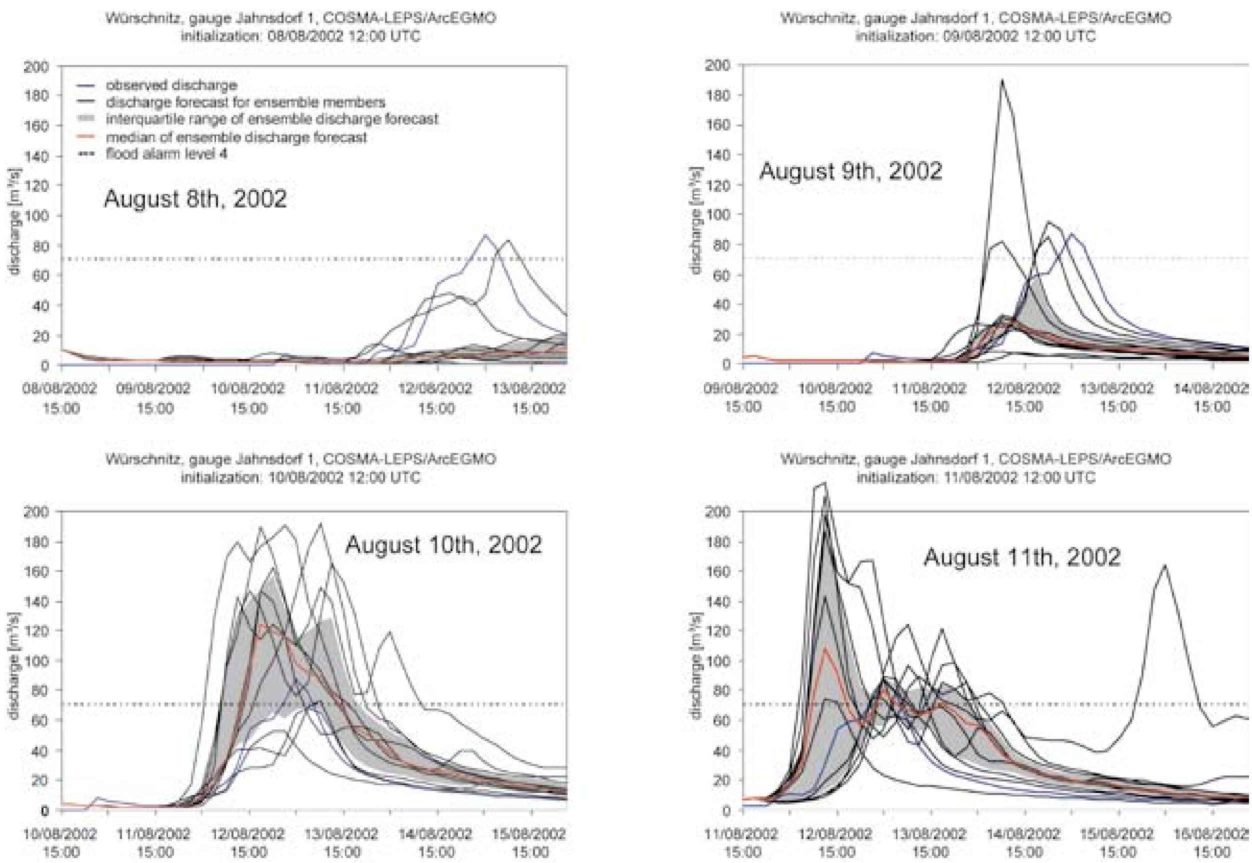


Figure 4 *Spread of ensemble forecasts generated by means of the COSMO-LEPS ensemble system (MULDE, 2008)*

The ensemble forecasts characterize the possible hydrological development within the forecast period. Resulting from the wide spectrum of the possible development, the results may not lead to a direct decision to issue a flood warning. To appraise the necessity of issuing a warning, two criteria are used:

- The hazard situation deduced from the runoff ensembles based on the distribution of the different parallel forecasts
- A probabilistic assessment of the individual ensemble elements updated with measured precipitation and runoff data

The appraisal is carried out based on a decision support system that analyses the differences and analogies of the parallel forecasts and considers the uncertainties of the ensemble elements. With progressing time, this results in opportunities for probabilistic reassessments of the individual forecasts, utilizing the recorded precipitation and runoff data recorded by then (Figure 3, lowest part).

Dams located in the MULDE basin have different flood protection functions, varying according to flood events and control strategy. As a base for the flood management task, the possibilities and limitations of the dams in combination with their operation, their control strategy and technical components were investigated. In line with the assessment, the dams were integrated into the flood forecast system. Their effects on altering the flood properties were simulated in order to assess their effect on the flood behaviour in the downstream areas. In addition, event-based control schedules have been developed to optimize dam operation during flood events.

Collecting, processing and analysing flood-relevant, cutting-edge data – a prerequisite for utilization in the decision-support system – was an important element of the MULDE project. The database also needed to be permanently fed with current data for real-time tracing and feedback of measurements into the meteorological and hydraulic models.

The management system applied to tackle this task was the centre piece of the flood management system. The main components of the described processes of the flood management system are shown in Figure 5. The colours represent the different elements involved.

In summary, the MULDE project has dealt with the following elements; a more detailed description is given in the subsequent paragraphs:

- Data acquisition of runoff time series, geo-information data, soil data, land use, stream network, elevation model, catchment areas, hydro-meteorological data
- Development of optimization algorithms and parameterization schemes for distributed hydrologic flood forecast models for watersheds
- Setup of hydraulic model for flood prediction including tracking and consideration of measurements
- Development of a methodology that allows to evaluate and track forecast uncertainty based on ensemble prediction and integration of measurements
- Evaluation of the flood protection capability of existing technical structures, considering different downstream flood protection goals
- Assessment of possible advantages of event-based and flexible control of dams and reservoirs, setup of control optimization schedule

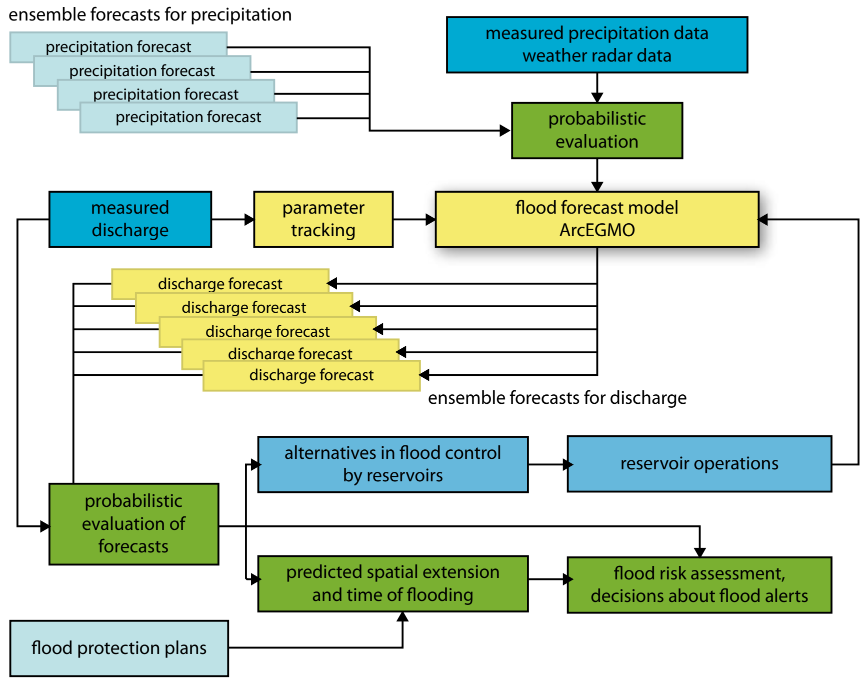


Figure 5
Project structure
(after MULDE, 2008)

- Information system development using risk analysis
- Recommendations for issuing alerts considering multiple criteria regarding the current hydrological situation, scenarios of future developments and the resulting likely damage

Precipitation forecasts have been improved by applying multiple coupled models. As input parameters for the flood forecasting system, numerical precipitation forecasts based on different spatial and temporal scales were used. These were generated by different meteorological models and ensemble systems with different forecasting periods (Figure 6).

The number of scenarios used to populate the ensembles depends on the potential of the actual weather conditions. Ten scenarios were not to be exceeded, anyhow. Precipitation data for hydrological modelling were based on a 1 km raster. Ambiguous precipitation forecasts were considered using statistical methods.

The flood forecast model was set up on the basis of a spatially differentiated description of flood generation in the MULDE area utilizing mathematical models, and converting precipitation forecasts into runoff forecasts. Dams and flood retention basins were integrated into the flood forecasting system based on discharge values and operation schedules of the individual installations. Runoff and water levels were predicted as ensembles, the different runoff forecasts were compared against measurements in real time to assess their probability and plausibility. The forecasts were adapted considering the measurements, and the probability of the forecasts was adjusted accordingly. The flood forecast was generated by means of ArcEGMO, a GIS-based hydrological modelling software package developed by Büro für Angewandte Hydrologie (BAH), Berlin and Potsdam Institut für Klimafolgenforschung (PIK).

Spatial differences in the MULDE catchment were considered in the model to capture the different reactions of sub-catchments and conditions along the river impacting on flood wave propagation and flood forecast, and also included critical cross sections depending on hazard points. In line with the spatial structure of the model, new optimization elements for model calibration were developed, considering the interaction of model components. Parameter tracking, based on measured discharge data allowing transmission in error-corrected real time, was an important element in this work. Correcting precipitation predictions by means of measurements was automated in such a way that synchronized parameter sets for the sub-catchments of the river system were provided. Real-time data and discharge forecasts for dams providing a significant retention potential were considered in the flood forecast model. The model was calibrated and validated on the basis of historical flood events. A hazard analysis was then carried out considering information on flooded areas, water levels and discharges supplied by the hydraulic data sets.

The MULDE basin is equipped with technical flood retention facilities in the form of dams. The flood protection potential of the individual facilities was appraised, while taking into account that the operation

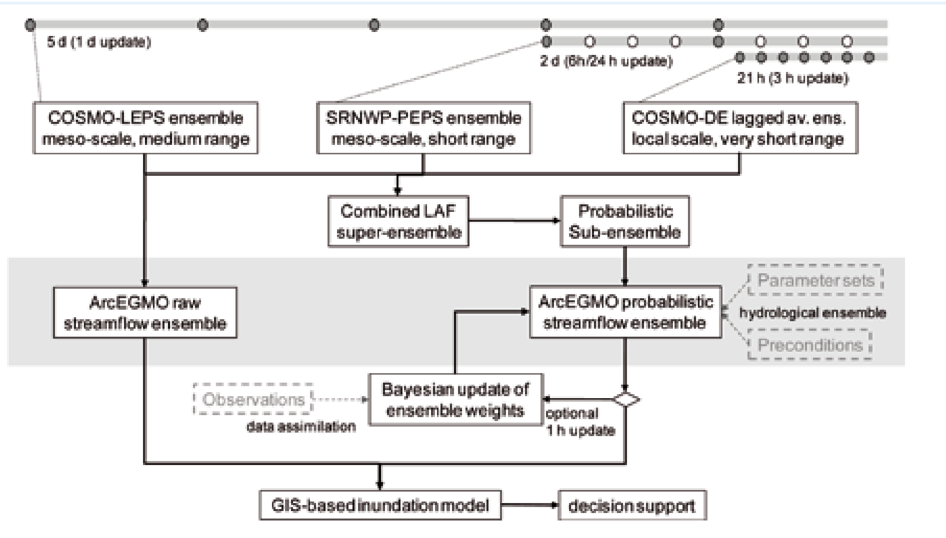


Figure 6
Application of meteorological ensemble forecasting systems (MULDE, 2008)

of the individual dams is based on different and partly competing objectives, including flood protection and water supply. The operation schedules were optimized for balancing the multiple tasks while considering site-specific technical and operational restrictions.

Hydrological conditions were considered with regard to the spatial and temporal distribution of floods as well as the flood protection targets for the downstream areas. As retention volumes were decreasing relative to the magnitude of flood events, decisions needed to be taken on how to deal with frequent flood events of a smaller magnitude and less frequent flood events of a higher magnitude, especially in view of the fact that the events cannot be classified in advance. Different options of minimizing impacts through event-related flexible control strategies were therefore assessed while integrating short-term meteorological forecasts and current as well as expected conditions for decision-making purposes. Ensemble forecasts of possible flood events were then used to judge the different control strategies. In view of the remaining forecast uncertainty, comparisons with statistical flood control concepts had to be implemented, with water resource requirements having to be taken into account in all control scenarios.

Data management systems are based on data with varying spatial structure including point measurements, two- and three dimensional records (e.g. flooded areas with area and water depth) and varying temporal resolution. Probabilistic data of different ensemble forecasts had to be managed in parallel. Hydrological information was also combined with hazard analysis as well as local and event-specific flood protection measures. The data were organized by means of GIS tools allowing multiple layer analyses of flooded areas incorporating factors such as population at risk and infrastructure. A geo database information system was established on the basis of these results, containing all relevant data including measurements, derived information, model results and metadata. For further evaluation, GIS based analysis modules for the processing of measurements and forecasts in form of maps, time series, tables and hazard analyses were set up to support decision makers in the field of operational flood management

The established decision support system is capable of integrating and appraising the uncertainty of flood forecasts as well as the possible effects of the application or non-application of control measures on the execution of control decisions. A methodology was developed to update probabilistic information using measured precipitation and runoff data. Within the management system, a connection of uncertainties inherent in input data, modelling results and the effects of the possible control options was established. The decision support system reflects the actual flood situation, evaluates processes and appraises forecasts in a probabilistic way. It provides computed recommendations for flood warnings under consideration of multiple criteria of the actual hydrological situation and scenarios of potential future development as well as the resulting possible damages.

Box 1 Ensemble forecast

Ensemble forecasting is a numerical prediction method that can be used to generate a spectrum of possible developments of a dynamical system. Ensemble forecasts can employ different forecast models or different settings of a forecast model to predict a range of possible scenarios.

Multiple simulations with varying parameters are conducted to account for uncertainties of boundary conditions and structural errors of the model.

The spectrum of possible results as well as their statistical distribution can be used to judge the probability of runoff developments resulting in potential damage. Based on measured data, the ensemble forecasts can be calibrated over time as to the probability of certain events. It needs to be kept in mind anyhow that the inherent restrictions of the modelling system used as well as the inaccuracies in the input parameters may cause a bias, the overall range of natural conditions being inadequately reflected.

Box 2 Main principles of MULDE

Need for improved reliability of flood forecasts despite uncertainties and technical limitations

- Acceptance of the fact that it is impossible to issue perfect weather and flood forecasts
- Probabilistic approach to deal with these uncertainties
- Establish group of alternative scenarios of possible future development
- Ensemble techniques to deal with ranges of scenarios
  - in weather forecast
  - in runoff forecast
- Setup of operation alternatives and flood management and protection plans based on ensemble forecasts and probabilities

2.2.2 OPAQUE – Operational discharge and flood forecasting in head catchments

Overview

Due to short lead times and rapidly increasing water levels, floods in head catchments have a high potential for damage to communities and environment. Therefore, the management of extreme floods requires very precise operational predictions of rainfall-runoff processes as well as matching controls of reservoirs and retention basins. Reliable operational predictions of rainfall-runoff processes in head catchments are very difficult because of the high spatio-temporal variability of precipitation and the non-linearity of the catchment response. OPAQUE has reduced the uncertainties of these predictions by, improving and customizing hydrological models and defining the necessary methods for identifying critical states of the catchment (e.g. critical soil moisture). The more reliable warnings (in terms of time, location, and water level) allowing for an improved flood management in the relevant areas have a high potential for risk reduction.

Uncertain precipitation prediction, deficits in describing discharge formation in hydrologic models, and the lack of reliable procedures for the identification of critical catchment conditions such as soil moisture and snow cover conditions are currently considered the primary reasons for uncertainties in the operational prediction of floods in headwaters. Based on this problem in connection with the need to improve early warning and flood management the project has tackled the following tasks:

- Early warning for critical atmospheric situations and critical catchment conditions
- Operational estimation and short-term prediction of area precipitation
- Operational prediction and long term prediction of discharge
- Flood management through optimized dam control with better advance warning and prediction

The flood warning and prediction system developed is a multi-level arrangement of different warning modules. For the selected test sites, an early warning system triggered by certain weather conditions was implemented, followed by a long-term prediction of station precipitation based on adapted climatological downscaling. The catchment soil moisture and snow conditions were determined by a combination of innovative TDR (Time-Domain-Reflectometer) technology, geo-radar and radar remote sensing using a suitable land surface model. Using these input data, the estimation of the flood-relevant precipitation fields for the simulation mode as well as a short-term (duration of 2 – 3h) prediction of the local precipitation situation is implemented by means of a combination of precipitation radar and ground observation. A tool for automatic error correction of the forecast for the prognosis period from 3 to 48 hours was then applied. At the end of the warning chain, the flood discharge from the affected areas is predicted using the initial and boundary conditions of precipitation and catchment. Based on the improved predictions of precipitation and discharge, the possibility of reducing the flood risk downstream of the dams through optimal control mechanisms, has been analyzed. The likely ensuing damage was quantified for the different users (flood protection, drinking water supply, low water replenishment, energy production, tourism) and the downstream communities, in order to achieve a control mechanism resulting in as little damage as possible. The project structure is shown in Figure 7.

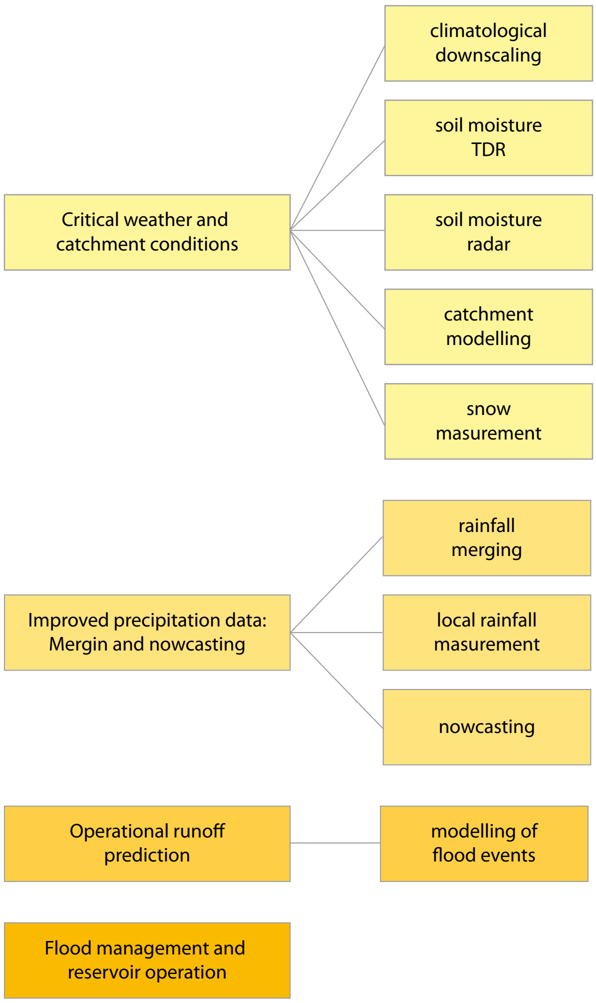


***Figure** 7 OPAQUE project structure (OPAQUE, 2008)*

Project description
Flood events in headwaters of large rivers hold an enormous damage potential for humans and environment based on their very small generation times and rapid rise of runoff. The management of extreme flood events therefore demands exact operational forecasts of the rainfall-runoff process and synchronized control operations of dams and retention areas. On the other hand, reliable operational forecasts of the rainfall-runoff processes in headwaters are extremely difficult due to the high spatiotemporal variability of precipitation and the non-linear behaviour of the area.

The project has improved the operational forecasting of large flood events in headwaters of large rivers. Large and also extreme flood events are mostly generated in these regions, caused by the poor retention capability of the thin soil layers typical in mountainous areas, the high relief energy and the frequent extreme precipitation quantities and intensities. Reaction times are normally short resulting in correspondingly brief warning lead times, leading to an increased risk for downstream communities and dams as well as for human life. Forecasts of extreme flood events in headwaters have a certain degree of inherent uncertainty as highlighted by historical events, the primary reason being the vagueness of precipitation forecasts for these areas, deficits in the applied hydrological models with respect to the description of runoff generation, and the lack of reliable methods for the identification of critical area conditions such as soil moisture content.

Improving forecasts (location, timing, quantity and intensity) and flood management (storage control, warning and alarm plan) in these areas were found to be suitable tools for risk minimization. In areas of quick hydrological response, increasing the lead time for flood warnings by just a couple of hours already brings about a significant improvement of the reaction time available. The improved warning lead time also allows for a more efficient management of storage capacities in dams and an adapted management of flood retention areas. This results in a significant risk reduction including a reduced potential for less probable scenarios as well as a minimized damage potential. An optimized dam management allows for the reduction of extreme discharges with their related damage potential for downstream communities. In addition, a more timely warning can reduce the overall damage potential due to flooding. This results in a significant reduction of the flood risk in these areas.

As shown in Figure 8, the activities focused i.a. on improving precipitation estimation, registration of area conditions and their parameterization in the models as well as the related runoff forecast during heavy rainfall. The following issues were dealt with in detail:

- Improvement of operational estimates of heavy rain fields for simulation and forecast through combination of precipitation observations and rainfall radar
- Improved observation of soil moisture situation through utilization of TDR (Time Domain Reflectometry) technology in combination with geo-radar, remote sensing and a land surface model
- Improved determination of extent and condition of the snow cover by combining remote sensing, observations and a snow model
- Improved operational forecast of runoff generation and concentration through integration of information regarding spatial rainfall fields, soil moisture and snow cover condition

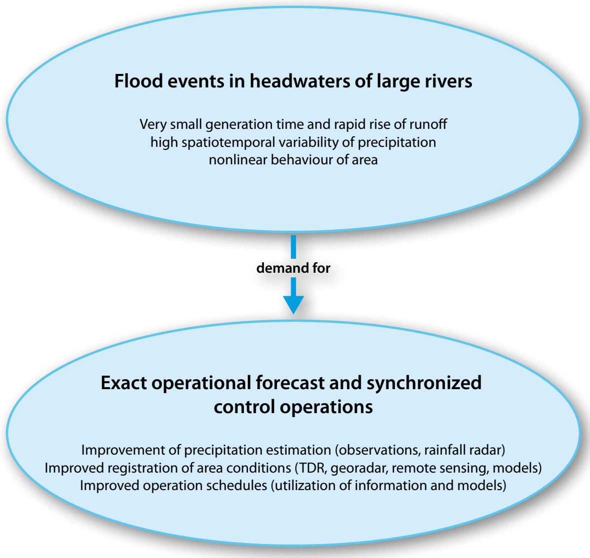


***Figure 8** Elements of OPAQUE*

Based on these steps, an integrated concept to minimize flood damages in headwater areas was developed. Especially for communities within small catchments, the option of an integrated technical flood protection may not be feasible due to economic or environmental circumstances. Therefore flood management for settlement areas, especially through optimized flood control mechanisms of existing dams but also through forecast-adapted alarm plans and timely protection measures, is of major importance next to an efficient flood forecast and warning system.

In addition to a quantification of uncertainties in operational rainfall-runoff prediction, an improved long-term forecast of precipitation (3–5 days) plays a major role in an optimized dam operation system, as erroneous control decisions may entail higher costs for any dam owner. Assessments included:

- Possibilities for improved-long term forecasts of strong precipitation events (>3 days) for important locations in the area
- Quantification of damages caused by dam control operations for downstream riparians during flood events
- Determination of synthetic runoff time series for simulation purposes during dam operation

In addition, new monitoring and modelling methods (e.g. radar measurements, remote sensing) were introduced and integrated. Developments included the coupling of reservoir controls with flood forecasts as well as predicted downstream damages.

Methodically, the flood prediction and warning system developed under OPAQUE consists of a set of modules combined in a series of multiple steps as shown in Figure 7. The initial step consists of advance warnings. These are issued based on critical weather conditions and long-term precipitation predictions obtained from expanded downscaling techniques. The next step is a sufficient knowledge of the snow cover and the soil moisture in the catchment. This information about the catchment state is obtained by combining spatial Time Domain Reflectometry (TDR), soil moisture radar, remote sensing and modelling techniques. Improved estimation of the main driver of floods constitutes a central step: precise localized rainfall information supplied by rainfall radar combined with local rainfall measurements. A short-term prediction of the localized rainfall for a period of 2 to 3 hours is then performed. Based on this prediction, discharges are modelled and predicted to provide the flood forecast. A detailed description of the main components is given in the following paragraphs.

An early warning system was established utilizing current weather forecasts refined for flood forecasting by means of statistical models. These models are calibrated using observations of atmospheric conditions (re-analysis) on the one hand and local weather records (representing the catchment) on the other hand. The models were adapted to flood-relevant weather conditions. Both deterministic as well as probabilistic weather forecasts are considered. The first ones are used to identify particularly critical atmospheric circulation types, the latter ones to obtain an early warning system based on probabilities. Deterministic forecasts are derived from the global forecast model of the German Weather Service, and probabilistic forecasts from the ensemble prediction system of the European Centre for Medium-Range Weather Forecasts. From these models, those fields were used that optimally combine predictability and hydrologic relevance, such as pressure and moisture fields.

Box 3 Monitoring

Monitoring the important parameters characterising flood events provides the basis for modelling, interpreting and forecasting.

Parameters of interest vary depending on catchment characteristics, the approaches taken and goals to be achieved, but generally include the following non-exhaustive list.

Static parameters:

- Topography
- Geometry
- Soil parameters
- Land cover
- Reservoir data

Dynamic parameters:

- Rainfall
- Snow cover
- Soil saturation
- Operation schedules

Additional parameters may be necessary in individual catchments.

Methodologies:
A variety of technical possibilities exist for monitoring relevant parameters. Depending on the individual setting different approaches can be used, e.g. to monitor rainfall. Approaches could include CCC/CCD RFE evaluation, rainfall radar or ground station measurements in different grid dimensions. The approach needs to be defined based on the local circumstances considering catchment conditions, available resources, accuracy and financial or logistic constraints.

TDR Time-Domain-Reflectometry to determine soil moisture content

The listed parameters and methodologies are not comprehensive but need to be carefully selected according to the catchment conditions and problems to be tackled.

For soil moisture and snow cover, a suitable observation net for the spatial distribution of soil moisture was set-up featuring innovative spatial TDR technology measurements, geo-radar as well as microwave information supplied by airplanes and satellites. To measure the snow cover, a network of ground stations for the measurement of snow thickness and snow moisture has been established. Pressure sensors, so-called snow pillows as well as snow moisture measurement cables are employed. The data from the distributed, ground-based measuring network were then geo-statistically combined. In addition, a spatially distributed snow model was used for the description of energy balance, temperature and water regime of the snow cover.

Operational short-term prediction of precipitation in the catchment was based on two sources of information: Rainfall radar and ground station measurements. In case of warnings for heavy precipitation the hydrologic models are driven by the operational short time prediction for rainfall, by the so-called "on-line merging". The procedure is based on a method developed by Ehret (2002) at the University of Stuttgart which combines the advantages of both measuring systems, i.e. the accuracy of the ground station data and the spatial coverage of the radar measurements. Within OPAQUE, as a first step a systematic analysis of the existing merging procedures was carried out for different precipitation types and weather conditions over an extended period. The following improvements were implemented:

- Weighting method considering data quality of radar data
- Estimation of precipitation in the case of missing values
- Improved parameters based on longer time series
- Increased computing speed
- Preferential use of correlated radar and station data
- Estimation of the precipitation variance within the raster cells by extrapolation
- Reduction of errors by spatiotemporal interpolation of precipitation fields

In addition to the local median forecast a short-term prediction over 2–3h, a so-called Now-Casting of the local precipitation distribution on basis of radar data was developed. The difficulty of accurately predicting the precipitation situation in the radar image for the duration of a few hours suggested a stochastic approach. This enables the generation of ensembles and the identification of reference points over the range of possible developments.

For operational prediction and long-term forecasting of discharge, investigations were carried out regarding the calibration of the operational prediction models, used to assess precipitation in a high spatial resolution. For long-term prediction of the discharges, the respective long-term precipitation forecasts were used and improved to represent discharge formation processes in small areas. These models are operated with spatially interpolated point precipitation data from ground stations and/or interpolated local median forecasts.

To assess runoff, the water balance model LARSIM (Large Area Runoff Simulation Model) was calibrated based on the merged precipitation data of the short-term predictions. Interception, evapotranspiration, snow accumulation, snow compaction, snow melt, soil water storage as well as storage and lateral transport in streams and lakes are included in the model's calculations. The probabilities resulting from the grouping of the ensemble forecasts of the European Centre for Medium Range Weather Forecasting (ECMWF), are also considered. The resulting discharge ensemble predictions are consulted for optimizing long-term dam control used in flood management. The setup is shown in Figure 9.

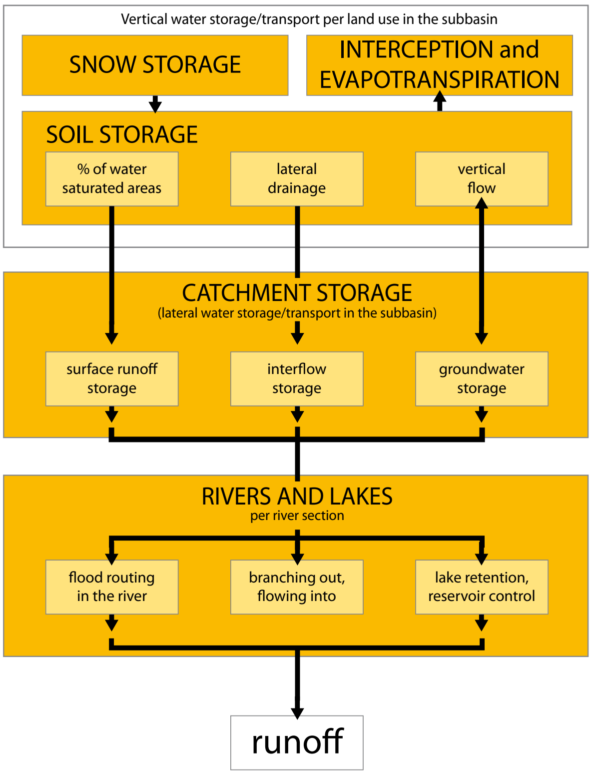


Figure 9 *LARSIM water balance model setup (NASA, 2008)*

The improved input data also allow for the consideration of small catchment areas in the operational hydrological modelling approach. Prior to the improvement, a certain minimum size of catchment was necessary in order to reflect the heterogeneity in precipitation and soil moisture, averaged over the area, and to define an averaged set of parameters. Due to the new initial conditions, deficits which exist in the hydrologic modelling of smaller catchments can be specified and tackled. Since a model represents an abstraction of reality and cannot reproduce all natural processes in detail, such an investigation allows identifying all relevant processes contributing to the generation of floods in headwaters.
The identified details can then be considered in the modelling approach.

Box 4 Main principles of OPAQUE

The main principles of OPAQUE aim at an improved flood forecasting for head catchments based on:

- Improving the forecast of runoff generation (weather forecast)
- Combining different methods to monitor essential parameters
- Improving simulations through incorporation of enhanced input data
- Advanced flood management through improved dam operation
- Consideration of multiple and conflicting stakeholder needs
- Quantification of potential damages

For flood management on the basis of optimized dam control, the determination and quantification of possible damages downstream of the dams is a central issue. Based on long-term prediction of precipitation and discharge, the possibilities of reducing the flood risk downstream of the dams were analyzed.

Based on the prediction of reservoir inflows and their uncertainties, retention capacity, water storage levels and the resulting discharges from the reservoir were optimized. Considering the competition between different uses of a dam (flood protection, water supply, low water replenishment, energy production, tourism) the optimum dam control scheme was designed based on the quantification of the ensuing damage for the different users and the adjacent localities downstream of the dam. Direct economic damage included the private sector (private and corporate structures) as well as damages to regional and national infrastructure facilities. Relative damage models (proportional damage during flooding) and value registers (values of the exposed objects in Euro) are used for the estimation.

2.2.3 URBAS – Prediction of flash floods in urban areas

Overview
Damage statistics in Germany show that a significant proportion of damages during floods in urban areas results from flash floods. In addition, recent studies on climate change show an increased frequency and intensity of such events.

The damages caused by individual flash flood events are generally smaller compared to flood events on large rivers. Due to their more frequent occurrence the damage potential is anyhow similar to that caused by floods. Human injuries are also frequent. Flash floods are mainly generated by locally restricted strong summer precipitation events, often in combination with thunderstorms. Suitable tools to record these events with a potential to minimize damages were not available.

URBAS main objective was to increase the preparedness and the range of possible actions of urban and other actors (e.g. communities, public enterprises, emergency services, insurances, weather services) before, during and after rare small-scale flash flood events. In addition, URBAS presents new information about German regions having a higher risk value as well as a higher probability of heavy precipitation.

The project has provided suitable forecast and warning systems, risk maps and regional risk distribution, and procedures for such events as well as information regarding type, intensity, frequency and typical damages for downpours in settlement areas. It also provides practical recommendations for risk minimization and damages. The results can be used by affected communities, insurers, emergency agencies, forecasting and warning institutions as well as the affected population.

Box 5 Flood Risk Mapping

Flood risk mapping is used as a tool to predefine flood-prone areas subject to certain scenarios. Probabilities like 1:10, 1:100 or 1:1000 year return periods may be used to distinguish between different zones.

Flood maps are generated using modelling tools based on a set of input parameters defining static as well as dynamic conditions influencing the flood event. Generally these include floodplain cross sections or a digital terrain model, domain inflow and outflow conditions and parameters within the domain such as evapotranspiration, rainfall and infiltration. In addition, hydraulic measurements within the domain are used for model calibration and validation purposes, resulting in a tool that is able to reproduce natural events within a certain spectrum of events. A sensitivity analysis is used to judge the level of confidence in the model results based on the reactivity of the model to changes of individual physical and numerical parameters.

The flood risk maps may then be used for planning or operational purposes, to control developments in certain flood risk zones or to prepare emergency plans. Such approaches allow for a long-term reduction of flood damage potential by avoiding and/ or managing highly flood-prone areas.

Project description

The main achievements of URBAS can be summarized as follows:

- Improvement of knowledge of events (type, occurrence, frequency, significant parameters)
- Improvement of knowledge of regional risk and hazard distribution
- Improvement and development of forecasting possibilities and methods
- Improvement of knowledge about flood damages in urban areas
- Development of action guidelines for prevention, warning and protection to be used by communities and administrations as well as private households and commercial businesses

The project has generated an overall picture of the chain of events including precipitation, runoff, damages and risks as well as the development of new knowledge and guidelines for action to be used as application examples in other areas (Figure 10). The outcomes are innovative and practical, have a good cost-benefit ratio and supply both communities and individuals with action options.

URBAS provides the following results:

- A database with almost 400 flash flood and heavy rainfall events that caused damage in urban areas in Germany
- A detailed analysis of 15 case studies
- Methods of hazard and risk analysis in urban areas and design of hazard and risk maps
- Development of innovative and feasible actions and precautionary measures and recommendations for a preventive flood control of flash floods in urban areas
- Quality improvement of heavy precipitation forecasts using the upgraded KONRAD (Convection by radar) prediction tool of the German Weather Service (DWD)
- An approach to a heavy precipitation hazard map for Germany based on statistical analyses of radar data of eight years in Germany

An initial case study of 15 selected municipalities focused on a detailed analysis of historical damage producing-events. Besides flash flood events occurring in the participating municipalities Hamburg and Paderborn, 15 other towns and municipalities were analysed with the objective of obtaining a representative sample for a further generalisation of results. Selection criteria for the assessed locations included:

- Spatial distribution of urban flash flood occurrence in Germany, representing the overall area of interest
- Geographic, topographic, meteorological and climatic classification
- Event development and damage symptoms
- Structures of urban areas and public space
- Surface characteristics, land use structures and drainage system structures of affected areas
- Up-to-dateness of data, data quality, disposition to cooperate

The investigation was supplemented by an analysis of existing event descriptions, evaluating event type, region, topography and structures of urban area and public space, resulting in the identification of particularly vulnerable areas. In addition the structure of the administrative organisation and the responsibilities during emergency actions as documented in the case studies was assessed, highlighting the actors' interactions and decisions.

Meteorological research and hazard analysis of precipitation was carried out in order to judge the events that triggered flash floods and their magnitudes.

In view of the fact that a complete and exact record of local extreme precipitation events can rarely be achieved by using conventional precipitation recording systems (such as precipitation gauges and recording rain gauges), new remote sensing methods such as radar and satellites were applied that are capable of locating small-scale precipitation fields more precisely. However, a reliable quantitative precipitation measurement still poses a challenge and needs careful analysis and calibration involving all available data.

Heavy rain forecasts are generally lacking precision in location and/or volume for forecast ranges of 30 minutes or more in convective cases. Severe storm warnings can be issued based on predicted meteorological conditions and on forecast models. However, answering the question where a thunderstorm is exactly going to happen poses a big challenge. The German Weather Service has developed a three-class warning system with a spatial extent of a county. In general, a heavy rainfall warning is given if 10–25 mm of rain are expected within one hour or 20–35 mm of rain within 6 hours. If these thresholds are likely to be exceeded, a heavy rainfall warning is given. There are single findings about significant local climate conditions over bigger cities and their influence on rain generation, however, so far they have not been systematically analysed as to this kind of task. Future climate trends and their expected impacts on rain generation and behaviour pose another challenge to cope with.

Steps and approaches used for forecast improvement

1. Identification of particulary vulnerable areas
→ analysis of existing event descriptions
2. Judging the events that trigger flash floods and their magnitudes
→ meteorological research and hazard analysis of precipitation
3. Improve exact reccording of small local extreme precipitation events
→ use new remote sensing methods such as radar and satellites
4. Implement reliable quantitative precipitation measurements
→ careful analysis and calibration using improved available data
5. Establishment of improved methodology for heavy rainfall warnings
→ use a three-class warning system for thunderstorm events

***Figure 10** Main approaches of URBAS*

After data processing and supply, the following issues regarding meteorological drivers of flash flood generation were analysed within URBAS:

- Limits and possibilities of various techniques for recording local and short-term extreme precipitation were assessed
  - Quality inspection of the conventional meteorological network regarding its ability to record the real precipitation intensity during localized events (e.g. a thunder-storm cell only touches a rain gauge)
  - Localisation of thunderstorm cells with extreme precipitation in urban areas (Figure 11)
  - Experimental resolution upgrade of radar data from 1 km up to 250 m

- Flash flood characterisation based on flash flood type – selected case studies were used for this task
  - Analysis of local extreme precipitation, its typical course (routing) and behaviour depending on type, region and urban structure
  - Analysis of meteorological characteristics for flash flood producing rainfall (case study using selected flash flood events)
  - Topographical influences on local convective storm generation close to urban areas
  - Assessment of influence of the selected metropolitan area itself on flash flood generation

- Statistical approach for assessing risk areas struck by flash floods
  - Extreme value analysis of local extreme precipitation events using conventional ground records including assessment of trends
  - Climatic analysis of radar data for detection of typical thunderstorm tracks

- Investigations oft state-of-the-art forecast of local extreme precipitation (including nowcasting)
  - Improvement of forecast methods providing warnings for heavy rainfall events

Based on the detailed meteorological analysis, a runoff hazard analysis was carried out. Runoff resulting from heavy rain over urban areas differs significantly from inundation caused by river flooding and its delimitation can be sometimes ambiguous. Due to widespread anthropogenic sealing in urban areas precipitation triggers surface runoff almost immediately. The impact of different structures of urban areas and public space as well as topographical influences on runoff behaviour was therefore analyzed in detail.

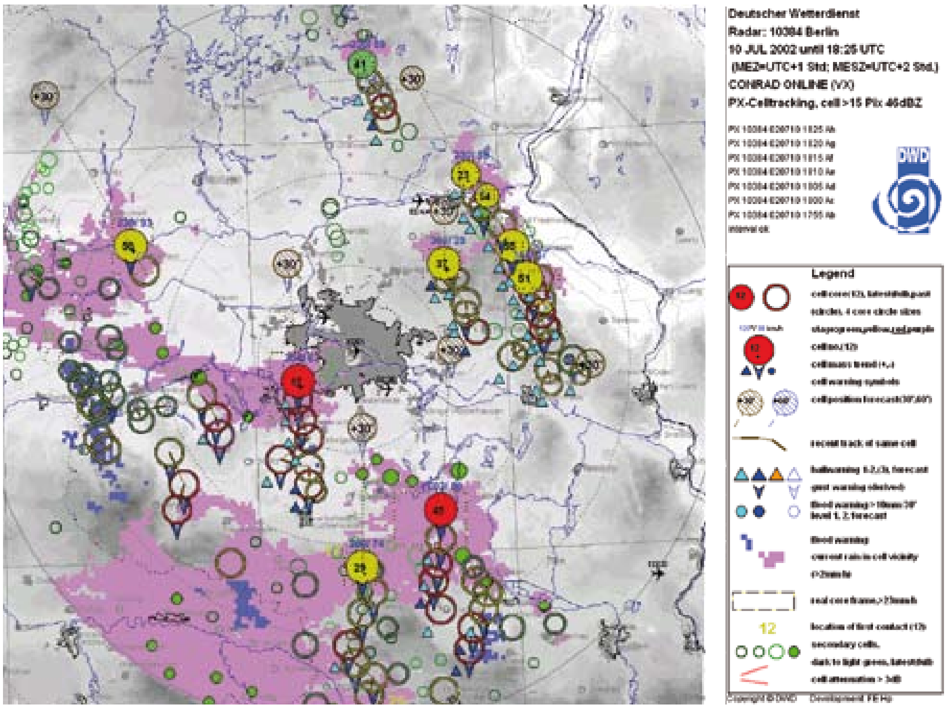


Figure 11
Thunderstorm cell tracking (URBAS, 2008)

Sewer systems are generally designed to accommodate flows for return period events of 5 to 30 years. Rare heavy rainfall events can therefore trigger runoff on streets and pathways because once natural streams and channels have been transferred into heavily regulated little streams and sewers with restricted capacities. In addition, surface runoff from nearby natural catchments can also flow into an urban area. Concentrations of runoff and development of flow paths depend on surface sealing, topography and estate structures. Water may also collect in artificial sinks such as underground carparks.

Runoff situations are additionally aggravated if hydraulic structures become blocked e.g. as a consequence of an extreme hail event or neglected maintenance. Technical structures of buildings such as eaves gutters or water supply tanks are not designed for heavy rain events, either. Thus, heavy rain is able to rapidly overload such structures and cause extreme damage to buildings and infrastructure. The specific areas that have been assessed include:

- Runoff development as a result of heavy rain over an urban area
- Special hazard areas in urban areas (industrial land use, infrastructure)
- Heavy rain impacts on buildings and building services
- Runoff drainage in urban areas depending on topography, structures of urban areas and public space as well as housing estates based on case studies
- Impacts of housing development related changes on the natural topography and flow paths
- Behaviour and capacity limits of structures for rain water drainage and secondary flow paths (streets, paths)
- Identification of hot spots within the floodwater drainage system in urban areas
- Runoff prediction through hotspot observation

Based upon detailed digital elevation models, a high resolution unsteady 2D-runoff-simulation was performed “in-between-buildings” and in various open space structures using HYDRO-AS_2D, a software package for detailed two-dimensional flow modelling. Thus spatially detailed and time-dependent depths of flow, flow directions and flow velocities were derived.
At the same time runoff drainage in the sewer as well as runoff losses (backwater in basements) were considered and evaluated. The analysis considered uncertainties in case scenarios such as runoff bottlenecks, sedimentation, clogging of intakes etc. Results show “typical” runoff situations and runoff routes as well as significant hotspots relevant for urban planning.

To mitigate flash flood effects, risk management measures were applied to the assessed study locations. Flood damages do not only result from intrusion of surface water into buildings, but also from backwater, flooding of streets owing to insufficient drainage capacity, and from overflow of sewers and other infrastructure. In addition, erosion damage can arise due to high flow velocities. Different damage symptoms result from these situations in combination with short warning times, allowing for different mitigation strategies.

Specific damage can be observed inside and outside buildings, e.g. damp buildings, leaking roofs, overflowing eaves gutters, as well as the consequential damage to home furniture, resulting from an insufficient design of home drainage facilities. Commercial and industrial facilities show different specific damage symptoms and risks.

Hazard and risk assessments in the event of flash floods need to consider the fact that knowledge about flow paths, flow characteristics and retention areas can be ambiguous and highly depends on the localization and intensity of a storm event. Areas without visible streams that are affected by flash floods lack sufficient capacities for runoff potentials as described above. Based on this situation hazards emerge for a variety of areas, with subways, underground parkings, tunnels etc. being mainly affected. Further hazards arise along the main flow paths due to inundation, high flow velocities, and potentially drifting objects (debris flow). The following issues have been investigated in this regard:

- Detection and definition of separate threats to population, industry, etc. due to extreme runoff in differently structured urban areas with varying land uses
- Definition of runoff conditions at which streets and footpaths are still accessible
- Evolution of hazardous areas depending on the course of an event
- Classification and mapping of hazard type and hazardous areas

Overall, hazards and risks caused by flash floods in urban areas were described and analysed for the selected case studies. Main impacts of parameters (such as flow velocity and flow depth, backwater residence time, flood wave gradient, impact impulse and impact direction) were tested and classified in order to define different hazard types and levels which could be mapped. Sophisticated schemes for hazard and risk maps were developed depending on urban structures. Such maps may help to point out threats to the public and can provide helpful information for aid programmes.

Based on the above assessments, recommended mitigation measures for extreme rain events have been defined. Consequently, suggestions regarding possible improvements, precautionary measures and disaster response to be considered for urban planning have been made. A general analysis shows that considerations regarding emergency measures should cover:

- Responsibilities and patterns of interactions
- Precaution measures
- Communication with the public
- Forecast
- Assignment of aid programmes

Box 6 Hazard mapping

Hazard mapping is the process of establishing the spatial extents of hazardous phenomena, in this case floods. In creating flood maps, the extent of floods of different probabilities or return periods can be displayed, allowing a judgement of the risks for certain areas. Considering this probabilistic information, the flood hazard maps can be utilized for creating flood risk maps.

The general approach for creating these maps is based on overlaying a digital elevation model with predicted flood water levels in order to establish the flood hazard for certain areas. Besides inundation depth, more sophisticated approaches may include current velocities as an additional parameter to be considered in risk appreciation.

A framework based upon municipal functions and responsibilities has been provided to the individual municipalities that defines further tasks and responsibilities. It provides a pattern of interaction, defining who is to assume responsibility for decisions and tasks in case of an extreme precipitation event and if there is a need for cooperation, information and further education.

Mitigation measures which aim at minimizing losses arising from flash floods in urban areas differ fundamentally from measures taken in areas affected by river flooding. Preventive measures such as establishing and assigning flood plains or setting up conventional flood protection schemes cannot be adopted or must be modified. In this regard, the suitability of certain preventive measures for distinct locations has been assessed as well as the question which disaster preparedness structures can be developed within the following fields:

- Urban management
- Police law
- Building construction laws
- Urban drainage systems

A main point was the question whether or not hazard maps make sense in urban areas. In cases where this could be answered with yes, the question about information content and level of detail needed to be assessed, again highly dependent on the individual situation. In addition to the maps, measures in the fields of urban planning, building laws, declaration of hazard areas, technical infrastructure, proposals for design and control and protective measures for objects were analyzed.

With flash flood information available, education and sensitisation of the population at risk are of great importance for hazard, risk and loss mitigation. Besides precautions for buildings, preparedness of the population is indispensable. Individual advantage as well as loss potential and its costs should be communicated to become a stimulus for changes in behaviour. Measures to think about and to assess are e.g. development of information panels, use of media and promotion of preparedness. Also effective warning systems in the event of a flash flood forecast should be established. Next to the physical setup, levels and ways of warning information flow, information pathways and communication devices between municipalities, rescue service, authorities and the public need to be established or improved and adapted.

2.3 Forecast and warning adaptation strategies

2.3.1 General Observations

Forecast and warning projects conducted under RIMAX provide, while being based on German conditions, methodologies that can be applied to a variety of environments if adequately adapted to the specific conditions in the area of interest. Generally there are a number of issues to be considered when utilizing foreign methods in a new environment and the general points shown in Figure 12 should be taken into consideration.

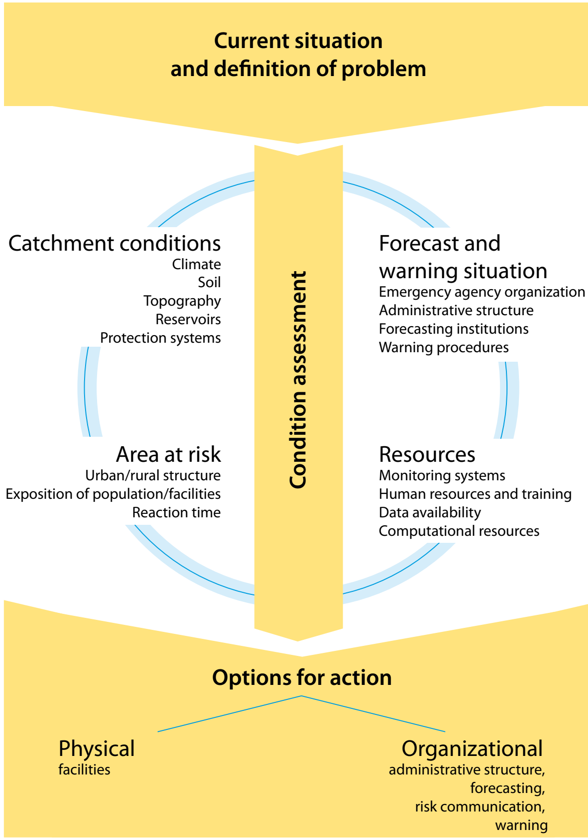


Figure 12 *General aspects to be considered in flood forecasting and warning. Priorities to be decided depending on individual circumstances.*

Within the framework of a flood forecasting system, the specific needs of the individual catchment type and size have to be met while incorporating the individual aspects of the area at risk. General decisions are required on the following questions:

- What is the minimum lead time required, i.e. the time required to produce and implement warnings
- What level of complexity / robustness is adequate and required for the task

In general, if large basins with slow flood generation processes are involved, relatively simple and robust systems for observation, data transfer and forecast modelling can serve the purpose of a timely warning. This may include:

- Manual observations of rainfall and water level
- Reporting of data at set intervals by telephone or radio
- Utilization of low-profile modelling resources

Where response times are shorter, or if there is a high value associated with risk, for example a major conurbation, or remoteness prevents the use of manual instruments, the requirements would be for:

- Automatic recording instruments and sensors
- Data to be transferred automatically from instrument to operational centre, at frequent, regular intervals
- Automatic quality control and reporting systems
- Automatic input into forecast model

In addition to ground measurements, other data, namely remote sensing information, may also be used. In this respect, a number of data sources are available that provide public domain data at no cost. These include digital elevation models, land cover information, satellite imagery (Landsat) and other products that can mainly be found on the USGS EROS database server, accessible via http://edc.usgs.gov/ or https://lpdaac.usgs.gov/.

In addition to data, software is necessary to carry out GIS assessments and modelling tasks. Next to commercial packages, highly useful public domain tools are available, e.g. Global Mapper for GIS use (http://www.globalmapper.com/) and HEC-HMS for hydrological modelling purposes (http://www.hec.usace.army.mil/software/hec-hms/). Numerous plug-in tools are also available for commercial software, enabling the user to tailor a software package to his needs, such as USGS GeoSFM (http://pubs.usgs.gov/of/2007/1441/), a tool that allows watershed delineation and basic hydrological modelling. Other tools may be found for a variety of different purposes.

With regard to the specific projects described in section 2.1, possible adaptation strategies and issues of specific interest are described in the following sections.

2.3.2 MULDE

Utilizing ensemble forecasts, MULDE aims at describing the uncertainty of the possible future development of a potential flood situation in larger catchments. By incorporating measurements, the forecasts are updated to reflect the most probable conditions. Considering this concept, the MULDE methods are generally applicable to larger catchments with longer reaction times. As shown in Section 2.2.1, a detailed problem description and identification of elements influencing the flood forecast and warning process is important to identify a feasible approach for the setup or improvement of the system.

The principles used in MULDE work for a range of catchment conditions and can significantly improve the flood forecasting and warning situation. On the other hand, it contains restrictions regarding the applicability to catchments with short reaction times (here OPAQUE and URBAS would be more adequate) and limited computational resources. The principle of using ensembles is anyhow not bound to strict numbers of models or processing speeds and even a limited number of model results would allow the generation of probability bands. These bands would need to be interpreted considering the level of sophistication and the sample characteristics used in the approach. Once evaluated in this way, the expected values could be treated in the same way as general model results. A sensitivity analysis of the different ensemble elements will help to understand the position of the individual model results within the ensemble and to accomplish an overall judgement of the quality and interpretability of the ensemble.

In the same way as the utilization of models is flexible in the MULDE approach, the incorporation of measurements and their time intervals can be adapted to local conditions and available resources. In any case, the number of locations and intervals at which measurements are included affect the quality of the model outcome requiring careful calibration. If an option exists to set up new or additional monitoring stations, the potential locations should be carefully considered and, in addition to logistic constraints, evaluated as to their potential benefit to the model results.

In addition to the main forecasting routines, MULDE was set up to provide decision support for judging risks and issuing flood warnings. When implementing the MULDE principles in new environments, the forecasting and warning mechanisms should be adapted and updated carefully, while keeping proven mechanisms and utilizing benefits offered by MULDE. An important component in this regard is the level of networking available for flood control and flood warning tasks, including the warning decision itself, but also control mechanisms, e.g. for retention dams and reservoir operation. When applying MULDE methods, their upgrading may be of central importance. The training of human resources in new technologies and methods is an important prerequisite for tapping the full potential of the MULDE methodologies. The general aspects of applying MULDE methodologies are shown in Figure 13.

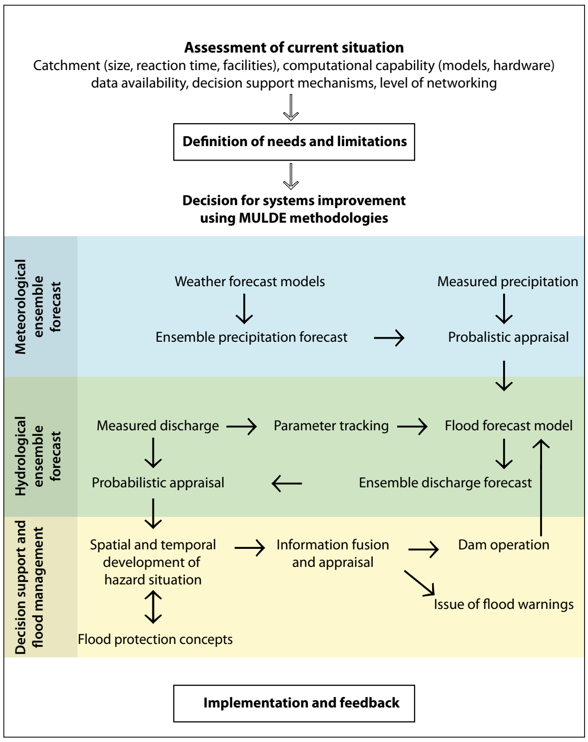


***Figure 13** General aspects of applying MULDE flood management methodologies*

Overall, MULDE provides an approach to improve existing flood forecast methodologies by utilizing a range of models to generate ensemble forecasts, reflecting a range of possible scenarios. Instead of creating one model output with a certain probability, the ensembles provide a means of describing the uncertainty of the potential future development of the hydro-meteorological and discharge situation.
For the decision maker, this spectrum of potential developments serves as a basis for planning and coordinating his flood information and management tasks, such as issuing alerts and forecasting damages. Potential fields of application of the MULDE approach include large catchments or sub-catchments.

2.3.3 OPAQUE

OPAQUE deals with flood events in head catchments of river systems. The methods described in this project are geared towards the application in steep source areas with intense precipitation events, high runoff coefficients and short reaction times. While being developed and tested in Germany, the principles of the developed methods are applicable in a variety of locations that are similar to the conditions described above. For larger catchments in the middle or lower reaches of a river, other methodologies would be more suitable and certainly more cost effective.

Given the fact that reaction times in head catchments are usually short, precipitation observations need to be transferred to the operation centre quickly. Monitoring intervals should be as short as possible or continuous. Depending on the nature of the meteorological and catchment conditions as well as the available resources, the monitoring setup can anyhow be adapted to suit the needs and local conditions.

Rainfall data collection includes automatic gauging stations and rainfall radar in OPAQUE. TDR gauges were used to monitor the soil state. Fitting a catchment with these units means a significant investment in monitoring equipment and telemetry. Adapting the methods to suit various environments is possible but needs to be planned carefully; emphasis should be on improving the monitoring of potential flood-generating events as well as fast data transmission to increase reaction times. Optimizing operational flood regulation processes on the basis of longer-term predictions is another advantageous step.

In order to optimize the flood forecasting and warning situation of an area, as a first step, specific locations at risk need to be prioritized and the relevant sub-catchments identified. Based on the meteorological situation featuring e.g. rain events with extreme local limitation or a more uniform rainfall distribution, decisions about the necessary monitoring equipment have to be made so that radar or conventional gauges may be selected. If radar is not a desired option, the density of the gauges may be increased in order to provide better area coverage. Data reporting mechanisms may be selected depending on the catchment size and pre-warning time required or desired.
Automated stations with telemetry provide the fastest data transfer while depending on the situation and staff availability, manual gauges may also be adequate or even superior to an automated solution. Measurements can be reported in close intervals via radio and extreme events could even be reported immediately and off-schedule.

Just as different solutions can be found to monitor precipitation conditions, monitoring of the soil state can be handled in different ways. Reporting intervals for soil moisture content generally can be much lower than the ones required for precipitation events.

While TDR instruments offer a convenient solution, monitoring can also be carried out manually by trained staff members. The density of monitoring points required depends on the homogeneity of the area considering soil composition, vegetation growth as well as exposure to wind and sun.

Optimizing the operation procedures of flood protection systems constitutes another important and valuable step in improving the flood security of certain locations. Based on an improved monitoring system and the resulting data series, the operation of the flood protection system can be enhanced both on a long term as well as on a short-term basis in reaction to potentially hazardous upstream precipitation events. If not linked to an automated system, provisions need to be made for adequate communication means, especially during flood events, to ensure proper operation in an overall coordinated way, suitable to tackle the flood event. The principle mechanisms of the OPAQUE approach are shown in Figure 14.

If the OPAQUE approach is to be adapted to new catchments, it needs to be kept in mind that a comparably high level of instrumentation will be required to achieve a positive result. On the other hand, in head catchments with short reaction times where floods may have a serious impact on the vulnerable population, it is only possible to monitor and control flood protection systems or infrastructure in a way similar to the one shown in OPAQUE. As described, a number of alternative instrumentation options are available allowing the user to decide depending on his needs and based on local circumstances. A decision in favour of implementing an OPAQUE approach should reflect the benefit of addressing flood issues in headwater catchments. This stands in contrast to standard flood protection approaches requiring highly sophisticated flood protection systems – also in the form of structural measures – that involve high costs.

Being developed as a method for fast reacting head catchments, the OPAQUE approaches are also directly applicable to wadi flows in arid regions where the issue of flash floods has a particular importance. In such areas it is essential to take special account of geological and wadi bed conditions that have a significant effect on runoff formation.

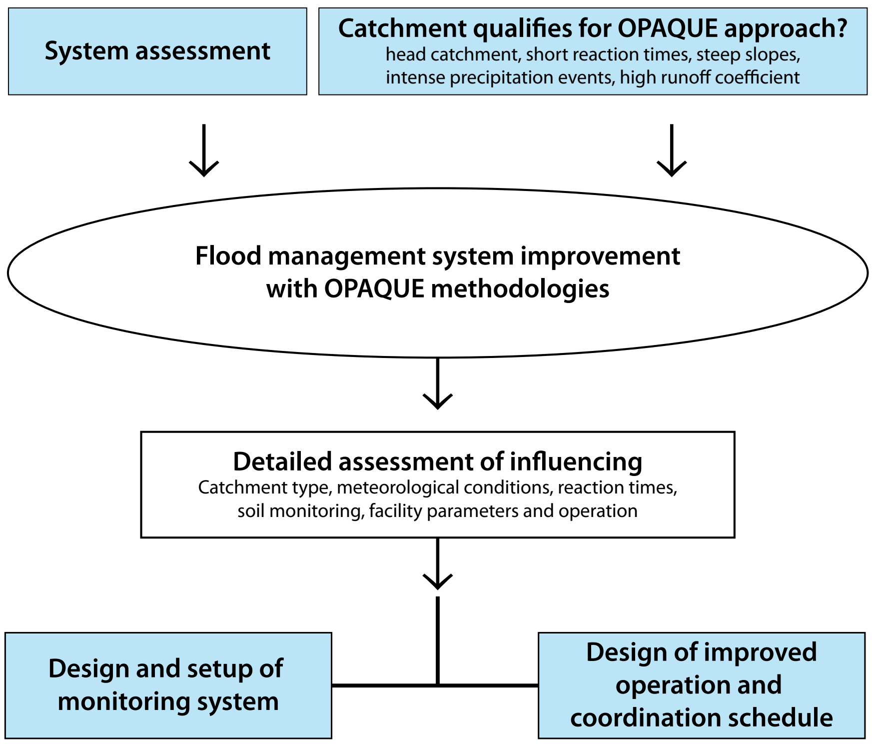


Figure 14
The principle mechanisms of the OPAQUE flood management in headwater catchments adaptation approach

2.3.4 URBAS

URBAS uses case studies to assess impacts, as well as prevention and mitigation possibilities for flash floods in urban areas through an interdisciplinary approach. The developed methodologies show the procedures to establish a suitable forecast and warning system, tailored to local conditions. They can serve as examples of how to improve flash flooding preparedness and preventive measures for a specific area. In the same way, the case studies were assessed in URBAS. Specific areas of interest in any other regions can be analyzed, provided that a certain amount of data is available. Regarding the spatial extent of considered areas it may be advisable to start with a first-level assessment for a larger area and then refine the approach, once more specific areas at risk have been identified.

The prerequisites for the application of URBAS include sufficient data availability to assess the nature of the problem in the area of interest. These data are required for the calculation of runoff potential, for instance to draw up risk maps. Operational data need to be available for running an operational forecasting and warning service, a sufficient monitoring network being the basic prerequisite for this purpose.

After an area for investigation has been identified, a detailed analysis of damage-prone events is intended to reveal the types of events leading to flash floods as well as to define the main areas at risk. Forecasting systems relevant to the catchments of these areas then have to be assessed regarding their early warning potential. Calibration of these forecasts is conducted utilizing the historical records of damage-producing events with the quality of calibration being dependent on the amount, resolution, representativeness and quality of available data. It may be advisable to improve the existing monitoring networks of the relevant catchments during this step, employing methods as described in Opaque in Section 2.2.2.

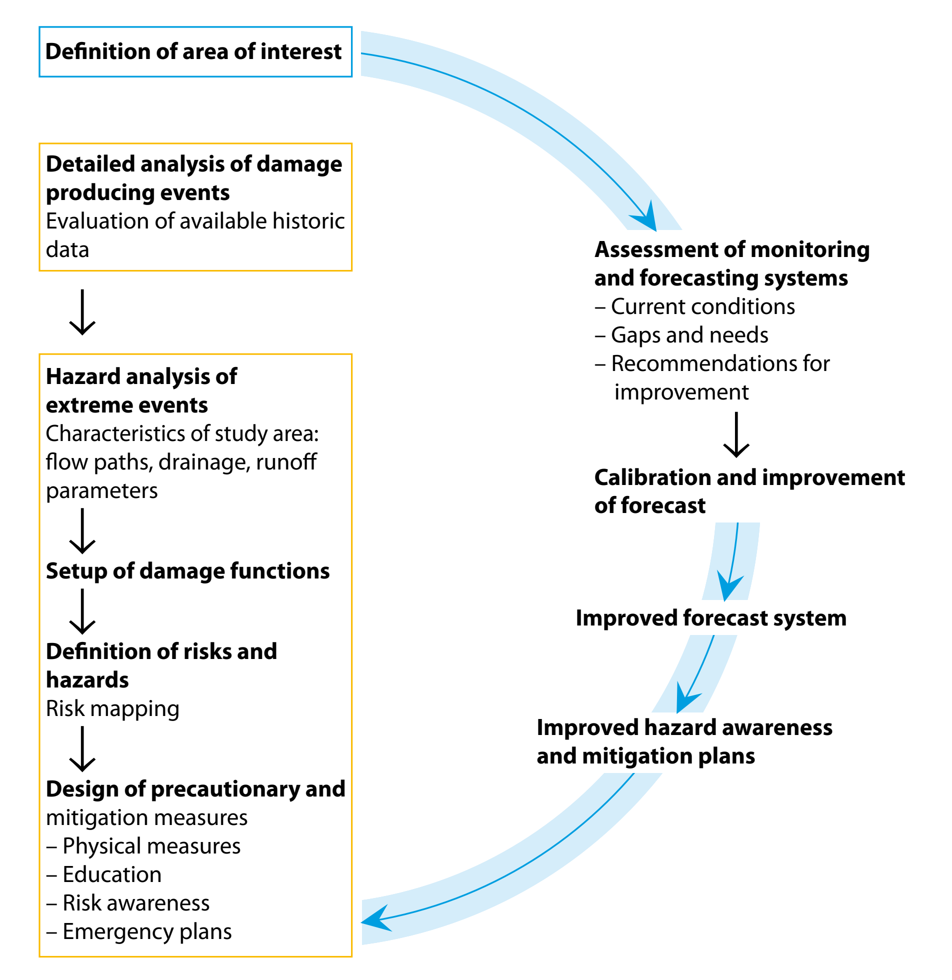


Figure 15
Flow chart of steps involved in assessing and mitigating flash floods in urban areas using the URBAS approach in flash flood management

A hazard analysis of the generated runoff can, depending on availability, be carried out based on data as well as on vaguer information from lessons learned. The utilized information may include anecdotal evidence as well as spatial maps of the area characteristics including sealed surface area, topographical flow paths and drainage situation of both the affected area as well as the surrounding runoff area. In this approach, it is important to consider uncertainties such as blockages that could alter flow paths or seasonal variations that might change runoff characteristics.

Following the above analysis, the risks and hazards are defined based on damage functions that take account of damage symptoms in relation to event intensities in the affected area. This step is followed by an assessment of the resulting threats to human life, residential and industrial areas and infrastructure. The information can also be used to define limits of safe runoff conditions and to conduct a mapping of flow paths, depth and velocity distribution, speed of rise and residence times of the floodwaters, giving an overall overview of hazards for different events. Based on this information, precautionary and mitigation measures tailored to the local circumstances can be established. Precautionary measures meant to minimize losses in a flood event include physical measures taken in the urban and catchment area, for instance to reverse surface sealing, restore woodlands, reroute possible flow paths and influence land use. In addition, educational measures are important in this regard to raise awareness of the potential risks and hazards.

Improved forecast methods including updated monitoring systems enhance the opportunities to issue flood warnings. Mitigation measures include setting up and improving emergency plans and patterns of actions / interactions in case of flood events, e.g. for rescue services. It is important to note that the series of steps described above is an individual exercise for each problem area and that assessments and planning exercises should always take account of local circumstances and resources. A flow diagram of steps is shown in Figure 15.

Flash floods generally occur in areas with steep gradients and / or high runoff coefficients. Depending on the nature and location of the area at risk from flash floods, different approaches for the assessment need to be taken. Furthermore, it needs to be kept in mind that the runoff generated by flash floods in far-away upstream catchments may have a strong impact on downstream locations. Situations like these can, for example, be observed in arid or semiarid regions where upstream rainfall causes high runoff events. In such cases, monitoring and hazard analysis paths require locally separated assessment. The monitoring needs of more remote catchments may differ from the needs of catchments in the immediate vicinity of the area at risk.

Next to the type of monitoring stations and their density, adequate protective means for the stations need to be considered. Where applicable, it has been proven useful to assign responsibility for a station to a local inhabitant.

3. Preparedness of defences

3.1 Projects

Flood management is a broad topic with many aspects needing to be taken into account. While many of the aspects to be considered are rather soft topics, flood defences, mainly dikes, are a hard topic. They are built with different means, different materials and to different standards, constructed since generations to protect people and property from flood events.

Dikes are geotechnical structures that can be constructed from different soils in a homogenous or zoned way, with the selected design mostly depending on the availability and quality of the materials used as well as the availability of construction tools and methods. Especially the latter have changed significantly over time, resulting in today's dike standards differing markedly from older structures. These differences in quality do of course have a direct impact on the resistance of the dikes to failure. Dikes may fail due to a number of reasons, the two most important ones being leeside erosion during overtopping and internal erosion due to seepage. An overview of failure mechanisms is given in Figure 16.

Dike failures may happen in different forms and during different kinds of loading condition, also depending on the internal condition of the dike. In general, dikes fail when the loading conditions acting upon the dike body exceed the loads the structure can withstand, be it through surface or internal erosion or sliding failure caused by water load or weakening of the dike body due to seepage. All these aspects can be monitored and calculated both in terms of the loads as well as of the surface condition and structural stability of the dike. Observation during events may also help to assess internal problems with the structure where e.g.

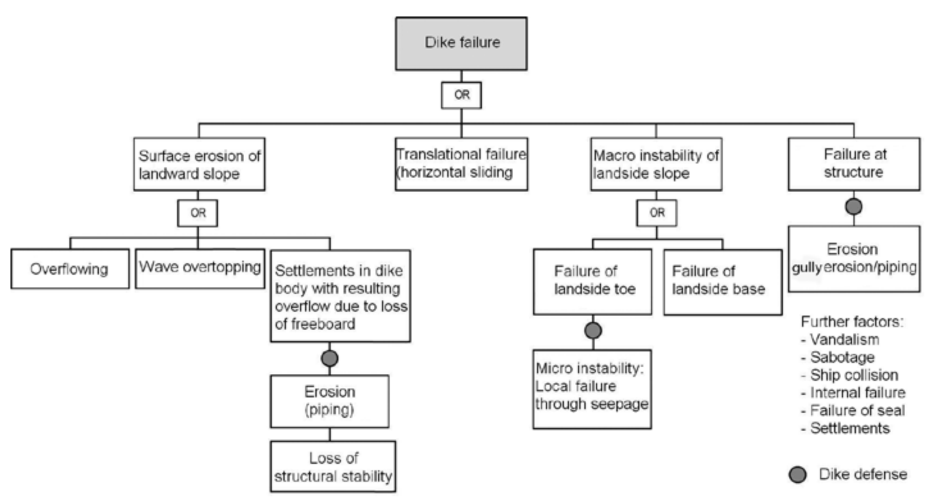


Figure 16
Failure mechanisms and functional chain with principal possibilities to act, warn, react, etc. (Draenelemente, 2008 (Drainage elements project))

seepage is reported. The use of local knowledge may prove a valuable asset for such observations.

Due to changes in climatic events, land use and land cover situation causing rising river levels as well as due to ageing effects on flood defence systems, dike breaches have become more likely. The research programs presented and evaluated in this section deal with this scenario through a range of approaches ranging from risk analysis, monitoring and the assessment of improvement possibilities to detailed suggestions of improvement options.

Three preparedness projects out of the RIMAX work are evaluated to describe methodologies for their adaptation and applicability in a wide range of circumstances:

- Optimizing Levee-Monitoring – Reliable identification and evaluation of vulnerabilities
- 'Sicherer Deich' – Investigations based on a full scale research dike to improve resistance and stability of river dikes during floods and dike overflow
- 'Draenelemente' – Combined stabilization of river dikes at risk of failing by means of drainage elements capturing seepage water and providing dike reinforcement

The projects describe a range of embankment analysis, monitoring and improvement methods that can, in principle, be used individually or in parallel, depending on the needs and circumstances. A short overview of the projects is given in the following paragraphs.

Optimizing Levee-Monitoring has developed a monitoring concept for dikes based on geo-statistical analysis. At first the reliable identification and evaluation of weak points in the dike system was accomplished. Subsequently the possible expansion of the monitoring concept to the whole dike system was evaluated.

The mechanical properties of the soil at a specific location were studied. Geo-statistical calculations and laboratory experiments were used to identify critical parameters of the failure processes and to improve the quality and validity of the results. Innovative monitoring procedures were developed in order to record the soil-water contents, the pore water tension, and the change of tension due to flooding. In parallel, laboratory experiments were conducted to determine strength parameters and their change due to saturation.
The geo-statistical procedures to determine spatial distribution and occurrence probability of weak points, were adapted to dike specifications.

'Sicherer Deich' uses assessments based on a research dike to improve the resistance and stability of river dikes during long-term flood events and overtopping. Innovative dike construction and dike rehabilitation concepts have been developed as a contribution to technical flood protection means, aiming at raising the economic efficiency of future dike construction and dike rehabilitation measures and at reducing the risk of damages. Within the field of dike construction and dike rehabilitation works, especially in view of long-term flood events and overtopping, the research program has yielded new knowledge about the suitability of new construction materials such as recycling products, geo-textiles etc.

Alternatives to traditional dike rehabilitation concepts are investigated which reduce effort and cost, while being equally effective (e.g. geo-textiles and rip-rap for bank protection and treatment of the dike with self-compacting mortar). Such rehabilitation methods can also be used for non-homogenous older dikes. The research results achieved make an immediate contribution towards innovating technical flood defences.

'Draenelemente' aims at stabilizing existing critical dikes by means of a low budget approach. The project is based on the fact that often hundreds of kilometres of dikes, constructed in old fashioned ways, exist along rivers. Mostly these dikes have been constructed and raised successively with materials that were available in the immediate vicinity of the dike. Such dikes are generally not fit to withstand the increased flood loads without damage or failure and to properly serve their purpose. As these dams are not zoned into core and filter layers, seepage through the dike body increases with time, finally leading to erosion on the landside slope. This may result in local or large-scale failure, leading to a collapse of the dike.

Due to financial constraints, the proper rehabilitation of large stretches of dikes is mostly a long-term process. Considering this fact, innovative techniques have been developed that can be implemented in the short and medium term or can be used on an ad-hoc basis in areas where an immediate danger of breaching is observed. These effective techniques allow for a sufficient stabilization of critical dike sections until proper rehabilitation measures can be implemented for long-term dike improvement.

3.2 Methodologies

Several approaches are applicable and feasible to monitor, prepare and improve flood defences. The approaches depend on the setting, logistic and financial constraints, loading conditions as well as the risks threatening the population and property to be protected. In most cases, however, applicable solutions can be found.

The methodologies employed in Optimized Levee Monitoring, 'Sicherer Deich' and 'Draenelemente' are described in the following sections. They do not only give examples of possible measures, but describe the points that actually can and should be adapted and enhanced to suit specific needs and circumstances.

The general fact to be appreciated is that not every dike within a defence system is in best condition or designed to the necessary standards of today. Monitoring and measurement techniques can identify locations where rehabilitation or improvement is necessary and can, during a flood event, inform about sections susceptible to dike failure, allowing for emergency works to be carried out.

On the management and control side, dams and other retention structures (e.g. polders) can be used to temporarily store water to reduce discharge peaks during flood events. Forecast calculations can be used to establish the design events and ensure that structures are built or improved to the required levels. For an optimum usage and operation of the flood defence units, control systems have to be employed that can flatten flood waves and avoid their superposition in case of joining river arms.

3.2.1 Optimizing Levee-Monitoring – Reliable identification and evaluation of vulnerabilities

Overview

For a reliable identification, appraisal and monitoring of weak points in a dike system it is necessary to obtain knowledge about the geotechnical parameters, soil inhomogeneities, the instationary behaviour of seepage and saturation as well as tensions caused by changing loading conditions. Within the Optimizing Levee-Monitoring project, monitoring concepts based on assessments and geo-statistical evaluations of the results have been developed. The geo-statistical analysis includes a reliable identification and evaluation of weak points in the dike system.

The detailed evaluation includes an assessment of the mechanical properties of the dike soils, geo-statistical calculations and laboratory experiments to identify critical parameters of a possible failure process. Parameters for which monitoring concepts were developed include soil water contents, pore water tension, the change of tension due to flooding and changes of strength parameters due to saturation.

It has to be noted that soil assessments based on intrusive samples, depending on the spacing of the sampling locations, only supply limited information about the structure of a dike body. The soil parameters obtained or deduced through laboratory and field experiments may vary significantly depending on the structure of the dike body. With carefully calibrated geophysical sampling methods on the other hand, continuous dike profiles can be obtained, but soil parameters are not revealed.

Based on these problems, the project has developed an innovative monitoring system to record soil water contents, pore pressures and internal tensions caused by the floodwater loading on the dike. A laboratory program run in parallel to the soil assessments revealed soil strength parameters and their changes during saturation. In combination with geo-statistical methods, these measurements are used to assess the spatial distribution of weak points and the probability of failure in the dike system.

Project Description

The project was carried out in phases as described in the following paragraphs. A main starting point was the definition of the hydrological conditions at the sample dike that was evaluated. Data had to be collected and evaluated and permissions needed to be obtained to carry out the sampling and monitoring activities. The geotechnical conditions of the dike body and its base were then assessed in detail to provide the base data necessary for the evaluation.

Box 7 Response Surface Method

The response surface method (RSM) explores the relationships between several explanatory variables and one or more response variables. The main idea is to use a set of designed experiments to obtain an optimal response. This model can only be seen as an approximation but is easy to estimate and apply, even when little is known about the processes themselves.

Box 8 Monte Carlo simulations

Monte Carlo simulations rely on repeated random sampling, model runs with changing parameters, to compute their results. Monte Carlo methods are useful for modelling phenomena with significant uncertainty in inputs, testing the effect of a possible range of a parameter. There is no single Monte Carlo method; instead, the term describes a large and widely-used class of approaches. However, these approaches tend to follow a particular pattern:

- Define a range of possible values for each parameter in question
- Generate random input data within the defined range
- Perform a deterministic computation using the parameters
- Include the results of the individual simulations into the final result

After this first step, geo-statistical methods were developed and sensitivity studies carried out regarding the predominant failure mechanisms as well as the conditions leading to these failures. An important point was to capture the effect of changing saturation levels and pore water pressures on the geotechnical soil parameters.

After having carried out the baseline surveys, suitable methods and equipment were developed and the instruments placed on site. Measurements commenced, followed by an evaluation of the records targeting to reconfirm the assessed soil conditions and to fine-tune the calculation model. The results were then verified with a second set of measurements based on which the monitoring concept was finalized and recommendations regarding suitable methods released.

Based on the results of the dike investigations and its instrumentation, a statistical analysis of the soil parameters is conducted to determine the probability distribution and distribution type of the individual parameters in their geotechnical spectrum. Based on known data, additional reference values, e.g. from databases, can be included in the assessment. To achieve an optimal description of the soil type, areas between points that were physically investigated were horizontally modelled using autocorrelation functions to picture the changing soil parameters over the distance.

To obtain a realistic picture of the underground and to detect the above-mentioned relevant underground areas and potentially related failure mechanisms, sensitivity studies were conducted.

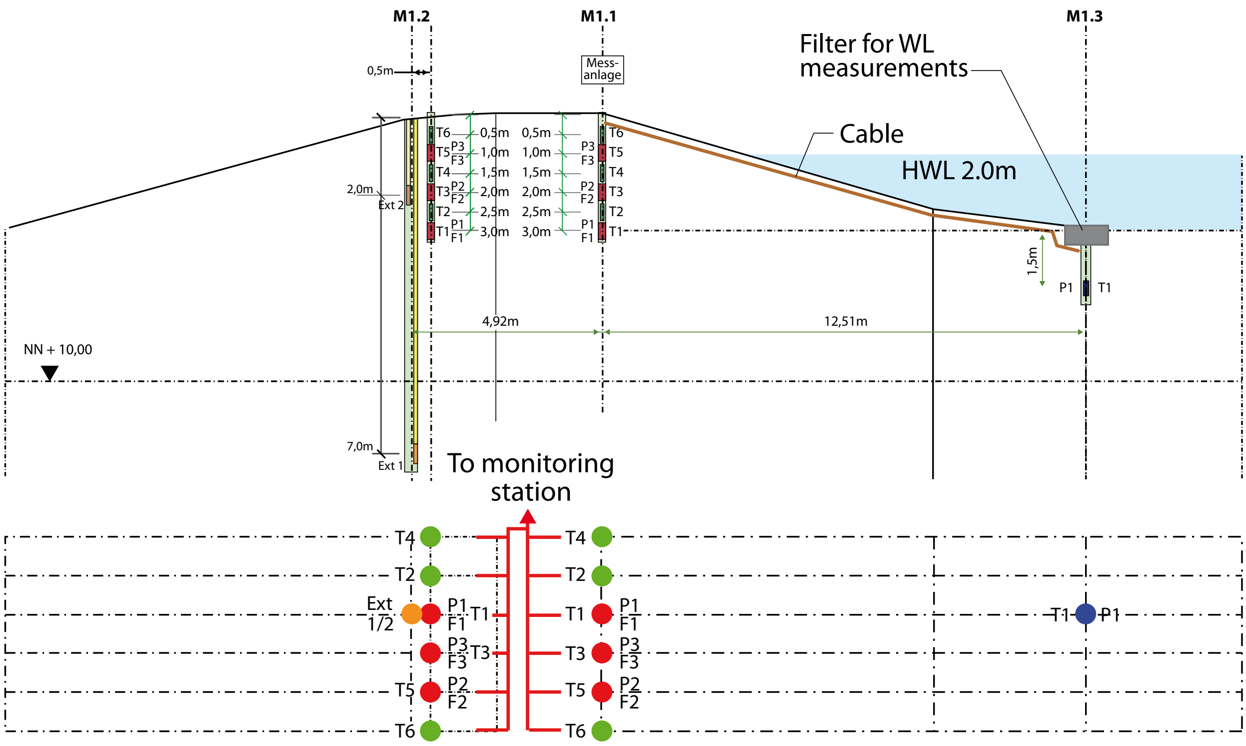


Figure 17 *Dike instrumentation (Optimizing-Levee-Monitoring, 2008)*

These studies were initially used to forecast stresses, deformations and temporal changes in the soil whilst considering different relevant parameters in a variety of combinations. The studies were then expanded using "Response Surface Method" as well as taking account of the stochastic distribution in the area. Monte Carlo simulations were used for comparison. Based on these investigations the relevant parameters for the soil could be deduced.

Through permanent adaptation of the model and recalculation of the sensitivities, the conditions inside the dike body can be calculated. Over time, with additional measurements, an increasing factor of reliability for the calculation of structure deformation and safe level of loading conditions can be achieved. In this way the relevant actions for structure maintenance can be initiated to guarantee functionality.

Based on the sensitivity analysis, an individual design of the relevant monitoring concept was carried out to determine the locations as well as the soil parameters to be monitored for optimized stability calculations based on changes over time as well as inter-correlation of different parameters. Parameters that were observed inside and underneath the dike body include tensions, pore water pressures, and deformations (using tensiometers, pore water gauges, inclinometers, extensometers, levels and similar). Exemplary dike instrumentation is shown in Figure 17.

The selection of suitable measuring devices and methods was based on the requirements of the individual and isolated measuring locations in order to guarantee high quality measuring results. The method to establish the monitoring concept is shown in Figure 18.

Box 9 Seepage line factors

A significant parameter for the reliability and failure possibility of a dike is the location of the seepage line within the dike body that is depending on:

- Permeability of the materials
- Geometry of the dike
- Dike structure
- Duration and level of flood event
- Moisture distribution inside the dike
- Possible defects through animal burrows, vegetation and defective seals
- Erosion and suffusion caused by previous flood events

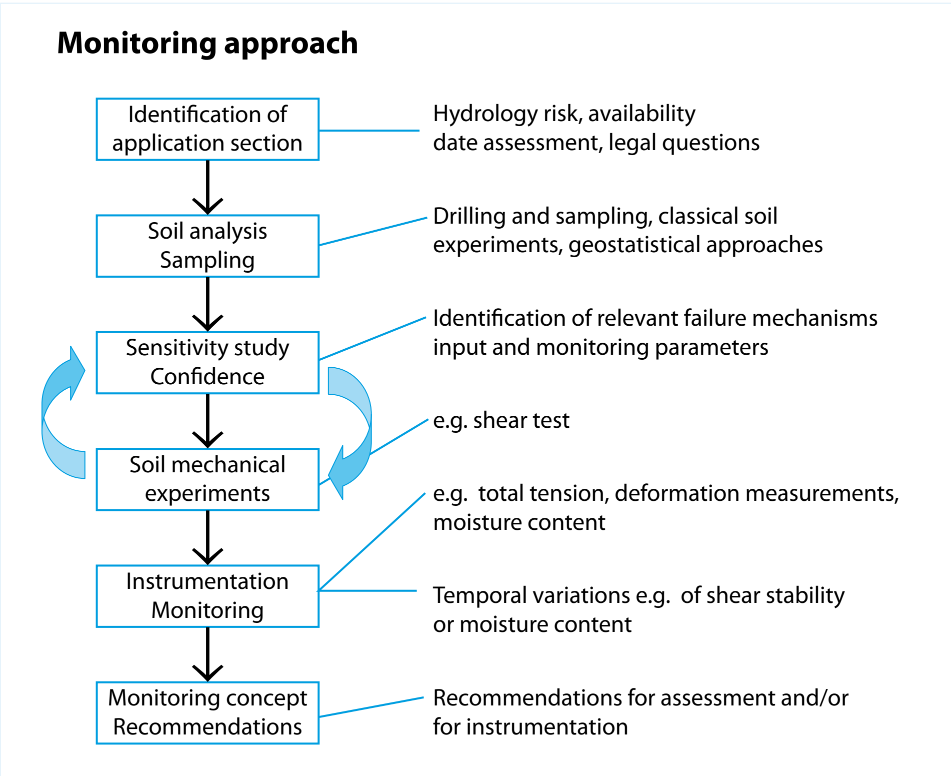


Figure 18
Implementation plan for a monitoring concept (Optimizing-Levee-Monitoring, 2008)

An important point for the practical implementation of the concept was the structured setup of the studies. Based on a risk analysis regarding the subsoil and dike soil conditions and forecast models, the following points were identified while an action list was established on the basis of the results:

- Endangered areas
- Monitoring equipment
- What needs to be measured and how often (monitoring concept)

The results of the monitoring concept in combination with flood forecast calculations that identify critical areas lead to the definition of optimized measuring systems at critical locations or to early decisions for dike improvements.

Box 10 Points to consider when working with soil dikes

Important points when working with soil dikes

- Soil is not produced in a uniform way but a product of various geological and anthropogenic processes
- The construction process of dikes in the past was strongly influenced by local conditions
- The knowledge of soil parameters of isolated locations does not allow for a reliable judgement of conditions at other locations
- Quantitative physical forecast models are non-existent
- When transferring laboratory results to in situ conditions it needs to be borne in mind that only correlative judgements can be made

Box 11 Main principles of optimized levee-monitoring

Problem: Why do dikes collapse?

- Seepage and softening up is one of the main causes of dike failure
- Seepage monitoring and control is an effective means of reducing the risk of failure
- Assessment of soils using geotechnical tests (material-based risk analysis)
- Decision for customized monitoring concept
- Appraisal of dike system using monitoring results, identification of sections at risk
- Prioritized list of necessary improvement works

3.2.2 Sicherer Deich – Improve the resistance and stability of river dikes

Overview

Dikes, crucial for successful protection against floods, are structures mostly built over several generations, often older than 100 years that have not been redeveloped since their construction. The flood disasters of the past years emphasize the significance of the strength of these dikes in order to maintain their function as efficient flood control systems. Thus, for instance, the condition of the Elbe dikes in Germany led to the enormous damage during the flood in 2002.

During extreme floods sections of the dike line may be overflown. If erosion takes place, this scenario may lead to the complete collapse of the dike, one of the most common reasons for dike failure. The 'Sicherer Deich' project has investigated the suitability of innovative materials like recycling material and geo-synthetics in order to strengthen dikes. The materials are used to construct and remediate river dikes and analyse their stability and resistance against erosion during sustaining floods and dike overflow.

The research project investigated inovative approaches for the usage of new materials like recycling products, geotextiles and others in dike construction and dike rehabilitation, considering the impacts of long term flood events and overtopping. In addition, alternatives to the traditional dike rehabilitation concepts have been established to reduce effort and costs while maintaining effective improvements (e.g. using soil stabilization). Figure 19 shows examples of geotextiles in dike construction.

The project focuses on weak points of traditional dike construction concepts, especially related to erosion during overtopping of the dike crest during flood events.

Project Description

'Sicherer Deich' looks into innovative concepts for dike rehabilitation, improving traditional standard approaches. Besides natural materials, artificial products such as recycling materials, waste products and clinkers were also considered suitable for dike rehabilitation tasks. The suitability of these products for being used in dike construction and rehabilitation with regard to structural stability and environmental impacts is investigated in full-scale trials.

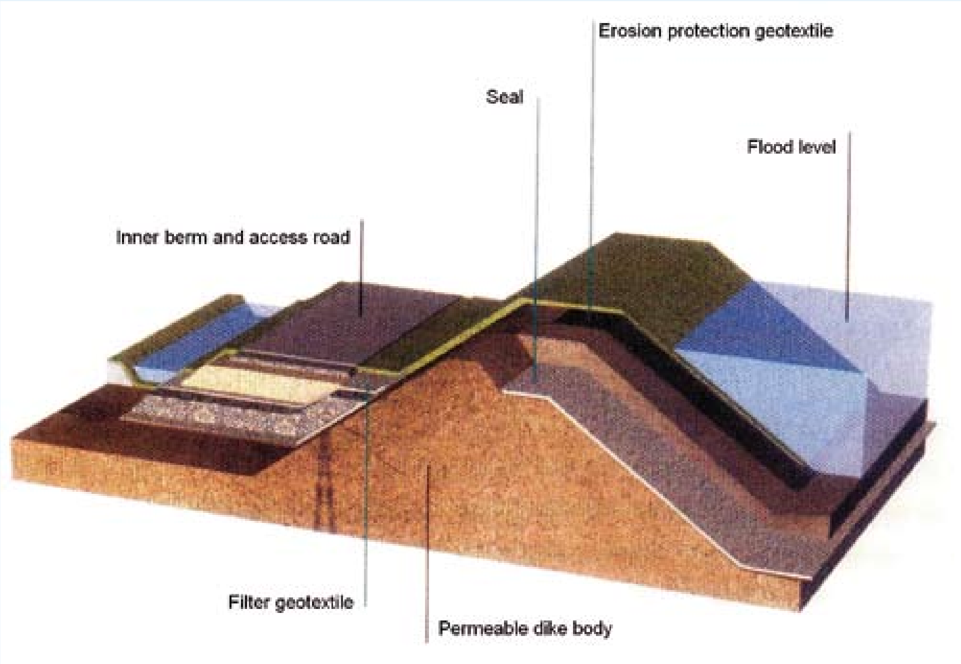


Figure 19
Examples for the use of geotextiles in dike construction (Sicherer Deich, 2008)

The hypotheses is that using geotextiles in surface layers, the dike crest and the landside slope can be protected against overtopping erosion and breaching of the dike. Different kinds of geotextiles have been used for several years in dike construction, especially as impermeable sealing elements and filters.
By combining geogrids and fleece webs, the surface layers may be improved regarding their resistance to erosion due to overtopping. For dike bodies with otherwise undamaged structure, an effective erosion protection may be feasible in such a way. The suitability of this type of surface protection and possible construction alternatives are tested in full-scale overtopping trials (Figures 20–22).

A general problem for river dikes is the sensitivity to erosion during overtopping. As the design water levels may be exceeded during extreme flood events, the over-

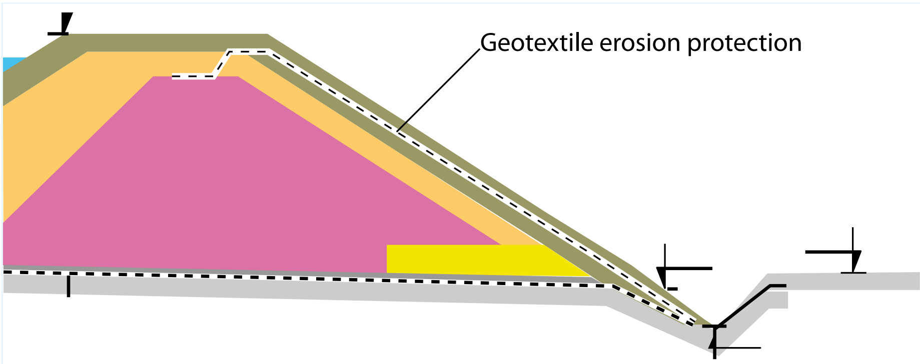


Figure 20
Classic use of geotextiles in dike construction and erosion protection through combination of different materials (Sicherer Deich, 2008)

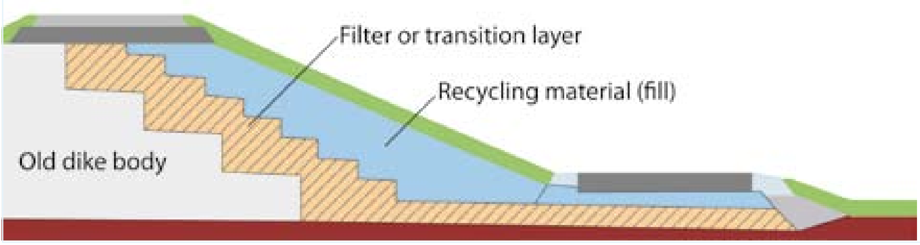


Figure 21
Use of recycling materials in dike rehabilitation (Sicherer Deich, 2008)

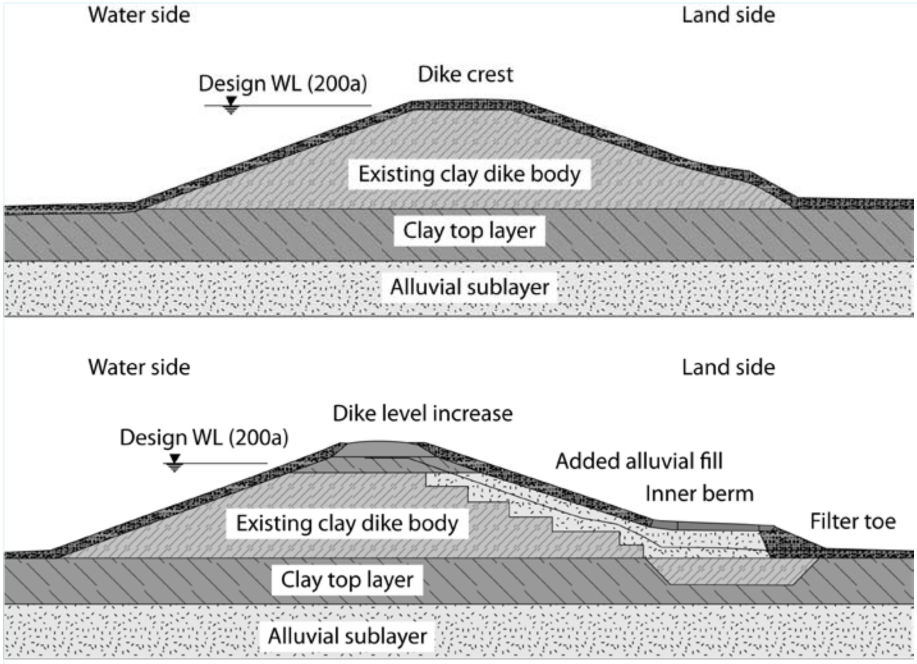


Figure 22 *Standard cross section of an aged dike (top) and a rehabilitated dike (bottom) on the Rhine (Sicherer Deich, 2008)*

topping of parts of the dike system needs to be taken into account (Figure 23 and 24). To minimize the risks of a dike breach caused by erosion due to overtopping, the dike crest as well as the landside slope need to be protected.

Figure 23 *Overtopping of an unprotected river dike (Sicherer Deich, 2008)*

The extensive protection against erosion of many kilometres of dikes along rivers requires an efficient and low-cost solution. Apart from the costs of the material, the building costs are important. The protective measures should not only be suitable for new dikes but also for remediation purposes. Therefore the erosion control should be embedded near the surface of the landside and/or at the dike crest. Intervention in the core or the sealing should be an exception.

A different problem with river dikes that may cause erosion is seepage through the dike body. During long-term flood levels and in view of insufficient filter layers, the seepage line inside the dike rises until water exits the dike body at the landside toe or slope. The seepage water can lead to internal erosion or erosion of the landside slope, followed by piping that may lead to the collapse of the dike body at a later stage.

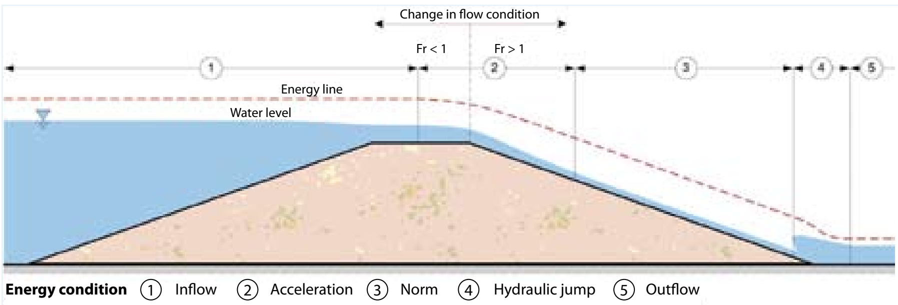


Figure 24 *Cross section of a dike during overtopping showing different flow states (Sicherer Deich, 2008)*

The project is conducted on the basis of a full-scale sample dike section of a length of 60 m, a width of 17.5 m and a height of 3 m. The slopes were inclined 1:2.5. On the landside toe, a toe drain from gravel-sand material was located. The trial section was therefore representative of typical river dike geometries in Germany.

Based on the sample dike geometry, hydraulic calculations for the design of erosion protection layers were conducted, which was essential because erosion is even triggered by relatively small overtopping quantities. The natural erosion protection of a slope cannot withstand the enormous loads caused by overtopping flows.

Next to the hydraulic stresses on the dike slopes the influence of seepage through the dike body needs to be considered. Here the effects of seepage from the water side towards the landside slope need to be distinguished from the effects of infiltration of the overtopping waters into the dike crest and the landside slope. This infiltration and seepage leads to an increased risk of failure compared to the loading conditions in case of purely high floodwater levels.

To investigate the structural stability of the dike, seepage conditions were calculated based on a two-dimensional numerical model using the finite element method. The conditions under floodwater load both with and without overtopping were calculated. It was found that the risk of erosion and the related breach of the dike due to overtopping could be reduced by generally improving the erosion stability of the dike surface. Using this method, expensive work needed to raise the dike level can be avoided. A both functional and economically efficient solution had to be found for protecting large areas against erosion. In addition to material costs, construction and handling costs were integrated into the economic appraisal. It must also be ensured that the methods are suitable both for dike construction and rehabilitation of existing dikes, resulting in the need to use an erosion protection layer close to the surface of dike crest and slope.

In case of overtopping the erosion protection needs to meet the following requirements:

- stability against breaking up into individual components
- increased stability starting from lower layers
- stability against sliding on top of the lower layers

In all cases the exposed dike core would be very vulnerable to the erosion forces of the overtopping floodwaters, which would finally lead to a dike failure.

Experiments at full-scale trial dikes explore erosion protection options by means of novel combinations of different geotextiles (Figure 25).

The different types of geotextiles employed serve various functions:

- A classical erosion protection geotextile composed of UV-stabilized polymer webbing stabilizes the topsoil layer and avoids surface erosion. It is applied to steep slopes where erosion problems can be expected
- Geogrids are used to reinforce steep slopes and can handle high shear stresses
- Fleece layers are used as filter elements. They have high permeability and separate adjacent soil layers to avoid internal erosion

The possible applications of combination products are manifold, given that the different products can theoretically be combined in a variety of ways. Geogrids are often utilized in combination with fleece filters acting as reinforcement elements while the fleece is supposed to avoid washout of soil particles. On the other hand, fleece layers combined with erosion protection geotextiles have been used as drainage mats, with the erosion protection geotextile acting as the drainage element and the fleece layers avoiding soil washout.

The forces acting onto the erosion protection layer are introduced into the dike body through a linear connection at the dike crest as well as through soil nails on the slopes. Grasses growing on the slopes seem to further stabilize the surface and geotextiles via their root system, constituting a part of the erosion protection.

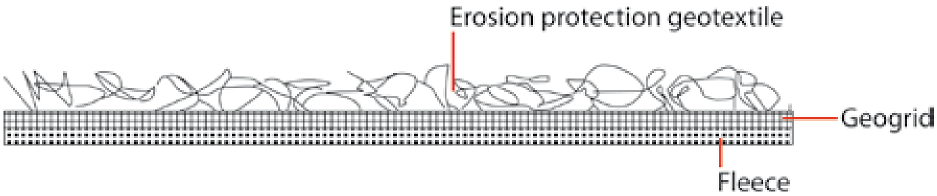


Figure 25
Erosion protection based on a combination of different geotextiles
(Sicherer Deich, 2008)

The fleece layer combined with the erosion protection geotextile is supposed to act as a filter to avoid erosion of the dike core in case of failure of the surface layer.

Box 12 Main principles of Sicherer Deich

Overtopping of dikes as it can be expected during extreme events may lead to erosion and failure of dike sections. The risk of these failures needs to be reduced.

- The risk of erosion can be reduced by using new/different materials for surface protection
- Geotextiles are tested to improve stability; the grass growing on the slopes seems to play a major role in stabilizing the dikes
- The dike structure may be enhanced by means of partial improvement without the need for full reconstruction

3.2.3 Draenelemente – Stabilization of river dikes at risk of failure

Overview

In Germany as well as in other countries, hundreds of kilometres of old-fashioned river dikes exist along rivers and streams. The dikes have mostly been developed and built over extended periods of time using materials available in the direct vicinity of the river. Such dikes are often not capable of withstanding the loadings caused by long-term flood events and overtopping without getting damaged and loosing their function. Increasing seepage through the dike body can lead to erosion on the landside slope, resulting in slope failure and collapse of the dike.

In recent years, dike failures entailing considerable damage have been a common occurrence during floods. Besides extreme meteorological conditions, ageing and the above-mentioned historical design of the dike structures must be considered as main reasons for failures. Any overall rehabilitation of the dike systems can only take place on a long-term basis due to the considerable costs involved. Based on these aspects, techniques for short term refurbishment were developed that:

- can be deployed on a short or medium-term basis in case of flood events where the risk of dike failure is acute
- can be used at identified critical dike sections (e.g. as known from previous flood events) for an effective and economically efficient improvement until further rehabilitation or reconstruction efforts can be performed
- lead to a permanent stabilization of locally restricted sections by improving drainage and reinforcement

In the case of long-lasting flood events and a resulting seepage through the dike body it is necessary to stabilize the landside toe of the dike body as shown in Figure 26.

'Draenelemente' deals with the stabilization of river dikes at risk of breaching using drainage elements to collect seepage water and reinforce the dike body using innovative geo-synthetic structures. Stabilisation techniques are developed to improve stability by means of mechanically installing these drainage elements, thus preventing dike failure by controlling the seepage in the structure.

The design and effectiveness of the drainage elements has been assessed by numerical parameter studies as well as practical trial implementation in test embankments. Results of hydraulic calculations like the location of seepage surface and pore water pressure

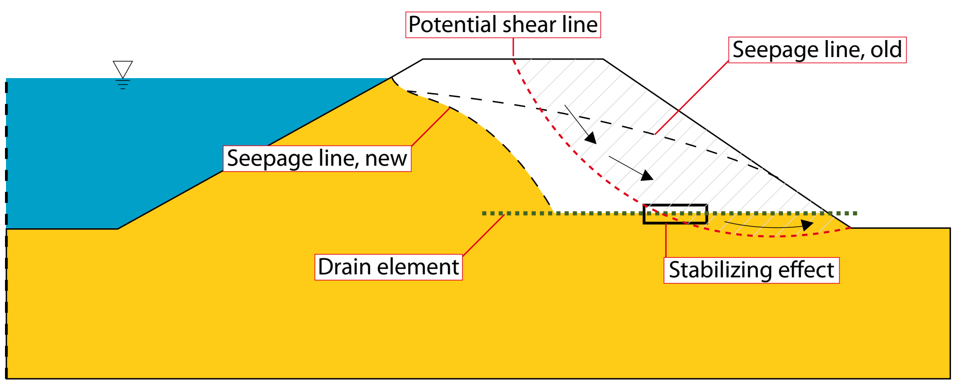


Figure 26
Example of a dike slope that was stabilized using drainage elements (Draenelemente, 2008)

are provided as input data to carry out stability calculations. Calculation results are verified by model tests in the laboratory and by means of a dike model on a technical scale, where drainage elements are installed using a standard drilling crawler.

Project Description
In the 'Draenelemente' project, an engineering method for the improvement of river dikes by means of horizontal drainage elements (Figure 27 to 29) has been developed, taking into consideration the hydraulic impact and different working stages.

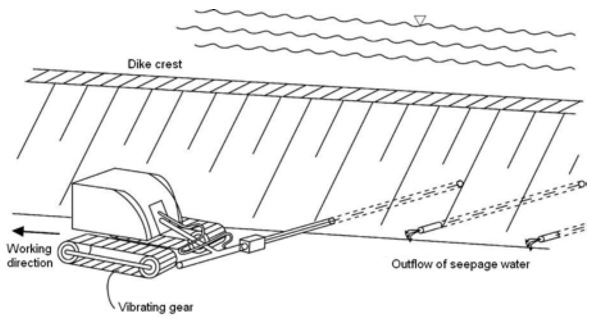


Figure 27 *Stabilisation of river dikes by means of installed drainage elements (Draenelemente, 2008)*

Figure 28 *Installation of a drainage element in the dike body (Draenelemente, 2008)*

Historically, sand bags were used on the toe of the dike in case of seepage water appearing on the landside slope and toe. This method relied on increasing the weight of the toe section as well as using a permeable material for stabilization.

Other, more recent procedures include the placement of big bags filled with large volumes of sand or water. The advantage of this solution lies in the efficient mechanized filling process and economic transport. Problems occur when attempting to transport the equipment in the mostly saturated and soft slope areas.

The utilization of plastic sheets to seal the waterside slopes of river dikes can only lead to acceptable solutions when visible failures, e.g. cracks and significant flows occur through the dike. For all other situations, assessments have shown that this method is unable to significantly reduce seepage flow nor the level of the seepage line within the dike body.

The 'Draenelemente' project aims at stabilizing existing dikes with minimum financial effort using simple construction methods. The method's general applicability has been proven using relevant calculations. Basic numerical calculations (2D- and 3D-calculations) confirmed the essential drainage capacity of the drainage elements with a defined length and diameter to be arranged at regular intervals near the foundation of a river dike. According to Figure 29, a considerable lowering of the water table due to the installed drainage elements can be achieved

After verifying the numerical calculations – in particular the modelling of the drainage elements – a numerical parameter analysis was carried out by means of small scale hydraulic model tests. The effects of varying lengths and distances of drainage elements on seepage and draining capacity were examined. The geometry of the dike structure was defined according to the conditions of aged dike structures in Germany. The dike structures were assumed to be homogeneous and soil parameters were predefined. Parameter analyses were carried out for either sandy or loamy dike structures. Based on the results of the numerical parameter analyses, the effects on the dike stability were assessed. 3D-data of pore water pressure distributions and locations of the phreatic surface were provided for stability calculations.

Slotted PVC-drainage-pipes – 2 inches in diameter – are considered as standard drainage elements. Besides their cost effectiveness, PVC-drainage-pipes can be employed for a wide spectrum of soil materials. According to the experimental filter criteria the slot width has to be adapted to the soil material in order to prevent negative erosion effects.

A suitable installation technique adapted to the chosen drainage elements is an important aspect for ensuring the feasibility of stabilizing quasi-homogeneous dike structures with drainage elements. The basic requirements of a suitable installation technique are cost

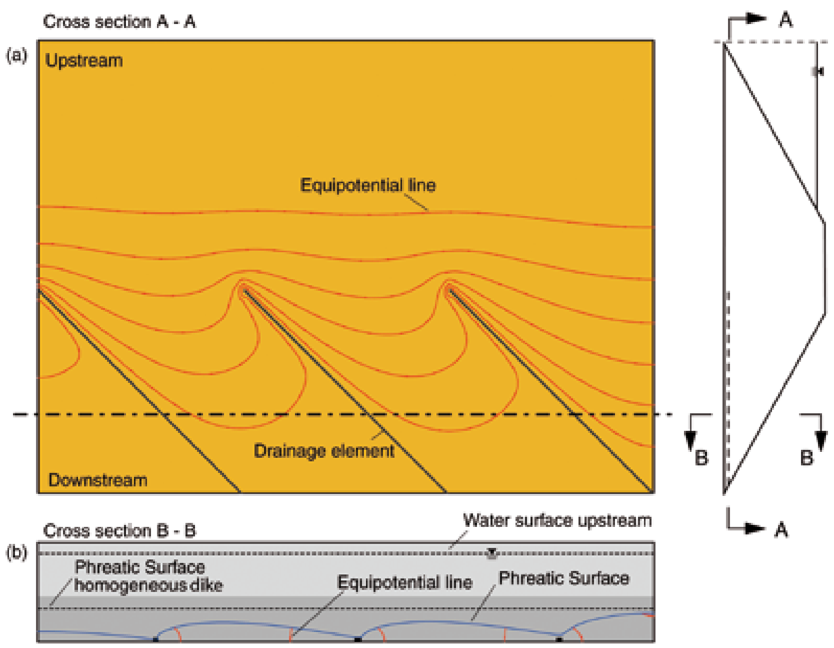


Figure 29
Water-table lowering capacity of drainage elements – horizontal section at foundation level (a) and cross section B-B (b) (Draenelemente, 2008)

effectiveness, the possibility of horizontal installation at a minimum height above the dike foundation and minimum influence on the drainage capacity of the drainage element. To verify both the feasibility of the stabilization technique and the hydraulic performance of drainage elements, tests were carried out by means of dike models on a natural scale. The geometry of the dike models was identical to the boundary conditions of the numerical parameter study. In the first step different installation techniques were tested on a dike model with a standard drilling crawler.

After determining a suitable installation technique, one drainage element was installed in a flooded dike model on a natural scale under stationary seepage conditions. Multiple measurement devices such as TDR-Sensors and tensiometers, among others, permitted a spatial investigation of the seepage inside the dike structure.

In addition to the drainage aspects, three main factors which may influence and increase dike stability were investigated in detail:

- The lowering of the seepage line and the simultaneous change of the soil material’s specific weight.
- A reinforcement effect produced by the drainage elements.
- The suction effect due to the lowering of the seepage line

Box 13 Main principles of Draenelemente

Dikes that have been built over the last century may be at risk of failure under today’s loading conditions, while complete dike rehabilitation is generally too expensive and time-consuming.

- Low-cost stabilization approach necessary

Drainage elements can be used to stabilize dikes

- Lowering of seepage water level
- Speedy and cost-efficient installation
- Feasibility of method in advance of and/or during flood events
- Applicability of standard equipment for task

3.3 Preparedness of defences’ adaptation strategies

3.3.1 General observations

In many countries, flood defence systems and namely dikes have been built a long time ago, to unknown or non-existing standards, which on top of that may also suffer from a lack of maintenance. Dealing with such conditions is reflected in the RIMAX approaches. Considering suitable adaptation strategies, the know-ledge generated in various RIMAX projects can be used to substantially increase the systems' defence potential. Different approaches have been applied in the projects to improve dike stability. Tailored monitoring approaches to identify sections at risk, means to avoid dangerous seepage conditions through drainage elements and the use of geotextiles to avoid erosion during exposition to overtopping have been presented.

The projects describe sample applications of innovative approaches to tackle certain problematic situations. The presented approaches may be applied to similar or other conditions but they may also serve as a source of inspiration to trigger ideas for problem solving. It needs to be kept in mind that conditions vary according to the individual locations with their own material parameters, climatic and topographic circumstances, entailing the need to individually appraise different sections of the defence systems. Based on the individual outcomes of the appraisals, potential improvement strategies can then be defined. The following factors may be relevant for appraisal:

- Soil parameters
- Dike geometry and dimensions
- Surface protection
- Climate and related vegetation
- Potential loading conditions
- Exposure to accidents and attacks
- Local knowledge about dike behaviour during previous events
- Knowledge about circumstances of historic damages or failures

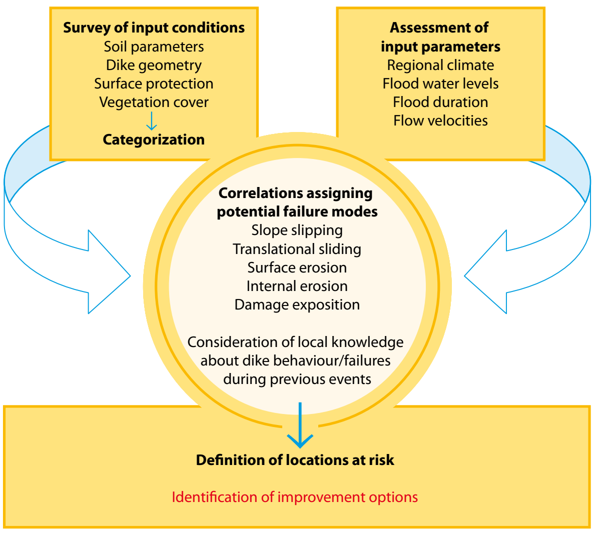


Figure 30 *Strategy outline for assessing risks and identifying improvement options*

The above factors will have to be considered in a holistic approach while identifying improvement strategies that can handle and improve the reliability of the defence system considering the overall circumstances of a location. A potential strategy for assessing and improving a defence system is outlined in Figure 30.

A list of possible improvement strategies can be summarized as follows. Local factors influencing the condition of the facilities, loading conditions and means available to implement improvement actions will impact on the feasibility of the individual options:

- Reduction of current velocities
- Improvement of surface protection to avoid erosion during overtopping
- Lowering of seepage line
- Protection of landside toe where seepage occurs

3.3.2 Optimizing Levee-Monitoring

The concept of optimizing levee monitoring considers both hydrological as well as geotechnical conditions of defence dikes to establish a monitoring concept to observe the flood defence system and identify weaknesses that need to be improved. The approach used under RIMAX has utilized an extensive monitoring system based on a dike sample section to prove the applicability of the method. Under real conditions, the method needs to be adapted to the larger-scale flood retention system conditions anyhow, while taking account of local circumstances impacting on type and intensity of the monitoring approach. Depending on the circumstances and considering the range of possible hydrological events, limited seepage monitoring activities may be sufficient to evaluate the improvement needs in one dike system while the circumstances in another system may demand more sophisticated monitoring efforts.

The main aspect of optimizing levee monitoring is based on a combination of the hydrological conditions to be expected with the geotechnical parameters of a dike. Given that the resources for setting up a monitoring concept are usually limited, a first step on the way to implementing the approach in a larger-scale dike system would be to identify areas at risk by means of an initial visual inspection of the dike system as well as local knowledge and observations. This inspection allows the identification of vulnerable dike sections that would benefit from an optimized monitoring concept. A baseline geotechnical survey and a detailed assessment of the potential hydrological conditions would then have to be implemented for the selected sections to judge the vulnerability of the dike body as well as the loading effects acting on it.

The parameters to be assessed and the investigation grid to be selected depends on on the individual on-site conditions. Expected materials, level of inhomogeneity of dike body and underground as well as variability of hydrological conditions are vital factors in decision-making. The experience of the staff performing this important work is another factor to be taken into account.

Evaluations and sensitivity analyses conducted using hydrological and geotechnical information to assess potential failure modes should include general seepage, erosion and stability calculations, with the applicable approaches depending on the dike materials. Methods can range from hand calculations to numerical analyses using for instance FEM (Finite Element Method) approaches. The more sophisticated the approach, the more it will rely on prime quality input data. Where less data are available, more robust hand calculation methods may be advantageous.

Baseline calculations facilitate decision-making regarding a suitable instrumentation concept, including type and distribution of sensors. Again, the level of inhomogeneity and the variability of hydrological conditions should be considered while the decision-making process is dominated by the aspect of potential failure mechanisms. The monitoring setup should aim at observing potential risks related to these failure modes. If e.g. internal erosion leading to piping has been identified as a main risk, monitoring of seepage line level and seepage water would be advisable.

The exact setup and type of monitoring devices and recording equipment to be selected will depend on local conditions. Choices range between manually operated devices requiring routine checking by local staff on the one hand and fully automated, interlinked data transmitting devices on the other hand.

With the instrumentation in place and monitoring activities being carried out, over time the most vulnerable sections of the observed dike system can be identified taking into account the baseline hydrological and geotechnical conditions as well as the monitoring results as collected and evaluated for different loading conditions. The information can further be used to identify and prioritize maintenance needs and calculate dike improvement measures for sections at risk. A graphical overview for the approach is given in Figure 31.

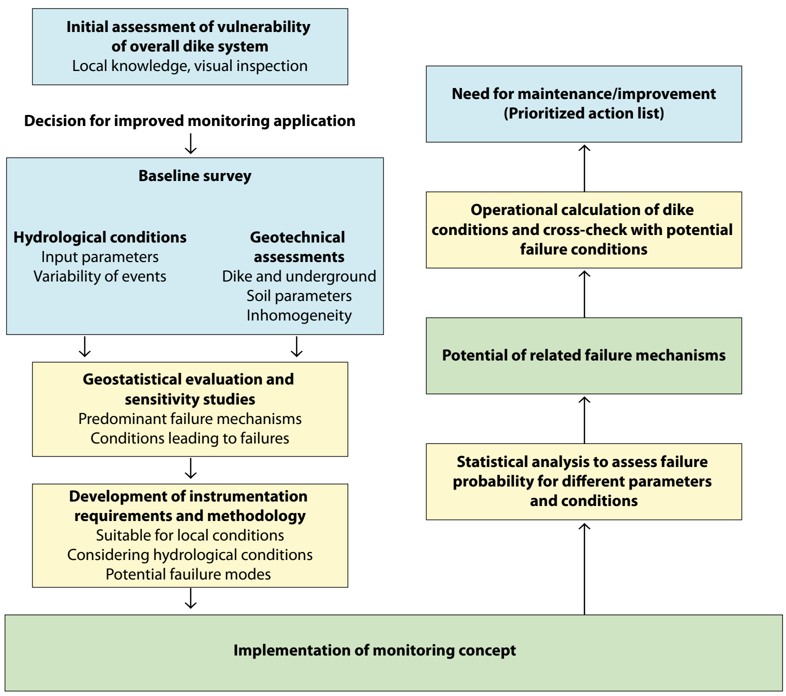


Figure 31
Approaches for optimizing levee monitoring

The optimized levee monitoring approach provides a strategic planning methodology for institutions concerned with flood retention system maintenance and flood risk responsibility. The flexible approach offers an outline how to assess and judge monitoring needs for levee systems in order to reduce the risk of breaching embankments by defining where monitoring efforts would make sense. The method can be applied to a variety of conditions and is very flexible regarding the actually implemented instrumentation that has to be tailored to the individual conditions. In terms of this flexibility, it needs to be noted that the level of confidence in the results will be strongly dependent on the density of geotechnical measurements and of the instrumentation network, given that density is a relative parameter depending on the inhomogeneity of the monitored dike sections.

Sample applications of the optimizing levee monitoring approach include flood retention systems that have deteriorated over time, of which details about construction materials used are unknown and that have not been earmarked for any immediate overall rehabilitation or reconstruction works. In such cases the optimized monitoring approach provides a cost effective means of identifying the most vulnerable sections of the dike system that need to be prioritized for rehabilitation work. The basic methodology can also be applied to other flood retention systems.

3.3.3 Sicherer Deich

The methodology used in 'Sicherer Deich' aims at protecting dikes from surface erosion during overtopping events, assuming that expensive dike raising costs can be avoided in favour of allowing overtopping if the dike surface is sufficiently protected so that no or little erosion occurs. The method is suitable for a wide range of scenarios and conditions, provided that the improved surface protection can cope with the forces generated by the overtopping flows and/or seepage water, disallowing the erosion of the dike body.

Main parameters to be considered in a possible application are the quantity and duration of overtopping flows with their respective forces acting upon the dike surface as well as the dike material parameters that provide resistance against internal and surface erosion during seepage and overtopping flows. Assessing both hydrological and geotechnical conditions of an existing dike system in line with the current as well as the required level of safety is therefore essential before dealing with possible dike strengthening methods.

Considering possible methods and materials for strengthening the dike surface to avoid erosion, the friction forces caused by the overtopping waters during a potential flood event and the respective erosion potential need to be calculated using standard formulas. Based on the results different surface protection options can be envisaged, taking into account the existing dike structure and dike materials as well as locally available resources. A surface protection approach can then be selected on the basis of a cost benefit analysis taking into account material cost, construction cost and handling costs. Under similar local circumstances dike improvement measures chosen may therefore vary depending on external parameters.

In the course of project trials performed in Germany, geotextiles, recycling materials, waste products as well as clinkers have been tested and approved for use as surface protection layers. Under other circumstances, locally available rock rip-rap may be utilized. Where no other materials can be found, importing geotextiles or soil stabilization additives may be a cost effective option that is still more advantageous than raising a dike. It needs to be considered that material mixtures may be required to guarantee filter stability against washing out of dike body material. The main practical consideration when calculating and selecting the protective materials is their resistance against erosion,

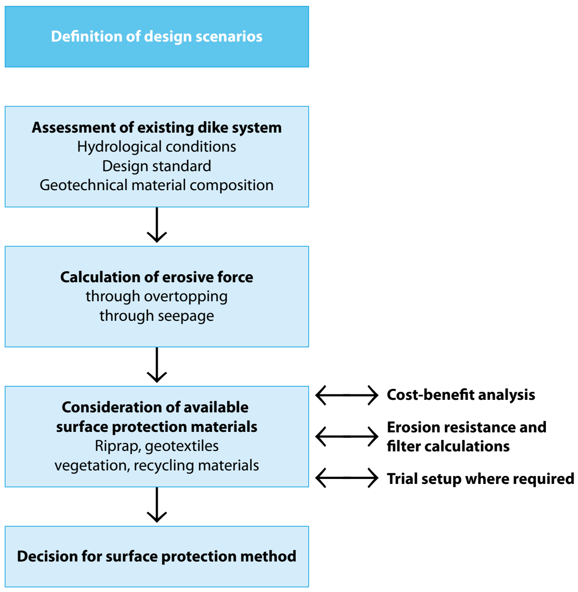


***Figure 32** Sicherer Deich approach structure*

sliding and uplift under overtopping conditions as well as the stated filter stability. The main principles of the general approach are shown in Figure 32.

When implementing the surface protection work, care has to be taken to drain away the overtopping waters e.g. through mitre drains to prevent damaging flows along the dike toe and avoid unwanted flooding scenarios in other vulnerable areas. Other factors requiring attention include the management of vegetation growth and animal access to the improved dike surface that may have a significant impact on the durability of the surface protection.

Applying the described methodologies, the main advantages compared to traditional dike raising work are the potential cost and time saving aspects through this approach as well as its universal applicability. Where doubts or uncertainties exist, the 'Sicherer Deich' trials can be repeated by using local materials to practically test the suitability of a design before a full length application.

The approach of the 'Sicherer Deich' project is a straightforward value for money method to be applied to dikes with an inadequate surface protection at risk of overtopping. By combining different surface protection materials the approach is suitable both for humid and arid regions, subject to local conditions. In humid areas, vegetation may be used in addition to geotextiles to provide additional reinforcement through the plants' root system.

Considering the local climate and material availability, rock rip-rap combined with flies and gravel filters may be the way forward in arid regions. Anyhow, decisions will need to be made on a case by case basis, showing consideration for locally specific environmental, logistic and economical aspects.

3.3.4 Draenelemente

'Draenelemente' uses a cost effective approach for fast and efficient reduction of risk of failure for dikes under load where excessive seepage occurs, threatening the dike stability through internal and toe erosion that may lead to piping and embankment breach. The applied drainage elements can be constructed as a precautionary as well as an emergency measure giving great flexibility to emergency response teams under conditions where seepage is the main problem threatening a dike system during a flood event.

While purely designed for seepage problems, the method can be applied under a variety of conditions regarding the material composition of the dike body with the design of the drainage elements regarding their collection and discharge capacity as well as their density to be calculated and adapted accordingly based on either numerical or hand calculation approaches (Figure 33). These calculations require a certain amount of information on the geotechnical conditions in the dike body. If this is not the case, the success of a first-stage application of drainage elements can be monitored to judge their efficiency and to decide whether additional elements would be required.

The described approach allows the use of different types of construction equipment, similar to the equipment described, to install the drainage elements globally available as standard industrial well appliances. Care needs to be taken when applying vibratory equipment under conditions where the dike body is saturated as liquefaction may occur so that lower frequency methods may be more adequate. After installation, the drainage elements and the surrounding areas should be monitored to supervise the success of the application and the reduction of seepage elsewhere, as well as any problems that may occur owing to the nature of the drains. Slotted open pipes, for instance, may cause internal erosion problems if unsuitable for the dike soil's grain size distribution or may become blocked.

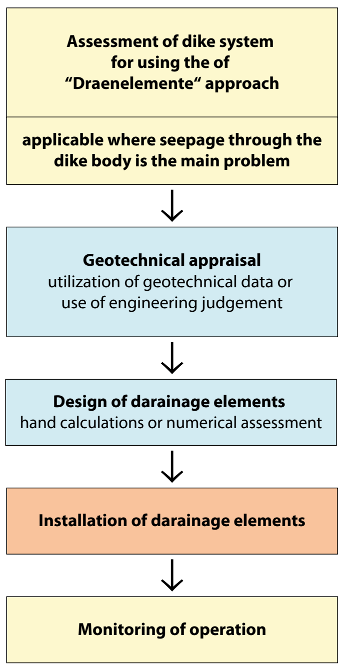


Figure 33 *Dike stabilization using drainage elements approach*

4. Disaster management

4.1 Projects

Disaster management is an important issue for agencies dealing with out-of-control-situations. Pre-planning, decision support tools and damage prevention plans can help mitigating the effects of disastrous floods by focusing on the most important tasks and prioritizing systems and actions.

Different aspects need to be distinguished when planning disaster management actions. Depending on local circumstances, areas of action can be split into emergency operation actions, emergency protection actions and evacuation actions. While timely and spatially interconnected and dependent on local circumstances, different action groups may be triggered by different circumstances. Scenarios with identified threshold values that are operationally updated can be used for decision support. It also needs to be kept in mind that actions taken for the benefit of one area may have adverse effects on others, leading to the need to consider multiple stakeholder aspects and take into account vulnerability as well as cost aspects in the management decisions. Local aspects such as alerting options and event-related aspects like the hazard potential also need to be thought of. A schematic overview is shown in Figure 34.

Different projects looking into different aspects have been implemented within the framework of RIMAX. A selection of these projects is described in the following sections; a comprehensive list is given in Section 8.

- REISE – Development of a risk-based decision support system for the identification of protection measures during extreme flood events
- Unstrut-Project – Planning Flood Control Measures in the Unstrut River Basin
- SAR-HQ – Flood and damage assessment using very high resolution space-borne radar imagery

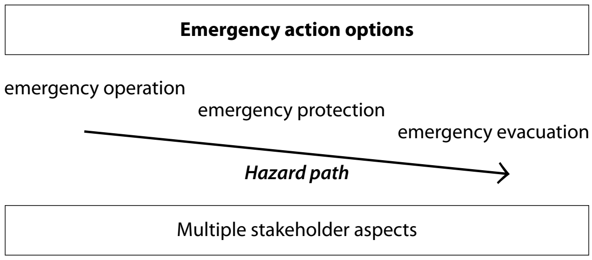


Figure 34 *Disaster management options along a spatiotemporal hazard path*

REISE deals with the development of a risk-based decision support system for the identification of protection measures during extreme flood events. The overall aim of the project was the setup of a robust methodology for spatial optimization of technical and organizational flood protection measures during extreme flood events for small and medium catchments. Existing interdisciplinary instruments, e.g. for cost benefit analysis, were refined and adapted to the specific conditions under extreme events. Innovative and sustainable methods and tools for the appraisal of economic, ecological and psychosocial results of extreme events were designed, taking special account of potential failures of the defences.

Considering decision processes by local authorities as well as aspects of communication and acceptance of risks from natural events as well as from the failure of defences, a methodology has been developed that includes a stepped action concept for integrated flood protection and risk minimization. The methodology can be used by local and regional decision makers as a multi-criteria decision support tool to optimize flood management both on the local and on the catchment level.

The **Unstrut-Project** has elaborated ways for the integrative use of technical flood retention systems, based on the example of the River Unstrut. The lessons learned during the flood disasters along the River Elbe in August 2002 and a series of other significant floods in the last years have highlighted the need for the development and implementation of new concepts for the reduction of flood risks. The project improves the scientific base for an integrated use of dams and polders, considering existing conflicts. The following goals were taken into consideration:

- Appraisal of existing retention areas and development of solutions to reduce the impact of different kinds of flood events, whereby socio-economic criteria have been taken into account
- Development of approaches for the appraisal of the efficiency of existing as well as planned retention areas for both individual as well as combined operation

The research results are used for the design and the optimization of flood retention systems and their operation. The interdisciplinary approach has generated a practical and complex design instrument based on the example of the River Unstrut. The methodologies can be transferred to other river systems with similar flood problems.

SAR-HQ assesses flood and damages using very high resolution SAR data. SAR-HQ explores and expands the applicability of very high resolution X-band SAR data for flood mapping and damage assessment. Since flood events are usually accompanied by overcast sky conditions, weather-independent SAR platforms are particularly suitable for obtaining spatially-explicit information about inundated areas in a time- and cost-efficient manner.

While past and current C-band platforms (ERS-2, ENVISAT ASAR, RADARSAT) have a proven track-record for large-scale flood mapping, their potential for deriving flood perimeters in complex and small-scaled scenarios such as urban areas is clearly limited. However, with the advent of the new European X-Band SAR platforms TerraSAR-X and Cosmo-SkyMed, which are capable of providing very high spatial resolutions, a highly detailed assessment of flood extent and damages is possible. Since an efficient flood mapping requires data acquisitions to match the maximum water level as closely as possible, a synergy of utilizing both X-band SAR-satellites complementarily also offers new opportunities in the temporal domain. In order to adapt to the demands and capabilities of these instruments, SAR-HQ is developing dedicated processing and analysis techniques. The project has integrated SAR data into operational processing and mapping workflows to ensure a fast and reliable access to detailed crisis information. By combining SAR-derived flood maps with ancillary data sources such as topographic and digital elevation data, information products are generated which are vital tools for disaster management, risk assessment and post-hazard reconstruction.

4.2 Methodologies

Methodologies for disaster management are a product that depends on the nature of the threat which can actually vary on a case by case basis, the type and vulnerability of the object at risk and other local circumstances that may vary over time or depending on the location within the area of interest. Methodologies therefore need to be shaped in line with these circumstances on a case by case basis, also taking into account different scenarios as they can be foreseen with different magnitudes of flood events or depending on e.g. seasonal variability in catchment characteristics that may influence runoff or seasonal shifts in risk patters e.g. through operational aspects or utilization levels e.g. of seasonally inhabited settings.

Based on the described influence of various possible circumstances, the disaster management methodologies shown in the RIMAX examples REISE, UNSTRUT and SAR-HQ as described in the following sections should be considered with care, using them as guidelines or examples of what is possible. For an implementation in a new setting, adaptation steps as described in section 4.3 would need to be undertaken.

4.2.1 REISE – Development of a risk based decision support system

Overview

REISE comprises the development of a risk-based decision support system to identify protection measures against extreme flood events. Nowadays, river flood protection measures are planned and optimized on the basis of risk assessment. Flood risk analyses are supported by the availability of elaborate engineering methods and tools. These allow for the detailed analysis of hydrologic and hydraulic processes, flood recurrence intervals and socioeconomic damage. As a result, flood risk management activities in Germany are mainly undertaken on the basis of scenario-based approaches for bounded river stretches with high damage potential. Risk-related feedback between flood protection measures provided at different locations in the watershed is usually disregarded.

This is only feasible in terms of an integrated risk management approach for a complete watershed. In the correct mathematical sense, integral flood risk for a catchment comprises the unbounded set of possible flood events, potential flood damage as well as the reliability of flood protection measures. New risk management concepts and methods have been developed for this purpose.

The scope of the project REISE includes the development of concepts and appropriate solutions for supporting decision-making in the field of optimum flood protection on a catchment scale. The interdisciplinary project focuses on the development of a decision support system (DSS) for the optimization of protection measures against extreme flood events in small to medium catchments. The project structure is shown in Figure 35.

In this DSS, hydrological analyses and simulations result in the characterization of precipitation and runoff ranging from frequently occurring to extreme events. These may cause a failure of technical flood protection measures, probabilistically accounted for in the DSS. Potential damage in the catchment is linked to natural inundation or breach-induced flooding. A special focus is set on approaching the potential damage from an appropriate interdisciplinary point of view. Tools are developed for deriving the overall damage as well as the costs of measures, i.e. economic, ecologic and psycho-social, on a uniform level of detail and significance. Risks and costs associated with these specific fields have to be combined into one statement. This multi-criteria approach constitutes one of the challenges within the DSS. Special attention is also paid to the demand for a methodically elaborated but still manageable and efficient DSS. Computation time required for a meaningful representation of the most relevant set of system states out of all possible sets in a catchment is a major issue. The approaches and tools developed in the REISE-project are tested in the medium-scale river catchment of the Wupper river in North Rhine-Westphalia (Germany).

Project Description
The flood events on the Elbe river as well as its tributaries in 2002 have shown that currently existing flood protection systems along many rivers are inadequate to protect against extreme events.
With rising peak flood levels, the cost of river flood protection against extreme and rarely occurring

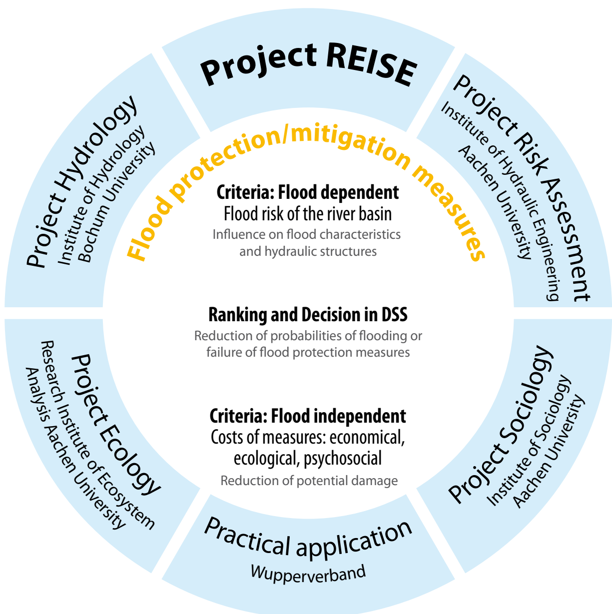


Figure 35
Concept of the project REISE
(Huber et al., 2009)

events increases extremely so that appropriate means need to be chosen with due care and diligence. Implementing an optimal combination of measures to reduce the overall flood risk in flood-prone areas in an economically, ecologically and psychosocially sustainable way continues to be a major task in integrated flood management. Numerous flood protection measures are available for risk management in a river catchment. These differ according to their effects:

- Measures to change the characteristics of a flood wave
- Measures to reduce the probability of failure of flood protection measures under extreme loads
- Measures focusing on the reduction of potential damage in floodplains

The decisions to be made concerning an optimized flood protection system have to take account of possible failures of flood protection measures which may occur for the full range of possible loads, usually entailing major consequences. When dealing with flood risk management on an integral scale, a reliable risk estimate comprises the integration of a wide range of consequences into the decision-making process on the basis of economic, ecological and psychosocial aspects.

A system failure always has an immediate effect on the flood wave propagation downstream of the specific failure location, thus potentially reducing the overall flood-related damage. A profound risk management approach must take account of the local disadvantages of failures as well as their benefits within the overall system and context.

REISE aims at developing a risk approach for an application on the river basin scale. In contrast to the planning of flood protection means for a specific flood event level, i.e. the design flood, the risk-oriented flood management concept deals with a whole range of possible flood and inundation events. These are characterized by the probability of natural flood occurrence and the probability of possible failure events of flood protection measures. The relevant interconnections between the relevant components of the system under risk-based investigation are shown in Figure 36.

Decisions are made on the basis of two different categories: The first category directly connects decisions with the portfolio of potential flood and inundation events in terms of risk. In contrast, the second category does not relate to a flood event. It introduces costs and efforts linked to measures, e.g. economical costs of construction, induced adverse ecological effects or deprivation, into decision making.

The quantification of flood risks on a river basin scale is one of the REISE-project's major challenges. This quantification is required for an objective and profound evaluation of the aforementioned risk-dependent criteria. For the purpose of a structured analysis, the river basin is subdivided into three sub-systems as depicted in Figure 36: the river with

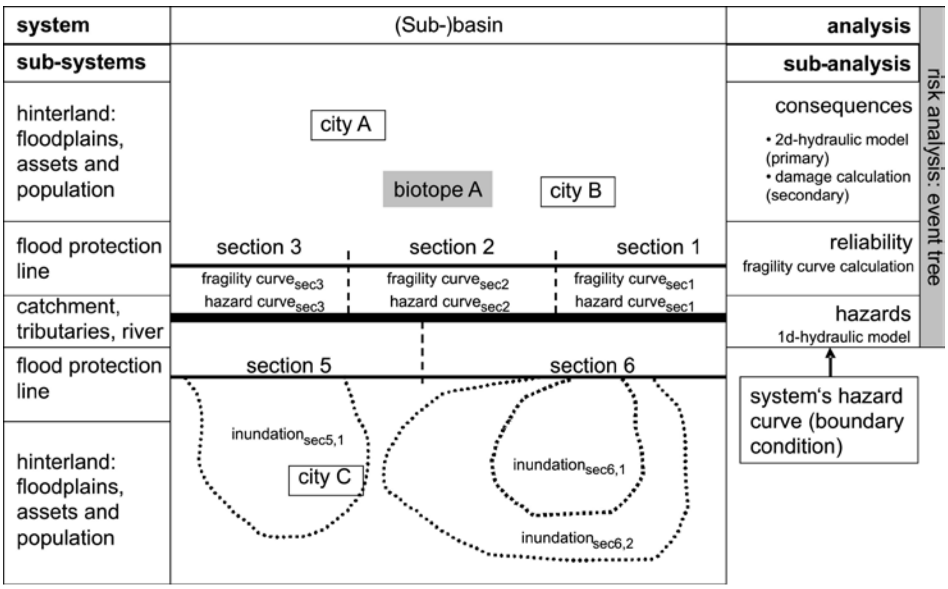


Figure 36
Schematic outline of the risk assessment on the river basin scale (Bachmann et al., 2009)

its tributaries, the lines of flood protection measures along the river banks, in the following referred to as the flood protection line, and the floodplains with their appropriate facilities and values.

Analyzing decision processes, selecting optimum technical solutions and implementing flood mitigation measures confronts decision makers with clear deficits regarding the interconnectability of the different disciplines involved. In order to overcome these deficits, an appropriate interdisciplinary approach must be developed and followed. In order to perform an effective decision support, the flood dependent and flood independent criteria are evaluated for each user-implemented measure. As a result of the different units present in the analysis, i.e. monetary versus non-monetary, the criteria are not comparable in a straightforward way. Thus, a ranking of available alternatives for flood protection is performed by applying multi-criteria decision support algorithms (MADM – Multi-Attribute Decision Making methods). The explicit definition and quantitative evaluation of criteria leads, in combination with a robust algorithm for ranking of available alternatives, to an objective and transparent decision making in terms of risk. Risk analysis comprises hazard analysis, reliability analysis and consequence analysis which are performed for the three subsystems mentioned before and visualized in Figure 36.

The hazard analysis is conducted in the first sub-system, the river. This sub-system is represented by a one-dimensional hydraulic model. Its upstream boundary condition is given by the so-called system hazard curve, which defines the link between extreme discharges and the probabilities of their occurrence (Figure 37).

The appearance of the hazard curve depends on the hydrological characteristics of the river basin under investigation. Thus, a hydrological analysis of the catchment area is one essential contribution to risk-based decision making on the river basin scale. For the project test case, the catchment of the Wupper, a stochastic rainfall generator is applied in combination with a multivariate spatial-temporal rainfall disaggregation model allowing for the generation of loads at variable time scales. The resulting extreme discharges are transformed into water levels at discrete river sections of the river by applying the 1-d hydraulic model. As a result, water levels at specific locations of the flood protection line become conditional upon the probability of a specific flood event.

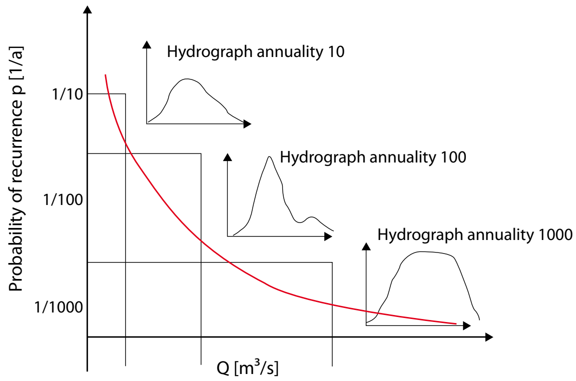


Figure 37 *Hazard Curve. Aim of this approach is the probabilistic synthesis of extreme hydrological conditions considering special system conditions in the catchment and the influence of dams and other storage and flood retention systems (Huber et al., 2009)*

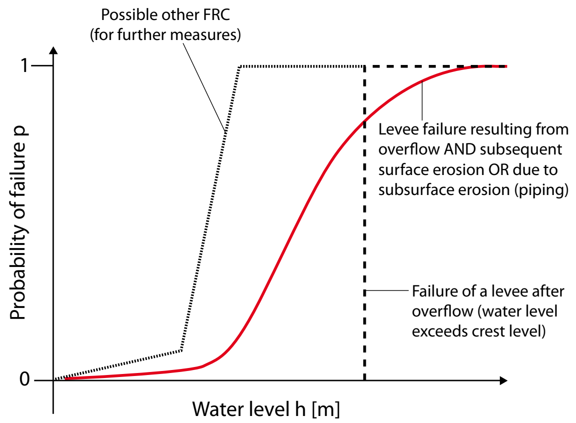


Figure 38 *Fragility Curve to determine failure probability (Huber et al., 2009)*

Once the information on hydraulic loads is available, a reliability analysis of the second subsystem, the flood protection line, becomes necessary within the chosen approach. The flood protection line is divided into discrete sections corresponding to the river sectioning performed in the hazard analysis. The reliability of each section is represented by a fragility curve (Figure 38). It shows the probability of a failure or non-failure event, respectively, of one section conditional upon the applied stress, e.g. the water level in the particular section. The shape of the curve directly depends on the structure's characteristics: its type, i.e. dike, wall or mobile flood protection system, the load and resistance parameters defining the structure's reliability and the associated parameter and design model uncertainties. For generating fragility curves merging different failure modes and mechanisms into an overall reliability statement, probabilistic methods such as Monte-Carlo simulations must be applied within the framework of failure mode representations, e.g. fault trees.

The annual probability of failure of the flood protection line in each section is derived by linking the section hazard curve and the measure-specific fragility curve via the water level. The joint probability of an inundation event in a specific floodplain behind the flood protection line or selected sections can thus be derived.

An analysis of consequences is performed for the third sub-system, the floodplains. Within the whole DSS, floodplains are basically represented by means of a two-dimensional hydraulic model. In direct linkage with the 1-d model, its application allows for the case(event)-sensitive determination of inundated areas and, thus, primary consequences in terms of hydraulic loads. Hydraulic loads at specific locations in the floodplains directly depend on the water level in the river during failure, the duration of the specific flood event, i.e. the flood hydrograph, and the location of a failure event in the flood protection line. The coupling of the 1-d hydraulic model representing the river and the 2-d hydraulic model for the adjacent floodplains demands efficient and robust approaches. The 1-d model is based on a diffusive wave approach, whereas a storage cell approach is applied in the 2-d model.

The analysis of the secondary consequences of an inundation event, i.e. damage to economy, ecology and population at risk, is performed by including information on vulnerabilities with respect to defined hydraulic loads or primary consequences, respectively. The estimation of potential economic damage is widely spread within flood risk management approaches. A considerable set of damage functions by means of which the relative mobile or immobile damage for specific land-use categories can be derived on the basis of flow depth, e.g. in defined grid cells, is available and for example also subject to the MEDIS-project. Damage functions allow for the estimation of relative damage from inundation depths. Multiplication of the relative damage by, firstly, a specific property value which is assigned to the affected land use category on the basis of regional economic statistical data and, secondly, by the inundated area results in a monetary estimate of economic damage for the failure event.

The analysis of the exposition of the ecosystem focuses on the three hydraulic loads duration of inundation and submergence, flow depth and flow velocity. Following the process of ecological risk analysis, the exposure is superimposed with the vulnerability of biotopes and soils. As depicted in Figure 39, the vulnerability and thus the potential ecological damage is aggregated and assessed on a spatial grid. Therefore, for each cell of the grid the information on exposure and loads must be provided. Due to this demand, the grids for the assessment of damage and for the 2-d hydraulic calculation coincide in the DSS.

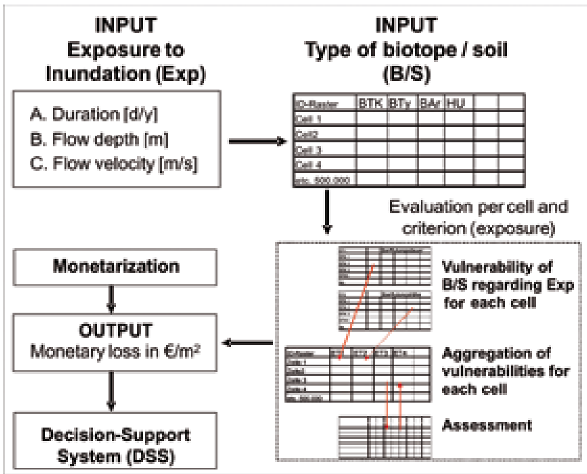


Figure 39 *Calculation of ecological flood damages (Huber et al., 2009)*

For the purpose of developing psychosocial criteria for assessing flood damage to the population at risk, a survey of people affected by floods in Germany is conducted. A vulnerability index, triggered by selected socio-structural criteria such as age, gender and ownership rate, serves as a quantitative indicator of psychosocial damage.

Additionally, structures in decision making in the field of flood protection and flood risk management are analysed. Combining these two constituents generates the overall concept shown in Figure 40.

In the risk analysis, the results of the three analyses regarding hazard, reliability and consequences are combined on the river basin scale. As the combination of one flood event with a concrete situation, regarding failure events of the flood protection line, defines one specific system state, an infinite number of system states plus their corresponding consequences , is theoretically possible.

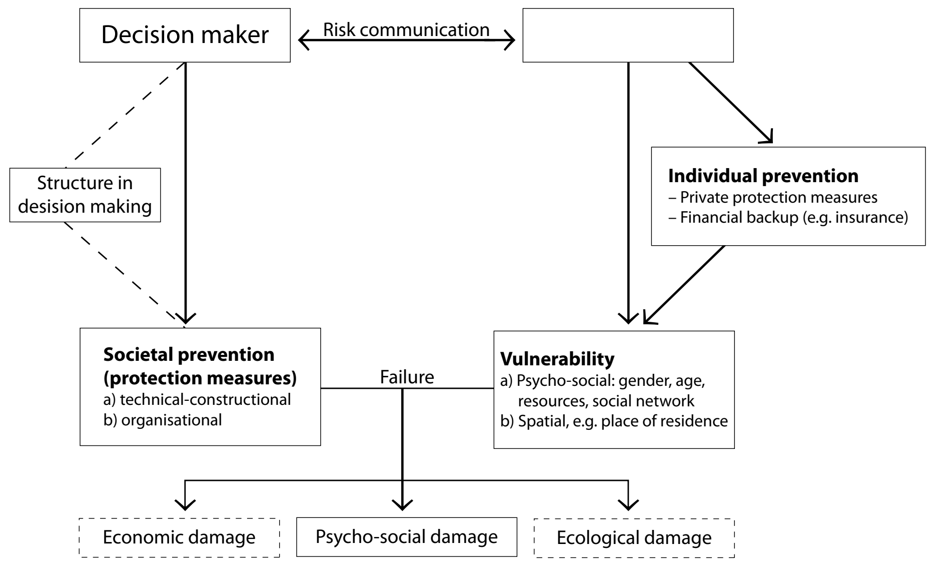


Figure 40
Sociological inter-connections relevant to decision support processes (Huber et al., 2009)

Figure 41 schematizes the overall space of potentially discrete system states in a river basin by utilizing the methodology of event trees. Making decisions within this set of system states requires the isolation of the most relevant system states in terms of relevant contributions to the river basin risk. The DSS developed in the REISE project is capable of efficiently dealing with this demanding task.

Box 14 Main principles of the REISE risk based decision support system for identification of flood protection measures

Requirements for flood protection planning in a river basin

- Limited resources lead to need for prioritization of actions
- Integration of different interests by evaluating measures, e.g. economical, ecological and psycholo-gical interests
- Consideration of the full spectrum of flood events
- Consideration of feedback of measures taken in the river system
- Spatial optimization of technical and operational flood protection
- Stepped action concept and multi-criteria DSS

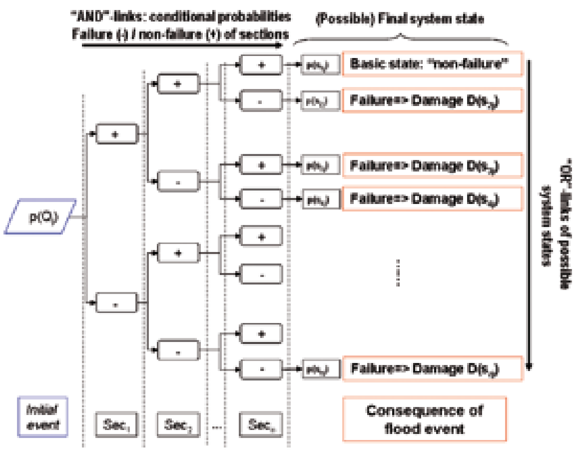


Figure 41 *Event-tree analysis combining hazard analysis, reliability analysis and risk assessment on a river basin scale (Huber et al., 2009)*

4.2.2 Unstrut Project – Planning flood control measures

Overview

The project is based on an integrative use of technical flood retention in polders and dams based on the example of the River Unstrut.

The experience made in the devastating flood events along the River Elbe in August 2002 and a series of other large flood events in the last years show the necessity of developing and implementing new concepts by developing optimized approaches for managing existing retention areas. One of the conclusions drawn from these events was the need for new risk management approaches. The risk management process consists of three main components: risk estimation, risk evaluation and risk control/communication (Fell and Hartford 1997). Along with the need of risk characterization, a shift has occurred from the concept of safety-oriented flood defence towards an acceptance of a remaining flood risk. Based on the consideration that any absolute protection against flooding is impossible, decision makers are forced to accept and even include the concept of risk into their management plans. Integrated flood risk management must combine flood risk analysis and risk reduction, differing from safety-oriented flood planning in the past. Safety-oriented planning defines a certain flood event which is then used as a design flood. The two basic assumptions of this flood design are:

- The design flood defines the limit up to which a flood can be controlled completely by technical measures.
- A failure of the system has to be expected only in cases where the design flood is exceeded.

Under these assumptions, design floods with very small probabilities were used. Thus the risk of a flood beyond the design flood seems to be very small. In many cases this risk has even been neglected.
In the risk-based planning approach it is accepted that 100 percent safety cannot be achieved by technical means. The remaining risk of failure, which may result from the hydrological risk of an extreme flood, but also from other sources e.g. from operational and technical risks, has to be allowed for.

The classical definition of risk (R) as "the product of the probability that loss occurs (P) times the value of loss or the damage (D)" (R = P x D) was replaced by "the product of the conditional probability of consequences, resulting from unsatisfying performance P (consequences| U), times the probability of unsatisfying performance of the flood protection system P(U) times the consequences (endangered persons, flooded areas, flood damages etc.) (C)":
$R = P[U] \times P[C \mid U] \times C$.

Obviously this approach to flood risk is much more challenging since a large variety of floods has to be taken into account. Hydrological scenarios specified by complex probabilities (including imprecise probability measures) are used for an appraisal of the existing flood retention system as well as for the design of the planned extensions regarding their operational efficiency. In order to create the relevant scenarios, historical flood events were analysed. An extensive stochastic-deterministic flood simulation procedure was used to generate a discharge time series of 10,000 years with a broad range of flood events. From this pool, flood events were selected to analyse the performance of a flood retention system in different planning stages. Using simulations, operation plans for the projected retention structures were designed in combination with the existing flood retention systems.

From the hydraulic and structural side, the appraisal of the technical functionality of the flood retention systems and the development of technical solutions for the improvement of flood retention capability were investigated. The technical flood retention systems were evaluated as to their efficiency under different hydraulic loading conditions.

The primary goal of the socio-economical appraisal was not only a cost-benefit analysis of regional and local effects of different flood protection strategies. The main advantage of the methodology was the rather holistic view on risk reduction and increasing risk, which were both caused by the same flood retention measures (see Figure 42).

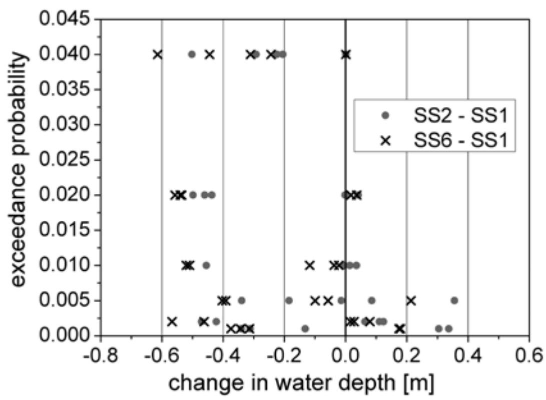


Figure 42 *Comparison of change in water depth for different states of the flood control system (SS1: current system, SS2: current system fully operational; SS6: extended system). Shown are results for different exceedance probabilities. It becomes obvious that the failure risk rises for events with low exceedance probabilities (Unstrut, 2008)*

Given that areas benefiting from improved flood protection and areas where the flood risk increases are separated, it becomes particularly important to judge between local and regional flood protection goals that can be achieved in a variety of ways, depending on different possible management scenarios.

To be able to process and integrate the variety of hydrological, technical and socioeconomic information, a decision support system has been developed that enables the user to balance the reduced risk under "normal" flood conditions with the increasing risk of unsatisfying performance of the flood retention system during unusual floods. It is suitable for developing and assessing technical solutions and action concepts for the system operation as part of the planning approach and provides the base for the incorporation of dam and polder management concepts for integrated flood risk management of the Unstrut basin.

Project Description

The integrated planning of the utilization and improvement of flood retention systems requires an interdisciplinary approach for a problem-focused connection of hydrological, structural, hydraulic and economic assessments with modern socio-economic and decision support methods while allowing for multiple user conflicts. The necessary coordination and incorporation of the different methodical approaches and the different spatial and temporal scales requires a high level of interdisciplinary coordination.

For the assessment of the possibilities and limitations of flood retention systems, different and partly contrary goals have to be taken into consideration in larger river systems. Significant problems result from the following aspects:

- Large river systems are generally spread over different institutional or administrative areas
- There are complex interactions between hydrological events and operational strategies, especially for the lower river sections
- There may be problems in strategy implementation due to distribution imbalances between upper and lower river sections regarding costs and benefits of flood protection measures, leading to acceptance problems
- Costs and benefits of technical flood protection systems are generally disparately distributed between the upper and lower river sections leading to utilization conflicts and acceptance problems
- Effects and interaction of the individual components of complex flood retention systems are dependent on the individual flood conditions in combination with the local flood protection goals
- If natural flood retention areas are used for technical flood retention, the flood conditions downstream can be affected adversely as the hydraulic conditions during large floods are changed

The last two points are particularly challenging, as the flood retention potential of technical systems so far has mostly been designed on the basis of local needs. An integrated operational management can improve the efficiency of the individual retention facilities in the overall system, while local goals may be overruled. Both local and regional requirements therefore need to be considered and balanced against each other when designing operation plans.

Further topics addressed by the project comprise sustainable ways of flood mitigation, especially the definition of flood protection levels and socio-economic damage functions involving indirect flood effects and costs (e.g. loss of production, diseases, and migrations). When assessing costs and benefits of alternative flood protection strategies, short-term as well as long-term costs need to be included as well as the cost benefits of alternative possibilities of polder and dam utilization, while taking account of conflicting interests. The benefit and cost-saving aspect of an increased flood security, especially for the lower river reaches, is another important criterion to be considered.

In line with an assessment of cost benefits of flood protection options and the increased flood risk in the event of a failure of technical retention facilities, integrated strategies were developed allowing a multi-criteria evaluation and the use of decision support tools for decision-making involving regional socio-economic conditions. These conditions were seen in the context of hydrological, water resources and technical aspects for optimized decision-making and risk appreciation. As a result, an integrated water resources and flood management system was developed that considered hydrological risks, technical possibilities and socioeconomic conditions. The main achievements of the project can be summarized as follows:

- The development of a methodology to evaluate the possibilities and limitations of technical flood retention systems in consideration of different operation strategies, technical conditions and potential improvements of the existing system

- A new approach to risk management considering a potentially increasing flood risk due to a unsatisfactory performance of technical structures
- The development of technical solutions to improve the effects of flood defence
- Development of a basis for socio-economic evaluations of cost benefit relations for the operation of technical flood retention systems in consideration of the stochastic character of flood events and the spatial distribution of cost and benefit of different strategies in the upper and lower river reaches (upstream protects downstream – approach)
- The development of new approaches to consider multi-criteria goals in planning and operation of technical flood retention systems in consideration of spatially differentiated goals (local and regional flood protection) as well as institutional parameters.

Project work as well as individual goals can be further described on the basis of the following individual project elements:

- Hydrology and water resources management
- Hydraulics, structures
- Socio-economic analysis
- Decision support

Hydrological scenarios derived from an extended data pool resulting from a stochastic-deterministic simulation of long time series (10,000 years) were used to evaluate the existing flood retention systems as well as to assess the effects of planned improvements and extensions with regard to their efficiency. The flood scenarios were characterized by different probability and possibility measures. So far unrecorded, but potentially possible events were generated as scenarios. Using simulations, operation strategies have been developed combining both existing and planned flood retention systems.

Hydraulic structures in the Unstrut basin were appraised with regard to their technical functionality in flood retention and new technical solutions were developed to improve their protection efficiency. Due to the restriction in storage capacity for any retention area, it was necessary to evaluate the technical flood retention systems in terms of their efficiency in relation to the magnitude of a flood event. It was found that the efficiency of polders is mainly influenced by the hydraulic conditions in the flooded areas. Under certain circumstances new polders may increase the flood risk as levees reduce the natural retention capacity. This issue was further tested by simulating flood wave propagation and assessing the behaviour of the river to certain changes in the individual or combined retention systems. As a second step, inundated areas as well as inundation levels were evaluated for different flood scenarios. Thus the technical functionality of the individual systems and the overall system could be assessed and technical solutions for the improvement of the flood retention systems were found.

Within the scope of a socio-economic analysis the costs and benefits of flood retention systems were evaluated considering direct as well as indirect costs and benefits. The cost-benefit ratio of flood retention attempts was found to be dependent on the stochastic character of the flood event. Even small events generally cause costs (e.g. owing to the restricted agricultural use of polders). The cost benefit ratio of large events generally depends on the smoothening effect of peaks in the flood wave that has beneficial effects. This smoothening effect is strongly related to the overall combined operation strategy of the flood retention measures.

A decision support tool has been developed to analyse and integrate the variety of hydrological, technical and socio-economic information. The tool allows the inter-comparison of performances of different flood retention systems under different flood conditions and the balance between reduced and increased flood risks depending on the flood events considered. The tool considers the temporal variability of boundary conditions as well as the dynamic needs of the flood mitigation plans.
The main achievements of this part of the project can be summarized as:

- The development of a methodology for an event-specific appraisal of the possibilities and limitations and additional risk of technical flood retention systems, considering different operation strategies, technical boundary conditions and potential extension possibilities of the existing system
- The development of an interactive spatial decision support system, where the single elements of the flood retention system can be appraised regarding their possible operational effects during different loading conditions, extension stages and operation modes (see Figure 43)

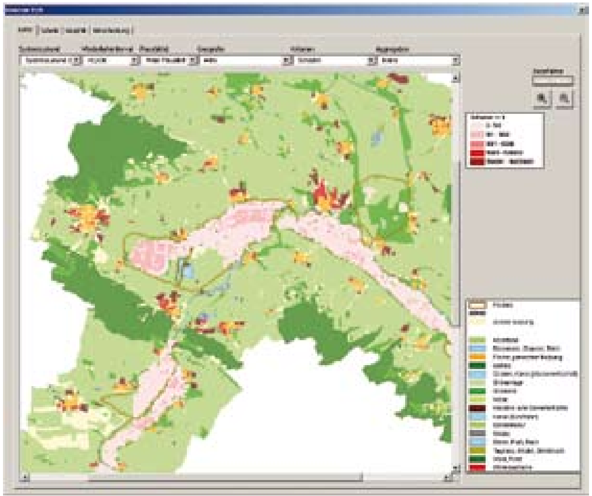


Figure 43 *Map viewer of the Spatial Decision Support System*

The connection within the overall structure of the project is shown in Figure 44, highlighting the integrated approach considering hydrological, technical and operational conditions (Unstrut, 2008).

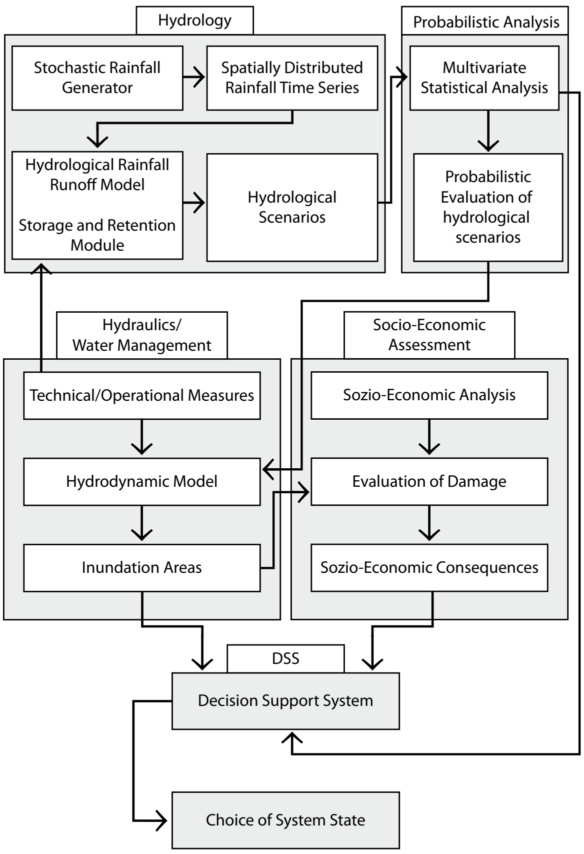


Figure 44 *Project structure (Unstrut, 2008)*

Box 15 Main principles of the Unstrut project

Need to manage identified flood hazards in a catchment

- Detailed flood hazard and risk assessment
- Assessment of available operational possibilities for optimizing the use of flood retention assets (dams, polders), considering multiple stakeholder aspects and potential conflicts
- Optimization of retention asset operation, considering socioeconomic aspects and combined multiple asset control
- Appraisal of remaining flood risk and planning of technical flood defence assets for protection against remaining hazards
- Consideration of increased flood risk if the performance of the flood retention system is unsatisfying (caused by exceedance of design floods, unusual hydrographs, failures of reservoirs situated upstream etc.)

4.2.3 SAR-HQ – Flood and damage assessment using very high resolution space-borne radar imagery

Overview

SAR-HQ aims at the assessment of large-scale floods and their damages using very high resolution Synthetic Aperture Radar (SAR) data. In recent years, the global demand for crisis information on natural disasters like severe flood events has increased substantially. Simultaneously, a rising awareness of the availability of satellite information has led to an increase in requesting the corresponding mapping services. Because of their specific illumination and all-weather capabilities, SAR sensors are optimally suited for providing reliable information on floods, which usually occur under rainy or at least cloudy conditions. Flood information is needed as quickly as possible to provide an overview of the situation and to improve crisis management and response activities. Analysing regularly acquired images allows the monitoring of floods, representing a valuable input for subsequent flood modelling techniques.

The following paragraphs give an overview of SAR applications for flood mapping and present first experiences gained using the very high resolution satellite system of TerraSAR-X as well as key processing elements and some of the most important analysis techniques used for the extraction of flood information. Furthermore, value adding and flood parameter derivation principles are presented and examples of recent floods in Europe shown, for which first TerraSAR-X data were analysed.

Figure 45
View of TerraSAR-X over Europe (DLR)

Over the past years airborne and spaceborne SAR systems have been used increasingly for mapping and monitoring of hydrological parameters, the most popular of these parameters being the flood extent. Operationally and routinely available spaceborne systems such as ERS-1/2, Envisat, Radarsat, etc. are very powerful systems enabling the mapping of flood situations in the C-Band (~ 5 cm) domain. The Shuttle Radar Missions SIR A/B, X-SAR SIR-C and the Shuttle Radar Topography Mission (SRTM) also enabled L-Band (23 cm) and X-Band (3 cm) observations, including different polarization modes from space during the operation of the missions and within range of the respective Space Shuttle orbits. The data obtained in these missions enabled the study of the backscatter characteristics and mapping capabilities with respect to the different features of water surfaces (e.g. Miranda et al., 1997). The ALOS PALSAR sensor allows studying and mapping water features in the L-Band and includes the different polarization modes (HH, VV, VH and HV) from a polar orbiting platform. Along with the successful launch and commissioning of TerraSAR-X and Cosmo-SkyMed a new class of space-based SAR systems suitable for flood monitoring became available for the scientific community in the X-Band domain and in the one-meter pixel spacing class.

Given that SAR systems generally have good cloud penetration capabilities, they are the preferred tool for observing flood situations from space, as these often occur during long-lasting precipitation and cloud cover periods frequently preventing an observation by means of optical imaging instruments. The new class of high resolution meter class SAR sensors offers great potential in the field of flood mapping; however, also new challenges for processing and analysis arise from these images. While the availability of several SAR systems in orbit strongly increases repetition rate and observation frequency, the systems' high spatial resolution results in a large variety of image objects and hence poses new problems for image analysis. This is especially true of areas with single strong scatterers dominating the radar reflection and impeding the analysis of the imagery, e.g. as is the case with urban areas (Solbø et al., 2004). Especially in complex imaging scenarios such as highly structured built-up areas, the spatial resolution of classical space-based SAR systems is too low for deriving flood perimeters with sufficient accuracy. Furthermore, the SAR signal in the X-Band at 3 cm wavelength also shows sensitivity to certain wave patterns induced by wind or heavy rain on the water surface. Water surfaces, under standard (calm) conditions, appearing black in a radar image suddenly turn out to be of strong scattering character. Also flood areas covered by vegetation, even if only partially, have different scattering properties in the X-Band than those observed in the C-Band (Townsend et al., 2002; Wang et al., 1995). To reliably identify water bodies in these high-resolution SAR images, object-based as well as pixel-based methods were further refined. Apart from the challenges of image classification, the high geometric accuracy and the repeated observation possibilities provide good options for the derivation of precise flood parameters like flood duration or flood dynamics. If further combined with high-resolution digital elevation data, the flood depth could be estimated.

A new sensor class, the TerraSAR-X radar satellite, has become available (see Figure 45).

Although current spaceborne C-band SAR platforms have already demonstrated their usefulness for large-scale flood mapping in a number of cases, they can only provide spatial and temporal resolutions hardly allowing any detailed and near-real-time assessment of floods. Hence, medium-resolution C-band SAR data have only seen a limited use for the operational assessment of large-area flood situations. In most cases, the low repetition rate typically merely allows one single SAR data acquisition per flood event, at best, with an even lower probability to depict the maximum water level.

The German TerraSAR-X satellite was launched on 15 June 2007, into a 514 km high, sun-synchronous and near-polar dusk-dawn orbit. While the nominal repetition rate of the satellite is 11 days, each point of the Earth can be targeted within two to four days depending on its latitude using a large variety of different viewing angles. The possibility to rotate the satellite system for an experimental left-looking mode can further accelerate acquisition times, which is particularly important in the context of disaster mapping and monitoring.

The active antenna of TerraSAR-X allows the following imaging methods to be used:

- In the SpotLight (SL) and High Resolution SpotLight (HS) modes, pixel spacing between 1 and 2 meters can be achieved. Depending on the mode selection (SL or HS), the size of the ground track is either 5 × 10 or 10 × 10 km. Although both modes are very similar, the HS mode increases the geometric resolution in azimuth at the expense of azimuth scene extension.
- In the StripMap (SM) mode, TerraSAR-X images a strip of 30 km width and a maximum length of 1500 km. Depending on the incidence angle and processing options, pixel spacing can be up to 3 meters.
- The ScanSAR mode (SC) combines four adjacent sub-swaths with quasi-simultaneous beams to a total swath width of 100 kilometres and maximum length of 1500 km at a pixel spacing of 16 meters.

For each imaging mode, a plethora of different acquisition parameters can be defined (incidence angle, polarization, look direction, processing parameters), which makes the SAR very versatile and adaptable to different application requirements. In addition to TerraSAR-X, the Cosmo-SkyMed satellite system provides X-band SAR data with similar characteristics. Cosmo-SkyMed is a system comprising a final configuration of four medium-sized satellites. As the first three satellites have already been successfully launched in June and December 2007 as well as October 2008, the possibility of observing an area of interest with a high temporal and spatial resolution has increased considerably. Together with the new Radarsat-2 satellite operating at C-band and the upcoming launch of the fourth Cosmo-SkyMed satellite in 2009, a considerable number of spaceborne SAR systems will become available that will allow for rapid response times in order to map flood events in near-real-time. In conclusion, the advent of these high-resolution X-band SAR satellites dramatically increases the potential to detect water in complex, local monitoring scenarios and potentially fosters the application of satellite SAR imagery in the context of a rapid flood mapping and detailed post-disaster damage assessment.

Project Description

The derivation of flood outlines is the main task of the SAR-HQ project. Within this task, different backscatter characteristics of water in high resolution SAR data were one of the assessed characteristics. The availability of high resolution TerraSAR-X satellite imagery allows the image interpreter to distinguish more feature details on the earth's surface. Even waves with a wavelength in the range of the sensor resolution, of up to 1 m, may be visible as bright linear features on the surface of lakes or the sea. These regular features allow a classification as water bodies by conducting a texture analysis. Vegetation standing within a water body can also increase the backscatter values, which in turn leads to regions that appear brighter than regular surfaces of water bodies. The use of dual polarization data can help to distinguish between dry surfaces, flooded vegetation and standard water bodies. In built-up areas it is often difficult to distinguish between radar shadow areas and water bodies, which both appear dark. In the context of flood situations, the improved pixel spacing of high resolution TerraSAR-X data potentially helps to map the inundated urban areas more reliably, although the limitations in very small-scaled scenarios also need to be assessed carefully.

Figure 46 shows various potential backscatter characteristics of water bodies: Rivers are not very susceptible to wind-induced waves due to their small width and hence appear predominantly dark in SAR data. If the flow velocity and the river dynamics

increase and the river surfaces therefore become rougher and more turbulent, this can also lead to higher backscatter values. This effect can be seen in the TerraSAR-X example of the Rhine Falls (Figure 46a). Although X-Band radar waves are claimed to be independent of atmospheric disturbances, there can be situations with heavy thunderstorms containing big raindrops which may influence the radar image. Such an event can be seen in the Louisiana TerraSAR-X image as a dark veil (Figure 46a).
High mountainous terrain with steep slopes may cause radar shadow when the SAR data are acquired at shallow wave angles. Auxiliary data like digital elevation models can be utilized to distinguish between the dark radar shadow western slopes and the dark water surface of Lake Lucerne in the Swiss Alps. Another problem for the automatic classification of water bodies are man-made obstacles like fish farming basins, ships or bridges with ghost effect caused by multiple reflections at the bridge and the water surface, which can be seen in the SAR image of the coast of Spain (Figure 46b).

Regarding different methodologies, pixel-based and segmentation-based classification techniques can be distinguished as the two main concepts for the identification of flooded areas in radar imagery. Traditional classification approaches use pixels as smallest geometrical components of raster data. The grey values of the pixels which correspond to the spectral properties of a target can be used to group the image information into different semantic classes. Routinely, these approaches are widely applied to low and medium-resolution remote sensing data. However, parameters for the classification are limited. Additionally, pixel-based classifiers do not make use of spatial information of the image and thus are not suited to deal with the inherent heterogeneity within land-cover units. Furthermore, even if noise reduction by speckle filtering is applied, classification results usually suffer from a salt-and-pepper effect and a post-processing classification by the use of morphological operators becomes necessary. However, these smoothing methods work without considering the original information.

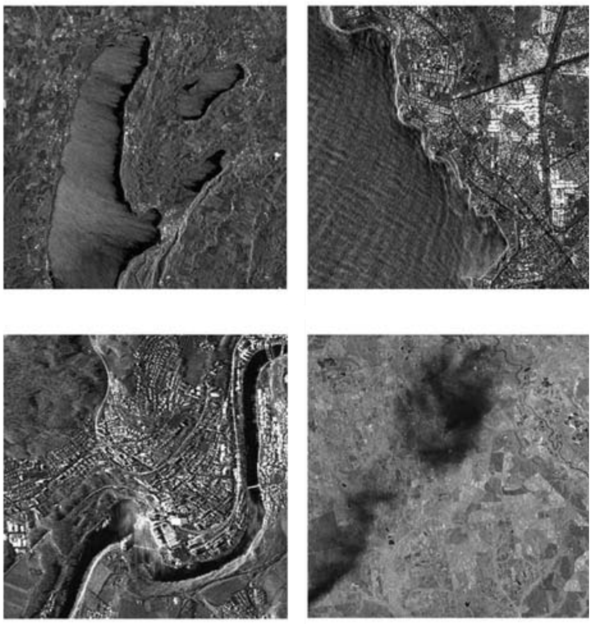


Figure 46a *Different forms of appearance of water bodies in TerraSAR-X data, © DLR (2007, 2008) Top left: Wind pattern on Lake Ammersee (Germany); Top right: Reflected waves at Dakar coast (Senegal); Bottom left: Turbulent water surface at the Rhine Falls (Switzerland); Bottom right: Heavy rain/water drops in Louisiana (USA) (SAR-HQ, 2008)*

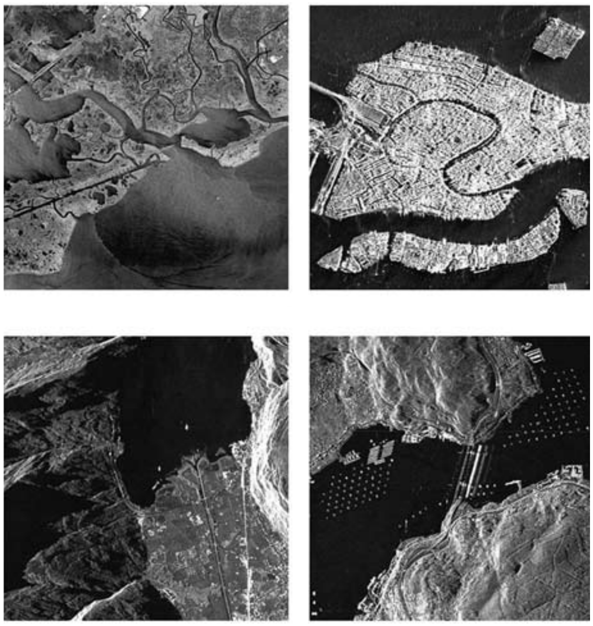


Figure 46b *Different forms of appearance of water bodies in TerraSAR-X data, © DLR (2007, 2008) Top left: Mississippi Delta wetlands (USA); Top right: Urban area water bodies in Venice (Italy); Bottom left: Radar shadow at the western slopes of Lake Lucerne (Switzerland); Bottom right: Obstacles like a bridge with ghost effect and fish farming basins near Vigo (Spain) (SAR-HQ, 2008)*

Some problems of pixel-based image analysis can be solved by using image segmentation techniques. The created homogeneous, non-overlapping segments have a strong correlation with real objects or areas of the earth's surface. Image segmentation methods become more and more important in the field of remote sensing image analysis – in particular due to the increasing spatial resolution of the satellite systems. Especially for data of the new generation of very high resolution optical and SAR sensors with a geometrical resolution of less than 1 m the use of segmentation-based methods appears promising (Figure 47). A disadvantage of this technique is the high processing demand of the segmentation step.

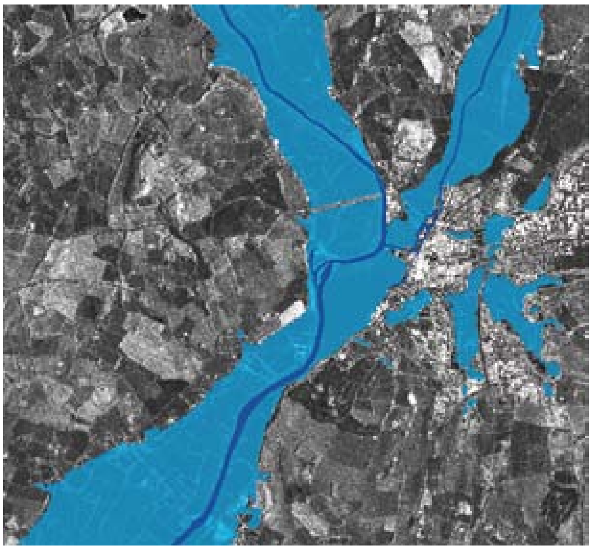


Figure 47 *Flood extent around Tewkesbury, England, derived from high-resolution TerraSAR-X data by the use of segmentation-based classification (acquisition date: 25/07/2007; dark blue: normal water level, light blue: flood surface)*

Thresholding is one of the most frequently used techniques to separate flooded from non-flooded areas in a SAR image (e.g. Townsend et al., 1998; Brivio et al., 2002, Martinis et al., 2009). Commonly, classification is performed by assigning all elements of the SAR intensity data with a lower scattering cross-section than a given threshold to the flood class. One of the main advantages of this classification method is that it is relatively inexpensive in terms of computation and therefore suitable for rapid mapping purposes. Its results are reliable and commonly, most of the extent of an inundation area can be derived by applying this technique. Thresholding works satisfactorily for calm water surfaces, which can be regarded as specular reflectors with low backscatter values for the used radar wavelengths. In contrast, the surrounding terrain exhibits higher signal return due to strengthened surface roughness. The applied threshold will depend on the contrast between the water and land classes as well as on the deviation of the flood area from a smooth surface due to influences of wind-induced waves, precipitation as well as of diffuse and corner reflecting vegetation.

Given this drawback, active contour models (e.g. Williams and Shah, 1992; Horritt et al., 1999) have recently gained popularity as a means of finding smooth boundaries from incomplete and noisy images using local tone and texture measures. These "snake" algorithms had been used by e.g. Horritt et al. (2001) and Matgen et al. (2007) for flood boundary delineation in medium-resolution SAR imagery. Thus, flooded areas are identified as regions of homogeneous speckle statistics. Due to the fact that the snake originally has to be initialized manually for each water area, too much user input is required to extract flood masks from very high resolution SAR imagery on which large inundation areas are mostly divided into numerous flooded parcels. Approaches which are approximating the numerous flood areas by thresholding and transferring these initial polygons to the active contour algorithm therefore appear more promising (Heremans et al., 2003). However, care must be taken when initializing the algorithm both manually and automatically.

In most cases, multi-temporal analysis has proven superior to single data approaches. However, reference data are frequently unavailable for the respective flood area. Different change detection approaches for the derivation of flood dynamics between registered SAR data have been successfully applied in the past. These include amplitude-based (e.g. Townsend et al., 1998; Heremans et al., 2003) as well as coherence-based techniques derived from the use of C-Band SAR interferometry (e.g. Geudtner et al., 1996; Dellepiane et al., 2000; Nico et al., 2000). However, at the moment repeat-pass X-Band SAR interferometry is not very suitable for mapping flood areas due to the strong temporal signal de-correlation during the repetition period of 11 days of TerraSAR-X. In the near future this method will become more interesting due to the upcoming short temporal baseline interferometric SAR systems of the TerraSAR-X and COSMO-SkyMed tandem missions. Using amplitude change detection in combination with C-Band multi-temporal SAR imagery, areas of flooded dense vegetation were mapped successfully e.g. by Townsend et al. (2002). This arises from the fact that microwaves at longer wavelengths can penetrate the forest canopy and are double-bounced at the smooth water layer and the forest stems, causing a significant increase in backscatter.

For the purpose of flood risk and flood damage assessment, flood related parameters other than flooded area, such as inundation depth and flood duration are required. Since these parameters cannot be derived directly from satellite data, ancillary data have to be included. The factor of most concern with respect to damages caused by flooding is water depth. A standard approach for the estimation of direct physical damages to housing and property are stage-damage-functions for different building types (Thieken et al., 2005). Hence, damages measured in monetary loss can be described and modelled as a function of water depth. Other more complex damage modelling approaches also include the duration of floods and flow velocity. The latter has to be seen as the major damage factor in case of flash flood situations especially on smaller rivers. Apart from flow velocity which can only be estimated by hydraulic models, remote sensing has the potential to derive flood depth and flood duration with a very high spatial resolution compared to hydraulic approaches. In addition, remote sensing based approaches can be valuable for the validation and verification of hydraulic model parameters.

The derivation of inundation depth requires the incorporation of a high-resolution digital terrain model (DTM). DTM's from LIDAR with 1 – 2 meters pixel resolution and 0.1 meter height accuracy are nowadays available for certain river flood plains and have been satisfactorily used for hydrological applications and for the purpose of flood depth assessment. Promising methods of the latter are presented by Matgen et al. (2007), Bates et al. (2006) and Zwenzner et al. (2008). A raster layer of flood depth can be derived by subtracting the terrain elevation from the elevation of the water surface. For the derivation of the flood water surface elevation the flood mask must be interlinked with the terrain data. Usually, variations and irregularities due to classification errors or location discrepancies between the DTM and the flood mask require correction steps to be applied. This can be accomplished by drawing measured cross-sectional profiles connecting the left and right river banks. According to these profiles the flood mask boundary can be adjusted (shifted) and rectified to the terrain model in order to generate a "smooth" water surface layer from which a TIN (triangular irregular network) and inundation depths (Figure 48) can be derived.

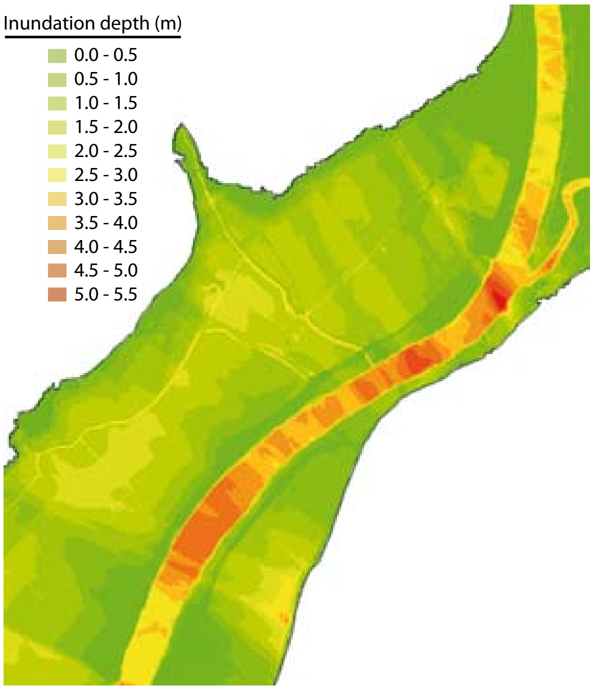


Figure 48 *Inundation depth estimated by means of interlinking the flood extent derived from TerraSAR-X satellite data with a high resolution digital terrain model. Location/Date: River Severn near Tewkesbury, England, 25-07-07 (SAR-HQ, 2008)*

Generally, the great advantage offered by SAR satellite systems for assessing floods is their reliable and genuine spatial representation of the flood extent. However, the temporal delineation of floods is limited because one satellite data take is only a snapshot in time. The assessment of flood dynamics and flood duration from satellite data requires a number of data takes recorded in different time steps during the flood period. A common technique for displaying changes in flood extent between two or three SAR satellite scenes is the generation of a colour-composite as shown in Figure 49. In this technique the grey values of one image are reassigned to one of the three colour channels blue, green or red. A certain colour can then be attributed to changes in flood extent.

In the future, multi-observation conditions can be fulfilled with the various operational high resolution SAR satellite systems. Through the combined use of different satellites, a repetition rate of less than 12 hours can be achieved.

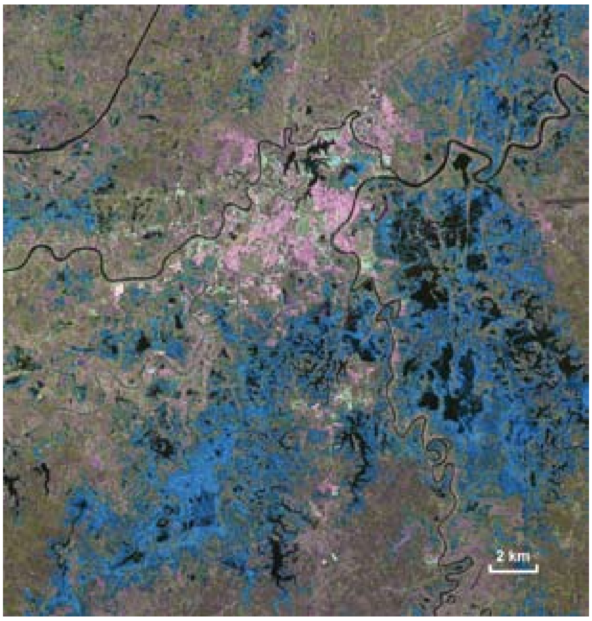


Figure 49 *Colour-composite of two TerraSAR-X scenes showing the flood situation around the city of Villahermosa/Mexico (shown in pink colour) on Nov 8th, 2007 and the post-flood situation on Dec 2nd, 2007. The blue colour stands for changes in flood extent and thus reflects areas flooded only on Nov 8th, 2007. Areas which were inundated on both dates appear in black colour. (SAR-HQ, 2008)*

Box 16 Main principles of SAR-HQ

Need for fast quantitative assessment of flood damages during flood events to define affected area and prioritise actions

- Utilization of remote sensing SAR technology for weather and illumination independent flood assessment
- Accurate and fast flood extent mapping
- Derivation of inundation depth through combination with DTM data

4.3 Disaster management adaptation strategies

4.3.1 General observations

Flood management depends on two preconditions: Risk analysis and risk assessment. It contains different aspects: Planning which may increase or reduce flood risk management and operational flood risk management. The Unstrut project, described above was dedicated to flood risk reduction by new retention facilities. Risk reduction is the main objective of planning. On the other hand, if floods occur and cause disaster, they need to be managed as efficiently as possible to minimize damages and avoid loss of life and property. General issues that need to be considered when attempting to manage extreme flood events mainly aim at who and what can be protected and how much time it takes. In order to be efficient, preplanning of the possible range of events that may affect a catchment is a key task. Disaster management can only be carried out effectively if prioritized plans, tailored to individual scenarios, exist and the involved players including the affected population as well as the emergency agencies and administration know what to do.

Therefore, a number of levels exist on which disaster management needs to be planned and implemented. Emergency plans need to be in place, involved bodies need to be clear about their action strategies, responsibilities and report chains. Another vital factor to be considered is communication with the affected population to provide them with information about flood warnings and evacuation. A general outline of important points and interconnections is shown in Figure 50.

The emergency plans drawn up based on different scenarios may be available as simple checklists that can be applied or set up in form of operational decision support tools that are handled by a control centre. The level of communication and sophistication of methods and systems is another important issue to be kept in mind. It also needs to be taken into account that a simpler and more straightforward method may be the better one in the event of a disaster.

As a cornerstone of flood disaster management, flood maps are a useful tool that can be set up based on local knowledge from historical events or on modelling approaches defining different areas of risk.

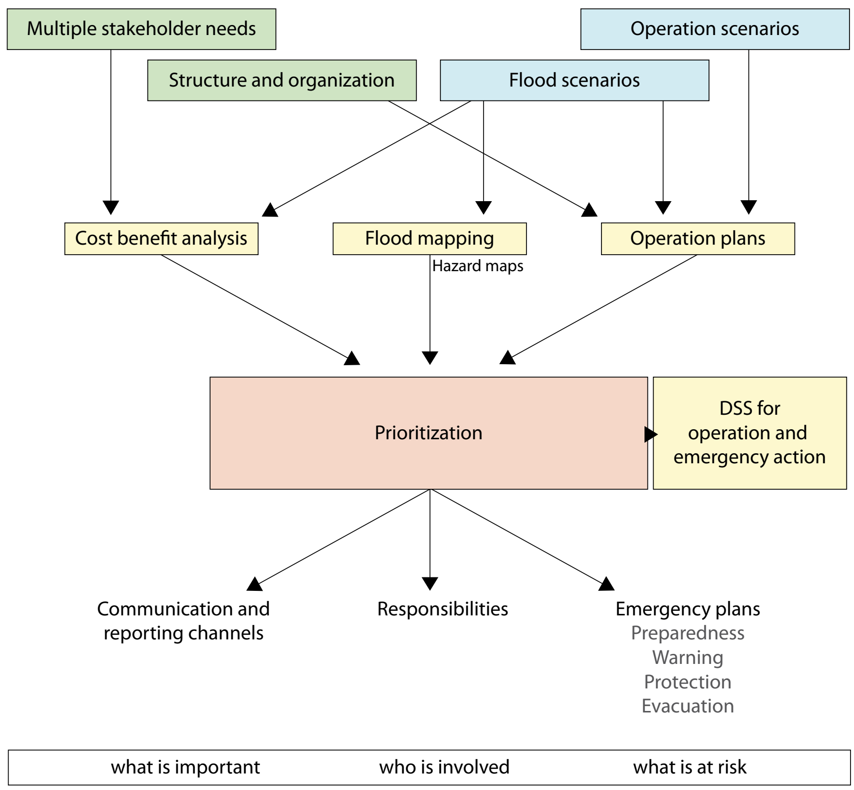


Figure 50 *General disaster management strategy, outline and interconnections*

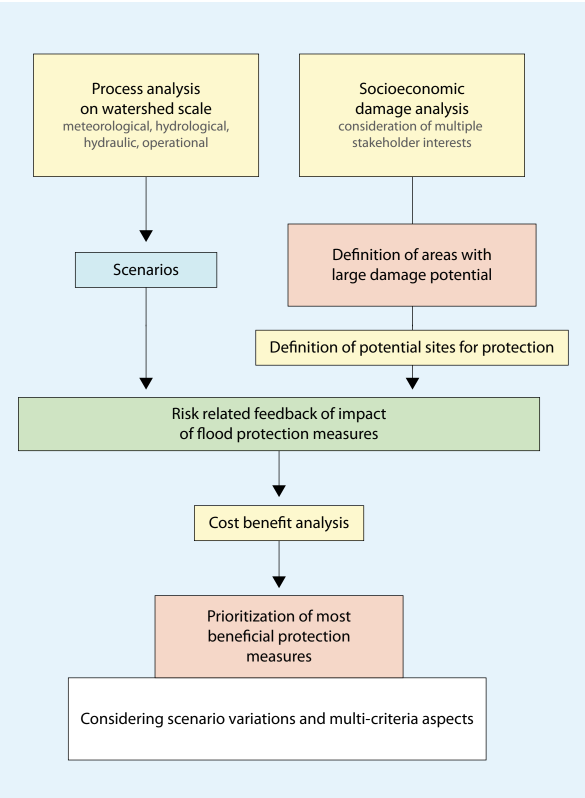


Figure 51 *The REISE approach to risk-based decision support for flood protection measures on the catchment scale*

Prioritization aspects for protection and evacuation, accessibility of areas, emergency access and egress routes can be planned with these maps.

When drawing up the emergency plans, multiple stakeholder conflicts are to be expected. Resources and time in flood- and disaster management are limited, hence requiring the implementation of a cost benefit analysis considering holistic aspects to prioritize resources and actions.

4.3.2 REISE

The development of a risk-based decision support strategy for the identification of flood protection measures in small to medium watersheds has been the objective of REISE. The project has dealt with the fact that integrated risk management and holistic multicriteria decisions can only be made on a catchment scale. In order to investigate risk-related impacts of flood protection measures, it is useful to contemplate the effect of different flood scenarios on these impacts. The structure of the approach is shown in Figure 51.

The approach as described needs a specified set of input data, basically hydrological as well as socioeconomic data, to implement the necessary assessments. The quality of data availability is an influential factor. It is of special importance to capture both the possible range of hydrometeorological scenarios and the multicriteria aspects of the vulnerable objects and locations in the overall catchment. The approach can of course also be applied to sub-catchments or stretches of a river system where, due to specific upstream conditions, connections can be excluded or where the decision to neglect part of the watershed including the resulting potential impacts has been assessed and accepted.

Within the catchment in question the definition of areas with large damage potential is the key step in the approach. Such areas can be defined by high population densities, fragile environments, areas of considerable agricultural, commercial or industrial value, cultural inheritance sites or sites that would cause additional hazard when flooded, such as industrial facilities that could release pollution, entailing adverse ecological and health effects. In addition to these direct impacts, indirect impacts as described in Section 5 should also be taken into account.

The identified areas with large damage potential are then further evaluated regarding the level of probability and related flooding hazard. It needs to be kept in mind that even hardly probable effects of a flood event may be significant and therefore constitute high risks. These aspects can be deduced from the assessment of hydrometeorological conditions including probable scenarios.

As mentioned above, data availability and data quality play an important role for the results of the decision support approach. On the hydrological side, events and scenarios can be assessed based on evidence of historical events or through different forms of modelling approaches. Missing data can generally be supplemented by means of interpolation or judgement of historical evidence. In order to obtain an overview of a possible bandwidth and probability distribution of the hydrological situation, Monte Carlo runs as described in Section 3 can be used. As regards the socioeconomic situation, the even spatial distribution and density of data collection can be rated higher than more detailed assessments in single locations with an uneven distribution. The latter case may result in an unbalanced judgement of objects at risk, followed by a biased prioritization and implementation of flood protection measures leading to unforeseen impacts elsewhere. Such a situation would jeopardize the sense of this approach, as the costs of possibly unexpected impacts may outweigh the benefits achieved. In summary, points to be included in the data assessment exercise should comprise the following multidisciplinary aspects implying both direct and indirect impacts:

- Hydrological
- Technical
- Operational
- Organizational
- Economic
- Ecologic
- Social

The results of the assessment will be dynamic. Changing one parameter, e.g. in flood retention dam operation, will trigger a whole chain of changes in the multi-criteria approach. Integrating multiple aspects, of hydrometeorological as well as operational concern, into the assessment of different protection approaches is therefore essential.

It should also be considered that the prioritization exercise deciding which objects and locations to protect, should be conducted in a structured and arguable way as stakeholders that will not benefit from flood protection measures may complain, causing a need for convincing explanations. In addition, it should be considered that overcomplication of the approach should be avoided to remain arguable, manageable and efficient.

4.3.3 Unstrut Project

The Unstrut project looks into the integrated use of flood retention systems, particularly in terms of system operation to optimize their utilization with respect to flood protection aspects. The approach aims at improving or entirely renewing the operation concepts based on a holistic, basin-wide approach, considering multiple stakeholder aspects via a cost benefit analysis. As it stands, the approach is well suited to be applied to a variety of conditions. Adaptations are solely necessary depending on the local administrative as well as logistical circumstances to ensure maximum use of the available data.

Based on a set system, initial appraisals of the base conditions including hydrology, socioeconomy, system operation and administrative structure conditions, followed by the design and appraisal of different potential improvement strategies need to be implemented. As with the approach described in the

REISE project, quality, quantity and distribution of the data used in the approach play an important role. A basin-wide approach needs to be diligently planned (upstream protects downstream) in terms of obtaining data and the later acceptance of the results that may contain certain challenging decisions for some stakeholders, in favour of the overall benefit of the flood risk management concept. An integrative approach, describing the overall planning goal and benefits in line with providing mitigation possibilities as described in other RIMAX projects in this guide can be beneficial, while a locally suitable approach always needs to be selected depending on the local circumstances. In larger basins, the conditions may vary significantly between upstream and downstream areas, especially in view of the fact that in addition to flood protection functions (that mainly benefit downstream riparians) other uses of dams and polder areas may be favoured by the local communities. An overview of the approach showing the major interconnections and points for consideration is given in Figure 52.

The aspects highlighted in the Unstrut projects are important for dealing with larger and especially transboundary catchments. Particularly here the issue of administrative boundaries may have a restrictive effect on an overall beneficial approach. Careful political work may be required to lay the foundations for a transboundary management of a river system. Strongly substantiated arguments will be necessary to go ahead with the planning and implementation of such an overall approach. Examples illustrating problems as well as solutions can be found in many of the world's large river systems, but smaller-scale national catchments may also reveal challenges in respect of uniting administrative units.

4.3.4 SAR-HQ

SAR-HQ utilizes remote sensing products and GIS techniques to derive flood extent and inundation depth as well as the temporal development of a flood event. The methods have been applied and tested during national and international crisis response activities undertaken by the Centre of Satellite Based Crisis Information (ZKI). The ZKI is a service of the German Aerospace Centre (DLR) in charge of rapid acquisition, processing and analysis of satellite data and the provision of satellite-based information products on natural and environmental disasters, for humanitarian relief activities, as well as in the context of civil security.

When planning to apply the SAR-HQ approach as shown in Figure 53 during in a flood event, a user needs to be aware of the requirements and behaviour of the sensor he wishes to use in the area of interest.

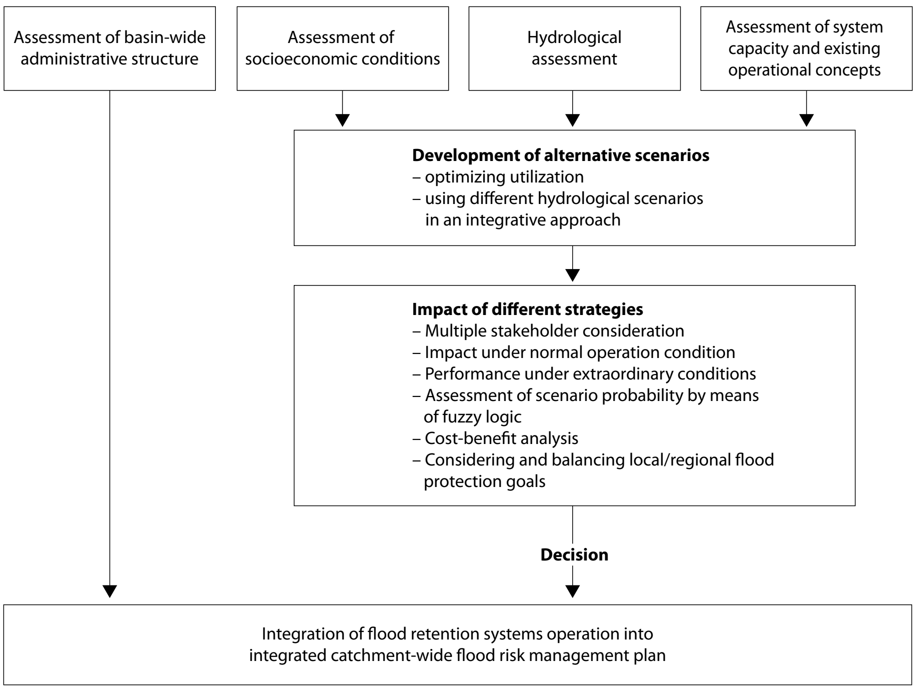


Figure 52
Integrative use of flood retention systems – interconnections and points for consideration (Unstrut, 2008)

The main parameters of interest are spatial resolution, geographical coverage and intended acquisition date. While the acquisition date is generally predetermined by the satellite orbit, a compromise between spatial resolution and geographical coverage needs to be found. Since high-resolution acquisitions are only feasible to a relatively small geographical extent, the assessment of large-scale flood situations is usually performed with medium spatial resolution acquisition modes.

A variety of satellite-based sensors and different data are available that are suitable for the SAR-HQ approach. In addition to being available from the TerraSAR-X instrument (http://www.infoterra-global.com), SAR data are also obtainable from a number of other sources like ERS-2 and JERS (http://earth.esa.int/ers/sar), Envisat (http://envisat.esa.int) or Radarsat (http://www.radarsat2.info). While being based on the SAR data, optical sensor products such as Landsat (http://landsat.gsfc.nasa.gov)or ASTER (http://asterweb.jpl.nasa.gov) could also be used for flood mapping exercises provided that cloud-free images can be obtained which may be possible in river basins where the flood events happen far away from the source of the event or where e.g. regular seasonal flooding shall be monitored. The resolution required will also have a strong influence on the selection of the data source.

In addition to remote sensing data which are used to map the flood extent, digital terrain data are required for determining inundation depth. Depending on data availability and accuracy requirements, different types of elevation data can be used, e.g. SRTM DEM data (http://edc.usgs.gov/) obtained during the Shuttle Radar Topography Mission or Lidar (Light Detection and Ranging) data acquired during specific flight missions for certain areas.

After suitable preparatory work has been performed, the methods have been established and tested and depending on the temporal resolution of the remote sensing data sensor, operational flood mapping can be implemented. Based on different time steps, change analysis can be conducted using various image processing and classification techniques. The results may be used to monitor remote areas, and/or to establish hydrological trends. The data are also suitable for further applications such as damage assessments based on inundation depth and inundation time, as it can be applied to urban and agricultural areas. Depending on the spatial and temporal resolution of the sensors, other potential applications may include the monitoring of remote reservoirs, seasonal flooding or seasonal wadi flows.

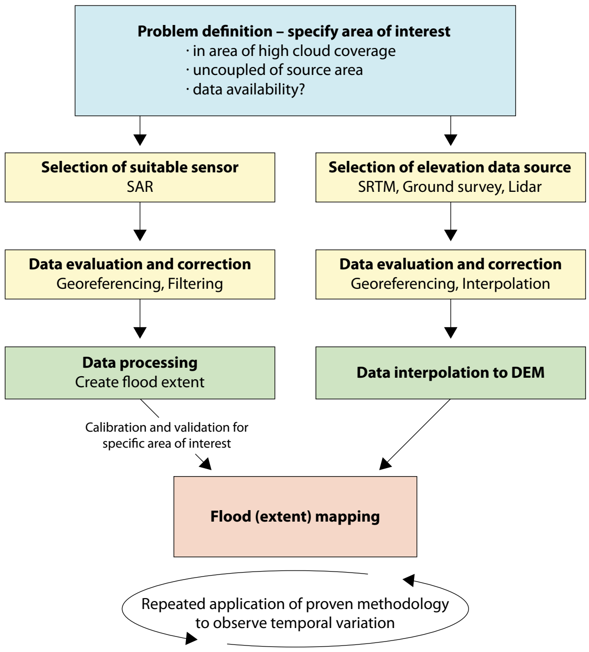


Figure 53 *SAR-HQ approach for assessment of flood events using remote sensing data*

5. Damage assessment and social impact

5.1 Projects

The assessment of damages and social impacts of flood events is an important element of integrated flood risk management. Such an assessment provides a basis for decision-making processes and lessons learned to improve the management of future events. It is important to spot the different areas that may sustain losses during floods. Agricultural areas are normally the first ones to be affected. Damages, however, are not limited to the agricultural sector, but also occur to residential property, businesses and public infrastructure, particularly in the event of larger floods. On the far end of the scale losses in human life can also be encountered.

Flood damages can be classified differently, but a general distinction exists between direct and indirect damage. Direct flood damages result from the physical contact with floodwaters and the actions of inundation and flow on property, structures and people, while indirect damage is induced by flooding, but occurs – in space or time – outside the actual event. Usually, both types are further classified into intangible and tangible damage, reflecting the ability to assign monetary values. Intangible damages arise from adverse social and environmental effects caused by flooding, including factors such as loss of life and limb, stress and anxiety.

Tangible damages are monetary losses, e.g. costs for the repair or replacement of damaged objects (direct flood damage) Indirect monetary damages arise from the disruptions to physical and economic activities caused by flooding. Examples are the loss of sales, reduced productivity and the cost of alternative travel if road and rail links are broken.

Three RIMAX projects were selected for a detailed presentation in this guide that give a good overview of a range of possible approaches in the damage assessment sector.

- MEDIS – Methods for the Evaluation of Direct and Indirect Flood Losses
- VERIS-Elbe – Change and Management of the Risks of Extreme Flood Events in Large River Catchments – the Example of the Elbe River
- INNIG – Integrated Flood Risk Management in an Individualized Society

The projects are described in detail in the following sections.

MEDIS aimed at developing improved methods for the appraisal of economic damages, standardized flood loss data collection methodologies and enhanced communication about flood risk mitigation. Methods for the appraisal of direct and indirect flood damages were derived from data collected after recent flood events in Germany. The new models were validated by means of independent flood loss data sets at household and community level. These methods can be applied to support decision making processes about flood mitigation measures in the framework of cost benefit analyses, contributing to cost-efficient flood management.

For the improvement and harmonization of loss data collection, a workshop was held including representatives of government agencies, insurances, engineering consultancies and research institutions. Based on the results of the workshop and a survey among more than 50 experts, guidelines for data collection and damage evaluation were established. In addition, all flood loss data were gathered and organized in a new flood loss data base (HOWAS 21). Finally, a web-based brochure for improved risk communication at municipal level was developed (see http://nadine.helmholtz-eos.de/Vorsorgebroschuere.html). Altogether, the results of the MEDIS project have improved scientific knowledge of damaging processes, yielded new methods for damage appraisals and data collection and created a new risk communi-cation tool.

VERIS-Elbe looks at extreme flood events in large central European rivers, where floods have caused severe economic, social, and ecological damage since the mid-1990s. Thereby the urgency of an improved societal management of flood risks became obvious. On the one hand, the question arises how the complex interrelations between extreme floods and their damages can be assessed more precisely. On the other hand, higher effectiveness of mitigation measures and preparedness play a major role. In addition, especially the medium-term changes caused by climate change and other global change phenomena need to be taken into account.

INNIG deals with integrated flood risk management in an individualized society. Based on the background of the extreme flood events of the last years, practical knowledge for rational approaches to flood mitigation as well as for coping with flood events was provided. The project includes the fields of engineering and social sciences while using scientific approaches for risk analysis and employment of state of the art instruments and models. Moreover, a detailed analysis was conducted of the psychological as well as sociological dimensions of risk appreciation, risk communication and risk acceptance allowing for ongoing changes in social structures. As a result, concepts for an integrated flood risk management were established including a web-based information platform for risk communication.

5.2 Methodologies

5.2.1 MEDIS – Methods for the evaluation of direct and indirect flood losses

Overview

The assessment of economic flood damages is an important component for decision-making processes on flood mitigation measures based on cost-benefit analyses. Improved methods for damage assessments were designed in the MEDIS project, providing an essential component for cost-effective flood management. For different economic sectors (e.g. residential, commercial/industrial, agricultural and transport sector), improved methods for the assessment of direct and indirect economic damages caused by floods were developed. The new models were based on up to date damage information collected after flood events in August 2002, August 2005 and April 2006 in the catchments of the rivers Elbe and Danube in Germany. The results can be applied to three levels:

- improved and comparable methods for damage assessments
- recommendations and guidelines for damage assessments
- direct benefits for decision-making on flood mitigation measures based on cost-benefit analyses

The project was implemented in four areas, starting with an improvement of existing methods for the collection of flood damage information by compiling lessons learned in a stakeholder workshop and on the basis of own experience gained with surveys. The workshop results were accomplished by a survey among flood loss analysis experts leading to guidelines on flood damage data collection as well as to a new flood loss data base (HOWAS 21).

In a second step, new methods were established for the assessment of flood damages, including damages to private property as well as direct and indirect damages to the micro economy, industry, infrastructure and agriculture. This task also included the development of an appraisal system for the fragility of buildings, and the assessment of macro-economic effects of extreme flood events. The new methods were then validated using independent data sets and – where possible – applied to practical problems to test their capabilities. In addition, the models were compared with existing approaches. As a final step, the research results were combined to allow their use in practical applications (e.g. a cost-benefit analysis).

Improving risk communication was another objective of the project. Easy-to-understand information material about individual flood prevention options was developed and provided to municipal stakeholders. A project overview is shown in Figure 54.

Project description

The assessment of economic damages is a significant, but to date neglected methodical component for decision support processes related to flood protection

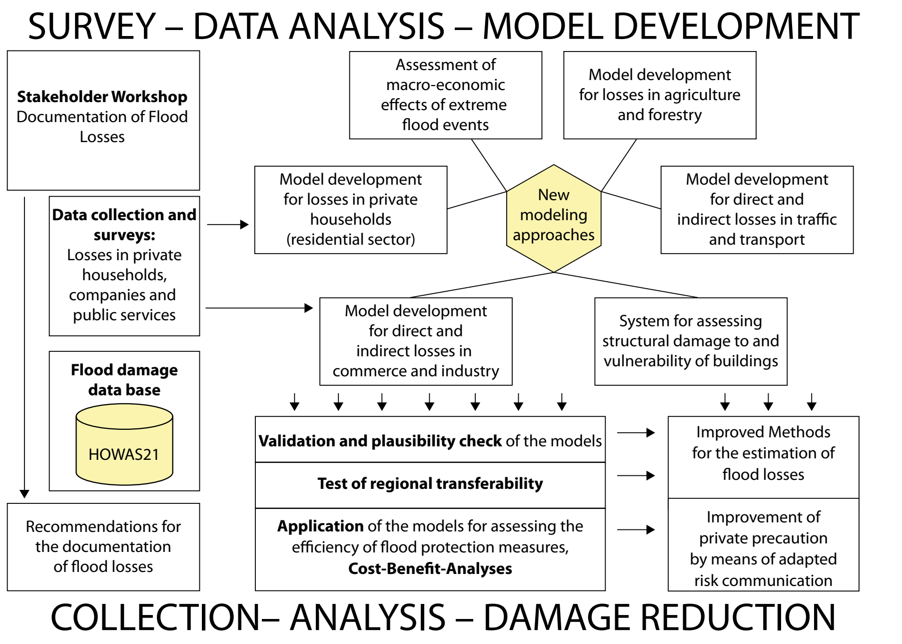


Figure 54
MEDIS project overview (MEDIS, 2008)

measures. Methods used so far (expression of damage value related to flood levels; general figures for evaluating indirect impacts) have significant deficits. Improved scientific methods for damage assessment therefore constitute an important aspect of cost-efficient flood risk management, including extreme events. MEDIS developed methods for the collection of flood loss data and the estimation of direct and indirect economic flood damages. The main results of MEDIS are described in the following paragraphs.

To improve collection and documentation of flood damages, practical experience gained with different data collection methods (questionnaires, local assessments, synthetic approaches), guidelines valid in various countries as well as experiences gained in documenting other damage types (e.g. losses due to hail, storms and earthquakes) were examined. Their applicability, strengths and weaknesses with regard to different economic sectors were analysed and discussed during a stakeholder workshop.

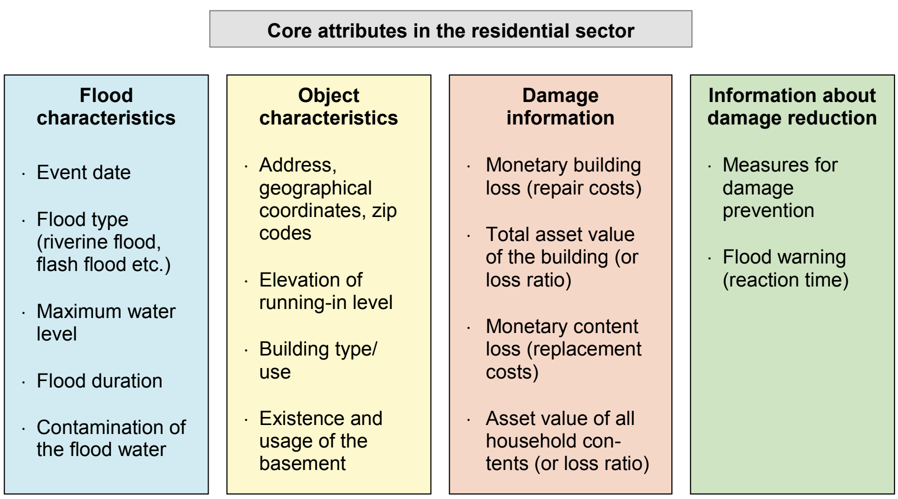


Figure 55
Core attributes for collection of damage data in the residential sector

The analysis revealed that flood loss datasets show differences in terms of type and amount of recorded attributes due to different foci placed by the stakeholders involved. Insurance companies, for example, mainly focus on the data collection of monetary losses (repair costs) and their relation to the total insured value of the damaged object, while datasets gathered with the aim to classify structural damage or to derive loss estimation models also contain information about the flood characteristics, building types, construction material etc. In order to allow a multi-purpose use of flood loss datasets, general standards for the collection of damage data were developed for five different damage sectors, i.e. residential, commercial (including industrial sites and public infrastructure except for transportation) and agricultural sector as well as transportation and water management (including damage to water courses and flood defence systems). Therefore, information needs were identified in a multi-step online survey among a panel of 55 experts from (re-)insurances, engineering companies, public water agencies and scientific institutions. To establish a guideline on flood loss data collection, all attributes were grouped into four main categories, i.e. flood characteristics, object characteristics, damage information and information about damage reduction, as shown for the residential sector in Figure 55.

Furthermore, a method to classify structural building damage was developed to establish a uniform engineering appraisal system for assessing the fragility of structures at risk of flooding. In the Mulde catchment, a tributary of the Elbe river, a survey of the structures in the flooded area of the August 2002 Elbe floods was performed. For the appraisal system, the following intensity-related methodology was used:

- Definition of damage levels, i.e. verbal damage descriptions that were transferred into damage levels ranging from 1 (moisture penetration) to 5 (building collapse),
- Allocation of damage levels to certain observational damages for different structure types,
- Grouping of structures into fragility classes based on their vulnerability,
- Usage of flooding depth and flow velocity as characteristic event parameters,
- The connection between event parameters and damage levels is established through design-specific vulnerability functions.

In a final step, the relation between damage levels caused by flooding and economic losses was assessed. On this basis, a new type of vulnerability functions was presented, allowing a differentiation with respect to the main structural (wall) material. The methodology enables stakeholders to analyse damage in terms of structural damage and monetary loss. Furthermore, local areas with highly vulnerable building stock can be identified ex-ante.

A similar approach was chosen to assess direct flood damages to traffic infrastructure with emphasis on damaged road sections. A database was established for this task considering road type, structures, and other investment elements related to sections of infrastructure. For a direct damage assessment, infrastructure costs were broken down to unit prices (e.g. square meter of road surface, km of road length). Using data obtained from local administrations, the dependency of infrastructural damages on event factors, differentiated into categories, was evaluated. This task was mainly conducted on the basis of data collected after the August 2002 Elbe floods in the city of Dresden. In preparation for and addition to the standardized questioning exercises, expert discussions were also held with administrative representatives to review suitable ways and methods for evaluation.

Due to the fact that agricultural plots are located in the immediate vicinity of rivers and creeks, adverse effects on plant growth and crop losses are an important damage category. Therefore, a new model was developed considering four influencing factors:

- seasonality of the flood event (per month)
- crop type (potatoes, sugar beets, corn, winter wheat, winter barley, winter rye, canola and grassland)
- region (38 rural districts in Germany)
- inundation duration (in four classes, i.e. 1 – 3 days, 4 – 7 days, 8 – 11 days, >11 days)

Crop loss is calculated as a percental deduction of the perennial averaged yields and is measured in Euro per hectare. The model solely focuses on the economic component of revenues (i.e. the yield multiplied by the sales price). For agricultural areas it can be assumed that owners will be able to minimize damages. It therefore needs to be analysed whether a total loss of a plantation is to be assumed or if damages can be minimized, for instance by means of recultivation. In this way, it is possible to give a rough appraisal of the expected crop losses for particular regions or boundaries in agriculture in conjunction with cultivation plans and seasonable occurrence probabilities of flood incidents.

Using data from a municipality where the flood of the river Elbe in 2002 caused agricultural losses of 644,000 Euro, it was shown that the new model is capable of estimating a realistic amount of crop losses – in case of the selected municipality 546,000 Euro.

In the aftermath of flooding in August 2002, August 2005 and April 2006 large datasets about flood losses and influencing factors were collected by computer-aided telephone interviews in private households and companies. These data were used to derive and evaluate new Flood Loss Estimation MOdels for the private/residential (FLEMOps) and the commercial/industrial sector (FLEMOcs).

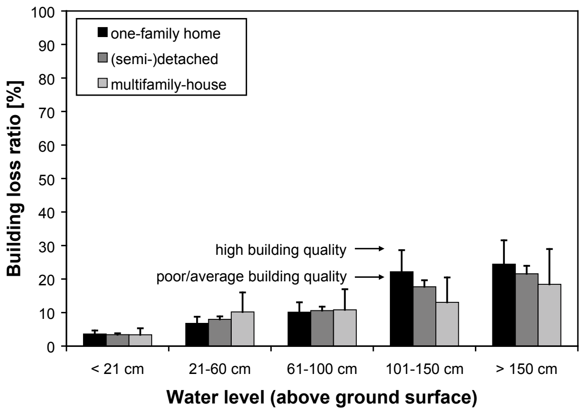
During the model development, the commonly used stage-damage-functions were expanded to form a multi-factor damage model. The idea was to also utilize other relevant factors such as flow velocities, inundation time and contamination that generally increase the amount of damage, but to also include early warning and structural measures able to reduce the impacts.

In FLEMOps five factors can be considered for estimating losses to buildings and objects in the residential sector. In a core model, losses are estimated according to the water level, building type and building quality. The model distinguishes loss ratios for five classes of water levels, three building types and two classes of building quality. In all sub-categories mean loss ratios per loss type (building, objects) were derived from the empirical data of the 2002 flood. In a second model stage (further called FLEMOps+), the effects of private precautionary measures as well as of the contamination of the floodwater can be integrated by means of scaling factors. Taking very good precautionary measures can reduce building loss to 41 %, while heavy contamination augments it by 58 %. By using this multiple parameter approach, an improvement of the existing damage models was achieved.

The FLEMOps model can be applied to the microscale level, i.e. single buildings, as well as to the mesoscale level, i.e. land use units. For the latter, a scaling procedure based on census data and a dasymetric mapping technique was designed for the whole country.

In a similar approach, FLEMOcs was developed for the assessment of direct losses to buildings, machinery and equipment in industry, services and trade.

The wide variety in equipment, company and property size, etc. among the individual industrial sectors, which significantly influences the factors relevant to damage determination, constitutes a critical factor in the assessment of industrial damage. A statistically proven differentiation of damage cases therefore needs to take account of the sectoral differences. Therefore, FLEMOcs looks at water depth in five classes, three sizes of companies with respect to the number of their employees (1 – 10, 11 – 100, >100 employees) and four different economic sectors (public and private services, producing industry, corporate services, trade). The results of this first stage are mean loss ratios for buildings, equipment and goods, products and stock (Figure 56). An optional second model stage allows for the integration of different possible combinations of contamination and precaution. Model validation on the micro and meso scale reveals that the incorporation of these damage-influencing factors and up-to-date damage data has improved the currently existing damage models.



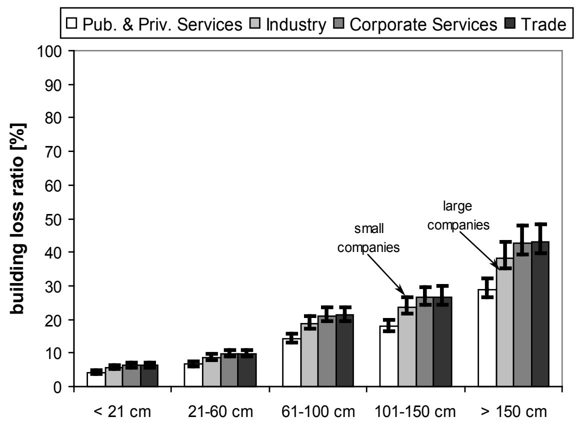


Figure 56 *Micro-scale models for the estimation of flood losses to private buildings (FLEMOps; left) and commercial buildings (FLEMOcs, right) considering water level, building type/business sector and building quality/company size*

In addition to elaborating models for the assessment of direct damages, some work has been accomplished in the field of the assessment of indirect economic damage in industry, the service sector and public infrastructure with the objective of evaluating the full range of damages caused by interruptions in production processes in a bottom-up/top-down approach. Data collected from the industrial sector in the form of questionnaires was extrapolated (bottom-up). On the other hand, existing statistical data were used to break down these general data according to individual companies (top-down), using suitable distribution methods such as company size, number of employees, land use structure, etc. The estimates were grouped into sectors. On top of that, costs for emergency services were analysed.

The indirect effects due to infrastructure damages and flooded sections mainly include increased transport and travel times. The traffic load within the infrastructure network is the defining factor to judge delays and rerouted traffic loads to be expected owing to the damages. The magnitude of impact is defined by:

- The rank of the failed infrastructure element in the network
- The regional location and the availability of alternative routes
- The size of flooded area and timeframe of the flood event

The indirect damages due to increased transport times can then be estimated by correlation with time unit prices. Despite the work done, there remain a lot of unsolved questions with regard to the assessment of indirect damage.

The developed damage estimation methods were validated separately and were then combined in order to generate overall results. To harmonize and apply different damage estimates for the purpose of cost-benefit analysis, they need to be implemented on a common base, complying with each other's spatial scales, level of detail and type of results. As an example, all estimated damage levels need to be related to the same value base. To be able to display events on a district level, for instance, micro scale assessments need to be upscaled, while macro scale assessments need to be downscaled. In all cases, a concept for the comparability of damage assessments needs to be developed and rules have to be applied to all individual work packages. This concept needs to be agreed with all parties involved, including a coordination of methodical approaches.

Finally the developed methods were tested in a pilot area to establish a cost-effective flood protection concept. In addition to existing flood protection concepts and cost estimates, the pilot area will profit from a cost-benefit analysis considering multiple conditions.

All loss data were collected in an object-specific flood loss database for Germany subdivided into different sectors. These are private households, trade/industry, public administration, agriculture and forestry, traffic infrastructure, watercourses and hydro-engineering facilities, and free settlement areas. The flood loss database developed in MEDIS is called HOWAS 21 (http://nadine.helmholtz-eos.de/HOWAS21.html). Furthermore, some of the models are provided as web-services to allow for their use in other projects.

In a last step, a web-based brochure was developed for an improved risk communication at the municipal level (see http://nadine.helmholtz-eos.de/Vorsorgebroschuere.html). Modules with easy-to-understand information about the individual preparation options and potentials were set up for the brochure. These can be adapted with community-specific information, e.g. local hazard maps. Municipalities can print and distribute the compiled brochure or they can publish it on their municipal website.

Box 15 Main principles of MEDIS

Need for economic assessment of direct and indirect flood damages

- Damage estimation in HOWAS21 for direct damage in/at
  - Private households
  - Industry, commerce and public assets
  - Traffic infrastructure
  - Agriculture and forestry
- Estimation system for structure fragility
- Approaches to estimate indirect effects

Overall integration of estimated aspects for application in a cost-benefit analysis

Overall collection of damage data in the data base HOWAS 21

Risk communication by providing interactive web-based information material

5.2.2 VERIS-Elbe – Change and management of the risks of extreme flood events in large river catchments

Overview

The extreme flood events in Europe that occurred over the last decades have caused severe economic, social and ecological damages and losses. This has led to the need to improve societal management during flood events, raising the question of how to better assess the complex relations between extreme floods and their consequential damages. Here, medium-term alterations caused by climate change and increase of property value have to be taken into special account. On the other hand, the efficiency of precautionary measures needs to be enhanced. To achieve these goals, changing risks caused by extreme flood events in large river catchments and the possibilities and benefits of their integrated management have been assessed. The transboundary catchment of the River Elbe has been used as a pilot area for this task. Flood risk, vulnerability and damages were simulated on a macro scale, attaching special importance to medium-term climate change aspects and land use change in the wetland areas. In addition, water resource management aspects, structural options and land use concepts were developed and analysed regarding their efficiency. Finally a multi-criteria appraisal of risks and possible options was performed.

Research questions include

- How may risks of extreme floods be holistically simulated with a high spatio-temporal resolution on the scale of large river basins? (Methodology)
- How do flood risks, flood vulnerability, and damage expectancy values alter through changing natural and societal conditions as well as through strategic alternatives of mitigation measures? (Cause-effect analyses)
- Which socio-economic and ecological efficiency as well as comparable cost-efficiency do the strategic alternatives of mitigation measures show and which instruments can support their implementation? (Evaluation, implementation instruments)

Because of the complex research topic the scientific approach of VERIS-Elbe is determined by two dimensions of integration: On the one hand, disciplinary models are coupled in a model scheme of the flood risk system, on the other hand, results of the model simulations are put in a planning context. These range from the ex-post analysis via the formulation of scenarios including development trends and mitigation options to their ex-ante analysis, multi criteria assessment, and implementation.

Project Description

The goal of VERIS-Elbe is the assessment of changes in extreme flood event risks of large river basins and the possibilities of their integrated management. Flood risk, vulnerability and damages were simulated on a macro scale, considering long-term changes in nature and society. Based on these simulations, the efficiency of strategic action alternatives was analysed and appraised. The project has developed a theoretic-methodological approach, followed by its application based on a River Elbe test site. The project consisted of the six following subtasks:

1. Integration, coordination, communication
2. Setup and coupling of the flood models
3. Setup of the damage simulation model
4. Multi-criteria analyses of the retention potentials of the whole flood plain
5. Design of extreme-flood scenarios
6. Ex-ante analyses and assessment of the scenarios

The analysis is based on a multidisciplinary approach and model scenarios for the main physical processes including precipitation, runoff, flood generation and damages. For medium-term scenarios (up to 2055), trends in regional climate and land use change of flood-prone areas were included. Mitigation options primarily involve the activation of retention potential and the reduction of vulnerabilities. The development scenarios were appraised as to multi criteria aspects regarding their economic, social and ecological efficiency. For their implementation innovative legal instruments and planning guidelines as well as recommendations were elaborated.

The described tasks required a complex research program. The interrelations between flooding risks needed to be evaluated and alternative development scenarios to be established and analysed. For flood risk simulation, a modelling system as shown in Figure 57 was used. It combines a high resolution DEM, the runoff simulation model LISFLOOD, the flood forecasting system WAVOS, the hydraulic Surface Water Modelling System (SMS), the GIS based flood scenario simulation model HOWAD as well as new statistical approaches. If e.g. water balance factors in the system are changing as it may happen through climatic changes, the overall effects can be simulated throughout all models. A schematic overview showing how to simulate a flood event throughout a catchment is depicted in Figure 58.

The LISFLOOD rainfall runoff model is used to calculate flows of defined return periods with special consideration of extreme events along the River Elbe. An example is shown in Figure 58. The assessment was carried out as a scenario analysis for the current situation and was also applied to climate conditions expected for future IIPCC scenarios. The appraisal of return periods of flood events was conducted using multi-criteria approaches of combined rainfall runoff statistics. In this way, both current as well as future flood risks were assessed in an improved way, providing the base for a realistic appraisal of damage potentials which can be used for flood preparation recommendations.

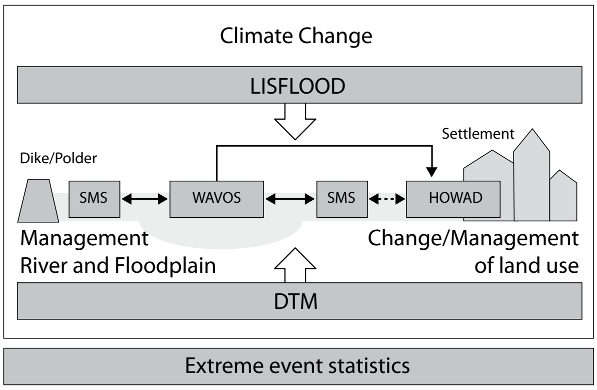


Figure 57 *VERIS model system including LISFLOOD rainfall-runoff model, SMS surface water modelling system (2D-hydrodynamic-numerical modelling system for surface waters), WAVOS water level prediction system, HOWAD flood damage simulation model and DTM digital terrain model (taken from Burek and Rademacher 2009, changed)*

Box 18 LISFLOOD

LISFLOOD is a grid-based catchment model that has been developed to simulate floods in large European river basins. Because the model is spatially distributed, changes, e.g. in land use, can be easily included in a LISFLOOD simulation. The typical size of one grid cell is 1 by 1 km, although the model can be run at both much finer and coarser resolutions if needed. The general structure and individual components of a typical hydrological model are shown in Figure 59

http://natural-hazards.jrc.ec.europa.eu/activities_lisflood.html (2008)

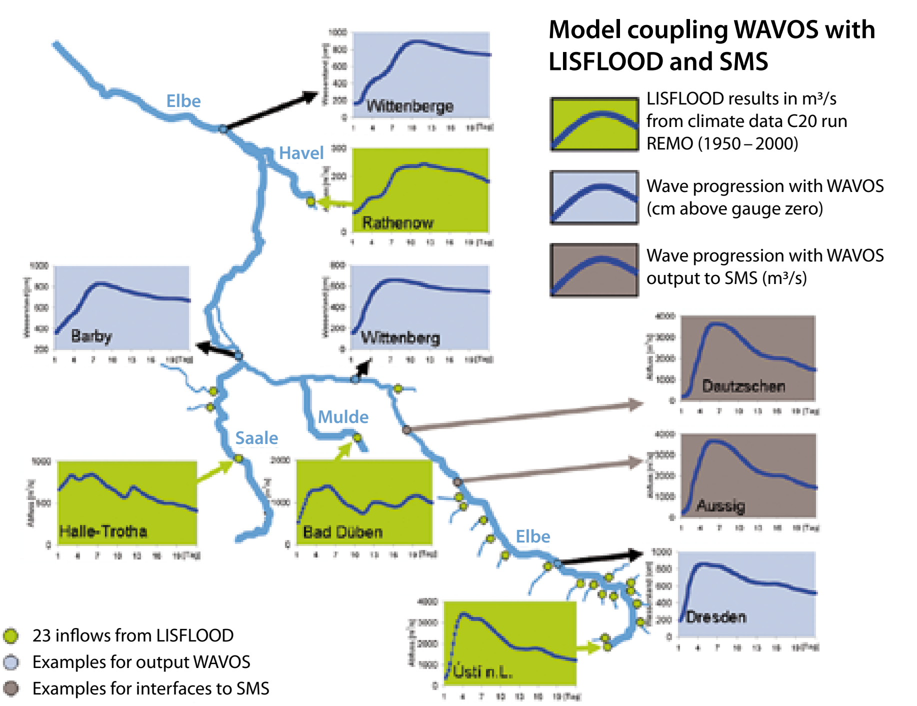


Figure 58
Flood wave calculation with LISFLOOD, WAVOS, and SMS (Burek and Rademacher 2009, changed)

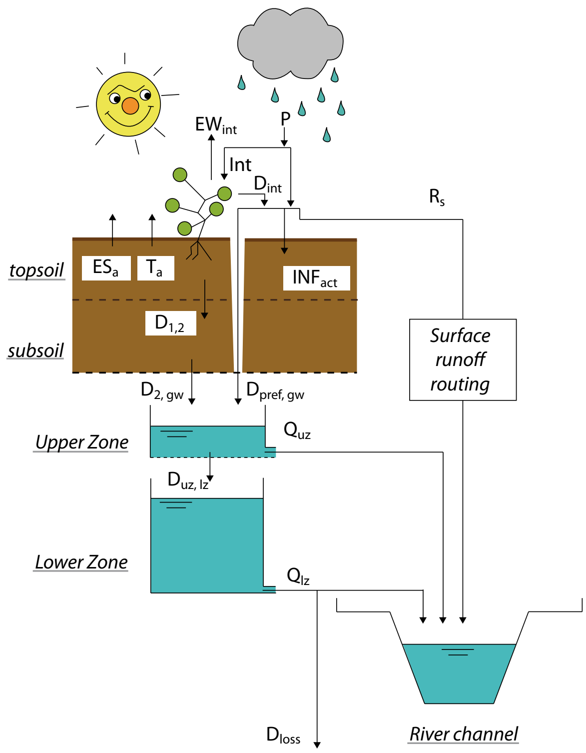


Figure 59 General structure and individual components of a typical hydrological model (http://natural-hazards.jrc.ec.europa.eu/activities_lisflood.html, 2008)

Based on the results of LISFLOOD, flood routing was conducted using WAVOS, followed by a two-dimensional simulation of the retention areas by means of SMS. The results were used to show the retention potential of polders and dams as well as to identify improvements in control structures. An example is shown in Figure 60.

Box 19 Main principles of VERIS

Long term socio-ecological damage assessment of flood events

Considering
- Changing risks over time
- Integrated management benefit aspects
- Hazards, vulnerabilities and risks

Integrated interdisciplinary modelling approach
Utilizing hydrological, hydrodynamic and damage models

Multiple scenario assessment
- Climate change
- Land use change
- Prevention means

Cost benefit analysis
Input into planning context of government agencies

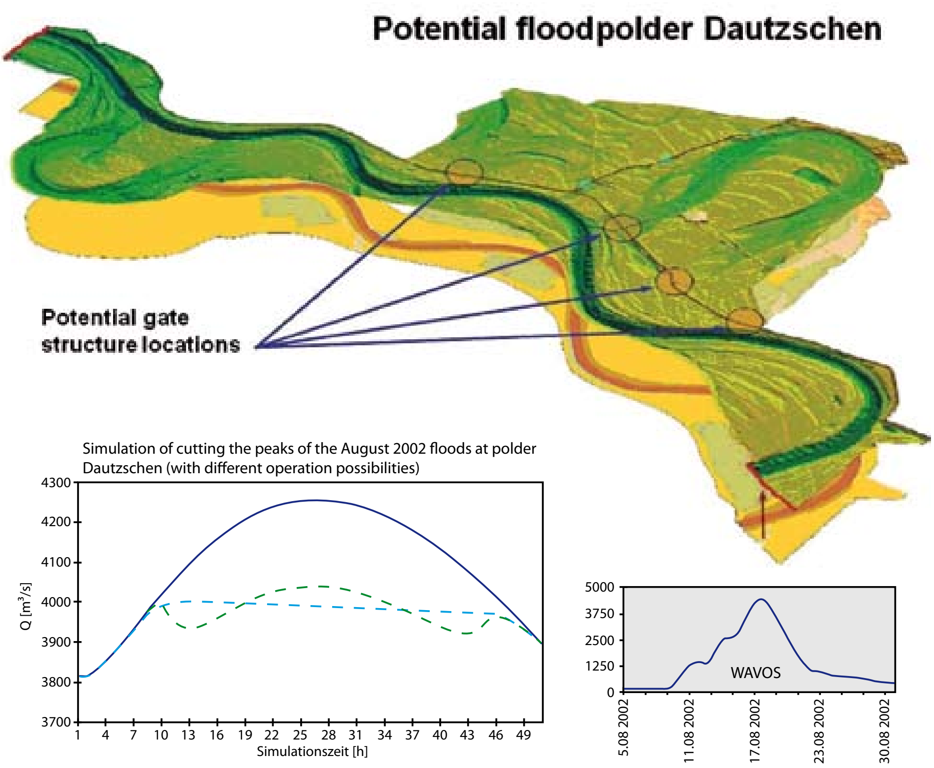


Figure 60
Coupling of WAVOS-SMS to (potential) flood polders (Horlacher et al 2009, changed)

5.2.3 INNIG – Integrated flood risk management in an individualized society

Overview

The interdisciplinary INNIG research team, has developed a risk analysis methodology using current research approaches to assess the flood risk in the city of Bremen and to compare options of risk communication to the city of Hamburg. Due to Bremen's location on the lower reaches of the River Weser, the consequences of a possible occurrence of an extreme flood event and a severe storm tide were analysed. Within the context of climate change, increased rain storm events in the catchment area of the Weser and higher storm tide water levels could aggravate this problem situation. Additional research on the psychological, sociological and political dimensions of risk perception, communication, acceptance and control was carried out. Here, special emphasis was placed on the influence of ongoing societal change on these risk dimensions. The results were merged into a concept for integrated flood risk management which also includes a modern internet based platform for risk communication. The concept should be applicable to other regions.

Risk communication, risk perception and acceptance of risk in Bremen and Hamburg were compared as both cities are prone to the same risks but rely on different risk communication strategies. While Hamburg actively communicates the residual risks (e.g. through storm surges) even resorting to public evacuation plans, this topic is not dealt with in Bremen. Additionally, different scenarios of annual changes and risks of extreme events as well as altered societal conditions were analysed.

The results were used as a basis for discussions with various stakeholders and focal groups. In summary the project had the following goals:

- Probabilistic analysis of flood risk in Bremen including the probability for a breach of the defences and the resulting inundation areas and flood damages
- Development of strategies to minimize and control flood risks (failure probability and failure consequences)
- Analysis of consequences of different forms of risk communication for the risk awareness and risk competence as well as recommendations for an efficient risk communication within an integrated flood risk management
- Definition of sensible and realistic goals for risk communication in flood risk management (promoting acceptance and preparation)
- Development of a concept for integrated flood risk management including an interactive information system and possible consequences for the political-administrative system

Project Description

INNIG assesses the methodology of flood risk analysis utilizing up-to-date tools and models. The project has evaluated psychological as well as sociological dimensions of risk appreciation, risk communication and risk acceptance. The results are used to design a modern integrated flood risk management concept.

The central element of risk analysis is the quantification of flood risk. In order to do this, the product of failure probability of flood defences and the possible related damages in the hinterland are calculated while considering the value of the objects at risk of flooding.

It was found that public communication about risks of extreme flood events is a central point for risk appreciation and perception given that floods seem to be a remote event in everyday life. On the other hand, readiness and preparation are essential for avoiding losses. Analyzing the relation between risk communication activities of professional actors and media and the perception of the flood risks in the population based on the two cities of Hamburg and Bremen was a vital element of the project. Data about the social context, risk presentation and appreciation in the population were evaluated on the basis of polls among representative groups in both cities. Recommendations for the optimization of public risk communication as a tool for flood risk management were deduced from the evaluation of the collected information.

The experience gained in extreme flood events shows that risk mitigation based on technical and political actions needs to be supplemented by protective measures on the part of individuals and communities. After flood events, the motivation for taking such individual measures normally decreases rapidly, even in areas that have been strongly affected. In areas at risk that have not seen any floods over the past decades, very low motivation can generally be expected. The goal of public risk communication therefore must be to raise the level of awareness that flood events with high damage potential may happen, even in spite of a low probability and return period. Therefore, individual measures should be developed and promoted.

Studying risk assessment and risk behaviour, basic patterns of behaviour to deal with flood risks were identified. Based on this, a psychological approach to support the risk appreciation of individuals was developed. Essential information content suitable for increasing individual preparation was identified. The evaluation resulted in the setup of a tailored internet-based information system making a major contribution to risk communication and individual preparation. The principles of this information system, tailored to the individual communities, can be transferred to any other region or risk. It was shaped in a way that stimulates motivation for taking protective measures against the individual flood risk of people while focusing on information that promotes personal risk appreciation and avoids an early negligence of risks. The information system was eventually refined on the basis of usability assessments appraising and improving the system's suitability.

The main motivation for implementing INNIG was to prepare for the upcoming climate change impacts that can be qualified but not quantified, and for which nonlinear changes are expected. New risks regarding the vulnerability of the society were identified. It was assessed how the different political-administrative bodies could deal with these challenges and adapt their concepts. The background to this approach was the idea that damages are only partly related to natural processes but also to quality and level of public and individual risk appreciation and preparedness.

In order to generate sound results, the political situations related to flood management in Bremen and, for the sake of comparison, in Hamburg were assessed in terms of necessary political decisions and scientific background. Flood risk plans were compared as to flood prevention and flood mitigation options, specifically considering problem definitions and defined protection goals. Structures of related organizations such as dike corporations and aid agencies were also taken into account. Finally, the results of the evaluations were presented, appreciating the current concepts and recommending conceptional, organizational and informational improvements. Phone interviews, document analyses, expert interviews and analytical methods were used to tackle this task.

In a final step, the results generated in INNIG were integrated to provide a control mechanism for the interdisciplinary task of keeping a community informed and for coordinating this process. The results were incorporated into an integrated flood risk management approach, and, as part of this concept, into an interactive, internet-based information system for risk communication.

In summary, the goals of the project were as follows:

- Probabilistic analysis of Bremen's flood risk including the probability of flood defence failure, expected flood areas and expected damage
- Development of strategies to reduce and control the risk of failures as well as their consequences
- Analysis of the consequences of different forms of public risk communication for risk awareness and competence; Recommendations for efficient risk communication for flood risk management
- Definition of (sensible and achievable) goals for risk communication to raise awareness, acceptance and preparedness
- Concept for an integrated flood risk management including an interactive information system and evaluation of possible consequences for the political-administrative system

A detailed description of the individual work packages of the project is given in the following paragraphs.

In work package 1, "risk analysis and control", the methodological base for the quantification of flood risks has been elaborated and tested using the example of the city of Bremen. To quantify the flood risk, which has been defined as a product of the probability of failure and the expected related damages, the failure probabilities for dikes and other flood protection facilities have been evaluated and recorded. Expected damages were quantified on the basis of their sensitivity to the flood level (vulnerability) due to proximity of possibly failing flood defence systems and under consideration of a monetary evaluation.

Work package 2, "risk culture", deals with public communication of the risks of extreme flood events against the background of the distance of such events from everyday occurrences. This perception results in a reduced risk appreciation which can only be counter-acted by actively communicating these risks to the public. The work package has analysed the specific local risk structure, conducting a comparative analysis of the relations of risk communication activities of professional bodies, media reports and presentations for Hamburg and Bremen. The studies concentrated on three main areas, i.e.: the appreciation of the social context based on communication materials and media reports, a representative opinion survey in both cities to assess risk appreciation and action potential in the population, as well as a social appraisal of risk information and communication channels. Based on these analyses, recommendations for the optimization of public risk communication as an aspect of flood risk management were developed.

Work package 3, "risk behaviour", considers the fact that while technical and political risk mitigation and control measures have their benefits, they need to be supplemented by the behaviour of individuals. The work package has identified basic behaviour patterns regarding flood risk appreciation that were used to define information contents suitable for increasing the individual risk appreciation through a tailored information system.

Work package 4, "political-administrative risk controlling", looks into the challenges and aspects different actors of the political-administrative system are being faced with in terms of changing boundaries for risk appreciation and setting up of their respective governance concepts. The background for this work package is the fact that the actual damage dimensions in a flood event are not only related to natural processes but also strongly depend on the adaptation and mitigation measures taken by a population, triggered by its risk awareness.

Box 20 Main principles of INNIG

Are flood preparation strategies within a community sufficient to maximize risk reduction during extreme events?

Strategies and lessons learned from other communities are used to gauge the system in question
Analysis of potential flood consequences

- Probabilistic analysis of flood risk
- Consideration of climate change
- What is the level of preparedness in the society
- How does the political/administrative structure address flood risk
- Sociological considerations

Recommendations for risk communication
Strategy concept for integrated flood risk management and limiting risks

Cooperation between the political-administrative actors and their relation to the public have been identified as important aspects in this regard. Restrictions and control problems may occur with conflicting interests of different actors which can be avoided through early cooperation.

Work package 5, "integration", was launched to set up a defined structure to control and coordinate the interdisciplinary processes and to combine the results of these processes into a concept for integrated flood risk management, including the development of an interactive information system for risk communication and risk prevention. All project partners were involved in the concept setup and implementation of this information platform.

5.3 Damage assessment and social impact adaptation strategies

5.3.1 General observations

The assessment of damages and social impacts of flood events serves as a basis for the appraisal of the effects of flood events through cost-benefit analyses, judging both direct and indirect damages. The results of these assessments are readily useable for improving damage appraisals as well as providing input data for flood preparedness planning exercises.

Generally the following sectors and areas have to be considered when appraising flood damages:

- Agriculture
- Industry
- Commercial sector
- Residential sector
- Infrastructure

But also:

- Environment
- Human safety and potential loss of life
- Interruptions of business and transport
- Stress

The general questions to be asked include

- Where do damages occur,
- Who is affected,
- What damages occur and what is the value,
- How do these damages occur and
- Why do they occur and how could they have been avoided

To link damages with a flood event, the location of different damages is of much interest. Different damages may occur in different areas of the flooded river itself and in the floodplains. In both areas, both direct and indirect damages may occur, depending on the interactions in the flooded zones.

To be able to measure and compare damages and interruptions, damage characteristics have to be defined and monetary values need to be assigned to the individual damages. In terms of direct damages, these values can either be taken directly from repair cost records or quotations or can be deduced from records of similar events. To avoid excessive concentration on details, damages need to be classified, for instance according to unit length of a specific road class, unit area of a certain commercial or residential setting, unit area of a certain agricultural crop class etc. As regards industrial settings, more individual assessments generally need to be made but reference values may be available here, too.

Assessment and appraisal of indirect damages may prove more difficult as damages may not be reported or fail to be directly visible. On top of that, damages may have an effect for an indefinite period after the flood event that also is difficult to judge. Different approaches would be available to tackle these problems. Productivity values of flood affected areas can, for instance, be relatively compared to previous year's figures, verified by trends of surrounding similar locations in order to show the impact of the flood event compared to the general trend. In such cases, interrelations with non-flood-affected areas have to be taken into account, as productivity may decrease in these areas as well.

Beyond nature and value of the damages, the question of how these damages occur is of much interest, in order to provide information on how to prepare for future flood events and avoid damages. Direct damages are generally caused by inundation as well as by current velocities, whereas indirect damages are a result of interruption and stress. Environmental damages may be another aspect to be respected, as damages may not only occur due to inundation, but also as a result of secondary impacts, such as spills from inundated industrial plants. As shown in the above overview, a wide range of impacts needs to be considered when assessing flood damages and social impacts. For data collection a variety of techniques can be used, including remote sensing data, technical on-ground surveys, information held by local authorities, direct polls in the affected community and monitoring of economic trends. Given that these methods monitor different parameters, using a mixture of information sources is advisable. An overview of aspects important for damage assessment and social impact assessment is shown in Figure 61.

5.3.2 MEDIS

The MEDIS approach aims at improving methods for direct and indirect flood damage assessment in order to provide an optimized input to cost-benefit analyses for supporting decision-making to develop flood mitigation measures and a cost-effective flood management. The approach relies on lessons learned from previous flood events and has developed a sophisticated multi-factor damage model supplied by a variety of data from sources as described in Section 5.3.1.

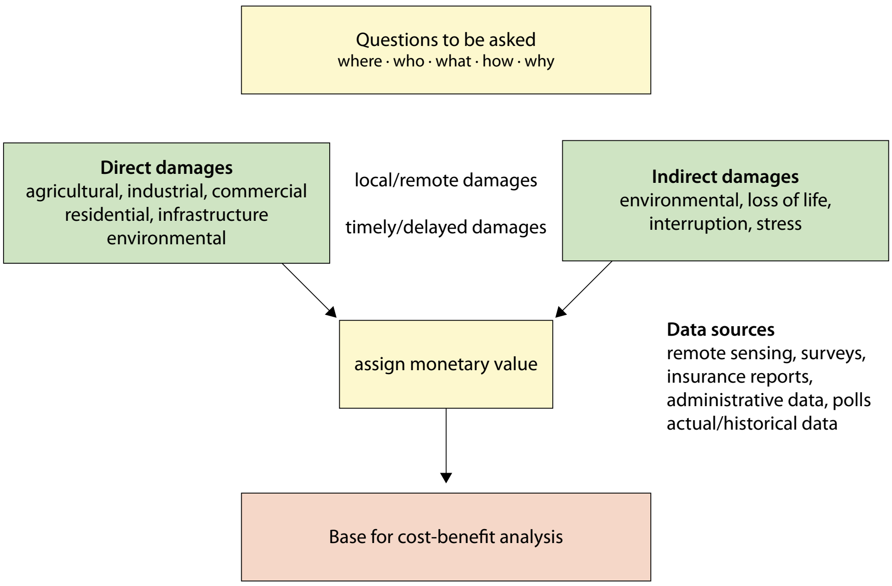


Figure 61
Aspects for assessment of flood damage and social impact

Integrating lessons learned is a key element in the MEDIS approach and should not be neglected when applying the method. Pertinent information can be obtained in the course of workshops attended by relevant stakeholders, via questionnaires distributed among the population and on the basis of historical records available from administrative bodies and similar institutions.

The level of sophistication of the damage model was adapted to the quantity and quality of data available. It needs to be kept in mind that the capability of the model and the quality of the model results are directly related to the quality of the input data appraised. Data collected from different sources cannot be utilized in a straightforward approach. In fact, the intermeshed nature of data collected during flood events needs to be considered when conducting the appraisal. A model may become unnecessarily inaccurate or even generate doubtful results if an excessive amount of input data is used lacking an adequate quality and full understanding of the relevant interconnections.

In order to fully understand the interconnected cause-consequences relations, a step-by-step approach in the model setup may be advisable to ensure a functioning model for which the influence of the contained parameters as well as the level of confidence is fully understood. The multi-factor setup can be maintained in this approach but should be scaled to a sensible level. The main principles of the approach to be considered are shown in Figure 62.

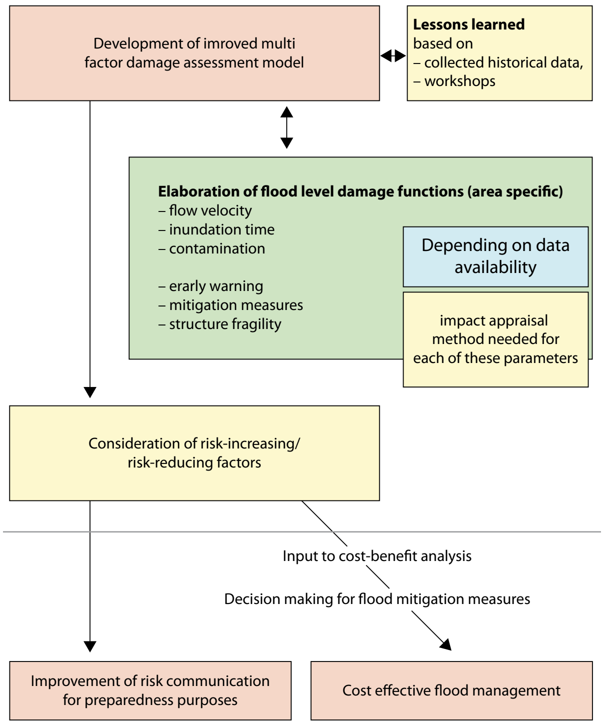


Figure 62 *MEDIS approach for improving multi factor damage assessment*

5.3.3 VERIS-Elbe

The assessment of changing risks of extreme flood events in large catchments and their integrated management possibilities are the topic of VERIS. The approach deals with a holistic picture including different changing parameters such as climate change, land use change and changing property values, simulating flood risk, vulnerability and damage for evaluating and planning efficient precautionary measures. The approach contains flexible assessment and appraisal strategies that can be used under a variety of conditions to assess and develop structural flood protection options, land use concepts and water resource management plans for a holistic flood protection concept. The approach builds on multi criteria appraisals combining individual aspects of risk and mitigation into an overall picture. Due to the extent and complexity of this concept it needs to be broken down into elements when setting up and conducting the required assessments. Based on the different disciplines involved but considering the relevant interconnections, model runs and appraisals are carried out and the results are combined into an appraisal or planning context to assess trends of future conditions or mitigation options of current or future developments.

In the project description in Section 5.2.2, a series of models for evaluating different involved aspects have been described. Depending on local circumstances, requirements, availability and resources these models can be replaced by others or be substituted by means of calculation. Overall, various levels of sophistication are possible in this approach, an overview of which is shown in Figure 63.

Defining the involved aspects and parameters as well as the level of sophistication used in the assessment approach is a key decision in any VERIS based project. To satisfy the multi criteria nature of the method, effort needs to be spent to ensure that all relevant parameters are captured. Following this first step, the level to which these involved aspects need to be considered should be established. This level may vary depending on the individual local circumstances

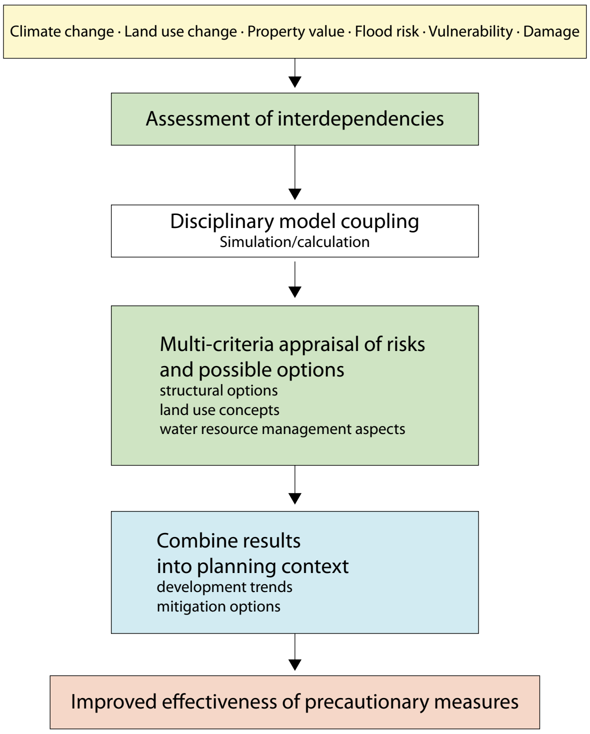


Figure 63 *VERIS approach for assessment of flood risk and integrated management possibilities in large catchments*

in a catchment contemplating both socioeconomic and technical aspects and notably the changing nature of all involved parameters over time.

Based on the socioeconomic and technical aspects in a catchment, both damage models and hydrological models have to be applied. Depending on the level of sophistication, several models for several aspects in the catchment can be used individually after carefully assessing possible interdependencies. The results can later be coupled, again using suitable strategies. An assessment of how to set up these coupled modelling approaches based on the available data is a key aspect in the successful implementation of the VERIS approach.

VERIS builds on a variety of individual assessment and modelling aspects that are integrated in the described approach. While flexible in its application, it needs to be taken into account that the project is geared towards a holistic view of problems in a catchment and care must be taken when weighing the importance and significance of individual parameters, especially in view of the fact that different levels of data quality and quantity will mostly be available.

Depending on the nature of the input data, the results generated will include development trends and mitigation options that can feed into decision support systems or into planning projects. When using these results, a sound knowledge of the utilized input data is required. Interdependencies and appraisal criteria are essential in avoiding unwanted effects due to changed planning parameters.

5.3.4 INNIG

The multidisciplinary INNIG project methodology combines the assessment and analysis of risk due to flooding (including the failure of flood defences) with the effects caused by the consequences of different forms of risk communication reflected in the level of flood preparedness of a population. The level of preparedness has been linked to how flood risk is communicated by the authorities and how it is perceived by the population. In addition to the evaluation of general flood risk communication channels and the perception in the population, societal changes and their effects on the forms of risk communication have been contemplated. The general approach is shown in Figure 64.

For the sake of probabilistic flood risk analysis, a variety of general scientific techniques can be applied. Factors to be integrated depend on the local circumstances prevailing in a specific area of interest. Next to the location of the area of interest within a catchment to which general types of flood hazard can be associated, data availability plays an important role in the selection of the approach. Some exemplary approaches, e.g. for upstream catchments, flash flood prone areas or basin-wide approaches of different sizes have been described in this document. Based on the risk assessment, potential flood damages in the area of interest – also caused by the failure of defences – can be deduced.

As communication aspects cannot be calculated in a straightforward way, communication practices and resulting risk perception of the respective local communities in different locations need to be compared for the analysis of consequences of different types of risk communication. For a selected set of sample locations questionnaires, for instance, can be used to assess risk perception and preparedness level within communities. Evaluating the results of the socioeconomic assessments in terms of a potential reduction of risk, lessons learned from the different sample locations can be utilized and merged selecting those risk communication approaches leading to the most significant preparedness levels without causing negative effects by generating adverse psychological conditions. As an important aspect for consideration, lessons learned under local circumstances need to be incorporated into future planning. Social as well as infrastructural conditions may vary and therefore approaches successfully applied in a certain area may prove unsuccessful in the target area. The boundary conditions of the sample and application areas therefore need to be carefully appraised, leading to the exclusion of certain sample areas or the need for a careful adaptation of the obtained results before their application.

Based on the abovementioned technical as well as socioeconomic assessments and issues for considerati-on, specific recommendations to reduce flood risk in the area of application can be drafted. Areas for which recommendations can be given include all aspects involved. Strategies to improve efficient communica-tion systems for creating an adequate level of risk awareness are essential. The recommendations need to be customized for the targeted administrations and infrastructural conditions in the application area to allow the respective institutions to effectively deal with the affected communities. The recommended communication strategies need to be shaped to lead to an improved awareness and respective preparedness within the targeted communities or parts of communi-ties, again considering the local requirements and conditions. Recommendations for the improvement of

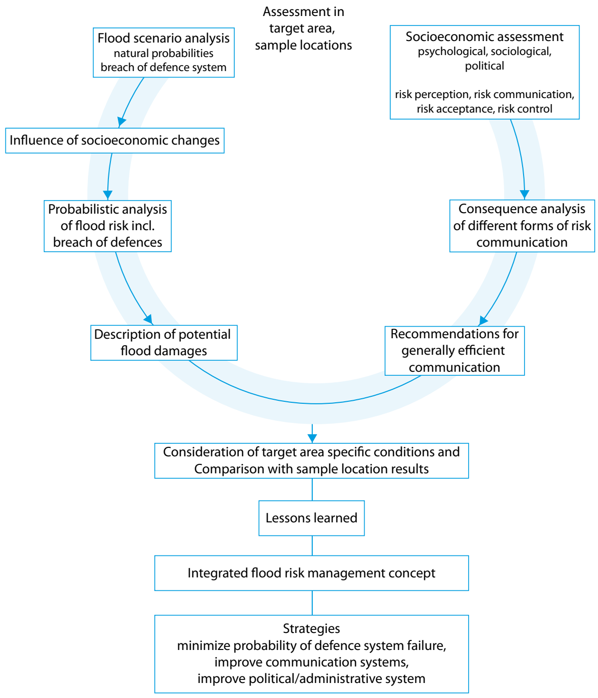


Figure 64 *INNIG methodology*

the relevant political administrative structures can go in line with the communication recommendations and would add an additional component to improved flood preparedness.

On the technical side, careful suggestions to reduce the failure probability of defence infrastructure, on the basis of the technical assessments performed, may be worth considering.

6. Working example

6.1 Catchment description

To show the potential of the RIMAX approach in a holistic way, considering sustainable options for catchment-wide implications, a schematic example is shown in this section, highlighting the different elements that need to be taken account of. A medium-scale river catchment in a semi-arid region has been chosen for this example, with the elements involved shown in Figure 65.

As regards the catchment, it is assumed that scattered, and partly only short term historical records exist, and that the monitoring network in the catchment is sparse. Rainfall patterns are non-frequent, highly localized and can be of extreme magnitude. Vegetation is sparse and erosion is a problem in the upper catchment as well as in the upstream river bed while in the downstream stretches sedimentation prevails, causing problems in the reservoirs. The river itself generally shows low-flow conditions, partly showing no surface flow during the dry season.

The scenario is depicted in Figure 66. It is further assumed that the reservoirs are managed according to an individual operation schedule and that some, partly deteriorated, flood defence systems exist in the urban area. Due to population growth, village settlements as well as uncontrolled settlements in the urban area are assumed to encroach upon the river-bed, normally having a low water level. Under flood conditions the banks may be overtopped. On top of that, the area shows declining groundwater tables due to over-extraction.

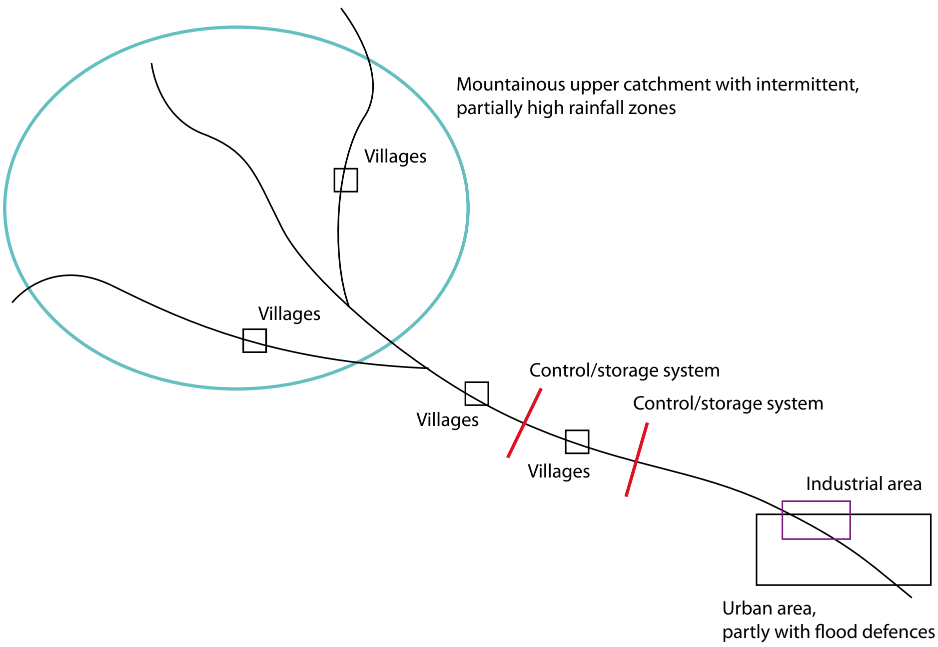


Figure 65
Schematic catchment overview in an arid region

Figure 66 *Catchment features showing mountainous conditions in the background and the river bed, hardly carrying any surface water, in the front. Further downstream the river enters flatter agricultural terrain*

Applying the RIMAX approach to this catchment, different assessments for forecasting and warning aspects, preparedness of defences, disaster management (flood management), damage assessment as well as social impact aspects can be implemented. These different assessments are described in the following paragraphs, leading to a holistic and sustainable proposal for the management of the catchment. It should be noted that a prioritization of the circumstances is a prerequisite for implementing the decisions taken.

6.2 Forecasting and warning aspects

To evaluate the forecasting and warning aspects of importance in the given catchment, considering the elements as shown in Figure 12, the current situation and major problems should be identified in a first step. As briefly described in the introduction to the catchment, the major problems in terms of forecasting and warning include a hydrometeorological monitoring station network disallowing the use of its data in advanced forecast modelling tools due to its inadequate spatial and temporal coverage. The available modelling tools, in return, are simple routines, not designed to generate ad-hoc flood warnings, generating an output that is insufficient for analysis, prediction and warnings. Consequently, warning procedures are non-existent. Preparedness aspects that could help in such situations are inadequately developed. On the other hand, areas that have proven to be at risk of flooding contain villages and agricultural areas in the middle reaches of the assessed catchment as well as industrial sites and the larger downstream urban settlements. While the areas in the middle reaches of the river do not contain any flood defence systems, the downstream industrial and urban areas are partly protected by river dike structures. Individually operated dams in the middle river sections contribute to control flooding by providing limited retention capacity that is threatened by sedimentation in the reservoirs.

Options for actions that can be considered under the given conditions are plentiful. On the physical side, the chain of potential improvements starts with the collection of data which could be implemented via a closer-meshed hydrometeorological monitoring station network. This network would allow for a better assessment of the conditions causing flooding in the catchment. Its use for the purpose of operational flood forecasting would require automated stations featuring data transmission possibilities. With the catchment experiencing highly localized rainfall events as typical for arid catchments, a spatially wide distribution of monitoring stations would not be suitable to capture the spatiotemporal distribution of rainfall in the catchment. A closer-meshed station network would need to be installed, or, depending on financial conditions and more detailed catchment characteristics, implementing a rainfall radar system could be an option. The meteorological station network would need to be supplemented with stream gauges measuring water depth in the river and its tributaries. Again, the better the spatial distribution of the gauges, the better the results relating to flood forecasting will be. An important aspect for these stations would be their ability to capture the sub-surface flow conditions in order to judge the remaining carrying capacity of the river bed. Another aspect worth mentioning is the fact that budgetary constraints all too frequently outweigh technical requirements in the design of monitoring station networks. Nevertheless, well-conceived engineering solutions still allow the design of a station network supplying valuable data. Based on historical data, hot spots and important nodes in the catchment can be identified and stations strategically positioned to provide optimum benefits. The approach may include neglecting parts of the catchment for which historical evidence regarding their non-contribution to flood events exist or which, e.g. based on terrain data can be judged as less runoff generating.

The improved station network needs to be connected to an optimized data centre with the facilities and computational power to handle and evaluate the incoming data. These data could feed into a range of possibilities of flood forecasting models which could be stepped or operationally updated. The model results in return could be incorporated into a Decision Support System designed for flood warning. The decision to what standard such a system will be implemented will depend on the quality of the monitoring station network providing the required data as well as – again – on budgetary constraints, leading to a vast number of possibilities, ranging between single standalone model approaches and ensemble forecast systems. It should be noted here, that depending on the data situation, a well-designed but simple flood forecasting system may have advantages over complicated systems, whose data needs cannot be satisfied to the required extent. In addition, it may be more advisable to use the budget for improving the monitoring station network and its transmission system than to spend it on software, given that even simple scripts suffice to evaluate the incoming data and generate flood alerts.

On the organizational side, data collection and evaluation, the decision for raising flood warnings and the dissemination of these warnings are the main steps where trained staff members and a good organization can make large differences in the flood warning process. In the described catchment, issues would include trained and knowledgeable staff for monitoring station maintenance, data collection and its transmission to the data centre. Where data transmission is not automated, clear procedures need to be in place for ensuring data quality and delivery in time. Again, this may range from ensuring automated transmission from highly sophisticated stations to low-key weather observations and their reporting via radio to the data centre. Both for highly automated systems as well as for purely manual flood monitoring and warning systems, organizational aspects are of importance. For automated systems, the parameters that lead to triggering alarms need to be clear, for manual systems a strict organization will ensure quality and timely delivery of the necessary data. Further effort would then need to be spent to improve and strengthen decision-making as well as dissemination aspects of a flood warning system, with the latter preferably being embedded in the general administrative concept of a flood-prone region to allow interlinkages and communication with emergency agencies. It should be kept in mind that the flood forecasting and decision-making process is also closely interlinked with the operational possibilities and control options that are further described in the Disaster Management section.

6.3 Preparedness of defences' aspects

Flood protection systems in the flood-prone catchment are found in the middle and lower reaches of the river system, protecting objects of higher value including industrial areas and domestic settlements. Based on Figure 30, key action to ensure optimum preparedness of the existing flood defence system consists of a thorough survey of the flood protection systems themselves as well as an assessment of the loading conditions that act upon them. Both groups of factors will then taken into account, combined with the locations at risk, to come up with prioritized decisions on improvement possibilities.

As regards the described catchment, the flood defence system comprises two dams including their reservoirs that are independently operated and cater for multiple individual users in domestic water supply, fisheries and recreation. In the downstream section, deteriorated river dikes protect industrial as well as urban areas. As a first step, detailed assessments of the reservoir facilities, stakeholder requirements and operation principles, followed by evaluations of the river dike system with regard to condition and implication of breaches in different locations are required. Findings may yield that the reservoirs are operated to maximize benefits for water supply aspects, maintaining the highest possible water level to be prepared for droughts. Findings on the river dikes may yield deteriorated conditions where the surface protection of the dikes is partly destroyed, local settlements occur and vegetation growth and animal burrows have weakened the dikes.

Following these hard engineering aspects, loading conditions acting on flood retention and defence systems are assessed. Results may show increasing magnitudes of flood events considering climate change scenarios, producing flow quantities and water levels beyond historical records. Overlaying these findings with the flood system parameters, reservoir storage volumes, and related to that spillways, may show inefficient capacity and dikes may show levels that are at the brink of overtopping. Where geotechnical investigation results of the dike body are available, recalculations may reveal problems with respect to erosion, seepage through the dike body and related secondary effects such as sliding and slip failures.

The outcome of these analyses is then used in combination with knowledge collected about objects at risks behind the flood defences. The differentiation of the impact of the failure of the flood defence systems and the consequence onto certain affected objects is of importance here. In the case of the reservoirs, the uncontrolled overtopping of a reservoir spillway may lead to erosion and breach of the dam, and depending on the breaching scenario itself, with enormous consequences for any kind of object located downstream. The river dike situation, on the other hand, may differ depending on where a failure occurs. Considering the described catchment, the downstream river dikes protect both urban as well as industrial areas. While in the urban areas loss of life may be the key parameter for decisions, in the industrial areas secondary effects including widespread pollution may be of higher importance, even overruling protection needs for smaller settlement areas. The aspects that are considered for these analyses are in close relation to those considered in the planning of disaster management options.

With the scenarios analysed and priorities identified, improvements of flood defences can be planned and scheduled, possibly using techniques as described in the RIMAX approaches. Given that – depending on the depth of the assessments performed – no assessment is perfect, immediate needs to stabilize endangered dike sections, e.g. close to the industrial sites, may also become necessary. Again RIMAX provides suitable approaches as described in Section 4 and developed in further RIMAX projects, an overview of which is given in Section 8.

6.4 Disaster management aspects

Disaster management is based on preparatory work, allowing decisions to be made quickly in the event of a flood. In the described catchment, mainly the middle and lower parts of the catchment are prone to flooding and would benefit from disaster management efforts. In the upper catchments flash floods may be expected, whose negative impacts may be mitigated by means of suitable planning efforts. Disaster management may also be seen as part of the work or going hand in hand with the activities performed for prioritizing improvements of defences as described in Section 6.3. Facilities on the one hand, and stakeholders on the other hand, need to be integrated into certain flood scenarios. Multiple layers of cause-consequences relations exist in-between the different elements involved, so that the development of a thorough methodological approach incorporating all these relations is imperative. In respect of the described catchment, the assessments can be performed according to sub-categories, i.e. subdivided into the upper catchment for flash flood events, and into the middle and lower catchment for main flood events. Any further descriptions in this section will focus on the more complicated management of the middle and lower catchment, with the main principles shown in Figure 50.

A possible approach for the described catchment could, based on the evaluation of hydrological data including the consideration of climate change scenarios, lead to a reconsideration of prioritization of stakeholder needs in the reservoirs. Multiple stakeholder needs in the case of disaster management would not only include reservoir users, but also downstream users such as fisheries, agriculture or settlements. These could benefit or suffer from certain operational changes or discharges of large amounts of water.

In view of the increasing flood risk, reservoirs may be operated at lower levels to provide more capacity for the storage of flood waters. In addition, operation rules for the reservoirs may be linked to utilize the benefits of a combined approach. Such changes do not necessarily imply the need for hardware changes in the dams or the utilization of extensive software packages, but could be based on operation rules based on upstream gauge indications as well as an improved communication between monitoring or flood warning agencies and the reservoirs as well as the reservoirs among themselves.

Having looked at a wide range of possible scenarios and different strategies, a cost benefit analysis, similar to the one conducted to assess improvement needs for flood defence systems, needs to be conducted. Each possible solution will have certain benefits and impacts which need to be judged and considered carefully. Based on a prioritization of benefits, a preferred solution may be found. For the described scenario, mid-catchment water demands, agricultural needs, the protection of downstream urban and industrial infrastructure are the main points for consideration. Prioritizing the downstream areas in order to prevent loss of life and pollution from flooding and destruction in the industrial areas, dam operation schedules for the two reservoirs would be adapted and generally operated at a lower level. The linked and coordinated operation plans would additionally ensure that – in case of a flood event forecasted or detected upstream – large amounts of water would be spilled and the reservoir levels drawn down to provide maximum storage. Low-level inundation in the agricultural areas downstream of the dams would be tolerated for an overall benefit as well as to prevent the downstream areas from even larger floods. The reduced storage of water for domestic and agricultural use in the dams that would lead to an increased utilization of ground-water resources would need to be considered for a holistic approach. Groundwater recharge plans could make up for the reduced amount of available surface water and prevent depletion of groundwater resources. Smaller recharge dams could be utilized for such tasks which would also work as small-scale flood retention dams. This topic could be further considered in the preparedness of defences section.

For judging the impacts of flooding as well as to avoid further developments in areas potentially prone to flooding, flood mapping exercises are strong tools. Such flood mapping would, contingent upon the available budget, be performed at least for the urban and industrial downstream sections as well as for other expanding areas with high population pressures, where development control would be beneficial. Besides the prevention of losses in the event of floods, floodplain reduction could be avoided by means of this planning and control mechanism.

As a result of the flood management work, scenario-related emergency management plans would finally be developed and anchored in suitable agencies which would be responsible for detailed implementation, enforcing and future updating of the strategies.

Talking about flood management, it should not be neglected that catchment management is also an important issue. Overgrazing of the upstream areas is a major factor that contributes to flooding. Moreover, erosion, also triggered by overgrazing, causes a fill-up of reservoirs due to accumulating sediments, further aggravating the flood risk by reducing retention storage volumes.

6.5 Damage assessment and social impact aspects

Damage assessments and social impact aspects in the catchment would be assessed from a holistic point of view as shown in Figure 61. The questions to be asked include: where does flooding happen, who will be affected, what damages will occur, how will they occur and why can they not be avoided. Depending on the measures taken when looking into preparedness of defences and flood management aspects, potential flood damages will vary. In the described catchment, as it stands, damages would be expected mainly in the medium and lower section of the river. With the propagation of the flood wave, flood damages are first expected to occur to agricultural areas as well as to village settlements along the middle sections of the river. Here, not only direct but also indirect flood damages, for instance caused by delays, need to be observed. Further downstream, the residential and also industrial areas are at risk, the latter causing secondary risks to the environment due to flood-related pollution. In addition, the floods may cause loss of life. Damages to road, rail, power, telecommunication and other supply infrastructure can be expected in the wake of a flood event. The floods will also interrupt daily life and lead to economic losses for both small and large businesses in the larger area affected by the flooding. Cleaning up requirements after the floods will cause additional losses in production.

Data sources used to carry out these assessments would include data and lessons learned from previous floods as well as information generated when developing the flood maps as described in the disaster management section. With a monetary value assigned to the described damages and interruptions, damage maps, based on the flood maps, can be developed and further evaluated as described in Section 5.

7. Conclusion and outlook

This guide gives an overview about exemplary results of RIMAX projects. Adaptation strategies for implementation in a variety of conditions are presented. The described projects have been classified into different sections including:

- Forecast and warning
- Preparedness of defences
- Disaster management
- Damage assessment and social impact

Depending on the individual circumstances, these individual sections or, where necessary, a combination of them need to be considered when evaluating a problem and planning changes to the system. Out of a variety of influential criteria to be accented for when approaching a problem, the following two points are of major importance.

Changes to a part of a system will always have effects on other parts, not necessarily only downstream areas of a system. A holistic approach is therefore essential to come to an overall beneficial solution, involving different stakeholder requirements, conflicting needs, multiple user aspects and cause-consequence criteria. When tackling the problems of a specific location, the overall system needs to be taken into account, given that changes to a certain system may entail negative impacts on other locations outweighing the positive effects in the target location.

Next to the need for a holistic approach, the application of engineering judgement in assessing, evaluating, planning and implementing flood management efforts is of paramount importance. Given that every system is unique, in most cases solutions cannot be transferred directly from other example sites but need to be adapted carefully, depending on the prevailing local and overall circumstances.

The adaptation strategies described in this guide should therefore be considered with care and the persons in charge need to thoroughly evaluate the conditions, needs and desired results for their respective location and circumstances.

Considering these two main points, the results of the RIMAX projects and derivations can be applied to a variety of problems, settings and circumstances. The other RIMAX projects that have not been described in this guide, but are listed in Section 8, will also provide valuable information and examples for problem approaches, given that adaptation strategies, tailored to these projects and the relevant problems and settings will be diligently developed. As stated before, a holistic and sustainable approach should always be preferred to avoid negative secondary effects. Further information on these projects can be found on the respective websites.

Another important aspect that should be kept in mind when planning and implementing changes to a river or flood management system, is that the changed system should be monitored in order to be able to optimize changes where possible and mitigate unwanted side effects. Changes and/or additional measures may be necessary or beneficial in this monitoring stage to improve the overall project results.

The monitoring process should include aspects affected by changes both on the local and regional level. Future monitoring may be beneficial to track long-term effects and learn lessons for future projects.

8. RIMAX projects

A listof RIMAX projects is provided in this paragraph, including the links leading to further project information, contact persons and responsible institutions. More specific project information is available from these institutions on request.

8.1 Analysis, forecasting, warning

Xfloods – Analysis of Historical Floods for Preventive Risk Management of Extreme Floods
http://www.xfloods.de
Prof. Dr. R. Glaser
University of Freiburg, Department of Physical Geography

Integration of Historical and Hydraulic/Hydrological Analyses to Improve the Regional Hazard Assessment and Increase Flood Awareness
http://www.elbe-extremhochwasser.de/
Prof. Dr. U. Grünewald
BTU Cottbus, Chair of Hydrology and Water Resources Management

Development of Methods for Improved Forecast of Extreme Flood Peak Discharges Based on Historical Data
http://www.uni-weimar.de
Dr.-Ing. K. Thürmer,
Institut für Wasserwirtschaft, Siedlungswasserbau und Ökologie GmbH, Freiherr-vom-Stein-Allee 5, Weimar

HW-BODE – Extreme Floods and Cumulative Damage Potential in the Bode River Basin
http://www.iww.uni-hannover.de
Prof. Dr.-Ing. U. Haberlandt
University of Hannover, Institute of Water Resources Management, Hydrology and Agricultural Hydraulic Engineering

VERIS-Elbe – Change and Management of the Risks of Extreme Flood Events in Large River Catchments – the Example of the Elbe River
http://www.veris-elbe.ioer.de
J. Schanze
Leibniz Institute of Ecological and Regional Development (IOER)

MEDIS – Methods for the Evaluation of Direct and Indirect Flood Losses
http://www.gfz-potsdam.de
Prof. Dr.-Ing. B. Merz,
GeoForschungsZentrum Potsdam, Engineering Hydrology
Prof. Dr. Annegret Thieken
University of Innsbruck and alpS – Centre for Natural Hazard and Risk Management, Innsbruck, Austria

REISE – Development of a risk-based decision support system for the identification of protection measures for extreme flood events
http://www.iww.rwth-aachen.de
Prof. Dr.-Ing. J. Köngeter,
Prof. Dr.-Ing. H. Schüttrumpf
Aachen University, Institute of Hydraulic Engineering and Water Resources Management

Precaution and Coping with Flood Events in Different Regional and Stakeholder-related Settings
http://www.tu-cottbus.de/fakultaet4/de/hydrologie/lehrstuhl/startseite.html
Prof. Dr. U. Grünewald
BTU Cottbus, Chair of Hydrology and Water Resources Management,
Prof. Dr. J. Pohl
Geographic Institute of the University of Bonn
Reinhard Vogt
Hochwasserschutzzentrale der Stadt Köln

INNIG – Integrated Flood Risk Management in an Individualized Society
http://www.innig.uni-bremen.de
Prof. Dr. M. Schirmer
University of Bremen, Department of Aquatic Ecology

EXTRA – Determination of Extreme Rainfall for Small and Medium Sized Catchments in low Mountain Ranges in Real Time with Increased Redundancy
http://tu-dresden.de
Prof. Dr. C. Bernhofer
TU Dresden, Institute of Hydrology and Meteorology

URBAS – Prediction and Management of Flash Floods in Urban Areas
http://www.urbanesturzfluten.de
Dipl.-Ing. F. Hatzfeld,
Hydrotec GmbH Aachen

OPAQUE – Operational Discharge and Flood Prediction in Headwaters
http://www.uni-potsdam.de
Prof. Dr. A. Bronstert,
University of Potsdam, Institute of Geoecology

HORIX – Development of an Operational Expert System for Flood Risk Management Considering Prediction Uncertainty
http://www.unibw.de
Prof. Dr.-Ing. M. Disse,
Bundeswehr-University of München, Institute of Water Resources Management

Operational Flood Management in Large-Scale Extreme Situations: the Middle Elbe River as an Example
http://www.iwk.uni-karlsruhe.de/557.php
Prof. Dr.-Ing. F. Nestmann,
University of Karlsruhe, Institute for Water and River Basin Management

MULDE – Ensemble Forecasts for Operational Flood Risk Management in the Mulde River Basin
http://www.ruhr-uni-bochum.de/hydrology/index.html
Prof. Dr. A. H. Schumann,
University of Bochum, Institute of Hydrology, Water Resources Management and Environmental Engineering

Retention Capacity of River Networks
http://www.retnet.rlp.de
Dr.-Ing. K. Röttcher
Roettcher Ingenieurconsult, Kassel

SARISK – Modelling of the Distribution of Pollutants in the Bitterfeld Floodplain
http://www.ufz.de
Dr. W. von Tümpling, Dr. Michael Rode
Helmholtz Centre for Environmental Research – UFZ, Dept. Lake Research

Artificial Neural Networks as a Basis for Decision Support in Operational Water Management
http://www.tu-dresden.de
Prof. Dr.-Ing. habil. G. H. Schmitz,
TU Dresden, Institute of Hydrology and Meteorology, Chair of Hydrology

New Planning Strategies for Flood Prone Urban Areas to Cope with the Increased Risk due to Climate Change
http://ufm-hamburg.wb.tu-harburg.de
Prof. Dr.-Ing. E. Pasche
TU Hamburg-Harburg, River and Coastal Engineering

MULTISURE – Development of Multisequential Mitigation Strategies for Urban Areas with Risk of Groundwater Flood
http://www.hochwasser-dresden.de
Dr. Th. Sommer
Dresdner Grundwasserforschungszentrum

SAR-HQ – Flood and damage assessment using very high resolution spaceborne radar imagery
http://www.zki.caf.dlr.de
André Twele, Dr. S. Voigt
German Aerospace Center (DLR)

8.2 Information and communication

International Teaching Module “Integrated Flood Risk Management of Extreme Events – FLOODmaster”
http://tu-dresden.de
Prof. Dr. C. Bernhofer
TU Dresden, Institute of Hydrology and Meteorology

DVD-ROM Floods – Causes, Risks and Strategies
http://www.mmcd.de
H. Frater
MMCD GmbH Düsseldorf

Coordination of the BMBF Research Activity RIMAX
http://www.rimax-hochwasser.de
Prof. Dr.-Ing. B. Merz,
GFZ – German Research Centre for Geosciences, Section Hydrology

8.3 Protection and control

Optimizing Levee-Monitoring by Reliable Identification and Evaluation of Vulnerabilities
http://www.igb-tubs.de
Prof. Dr.-Ing. J. Stahlmann,
TU Braunschweig, Institute of Foundation Engineering and Soil Mechanics

DEISTRUKT – Systematic Evaluation of Existing and Emerging Methods for Structural Investigation and Flaw Detection of Levees
http://www.deistrukt.bam.de/
Dipl.-Geophys. E. Niederleithinger
Federal Institute for Materials Research and Testing, Working group Non-destructive Environmental Measurement Methods

Sicherer Deich – Investigations on a Full Scale Research Dike to Improve the Resistance and Stability of River Dikes during Floods and Dike Overflow
http://wabau.kww.bauing.tu-darmstadt.de
Prof. Dr.-Ing. U. Zanke
TU Darmstadt, Institute for Hydraulic and Water Resources Engineering, Section of Hydraulic Engineering

Assessment and Prediction of the Stability of River Dikes by Monitoring Using Time Domain Reflectometry (TDR)
http://www.ibf.uni-karlsruhe.de/
Dr.-Ing. A. Bieberstein
University of Karlsruhe, Institute of Soil Mechanics and Rock Mechanics
Dr. K. Kupfer
Materialforschungs- und -prüfanstalt an der Bauhaus-Universität Weimar

Stabilisation of River Dikes with Draining Devices to Collect Seepage Water
http://www.ibf.uni-karlsruhe.de/
Dr.-Ing. A. Bieberstein
University of Karlsruhe, Institute of Soil Mechanics and Rock Mechanics

Geotextiles based on Sensors for Application in Dike Reinforcement
http://www.stfi.de
Dipl.-Ing. E. Thiele
Sächsisches Textilforschungsinstitut e.V., Chemnitz

Development of a Self-sealing Water Barrier for Windows and Doorways
http://www.stfi.de
Dipl.-Ing. U. Herrmann
Sächsisches Textilforschungsinstitut e.V., Chemnitz

PCRiver – Reliability and Risk Analysis in River Flood Protection under Consideration of Geotechnical, Hydrological and Hydraulic Factors
http://www.iws.uni-stuttgart.de
Prof. Dr.-Ing. P. A. Vermeer
University of Stuttgart, Institute of Geotechnical Engineering

Risk based Methods of Guaranteeing Adequate Flood Safety for Reservoirs
http://www.lwi.tu-bs.de
Prof. Dr.-Ing. G. Meon
TU Braunschweig, Leichtweiß-Institute for Hydraulic Engineering, Dept. Hydrology, Water Management and Water Protection

Integrated planning of technical flood retention in polders and dams applied to the Unstrut river basin
http://www.ruhr-uni-bochum.de/hydrology/index.html
Prof. Dr. rer. nat. A. H. Schumann
Ruhr-University Bochum, Institute of Hydrology, Water Resources Management and Environmental Engineering

Improvement of Dam Safety and Reduction of Flood Risk for Downstream River Sections using Optimised Operating Rules for Reservoirs and Polders under Consideration of Ecological Aspects
http://130.83.196.154/rimax33
Prof. Dr.-Ing. M. Ostrowski
TU Darmstadt, Section of Engineering Hydrology and Water Management
Prof. Dr.-Ing. R. Pohl
TU Dresden, Institute for Hydraulic Engineering and Engineering Hydromechanic

Development of an Integrated Management Strategy for Green Flood Retention Reservoirs and Polders
http://www.iws.uni-stuttgart.de/forschung/projekt.en.php?Abteilung=6&Projekt=114
Prof. Dr.-Ing. B. Westrich
University of Stuttgart, Institute of Hydraulic Engineering, Hydraulic Laboratory

HoT – Flood Retention and Drinking Water Supply – Preventing Conflicts of Interest
http://rimax-hot.ifh.uni-karlsruhe.de
Dr. M. Maier
Stadtwerke Karlsruhe

3ZM-GRIMEX – Development of a 3-Zone-Model for Groundwater and Infrastructure Management after Extreme Flood Events in Urban Areas
http://www.hochwasser-dresden.de
Dr. Th. Sommer
Dresdner Grundwasserforschungszentrum e.V.

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Abbreviations

DSS	Decision support system
FAO	Food and Agriculture Organization
FRIEND	Flow Regimes from International Experimental and Network Data
GEF	Global Environment Facility
GLOWA	Global Change and the Hydrological Cycle
GWP	Global Water Partnership
GWSP	Global Water System Project
HELP	Hydrology for Environment, Life and Policy
HWRP	Hydrology and Water Resources Programme of WMO
IHP	International Hydrology Programme of UNESCO
IPCC	Intergovernmental Panel on Climate Change
IWRM	Integrated Water Resource Management
NGO	Nongovernmental Organisation
RIMAX	Risk Management for Extreme Flood Events
UN	United Nations
UNEP	United Nations Environment Programme
UNESCAP	United Nations Economic Commission for Asia and the Pacific
UNESCO	United Nations Educational, Scientific and Cultural Organization
WHO	World Health Organization
WMO	World Meteorological Organization
WWAP	World Water Assessment Programme
WWDR	World Water Development Report

Web Sites

Cover picture:
Flood on the river Elbe, August 2002

Risk Management for Extreme Flood Events – RIMAX
www.rimax-hochwasser.de

Food and Agriculture Organization of the United Nations
www.fao.org

FLOODsite – Integrated Flood Risk Analysis and Management Methodologies
www.floodsite.net

Global Environment Monitoring System/Water
www.gemswater.org

Global International Waters Assessment
www.unep.org/dewa/giwa/

United Nations Development Programme
www.undp.org

UNESCO Water Portal
www.unesco.org/water

United Nations Human Settlements Programme
www.unhabitat.org

World Health Organization
www.who.int

World Meteorological Organization
www.wmo.ch

World Water Assessment Programme (WWAP)
www.unesco.org/water/wwap

WMO Associated Programme on Flood Management
www.apfm.info

The World Bank/Water
www.worldbank.org/water

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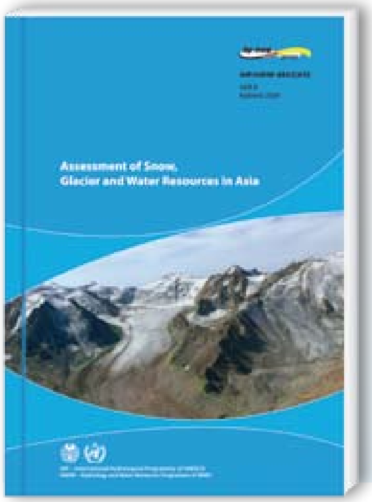

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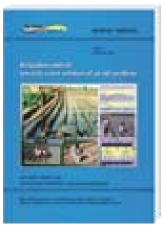

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