Advances in Flood Forecasting and the Implications for Risk Management

Report of an international workshop

Alkmaar, The Netherlands, 25–26 May 2010

The international workshop was organized by the International Commission for the Hydrology of the Rhine Basin (CHR)

KHR
CHR

and sponsored by:

COST 731 • Swiss Federal Office for the Environment • German Federal Institute for Hydrology • German IHP/HWRP Secretariat • German Association of Hydrological Sciences • the Netherlands National Committee IHP-HWRP • the Netherlands Centre for Water Management

cost 731

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Federal Office for the Environment FOEN

ihp • hwrp germany

Hydrologische Wissenschaften
Fachgemeinschaft in der DWA

Rijkswaterstaat
Centre for Water
Management

The Netherlands National Committee
IHP-HWRP

Rapporteur-in-chief:

Andreas Schumann

Co-rapporteurs:

Block 1: Eric Sprokkereef

Block 2: Sebastian Kofalk

Block 3: Peter Krahe

Final editing and formatting by **Michael van der Valk**, the Netherlands National Committee IHP-HWRP.

Aims of the workshop

In 2007 the European Flood Directive (European Commission, 2007) was established to reduce adverse consequences of flooding through the assessment and management of flood risk. Flood risk management plans aim to address all aspects of flood risk management, with special focus on prevention, protection and preparedness. Flood forecasts and early warning systems are essential components of damage prevention, and such systems should be tailored to the characteristics of the particular river basin or sub-basin. Thus the planning of flood forecasting is a challenge for river basin organizations such as the International Commission for the Hydrology of the Rhine Basin (CHR). The CHR has the task to expand the knowledge of flood hydrology in the Rhine basin through joint research, exchange of methods and information, and development of standardized procedures. In this way the CHR contributes directly to the implementation of the flood directive.

Flood risk management can be subdivided into two groups of activities: (i) planning activities, aimed at reducing the negative consequences of flood events ahead of time; and (ii) operational flood management during ongoing floods. Risk management during flood events depends on the state of preparedness achieved during the planning phase. This involves the establishment of flood forecasts and early warning systems, e.g. planning of disaster relief, flood evacuation and other measures. Timely and efficient measures for damage prevention during floods depend on hydrological forecasts. Therefore the establishment of effective forecasting systems is an essential part of flood preparedness. In this context the workshop was an important step towards the implementation of the EU Flood Directive. It provided a survey of advances and ongoing developments in flood forecasting and bridged the gap between hydrological forecasts and the practical aspects of their utilization in operational flood risk management.

The workshop was structured into three sections:

Block 1: New approaches to flood forecasting;
Block 2: Aspects of decision-making for flood damage prevention;
Block 3: Communication and acceptance of flood warnings.

An overview of the tasks, challenges to be addressed, and possible solutions were presented in an introductory session at the beginning of the workshop.

Introductory session

Following the welcome speeches, two stimulating contributions were given. **Günter Blöschl** (Technical University of Vienna) presented ‘Advances in Flood Forecasting and Implications for Risk Management’. He focused strongly on quantifying and reducing uncertainty by improved and extended utilization of local and global information and a quantification and consideration of uncertainties. These points were illustrated with many examples derived from applications of the TU Vienna – the flood forecasting system of the Danube River and tributaries. Blöschl emphasized that new technologies at the global/regional scale open new opportunities, yet local information is equally important and complementary. He criticized that local knowledge is usually not being accessed, e.g. field surveys, flood experiences of local population etc. In his conclusions Blöschl requested the interplay of local and regional/global information with a focus on maximizing credibility.

Roeland Allewijn gave an introduction to ‘Flood Forecasting and Crisis Management in The Netherlands’. Starting with the flood problems of the Netherlands, he presented the Delta Works Programme and its strategy of a coherent and comprehensive package of investments to ensure that the Netherlands can absorb the effects of climate change and will remain a safe and attractive country in the long term. The significant efforts that the Netherlands have made in the last decades to improve its state of flood risk management was clearly expressed.

Block 1 New approaches to flood forecasting

In this first part of the workshop two key topics were discussed:
- Forecast uncertainties, their specification (especially ensemble techniques) and their handling (e.g. by Bayesian processors);
- New technologies and their application in flood forecasting systems.

Forecast uncertainties

Forecasts are associated with different levels of uncertainty. Recent developments in flood forecasting allow for better quantification of uncertainties that are inherent to flood forecasting modelling. These uncertainties depend strongly on the forecasting lead time and the time of reaction of the hydrological system (watershed, river basin or river reach) of interest. For fast reacting systems, forcing forecast models based on observed data from different sources may be insufficient. In such cases the forecast horizon is limited by the time it takes for the flood producing precipitation to reach the river profile of interest. With regard to operational flood protection measures this time-span could well be too short. The lead time can be extended by quantitative precipitation forecasts based on numerical weather prediction (NWP) models. High resolution NWP can be coupled directly with flood forecasting systems. However, the quality of forecasted precipitation is often not sufficient for flood forecasts in fast reacting basins where the precipitation fields can vary significantly with time and space. Precipitation forecasts in mountainous regions are characterized by a wide range of uncertainties. For flood risk management the current uncertainties in NWP, as well as the handling of these uncertainties, have to be taken into account. Ensembles can be applied to specify the uncertainties of NWP forecasts.

In his presentation ‘Meteorological Ensemble Forecasting‘, **Paul Becker** from Deutscher Wetterdienst (DWD) provided an overview of meteorological ensemble systems. He explained the reasons why weather forecasts will always contain uncertainty. Specification of this uncertainty by ensembles has become a standard method in all major weather forecasting centres. Several meteorological Ensemble Prediction Systems (EPS) are operational at the global or regional scale (e.g. ECMWF, MSC, NCEP). The DWD offers weather forecasts with spatial resolutions of 30 km (GME) on a global scale, 7 km for the area of Europe (COSMO-EU) and 2.8 km for the area of Central Europe (COSMO-DE). Becker presented the three operational EPS (PEPS, COSMO-LEPS, VarEPS) for the European area and informed about the COSMO-DE-EPS (one of the first convection-permitting EPS) and COSMO-DE-EPS (2.8 km), which will become pre-operational in late 2010 and operational in 2012. The currently available EPS COSMO-LEPS is a Limited Area Ensemble Prediction

System for the medium range (3–5 days lead time). It was developed within the COSMO (Consortium for Small-scale Modeling) to improve the predictability of extreme weather events in Central and Southern Europe. The added value of the system consists in joining the skills of the ECMWF EPS to depict the possible evolution scenarios with the capability of the COSMO limited area model to improve the descriptions of local meteorological processes. It runs on a daily basis using 10 km grid spacing and 40 vertical layers, starting at 12 UTC and with a forecast range of 132 hours. Driven by a cluster of ensemble forecasts which is derived from 102 members of the EMCWF EPS a forecast ensemble with 16 members is provided as a physical ensemble. Another EPS which is available at present, but which is based on a completely different approach, is the short-range SRNWP-PEPS, a "Poor Man's Ensemble Prediction System", which combines up to 23 deterministic forecasts from 21 national meteorological services with a lead time of two days. It can be seen from case studies and probabilistic verifications for Germany that this ensemble may well be a valuable tool for severe weather forecasting. A major benefit of this multi-model EPS is the possibility to compare the behaviour of all operational European limited-area models. However, it became evident in the discussion that there are several problems regarding the interpretation of these ensembles in their relevance to hydrology. Most of the weather models yield accurate results when predicting small precipitation amounts but have strong problems in predicting large amounts of precipitation. Thus the informative value of ensemble forecasts of extreme rainfall is still unclear. A problem consists in the infrequence of such extremes, ongoing development of meteorological forecasting systems and limitations with respect to hind-cast extreme rainfall events in the past. Becker stated that the number of ensemble members should be expanded to produce the real uncertainty in the weather forecast. However, applied probabilistic verification measures (e.g. the probabilities for exceeding a precipitation amount 0.1 mm/24h) have relatively low significance for flood hydrology. He further elaborated on various attempts to analyse past errors of forecasts to estimate and correct probabilities for single ensemble members.

In general, hydrological applications of meteorological ensemble forecasts started in the late 1990s and are still the subject of research. In the workshop several applications of EPS were presented. For example, **Günter Blöschl** showed that in the Danube Basin ensembles of the ECMWF forecasts are used for early warning purposes. The main task of a forecast is to reduce uncertainty about future developments within the decision-making process. Here the specification of meteorological uncertainties is an essential component as it is often the main source of forecast uncertainty. However, it is not sufficient to only specify these uncertainties. Model and parameter uncertainties (including assessments of the initial state) have to be addressed as well. Such uncertainties and methods to handle them were also discussed in this part of the workshop.

Ezio Todini (University of Bologna) demonstrated the differences between predictive uncertainty and validation uncertainties. The hydrological model (figure 1) represents the knowledge about the hydrological system, its actual status and future developments. Unfortunately the predictive uncertainty $f(y_t|y'_t)$ can be characterized empirically only by analyses of differences between observed y_t and forecasted values y'_t. With regard to the rareness of floods such assessments are not possible. Instead all attempts to characterize predictive uncertainties are based on re-forecasts of observed floods. However, the uncertainty of simulations $f(y'_t|y_t)$ of an observed value y_t, by y'_t which was characterized by Todini as 'validation' uncertainty, is different from the predictive uncertainty $f(y_t|y'_t)$. In figure 1 the differences between $f(y'_t|y_t)$ and $f(y_t|y'_t)$ are shown schematically.

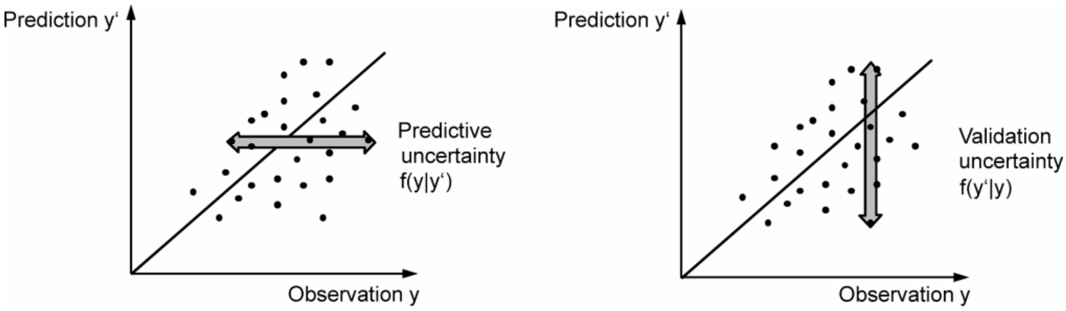

Figure 1: Differences between predictive uncertainty and validation uncertainty (from the presentation of Todini).

In his presentation Todini showed two discrete and three continuous probabilistic approaches to determine predictive uncertainty. He discussed the Hydrological Uncertainty Processor (HUP) (Krzysztofowicz, 1999; Krzysztofowicz and Kelly, 2000), Bayesian Model Averaging (BMA) (Raftery et al., 2003) and the Model Conditional Processor (MCP) (Todini, 2008). In particular, the MCP approach can be extremely useful in the assessment and the reduction of predictive uncertainty. Assessment is achieved by formulating the joint probability distribution of predictand and predictors in the normal space, from which the conditional distribution is then obtained. Reduction can finally be obtained by merging together several forecasting models of different natures and characteristics, such as physically-based and data-driven hydrological models. It became obvious that in flood forecasting confusion between validation and predictive uncertainties results in a limited operational use of predictive uncertainty. Todini urged hydrologists to convince stakeholders and meteorologists of the real benefits that can be derived from the estimation and use of predictive uncertainty in flood forecasts and risk management.

The European Floods Alert System (EFAS) which is under development at the Joint Research Centre of the European Commission (Thielen et al., 2009) has been using the ECMWF ensemble forecasts for some years. It provides medium- to long-range flood information for large-scale river basins relevant for decision at national or EU level. Based on these experiences **Peter Salamon** (JRC) presented possible improvements to the efficiency of medium-range streamflow predictions of EFAS from estimations of predictive uncertainty, error analysis and correction methods. Two different methods of uncertainty estimations were tested. The spatially distributed method is based on particle filters. Another method applies the Bayesian Uncertainty Post-Processor. Both methods have shown their capabilities to deal with uncertainty efficiently using the EFAS setup. They can be useful to derive more reliable and accurate medium-range forecasts. Currently, a method based on the Bayesian Uncertainty Post-Processor is being implemented at the European scale in a variety of different catchments in order to be evaluated in an operational environment. The next step towards an operational implementation of the particle filter will be a feasibility study for the operational assimilation of discharge data using the posterior distributions of the parameters and error multipliers derived in the previous case studies. Here, special attention needs to be paid to the computational feasibility and to the adaptation of alert thresholds in the flood forecasting system. Furthermore, both methodologies will have to be tested on a longer data set in an operational system in order to evaluate their robustness.

Efficient computational systems are essential for handling multiple ensemble forecasts (meteorological ensembles, parameter or multi-model ensembles, among others). In his presentation **Martin Ebel** (Deltares) discussed the problem that most operational forecasting systems are built around hydrological and/or hydraulic models. Such a model-centered approach can be quite successful and can lead to the rapid development of an operational system. However, it has some drawbacks. Major changes like extensions of lead times, introduction of new models or new approaches in uncertainty estimation are difficult to implement. Also, the utilization of new sources of input data such as weather radar, weather forecasts, satellite data and so on require greater focus on effective data integration in operational systems. Data handling and evaluation have therefore become major factors in the chain of detection, forecasting, warning and response. The major challenges of new forecasting systems can be summarized as follows:

- Efficient handling of large datasets;
- Flexible and open systems to enable easy model integration;
- A framework to handle uncertainties and processors to address them.

Ebel demonstrated how the software system Delft FEWS can provide a platform for these problems. It includes a time series viewer and editor, tools for data conversion, visualization, analysis, validation and error correction, as well as dissemination of forecasting results. It provides several interfaces that allow models and data to be flexibly integrated. Several tools which are implemented were discussed in greater detail: Data assimilation with ARMA correction and Ensemble Kalman Filter; interactive forecast display, with the possibility to adapt time series; model parameters; state variables with the option to be changed before the (next) model run etc.

The Bayesian Model Averaging (BMA):

- Evaluates the uncertainty of an ensemble forecast in a training period prior to the present forecast;
- Calculates weighted average of individual model forecasts, where each forecast is weighted based on the likelihood that that model is the best;
- Produces a weighted overall probabilistic forecast with confidence limits and determines a correction for the bias.

The Quantile Regression Method for determining conditional quantiles gives an estimation of the cumulative distribution function of a forecast error conditioned by the value of the present simulated river levels. This method is promising, but needs calibration and long time series for reliable results.

A presentation on the quantification of uncertainty and the application of new data systems in flood forecasting was given by **Massimiliano Zappa** (Swiss Federal Research Institute WSL). He represented the COST 731 Action. COST 731 is a European initiative which deals with the quantification of forecast uncertainty in hydro-meteorological forecast systems. It addresses three major lines of development:

1 Combining meteorological and hydrological models to form a forecast chain;
2 Propagating uncertainty information through this chain and making it available to end users in a suitable form;
3 Advancing high-resolution numerical weather prediction precipitation forecasts by using non-conventional observations from, for instance, radar to determine details in the initial conditions on scales smaller than what can be resolved by conventional observing systems.

The main objective of the COST Action is to address issues intimately associated with the quality and uncertainty of meteorological observations from remote sensing and other potentially valuable instrumentations, along with their impacts on hydro-meteorological

outputs from advanced forecast systems. Its main objectives are that radar data assimilation in NWP, radar data quality description and radar ensembles are able to represent uncertainties and can be applied to hydrological modelling including a standard methodology with the potential to become a reference for similar developments in the future, and to provide feedback for improvement of meteorological input data.
The Action is organized in three working groups:

- Propagation of uncertainty from observing systems (radars) into NWP;
- Propagation of uncertainty from observing systems and NWP into hydrological models;
- Use of uncertainty in warnings and decision-making.

Zappa explained why quantification of uncertainties in flood forecasting is a difficult task, resulting from the multiple and strongly non-linear model components implemented in such systems. Much effort has been – and is being – invested in the quest for dealing with uncertain precipitation observations and forecasts, and the propagation of such uncertainties through hydrological and hydraulic models within the forecasting chain. He pointed out the substantial gap which exists between the forecast information possibly available from the chain atmospheric modelling/ hydrological modelling or observation/ hydraulic modelling and the information that is actually used by the authorities or end-users. He presented results from the three working groups on the probabilistic quantitative precipitation estimation (QPE) from radar, among others.

The fact that uncertainties of hydrological modelling can result from divergence between model assumptions and nature became evident in the study presented by **Hubert Savenije**. (Delft University of Technology). He discussed the significance of changes in the hydrological balance of the Meuse catchment and their explanation through the use of a conceptual hydrological model. Savenije assumes that trends in model parameters are representative of catchment attributes that may have changed over time. It was concluded that the time lag of the catchment was very much influenced by drainage and river training works. Since forest land cover is dominant in the hydrological cycle and floods are generated on hillslopes that are often covered with forest, it is necessary to understand the hydrological effects of growing forests in greater detail. It was found that forest rotation and the resulting higher water demand for transpiration by up-growing trees may have a significant impact on the water balance of the catchment. To implement these land management influences a more physically-based, semi-distributed model and non-stationary parameters may be needed.

Block 1 conclusions

- EPS don't represent the predictive uncertainty;
- Ensemble weather forecasts contain more information than single deterministic forecasts. However, the number of ensemble members has to be expanded significantly to represent the real uncertainty in weather predictions of extreme events. More ensemble members would have a greater benefit to hydrology than finer weather grid resolution;
- Although the quantification of uncertainty is a difficult task, there are several approaches to address the predictive uncertainty. Hydrologists need to convince stakeholders and meteorologists of the benefits of using predictive uncertainty. To do so, additional information like persistency or possibility has to be integrated. Here, initiatives such as COST could be very useful;

- There is limited use of predictive uncertainty in flood forecasting. This is partly due to the lack of understanding, but also relates to the extreme problems of meteorologists to re-run their models on historical data of extreme floods;
- Data handling and evaluation become major factors in flood forecasting systems. Therefore systems with a data-centric approach have advantages compared to model centred systems;
- Local information is complementary to global and regional information. Local knowledge of forecasters should not be underestimated;
- There is a definite need for more knowledge on how a river basin behaves, both under normal and under extreme conditions;
- Applying many conceptional models there is a general deficit in our knowledge about thresholds and interactions of dominant flood processes and their dependencies on e.g. geology and morphology. Most conceptional models are based on macro-scale studies which cannot sufficiently consider the self-organization of landscapes. Here we need new approaches which are directly relevant to the scale of flood model applications;
- The stationarity of model parameters is a widely applied assumption which seems to be unreasonable if detailed mechanisms of flood generation have to be considered.

Needs for further research

There are several sources of uncertainties: initial state uncertainty, model uncertainties, parameter uncertainties and input uncertainties. Which one can be quantified and handled? Which one could be neglected? How can the uniqueness of the flood event, caused e.g. by thresholds of non-linear hydrological processes, driven by landscapes, seasonal aspects, etc. be considered in assessments of uncertainties? If we specify validation uncertainties we have an indirect measure of predictive uncertainties. Nevertheless this knowledge of validation uncertainty is of limited value for practical applications of models. How can we specify this ‘predictive uncertainty’?

Block 2 Aspects of decision-making for flood damage prevention

In his presentation **Jörg Dietrich** (University of Hannover) gave a short overview of Decisions Support Systems (DSS) and decision-making under known uncertainty. He subdivided decision problems into strategic, tactical, and operational decisions. With reference to the ontology used in the Cynefin Sensemaking Framework (ontology is a formal representation of the knowledge by a set of concepts within a domain and the relationships between those concepts) he described a generic decision context. He differentiated between knowledge contexts such as complex, knowable, chaotic and known contexts, which specify the crossing from tacit knowledge/expertise to explicit knowledge models. In differentiating between uncertain and unexpected information he specified these contexts in flood management problems. In the second part of his presentation he outlined a DSS architecture for operational flood management and some requirements for the design of such tools. Here the problems in assuming uncertainties and describing them in such a way that it could be useable for operational flood forecasting were presented by an ensemble-based DSS for the Mulde River in Germany (Elbe River tributary). To decide upon flood alerts based on thresholds he suggested persistence charts and forecast distributions versus observed event characteristics. In his conclusions Dietrich recommended ensemble predictions as an integral part of an operational DSS for flood management. However, uncertainties in data, missing data of past flood events (hind-casts!) and knowledge which is variable in time will require adaptive approaches for operational DSS.

In the discussion it was underlined that flood forecasts are always uncertain, but that more emphasis should be given to unpredictable chaotic situations, including the human factor, which are common during flood events ('expect the unexpected'). DSS should be tailor-made for the decision-maker(s) and should consider the risk of chaotic (non-foreseeable) factors which have to be integrated in the process descriptions. DSS are mainly related to discharge forecasts. Forecasts of inundated areas are often more critical in operational flood risk management than discharge forecasts. As inundation models are too complicated and computer-time intensive they cannot run in real-time applications. It was recommended to include their results in operational DSS, e.g. pre-calculated scenarios.

Kees van Ruiten (Deltares) reported on disaster management and how to deal with the response to flooding. He gave a short overview of the temporal development of flood management policy in the Netherlands starting with the flood disaster of 1953 and the impact on public risk awareness. He came to the conclusion that flooding fades from the collective memory and so does risk awareness. In his presentation he discussed the chain of flood safety (preparedness – response – recovery – mitigation) and explained the need to complement the dominating principle of flood prevention with preparation on floods. Flood prevention is the strategy to reduce the probability of flooding and its negative consequences. However, a core focus on prevention could result in a 'mega-crisis' should the flood protection system fail. Preparedness for flooding remains an essential part of flood policy. The national emergency plan (Taskforce Management Overstromingen (TMO)) forms the base for disaster management for floods in the Netherlands. It contains detailed planning and exercises worst credible flooding. However, many problems still exist. Van Ruiten mentioned the following challenges:

- Discrepancy between available time e.g. for evacuation versus lead times of early warnings;
- Lack of experience about regional impacts of flooding and the efficiency of operational flood risk management;
- Working with a limited number of scenarios;
- How to handle many uncertainties e.g.:
- Where and when storm surge hits the coast (affecting 3 million people, evacuation strategies);
- The behaviour of citizens is not known (self reliance, movement to the safest places, etc.);
- The availability of infrastructure (evacuation road capacity, traffic jams, etc.) is uncertain.

He suggested incorporating such uncertainties into emergency plans. In the concluding part of his presentation he specified the following research issues:

1 The 'safety paradox' leading to a lowered risk awareness;
2 Warning process as social process and the 'bureaucratization' of human factors;
3 Dealing with uncertainty.

The benefits from international cooperation were explained by the example of cooperation between specialists from the Netherlands and the USA in analysing the flood disaster of New Orleans. In his conclusion the following future tasks in the field of improved flood preparedness were specified:

- Introducing scenarios: build in flexibility by exercising;
- New planning approaches: dealing with time and space and limited resources;
- Risk communication: raising public awareness;
- Crisis communication: ensure self-reliance and own activities of citizens;
- Flood experts: build expertise by development und utilization of R&D networks;
- Adequate information and stakeholder involvement is crucial for successful disaster management.

Throughout the discussion the role of maintenance of the infrastructure was accented. The possibility of failures of dykes and other technical flood protection systems has to be integrated as a factor of uncertainty in flood risk management planning.

Marcela Brugnach (University of Twente) gave a presentation about aspects of uncertainty in collective water management. It was based on the outcomes of the NeWater project, which was focused on adaptive and participatory water management. She specified a new category of uncertainty which became evident within collective decision processes. Besides the types of uncertainty normally addressed (e.g. unpredictability and incomplete knowledge) Brugnach identified multiple knowledge frames as a source of ‘ambiguity’. Different stakeholders have many perspectives on a problem which may be valid. Brugnach explained the strategies to cope with uncertainties: accepting the uncertainty, gathering data/knowledge, support a common understanding of problems and the existing knowledge about uncertainties. This goal can be achieved by data collecting, modeling, uncertainty propagation in combination with communication-oriented techniques to learn about uncertainty. Examples from water resources management in Spain were used to demonstrate how a problem definition phase integrating all perspectives of stakeholders can be essential for the planning process. In her conclusions Brugnach emphasized that the combination of communication and knowledge transfer between all stakeholders will lead to better decisions in an adaptive water management.

In the discussion it was mentioned that a collective decision-making processes has to be based on democratic rules. The question arose if a weighting of stakeholders could be acceptable and how weights should be distributed among stakeholders? Could the majority of non-affected parties decide upon burdens of a minority? Using social knowledge capacities leads to a broader view on risks, however, the acceptance of risk depends strongly on factors such as personal risk, risk awareness and risk perception.

As the final speaker of this block, **Bruno Merz** (GFZ Potsdam) gave a presentation about the quantification of uncertainty in flood risk assessment. He specified the main sources of uncertainties (e.g. flood events are unique, they cannot be repeated to be studied in detail and the database, especially on flood damages, is small). For that reason the validation of flood risk analyses is not or hardly possible. Often are best guess assessments and expected values not useful. He specified two different types of uncertainty existing in decision-making:

- The aleatoric uncertainty results from stochastic processes and can be described by probabilistic distributions. It cannot be reduced by an improved knowledge base;
- The epistemic uncertainty results from insufficient knowledge and can be reduced by further research.

In his presentation Merz addressed the problem of overconfidence of experts in neglecting possible surprise. He gave an example from literature: 20–45% of true values could be located outside of a 98% confidence region which were subjectively specified by experts. The problems of applications of the Bayesian rule to specify conditional probabilities were demonstrated. Options to reduce epistemic uncertainties by integration of additional information were described by an example of the Elbe River. The combination of different models e.g. for inundation and flood damage assessments may result in wide uncertainty bounds. However, the epistemic uncertainties can be reduced by additional information through detailed studies dedicated to the most critical points in complex analyses. In his conclusions Merz stated that uncertainty analyses are often misused as a substitute for missing validations. Priority in risk analyses should be given towards the identification of weak points and the most critical assumptions. The results of multi-model simulations and sensitivity analyses can be used to think carefully about disagreements, their sources and handling. They guide efforts for assembling further evidence or for model refinement. In this way uncertainty analyses provide additional information for decision-making. Risk analyses contain assumptions and subjective meanings. The decision-makers should be aware of those assumptions. It is also important for decision-makers to see the degree of disagreement among experts as an indicator for (good) uncertainty communication.

Block 2 conclusions

The handling of uncertainties is the most critical point in operational flood risk management. All speakers have addressed the problem of 'uncertainties' as the key aspect in the decision-making process for flood damage prevention. Two perspectives were discussed:

- How to handle uncertainty at an operational level [technical/statistical];
- How to handle uncertainty at a strategic level as a problem which cannot be neglected in communication of emergency plans and other activities of flood preparedness.
- Ensemble Prediction Systems (EPS) are promising to handle uncertainty. Data assimilation techniques are recommended for adaptive DSS. It seems that we can handle the uncertainty better in a technical way using instruments like statistics, than to communicate the uncertainty in an adequate way to decision-makers. This should be an issue of further research. To combine knowledge of the natural system with the social, political and disaster control system is an important aspect to be regarded. Every decision-maker needs information about risk which is adequate for his field of responsibility;
- Stakeholder involvement is crucial for success. If decisions are made in a participative way for strategic planning, a set of possible problem solutions has to be explored;
- An open recent (research) task is to handle chaotic situations as part of the operational decision process. It is questionable whether they can be incorporated. To accept that chaotic behaviors and situations can never be avoided completely is a first step to handling them;
- The question of how to keep flooding awareness alive during long-lasting political decision processes should be answered in the future.

Needs for further research

There is a strong need for ‘due diligence’ guidelines on how to cope with uncertainty on a technical and communicational level, while making a clear distinction between strategic and operational decision-making purposes. Decision-making has many facets, from low-impact decisions at the local level up to decisions which are relevant for the national economy and public health at the national level. Methodological developments should not start with a flood scenario which has to be controlled. Planning should start instead with the vulnerability of societies and the capabilities to reduce risk by appropriate decisions in consideration of unexpected and unforeseeable aspects.

Block 3 Communication and acceptance of flood warnings

In accordance to rational decision-making, meteorological and hydrological forecasts can be regarded as successful only if the given warnings and alerts result in decisions which prevent harmful consequences of flooding. Thus it is essential that forecasts are communicated in such a way that they are meaningful for the specific situation of the addressee. Forecasts and warnings have to be interpreted and understood correctly, so that the parties involved take the right measures. Therefore, the development and operation of information platforms for disseminating flood warnings and severe weather warnings become as important as the accurate and reliable forecasts themselves. Moreover, the individuals' perception and awareness of flood risks has to be ensured and sustained permanently. Media presence of flood risk is a substantial component of this permanent process. Finally, it is important to utilize the knowledge about human behaviour patterns to optimize the communication process of different aspects of the flood risk cycle. These issues were presented in five lectures that are outlined and briefly discussed here.

First, **André Walser** (MeteoSwiss) reported on lessons learned from the research project MAP D-PHASE. It is a Forecast Demonstration Project of the World Weather Research Programme (WWRP) that is tied to the Mesoscale Alpine Programme (MAP). D-PHASE stands for ‘Demonstration of Probabilistic Hydrological and Atmospheric Simulation of flooding Events in the Alpine region’. Its goal is to demonstrate the ability to make reliable and operational forecasts on orographically influenced (determined) precipitation in the Alps and its consequences for the flood forecasting and warning. An important outcome of the project is – besides numerous technical improvements of the various meteorological and hydrological models and approaches involved – a Visualization Platform (VP) that is now providing a common information platform for natural hazards. The results of the different forecasting systems were made accessible in a user friendly way. The success of the project was demonstrated by the fact that end users were involved in an early phase of the project. This was achieved by workshops organized before and after the Demonstration Phase (DOP) of the project and by questionnaire polls concerning the clarity and understandability of the information provided. Also the need for guidance and training became apparent.

Joachim Mahrholdt (ZDF, German Television) discussed the problem of low media coverage of flood risk between flood events. He explained the basic principles of journalism in that media coverage has to be focused on extraordinary information. The understanding of these principles and maintaining good contact with the media are preconditions for the involvement of scientists and decision-makers in reporting flood-risk and risk management. The facts and the code of practice of flood-risk management have to be embedded in interesting stories. A certain presence in the media, even when nothing happens, helps to ensure the continuous awareness of the public and the competent authorities of flood risks and the necessity of flood precaution. The role of the local and regional press should neither be overestimated nor underestimated. Mahrholdt encouraged the experts to seek contact with media professionals.

Dominique Bérod (Swiss Federal Office for the Environment) explained the five general conditions which have to be fulfilled for effective flood warning systems. These led to the development of the common information platform GIN, which is now available to authorities responsible for managing natural hazards. He concluded that every piece of information concerning an ongoing event should be available to authorities and specialists. The authorities are organized in different hierarchical levels (internal, national, regional, local). Thus communication between authorities and the population is an essential factor during risk and emergency situations. Good cooperation between experts at different levels and locations and an efficient infrastructure for the flow of information and communication ensures added values. Additionally, Bérod tackled the problem of false alarms in the warning chain. The users should be informed about the uncertainties of forecasting products and the possibility of false alarms. There is a need for quantifying the costs incurred by false alarms objectively. Often decision-makers have their own expectations about these costs. In the presentation the need for investments to generate public acceptance and public trust became obvious.

Michael Schanne (Zurich University of Applied Sciences) examined the role of the media and how it functions. In each phase of the disaster life cycle, mass media and journalistic reporting may provide information to the general public, which can not be reached in other ways. Schanne underlined that in crisis situations the mass media is the most important – and often the only – source of public information for the majority of individuals. Furthermore, the people have more trust in the media than in authorities. Altogether, he demonstrated that close coordination and cooperation between the different units of disaster management and the unit responsible for issuing public information is as essential as the communication between the press office and the newsrooms. Due to the fact that journalistic coverage follows known empirical and anecdotal evidence, descriptions of mental and psychological states of ordinary people during and after a disaster are often more interesting than factual statements provided by local authorities.

The level of public flood awareness differs strongly according to the personal experiences of people who have been affected by floods. This became obvious in the presentation given by **Heinz Gutscher** (University of Zürich). He explained that persons who have been directly affected by a disaster exhibit the highest mental and psychological stress. He presented the results of an empirical study conducted in Switzerland which compared the perceptions of persons who were affected by a flood event in 2005 with the perceptions of flood risk by persons who resided in regions with a comparable susceptibility to floods who had no personal experience of flood damages. From this study, and based on general psychological knowledge, he came to the conclusion that information about the experience and personal perceptions of individuals previously affected by floods could be a good prerequisite for raising the risk awareness of others. This can lead to improved strategies to enhance individual preparedness within the disaster–response cycle. As an example, he mentioned that brochures concerning information about floods tend to be too technical. Negative emotions caused by flood experience are mentioned insufficiently or not at all. Homeowners in flood-prone areas should be informed about the experiences of affected persons. The role of eyewitnesses – which was formerly part of the 'oral history' – should be given proper attention. If more emphasis is given to this aspect, affected people can take timely and appropriate precautionary measures. In this regard, the challenge of risk communication lies not so much in providing rational information but in adequately addressing the body of experience ('experiential system') of an individual. Due to the fact that people have difficulty in imagining potential affective states, it is necessary to use a substitute for firsthand flood experience. Possible measures could be:

- Develop 'social engineering' against fading memories;
- Implement yearly 'flood days', i.e. exercises on irregular unannounced dates;
- Increase person-to-person communication;
- Activate emotional connection by evoking empathy.

Intensive discussions arose in direct response to the presentations given, and the participants were impressed by the more-or-less nontechnical aspects of communication and information policy. It was widely accepted that there is a need to take into account the reported findings within the context of the broad field of flood risk management, including the communication of meteorological and hydrological forecast products. The challenges in communicating facts provided by experts into mass media information for affected people were generally agreed upon. For example, issuing information like "the water level will overtop the critical level in the city [...] during the next 12 hours" is obviously insufficient to stimulate personal activities in an appropriated way.

Block 3 conclusions

The role of mass media should be given proper attention. The efficiency of the media in operational flood risk management depends on the processing of information at the interface between flood experts and mass media.

Needs for further research

The tools of empirical social research should be used to analyse the efficiency of communications of flood warnings after flood events. Deficits of flood information ("too uncertain, too spare, too unspecific") should be estimated and shared with the aim to set-up an information policy and communication networks which are useable and useful for affected people during flood events. In order to achieve the level of public participation demanded by the EU Flood Directive, new approaches are needed to raise public flood awareness.

❖