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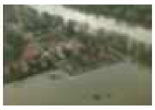
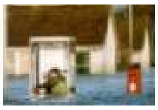
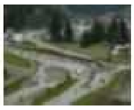
Integrate, Consolidate and Disseminate
European Flood Risk Management Research

First CRUE ERA-Net Common Call
Effectiveness and Efficiency of Non-structural Flood Risk Management Measures



CRUE Research Report No I-5:

Effectiveness and Efficiency of Early Warning Systems for Flash-Floods (EWASE)

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Effectiveness and Efficiency of Early Warning Systems for Flash-Floods (EWASE)

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ERA-NET CRUE Funding Initiative on Flood Risk Management Research

Risk Assessment and Risk Management: Effectiveness and Efficiency of Non-structural Flood Risk Management Measures

Effectiveness and Efficiency of Early Warning Systems for Flash-Floods (EWASE)

CRUE Research Report No I-5

Prepared by **Funded by**

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1st CRUE Funding Initiative on FRM research

ERA-Net CRUE is a network of European government departments who directly fund flood risk management programmes and related research actions. In order to tackle the challenge of rising flood risk and to develop effective policies and risk management practices, policy-makers and key stakeholders need a strong evidence base. Evidence-based policy-making is the key to modern, forward-looking strategies for dealing with increasing flood risk. Trans-boundary and trans-national flood risk management issues are becoming more and more important, requiring in particular joint research and development initiatives. The creation and implementation of a European research area in flood risk management – as intended by the CRUE ERA-Net - is an important contribution to an improved trans-national perspective for flood-related research in Europe.

Besides co-ordinating research between Member States, CRUE aims to contribute towards the presentation of research needs with its own trans-nationally based funding initiatives. Common trans-national research calls initiated by the partner countries are a principal activity within the CRUE ERA-Net which can be considered as specific actions to respond to current policy and development needs in Europe. With the launch of the first CRUE common call, a first step toward the integration of flood research in Europe was made.

The topic “Risk Assessment and Risk Management: Effectiveness and Efficiency of Non-structural Flood Risk Management Measures” was selected by six of the CRUE partner countries through an intensive consultation process and is to a great extent based on developments in European flood risk management policy (e.g. EU Floods Directive). In particular, the call was designed to investigate and critically assess the effectiveness and efficiency of non-structural measures in comparison to structural measures and to identify barriers to implementation of these "soft" techniques. The call was an incentive to develop innovative methodological approaches. Moreover, it challenged researchers across Europe to integrate knowledge across different disciplines such as natural and social sciences, and engineering.

Each of the seven successful joint projects within CRUE’s 1st Funding Initiative for FRM research was designed to understand different national approaches to the use and appraisal of non-structural measures, explore what is successful, and what can be improved in terms of efficiency and effectiveness of such measures themselves. The research results presented in this report will provide policy-makers with a better understanding of how FRM as a part of integrated river basin management can deliver multiple benefits, for example reduced flood risk and improved environmental quality.

I feel confident that the outcome of this research will be a valuable contribution to national policy development and the improvement of flood risk-related practice.

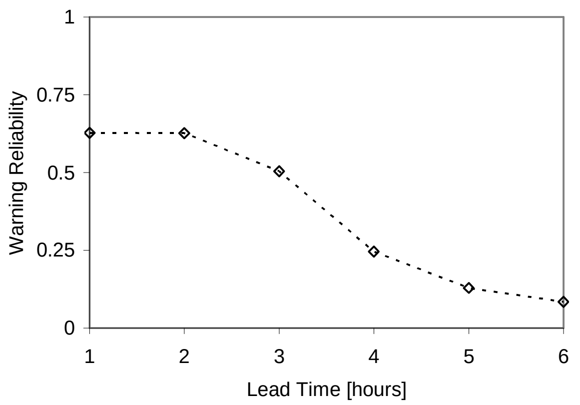
John Goudie
ERA-Net CRUE Co-ordinator, Defra, UK

Summary for Decision-Makers

EWASE evaluates the efficiency and the effectiveness of early warning systems (EWS) in small river basins that have short hydrological response times. EWASE provides information for optimal alerts through the analysis of the trade-off between the benefit of an increased lead time and the simultaneous decrease of warning reliability. The increase in lead time may provide valuable time for the completion of preventive measures, whereas the decrease of warning reliability will cause economic loss in case of a false alert.
Two study basins in Austria and Spain are presented to illustrate the application of the methodology proposed and to identify the key information required to integrate this approach into comprehensive flood risk management strategies. In this way EWASE synthesises data and experiences to help flood managers in finding better solutions for the operation of early warning systems.

After some background information and general definitions the newly developed approaches for the evaluation of flood forecast reliability and comparative risk assessment are introduced in chapter 3. Chapter 4 presents the exemplary application to the study basins and provides detailed information from hydrological and socioeconomic perspectives. In chapter 5 the findings from the study basins are summarised. This includes a comparison of similarities and disparities of both case studies, a discussion of the results obtained in order to provide a general overview of the project success. The findings from the analysis of warning reliability are integrated in terms of reliability curves, which reflect the hydro-meteorological characteristics of the study basins as well as the specific design of the operational EWS. The economic assessment estimates the potential benefit in form of avoided damages in an event dependent evaluation. The combination of reliability and avoided damages leads to the warning expectation as an indicator for the optimal alert. An event independent evaluation translates the avoided damages into a reduction of risk and compares the costs of the EWS with the benefits. The benefit cost ratio (BCR) for the EWS is compared to the BCR of structural flood protection strategies to appraise the economic dimension of EWS.

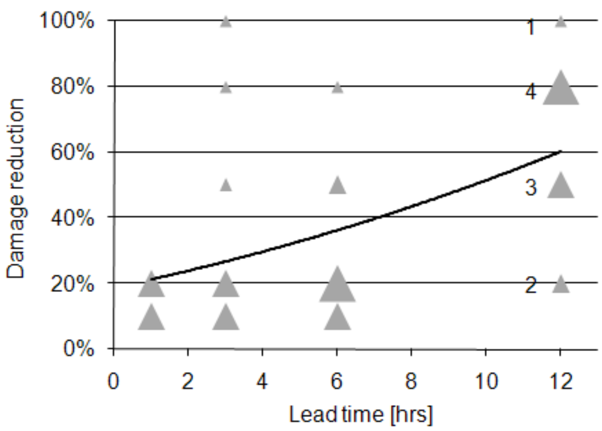
Reliability function as an integral indicator of system-inherent uncertainties



Warning Reliability as a function of lead time

Flood forecasting involves a considerable degree of uncertainty because the knowledge about the future development of meteorological conditions as well as the state and the behaviour of the hydrological system is still limited.
In view of different sources of uncertainty an integral measure to quantify the reliability of a flood forecast and the warning is adopted. This is based on a straightforward interpretation of flood forecasting errors obtained from the analysis of past flood events. **The information about the forecast errors is transferred to a measure of warning reliability**. The analysis of forecasts obtained for different lead times allows the representation of warning reliability as a function of lead time as outlined in the figure on the left. As can be seen from this graph the reliability of a forecast may decrease significantly even for short lead times.

Warning expectation as indicator for optimal alerts



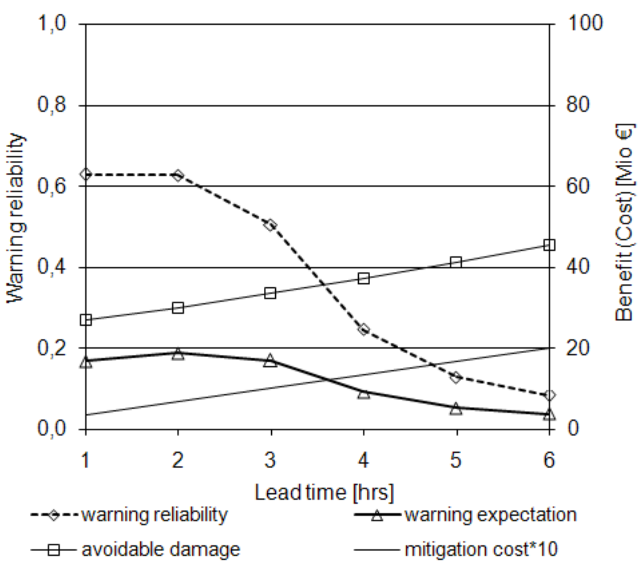
Damage reduction as a function of lead time. Result from a questionnaire based survey in the study basins.

For determining the ability of the companies to reduce flood damage in case of a flood alert, a questionnaire based survey was carried out. The most important question for assessing the benefit of an alert was:

"Supposed you receive an alert some time before a flash flood, by which percentage could you reduce flood damage?"

Respondents were asked to tick their estimate on a matrix. The answers are presented as grey triangles in the figure on the left. The size of the triangles is a measure for the frequency of a certain answer. To give an example, four respondents estimated, that they could reduce their flood damage by 80% if they would receive a warning 12 hours before a flood. Twenty one answers are at and below 20%, fourteen answers are at or above 50%. Obviously there is a clear correlation between preparedness and effectiveness of mitigation measures. The sample of answers has been analysed by means of a non-linear regression as indicated by the black line in the graph.

The diagram below presents **the Warning expectation as an indicator for the optimal alert** in a general form. With respect to the left axis, the warning reliability curve is drawn as introduced above. Avoidable damage as calculated from the regression line and the comparative risk analysis is drawn with respect to the right axis. According to this the potential damage reduction decreases continuously for shorter warning lead times. The line in the lower part of the graph introduces mitigation costs in terms of lost net value of production (the corresponding values have been scaled with a factor of 10). This curve indicates the cost per hour that arises if the active persons stop the productive work and turn to preventive measures.



Warning Expectation as indicator of optimal alert for the industrial sectors in the Besòs basin

In view of considerable costs in terms of lost production associated with an alert, there is good reason to reflect carefully about triggering an alert for a flood event which is still uncertain to occur.

The expectation of an alert is defined as the product of the warning reliability and the avoidable damage. The resulting curve, with units € per alert, is given as a bold line in the figure on the left.

Warning expectation is not constant but changes with lead time. The maximum of the warning expectation curve defines the optimal point of time for releasing an alert with respect to reliability and consequences.

Results and Key findings

Comparison of structural and non-structural flood protection strategies

Measure	Benefit-Cost Ratio			Source
	min	mean	max	
Polder use	2.20	4.00	5.80	Förster et al. 2005
Polder invest		0.10		Gocht 2004
FRBs		0.50		Merz & Gocht 2001
Local measures		5.20		
EWS	**2.60**	**4.60**	**9.00**	**EWASE**
Insurance		0.80		Gocht 2003
Derivatives		0.90		

The table on the left compares the results from one case study of the EWASE project to research work from the last years. A study on Polder use and construction at Elbe and Odra revealed the use of the Havel polders to be very beneficial in an event dependent assessment (Förster et al. 2005). The erection of a Polder under less favourable conditions at Odra river turned out to deliver no economic benefit (Gocht 2004). Whereas local protection measures showed significant benefit in a micro scale BCA, flood retention basins (FRBs) failed to meet the economic criterion of a BCR of at least 1 (Merz & Gocht 2001). A theoretical work on flood insurance and flood protection via precipitation derivatives resulted in BCRs close but below one (Gocht 2003). In comparison to these experiences the BCRs resulting from the assessment of EWS efficiency are compelling.

Consequently, in the light of current knowledge given the assumptions and region of investigation of this study, no FRM strategy appears to be more efficient than the combination of local protection and early warning.

Early warning as discussed in EWASE **offers a significant potential to transfer responsibilities from the state to the individuals**. The extent to which individuals are enabled to care for their safety and to optimise their benefit from the warning depends to a large part on the distribution of the warning. Particularly in the economic sectors high potential benefits can be realised, because of the ongoing presence of people at least during the day. As 60 to 70% of the risk arises in the economic sectors, there is a high potential for damage reduction due to early warning. It is therefore a promising means to implement the EWASE approach on the company level supporting managers to decide about releasing an alert for optimising their benefit from early warning.

Early warning systems as a non-structural protection measure induce very low detrimental effects on the natural environment. Therefore the implementation of early warning is a good opportunity to **reconcile the Water Framework Directive and the Floods Directive.**

Early warning is well in line with the **protection of the weak**. In fact timely warning may be the only possibility to evacuate the sick, the elderly, the children and the pupils from hospitals, resorts, kindergartens and schools.

Contents

1 Introduction

"This chapter provides a short introduction to the background of the EWASE project in relation to the first common call of the ERA-NET CRUE funding initiative and current research activities in the field of flood risk management in Europe"

EWASE approaches flood damage protection as a cross sectional and interdisciplinary task comprising different fields of politics, economics, sociology, environment and technology. Among experts it is widely accepted that flood protection is not simply an engineering problem which can be solved by technical measures only. The motive for current European flood research activities is the ambition to achieve a more deliberate and transparent discussion and dealing with flooding risks. In this context, it has become generally accepted that floods are a recurring natural phenomenon and complete protection against flood damage (zero risk) is an illusion. Within this development, it has been frequently stated that only an adequate combination of technical and non technical measures is suitable to provide efficient strategies for successful flood risk management.

Flood alerts provided by early warning systems (EWS) are an important element of comprehensive flood risk management strategies. The purpose of EWS is to provide information on expected flows and water levels prior to the actual occurrence of a flood peak and to generate alerts in order to take preventive measures for avoiding damages.

The potential benefit from the anticipation of imminent floods is unquestioned. Nonetheless, reliable forecasts are a basic requirement for warning system operators and responsible authorities to take robust decisions. Especially in river basins prone to flash-floods, critical situations develop quickly and make high demands on th warning lead time. However, uncertainties with regard to the formation and evolution of forthcoming storms as well as uncertainties inherent to the mathematical modelling of rainfall-runoff processes reduce the reliability of flood forecasts with increasing lead time.

The evaluation of the effectiveness of an EWS is basically related to the question whether a reliable alert can be set off with sufficient lead time to complete preventive measures. For the EWS to be efficient, the decision about a flood alert has to trade off the prolongation of the warning lead time and the decrease of forecast reliability. In this context, it is important to bear in mind that a successful warning will bring about (socio-) economic benefit whereas a false alert leads to (socio-) economic loss.

EWASE assesses the effectiveness and efficiency of the EWS by comparing two basic factors: the reliability of the provided forecasts and the economic benefit of this information.

For this purpose, on the one hand, the requirements of the warned concerning forecast lead-time will be determined based on an assessment of flooding risks in the catchment. On the other hand the reliability of the provided forecast will be quantified in view of uncertainties present in the different components of the forecasting chain.

EWASE develops its approach on the basis of two meso-scale river basins covering different physical and climatic conditions of a Mediterranean (Besòs) and an Alpine (Traisen) catchment.
Within the framework of these case studies EWASE takes into account the performance of existing structural protection schemes in the Besòs (Spain) and Traisen (Austria) catchments and investigates how the protection schemes are improved through the use of an EWS.

EWASE, firstly develops a methodology to quantify the reliability of flood forecasts as a function of lead time in view of uncertainties in meteorological forecasts and hydrological modelling. Secondly, a concept for risk analysis is worked out that analyses the vulnerability in terms of exposure and susceptibility and quantifies the response behaviour, i.e. the preparedness, of the stakeholders at risk. Special consideration is given the requirement to provide methods that can be applied European-wide. Therefore information from environmental survey as well as statistics which are largely available within European countries is preferentially used.

In this way, EWASE contributes to the assessment of the effectiveness and efficiency of non-structural flood mitigation measures in comparison to structural measures.

2 Objectives

The assessment of the effectiveness and efficiency of early warning systems involves two central questions. With regard to effectiveness this relates to the question whether an imminent flood is forecasted reliably and allows for a warning with sufficient lead time to avoid damages. The second question concerns the efficiency and is whether the benefit and the cost of this warning are at a reasonable ratio in the long run.

The EWASE project is embedded into current European flood research activities. Therefore, these problems are connected to more general questions concerning the assessment of structural and other non-structural flood protection measures in a flood risk management context. On that account, the motive of the EWASE project is to contribute to these activities by relating the concept of risk analysis to the evaluation of early warning systems.

In the following, the different problems addressed within the project work are detailed.

2.1 Analysis of flood forecast reliability

The warning production chain of the EWS is usually composed of a set of simulation models including meteorological, hydrological and hydraulic models. Quantitative precipitation forecasts are fed into hydrological models which are used to represent runoff generation, runoff concentration and flood routing processes. Hydraulic models provide the functionality to determine water levels and inundated areas.

Each component of the forecasting chain is subject to uncertainties which affect the reliability of the generated flood forecast. In addition to the uncertainties introduced by the precipitation forecasts, hydrological models are basically affected by the uncertainty due to the simplified representation of the real system in terms of the selected model structure as well as uncertainties concerning the system state and the model parameters.

The objective is to evaluate the reliability of the outcomes of the hydro-meteorological forecasting system taking into account the different sources of uncertainty. For this purpose the uncertainties associated to the precipitation forecast have to be embraced and propagated down to the flood forecasts in order to quantify the predictive uncertainty. This requires a consistent methodology to treat the uncertainties from the different sources. Hence, a practicable approach to assess flood forecast reliability of EWS as a function of forecast lead time in view of different sources of uncertainty has to be developed.

This includes work related to the analysis and quantification of precipitation forecast and hydrological modelling uncertainty. Further, it was intended to assess the implications of malfunctions in EWS operation on forecast reliability. However, this task could not be fully accomplished owing to limitations in available data and resources.

2.2 Risk analysis

A prerequisite for a reliable risk analysis is a detailed understanding of the local socio-economic conditions and how flood plains are used. A sound understanding of the present organisation of flood risk

management in the fields of information, prevention, protection and emergency will deliver the input data for further work steps in the project.
An analysis of the sectors:

- Public Services,
- Public Utilities,
- Private Dwelling,
- Trade and Service,
- Manufacturing Industry,
- Agriculture and Forestry,
- Recreation,

will deliver damages to be expected in case of flooding as well as damage mitigation if preventive measures are completed. Furthermore the cost associated with taking preventive actions is assessed. On this basis the flood risk can be quantified.
Existing structural flood protection measures are another point of interest. A point of special importance contributing crucial information for the project success is the establishment of a relationship between lead time and avoided damage.

2.3 Economic Evaluation

Economic Analysis of the EWS comprises a comprehensive survey of all costs associated with the EWS as

- Investment costs
- maintenance and repair costs
- operating costs

The Benefit Cost Analysis opposes the present value of the EWS to the present value of risk as Expected Annual Damage mitigated in the basins by EWS. This will lead to a Benefit Cost Ratio.

As we cannot monetarise all aspects of damage in the basin, we include such intangible damages in a qualitative multi-criteria Assessment. We will present the result in form of a simple decision support tool which enables decision makers to evaluate the influence of a certain lead-time on the damage avoided. As different system configurations for the EWS considered were not available, this aspect could not be evaluated.

3 Methodology

"This chapter introduces the methodology developed for the evaluation of early warning system effectiveness and efficiency in terms of forecast reliability and economic benefit."

3.1 Evaluation of Flood Forecast Reliability

3.1.1 Scope of flood forecasting

The motive of flood warning is to reduce damages by taking preventive measures. Hence, an effective warning system provides reliable forecasts sufficiently in advance to realize the according actions. Obviously, the required lead time depends on the specific tasks to be completed and, as a consequence, it is variable for the different stakeholders and objects at risk.

In flash-flood prone areas critical situations develop quickly and put high demands on the warning lead time (Anquetin, et al. 2004). Flood warning based on observations of upstream river gauges only capitalizes on the travel times in the water course and thus most often is insufficient in this respect. Instead, the application of advanced technologies is required. In this context, the use of rainfall runoff models is mandatory in order to extend the lead time which then starts from the moment rainfall is observed. Still, the gain of time is limited approximately to the response time of the basin. A further increase of the forecast lead time can only be achieved by including quantitative precipitation forecasts (QPF). Radar nowcasting is a promising technique for the short term anticipation of rainfall (Wilson, et al. 1998). However, these procedures provide useful information at the best two hours in advance. Beyond, QPF based on numerical weather prediction (NWP) models can be used to extend the flood forecast up to several days, yet with less accuracy as lead time extends (Collier 2007, Yates, et al. 2000).

Both the application of hydrological models and in particular the use of QPF information brings about considerable uncertainties concerning the flood forecast and the warning. In view of these uncertainties, the capability to reliably predict floods is determined by the anticipation and provision of accurate rainfall information in space and time (Yates, et al. 2001) as well as by the correct reproduction of the hydrological system in terms of the state and the dynamic behaviour by means of the hydrological simulation model.

Therefore, to evaluate whether or not an EWS is effective the reliability of the flood forecasts has to be quantified as a function of the lead time in view of the relevant sources of uncertainty in the forecasting chain. Further, it has to be discussed in view of the intended purpose of the warning and the required time to complete the preventive measures.

Given this background, the objective of this work is to develop a practicable approach to assess the flood forecast reliability of EWS. This provides important information concerning the effectiveness and efficiency of EWS within the context of a risk based evaluation of structural and non structural flood risk management measures.

3.1.2 Forecast reliability

Basically, the objective of hydrological forecasting is to provide quantitative information about the future evolution of discharges or water levels. In this regard, flood forecasts support the decision on flood alerts in EWS operation. However, the prediction of future events is always uncertain owing to the variability inherent to natural processes and, more importantly, owing to limited knowledge about the future development of meteorological conditions as well as the state and the dynamic behaviour of the hydrological system. In particular, the uncertainty concerning the predicted flood event exists with regard to the magnitude, the location and the timing of the expected flood peak. In this context, Krzysztofowicz (1999) and Todini (2007) pointed out, that the term predictive uncertainty refers to the actual values of the predicted variable.

In the case of model based forecasting systems using QPF the predictive uncertainty is conditional on the hydrological model applied, which represents the available knowledge about the hydrological sys-tem, and on the capability of the QPF method to anticipate the characteristics of forthcoming storms. Thus, predictive uncertainty characterizes the state of knowledge about the forecasted variable and is a function of the uncertainties in the data and the reproduction of the natural system with a simulation model.

In theory, predictive uncertainty can be expressed in terms of a probability distribution function that describes the variation and the expected value of the predicted variable. Todini (2007) illustrates how this distribution function can be inferred from the comparison of predicted and observed values using a Bayesian approach. However, practical approaches to determine the distribution function accounting for all sources of predictive uncertainty are still under evaluation (Krzysztofowicz 2001, Krzysztofowicz & Maranzano 2004).

3.1.3 Description of forecast reliability

The approach proposed within this study is based on the assumption that the predictive uncertainty can be approximated by the errors between predicted and observed discharge values. To this end, the capability of a flood forecasting system to predict discharges is evaluated on the basis of available observations from past events in terms of a statistical analysis of the prediction error defined in Equation 1.

$$\varepsilon_{i,\tau} = \frac{|Qsim_{i,\tau} - Qobs_i|}{Qobs_i} \qquad (1)$$

$\varepsilon_{i,\tau}$ Prediction error of forecasted discharge at time step i with lead time τ
$Qsim_{i,\tau}$ Forecasted discharge at time step i with lead time τ
$Qobs_i$ Observed discharge at time step i

According to this, the error is calculated for each time step i of the period analyzed as the absolute difference between the simulated discharge value for this point of time predicted with lead time τ (Qsimi,τ) and the discharge actually observed at this time step ($Qobs_i$) normalized with $Qobs_i$.

The prediction error $\varepsilon_{i,\tau}$ is the outcome of the different sources of uncertainty in the flood forecasting chain. In the ideal case of a perfect forecast the prediction would exactly match the observation of the real world discharge (within the range of the effective observational error).

From the analysis of equation 1 for one event or a set of flood events a sample of errors is obtained. Assuming that all error values stem from the same population this sample is statistically summarized in terms of a probability density function (PDF) or a cumulative distribution function (CDF) respectively. The CDF allows extracting the probabilities of having errors within a certain range. On this note, the evaluation of the CDF for a particular probability quantile provides an estimate of the magnitude of the prediction error with the according level of confidence. In line with this interpretation, the error at the 85% percentile of the CDF (ε_τ(85%)) is assumed to provide an appropriate estimate of forecast reliability. As reliability is usually defined on a scale between zero (unreliable) and one (reliable) ε_τ(85%) is inversely related to forecast reliability (FR) as in equation 2.

$$FR = 1 - \varepsilon_\tau(85\%) \qquad : FR \geq 0 \qquad (2)$$

$\varepsilon_\tau(85\%)$	0.85 quantile of the forecast error with lead time τ
FR	Forecast reliability

According to this, forecasts with small prediction errors are more reliable than forecasts with large errors. For illustration, the procedure of statistical analysis and evaluation of forecast reliability is exemplified in Figure 3-1. The PDF and corresponding CDF for error samples obtained for different lead times τ are shown as well as the dependence of FR on the lead time.

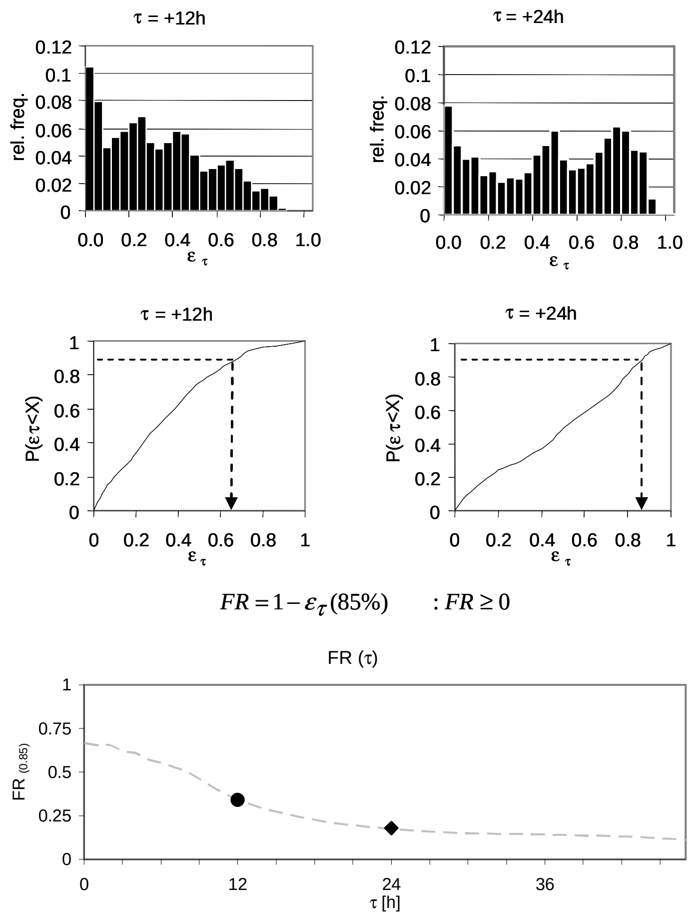


Figure 3-1: Procedure for the statistical evaluation of prediction errors and evaluation of forecast reliability

3.1.4 *Lead time dependence of forecast reliability*

Within this framework the dependence of FR on the forecast lead time is examined by evaluating equation 1 for hydrographs that are predicted with different lead times τ. To this end, a multiple step ahead forecast approach (WMO 1992) is carried out. This includes the generation of forecasted hydrographs for multiple time steps t_i (i = 1,…n) of an event using different lead time periods τ (τ = +1,…,+p [h]). Hydrographs are simulated using ob-served rainfall until t_i and the precipitation forecast available at t_i. The corresponding sample of $\varepsilon_{i,\tau}$ reflects the predictive performance of the forecasting system throughout the analyzed period.

3.1.5 *Accounting for different sources of uncertainty*

It has to be recalled that the sample of errors ε_τ is conditional on the QPF and the simulation model used for the generation of flood forecasts. Assuming that the uncertainties associated with the QPF and with the hydrological model considerably contribute to the reliability of the forecast, it is worthwhile to address these uncertainty sources more directly in order to obtain a more complete picture of predictive uncertainty. In this respect, ensemble modelling is a promising approach to explicitly incorporate these sources of uncertainty in the evaluation of FR.

The basic idea of ensemble modelling in natural sciences is to consider a set of different possible realizations of future conditions. In Meteorology, one method to obtain an ensemble is to introduce random perturbations to the initial state of a meteorological model (Lorenz 1963). In that way a set of possible future developments of meteorological states and resulting precipitation fields is generated, which de-scribes the uncertainty inherent to the prediction, e.g. (Buizza, et al. 1999) for NWP models and (Bowler, et al. 2006) for probabilistic radar nowcasts.

3.1.5.1 QPF uncertainty

Within EWASE the Traisen EWS incorporates QPF from the INCA-System (Integrated Nowcasting through Comprehensive Analysis) (Haiden, et al. 2007), which is made avail-able by the Central Institute for Meteorology and Geodynamics (ZAMG). INCA is based on a weighted combination of extrapolations from rain gauges and radar observations using motion vectors (nowcasts) with QPF from the NWP models ALADIN (Wang, et al. 2006) and ECMWF. Within INCA a deterministic QPF and an ensemble QPF are produced. The generation of the ensemble forecast is based on a random combination of the ECMWF ensembles with a pseudo ensemble of the deterministic ALADIN forecast. This ensemble is produced by shifting the QPF field on a random space lag. The nowcast data do not include a quantification of uncertainty in terms of an ensemble. Therefore, for short lead times ($\tau < +2$ h), where the nowcast data provide the essential part of information, all ensemble members are identical (Komma, et al. 2007).

3.1.5.2 Hydrological model uncertainty

The idea of ensemble modelling can also be transferred to the application of different simulation models. Every model is an interpretation of reality and relies on a scientific hypothesis about the cause-effect relations of the system under study. In this context, on the one hand the application of different hydrological simulation models provides insight into the suitability of different modelling concepts and process representations for flood forecasting. On the other hand, the prediction of one specific model represents only one realization of all possible predictions. In view of the fact that no model outperforms all other models all the time, it is expected that the combination of different models in a multi-model ensemble represents an estimation of the uncertainty related to the simulation model (Clemen 1989, Shamseldin, et al. 1997).

Within the scope of this study, following the reasoning of Georgakakos, et al. (2004) and Refsgaard, et al. (2006) the concept of multi-model ensembles is applied to characterize hydrological uncertainty in the forecasting systems.

Within EWASE the multi-model ensemble consists of two continuous (COSERO and WBrM) and one event based model (DICHITOP).

COSERO (Kling 2002, Nachtnebel&Kahl 2007) is a semi-distributed deterministic conceptual rain-fall runoff model developed on the basis of the HBV Model (Bergstrom 1992, Bergstrom 1995). The spatial representation of the catchment uses hydrological response units which are defined according to land cover, soil and height. The transformation of the flood wave along the river course can be represented either by a linear reservoir or a cascade of linear reservoirs.

WBrM (Lempert 2000) is a distributed deterministic hydrological model based on a detailed representation of soil moisture related processes. The catchment is discretised in square grids. These raster elements are the smallest unit to represent spatial heterogeneity of catchment characteristics and meteorological input data. For each raster element vertical and lateral process rates are determined based on a piecewise linear approximation of the process equations using conceptual approaches (Ostrowski 1991). WBrM uses a kinematic wave approach for flood routing.

DICHITOP (Corral 2004) is a conceptual distributed deterministic rainfall runoff model. Grid cells form the response units for hydrological processes. Runoff generation is described using the TOP-MODEL approach (Beven & Kirkby 1979) for rural areas and the SCS method (Mockus 1957) for urban areas. Flood routing is modelled using a diffusive wave unit hydrograph for each cell which are linearly superimposed at the basin outlet.

In addition, the predictive performance of the different hydrological models is compared in order to assess the suitability of alternative modelling concepts and system representations. The comparison of model predictive performance is based on various criteria summarised in Table 3-1.

Table 3-1: Evaluation criteria of model predictive performance

Criterion	Definition
Model efficiency (Nash and Sutcliffe 1970)	$E = 1 - \frac{\sum_{i=1}^{n}(Qsim_i - Qobs_i)^2}{\sum_{i=1}^{n}(Qobs_i - \overline{Qobs})^2} \quad , -\infty \le E \le 1$ The efficiency E is defined for -∞ < E < 0. The closer E is to 1 the more accurate is the model prediction. A. value for the efficiency of 1 (E = 1) corresponds to a perfect match of the simulated (Qsim) to the observed (Qobs) data. An efficiency of 0 (E=0) indicates that the model predictions are as accurate as the mean of the observed data, whereas an efficiency less than zero (-∞<E<0) occurs when the observed mean is a better predictor than the model.
Coefficient of determination (according to (Legates and McCabe, 1999)	$R^2 = \left\{ \frac{\sum_{i=1}^{n}(Qsim_i - \overline{Qsim}) \cdot (Qobs_i - \overline{Qobs})}{\left[\sum_{i=1}^{n}(Qsim_i - \overline{Qsim})^2\right]^{0.5} \cdot \left[\sum_{i=1}^{n}(Qobs_i - \overline{Qobs})^2\right]^{0.5}} \right\}^2 \quad , 0 \le R^2 \le 1$ R² is a statistical measure that describes the proportion of explained variability between two variables, here Qsim and Qobs. It is defined in the range of 0 to 1, with larger values indicating better agreement between the data series. For R² = 0.5 is not sensitive for additive or proportional relations between the series.
Mass balance error [%]	$MB = \frac{\sum_{i=1}^{n}(Qsim_i - Qobs_i)}{\sum_{i=1}^{n} Qobs_i} \cdot 100$ MB describes the percentage deviation of the simulated and observed flow volume within the evaluation period of the event examined. A value of 0% corresponds to a perfect match. Flow volume is underestimated for negative values and overestimated for positive values.
Peak ratio	$peak\ ratio = \frac{Qsim_{max}}{Qobs_{max}} \quad , 0 < peak\ ratio$ The peak ratio describes the proportion of the simulated peak discharge [m³/s] to the observed peak discharge within the event period. According to the definition $peak\ ratio > 1$ correspond to an overestimation of the observed peak and $peak\ ratio < 1$ indicate an underestimation of the flood peak.

3.1.5.3 Summary of the Approach

In brief, the approach proposed to assess the forecast reliability of EWS is based on the statistical analysis of the prediction errors calculated according to equation 1. The sample of errors results from the evaluation of hydrographs which are determined by cascading the ensemble QPF through a set of hydrological models, as illustrated in Figure 3-2.

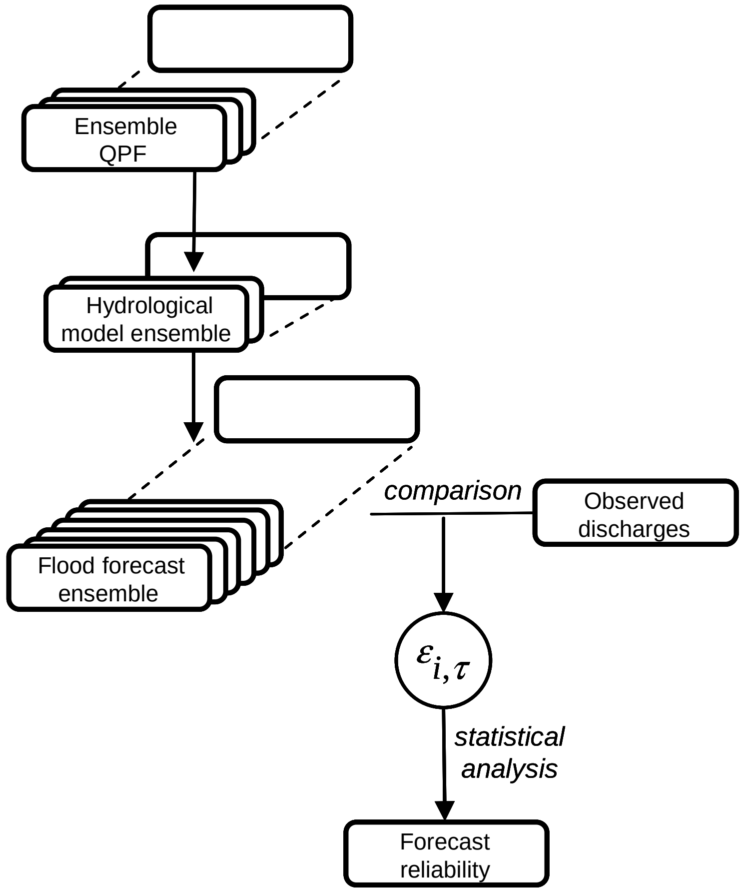


Figure 3-2:Outline of the methodology for the analysis of forecast reliability using ensemble QPF and multiple hydrological models

3.2 Comparative Risk Analysis

Whereas the effectiveness of an early warning system may be assessed without economic considerations, the economic assessment is central for estimating its efficiency. For answering this question several steps need to be undertaken. A comparative risk analysis was performed to reveal the potential damages in the area at risk and a questionnaire survey aimed at revealing the ability of the people at risk to respond to the hazard. The focus of this study was on the industry sectors. Therefore a methodology was developed, which lends itself well to the estimation of damage to industries. The households of the private sector contribute a significant share to the total damage. But as there already are studies focusing on this sector (Parker et al 2007) these studies where utilised for the private sector.

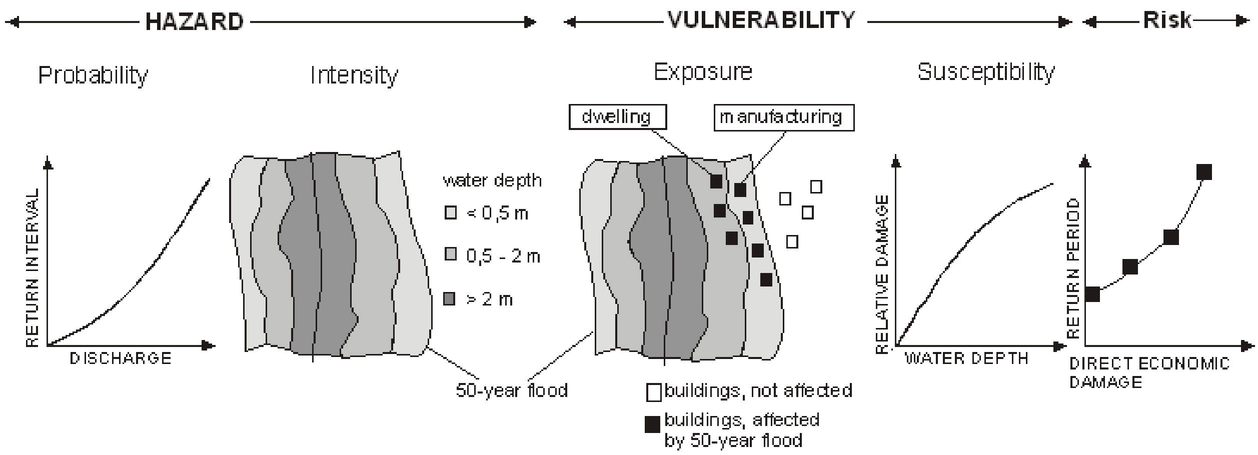


Figure 3-3: Risk definition (Merz et al 2007)

The term risk has different meanings. Therefore it is necessary to define it and to give indicators which allow to quantitatively describe and to map flood risks.

3.2.1 *Risk Definition*

3.2.1.1 Flood hazard

Flood hazard is defined as the exceedance probability of potentially damaging flood situations in a given area and within a specified period of time. Flood hazard statements do not convey information about the consequences of such floods on society, built environment or natural environment. Since these consequences depend, among others, on the intensity of the flood, flood hazard statements should quantify the intensity of the process that go beyond a flood frequency curve. The most prevalent indicator for the intensity of a flood is the inundation depth. Different studies identified the water depth as the flood characteristic which has the biggest influence on flood damage (Penning-Rowsell et al., 1994, Wind et al., 1999). Therefore, the discharges from a flood frequency curve are commonly transformed into inundation scenarios (Image 1: Risk definition (Merz et al 2007)).

3.2.1.2 Flood vulnerability

Besides the flood hazard, the analysis of flood risk involves the characteristics of the elements at risk. The term ‘elements at risk’ includes all elements of the human system, the built environment and the natural environment that are at risk of flooding in a given area. Such elements are the population, buildings and civil engineering works, economic activities, ecosystems etc. The extent of flood damage depends not only on the flood characteristics but also on the vulnerability of the inundated area. For the same flood, in terms of intensity and exceedance probability, a more vulnerable area experiences higher flood damages. Vulnerability is composed of two elements, exposure (or damage potential) and (loss) susceptibility. Exposure analysis answers the question “Who or what will be affected by floods?” Exposure can be quantified by the number or the value of elements which are at risk. Analysis of susceptibility answers the question “How will the affected elements be damaged?” Susceptibility is usually described by relative damage functions. Such functions give the degree of damage if the building is flooded. It is however clear that the direct economic damage to an inundated building does not only depend on the water depth and building use (Smith, 1994; Penning-Rowsell et al., 1994; USACE, 1996, Merz et al., 2004). Other important factors are characteristics of the building (susceptibility of building fabric, precautionary construction measures etc.), socio-economic variables (flood knowledge, financial status of building owner, age profile of the inhabitants/tenants etc.) and the quality of the emergency response (operational use of early warning systems, time taken for assistance to arrive, amount and quality of response etc.). The situation is even more complex when other types of flood damage (fatalities, indirect economic damage etc.) are analysed. Therefore, flood damage assessments are frequently limited to direct economic losses. This limitation is problematic since different damage indicators may lead to different conclusions concerning the flood risk. Flood risk might be evaluated as more severe if the flood risk analysis not only considers direct economic damage but also takes into account the adverse consequences on the population and on long-term economic activities in the flood-prone area (Merz et al 2007).

3.2.1.3 Flood Risk

Risk is defined as the probability that floods of a given intensity and a given loss will occur in a certain area within a specified time period. In this way, risk always implies a quantitative measure. As shown in Figure 3-3 risk results from the interaction of hazard and vulnerability. A certain risk level can be reduced by decreasing the - hazard, e.g. increase in the water retention capacity of the catchment, - vulnerability, e.g. reduction of the assets in the flood plain, or installation of a flood warning system (Merz et al 2007).

3.2.2 Hazard Analysis

A detailed Hazard analysis was not within the scope of EWASE. As there exist studies on Flood hazard in the Traisen basin as well as in the Besòs basin. The results from these studies where taken as input for the risk analysis.

3.2.2.1 Besòs: INUNCAT data base

In June 2001 a study for the Besòs and its tributaries showing the floodplains for 50, 100 and 500 years return periods was completed. This study was part of the so called INUNCAT-Plan - the Special Flood Management Plan for Catalonia - a state wide flood emergency management plan. It shows, beside basic issues on technical matters such as meteorological, hydrological and hydraulic data as well as flood plains and specific hazard zones, organisational structures for flood emergency management (Agència Catalana de l'Aigua 2001).

The INUNCAT-Plan is a refinement and development of the INUNCAT'97-Plan which was set up in the aftermath of the severe floods in the Barcelona region in 1982 (Parlament de Catalunya, 2000). The present INUNCAT-Plan contains floodplains for different return periods that were determined with mathematical models. The hydrologic modelling was carried out with HEC-HMS of the U.S. Army Corps of Engineers; a digital elevation model with a resolution of 100 x 100 meters was one of its most important bases. The hydraulic simulations were carried out with the software system HEC-RAS. The necessary geometrical information for cross sections was generated on the basis of a digital elevation model with a resolution of 15 x 15 meters. This digital elevation model was also used to delineate the flood plains on the basis of the simulation results.

In the course of the risk analysis in EWASE the floodplains and the digital elevation model were validated and the inundation depths for the different return periods at the investigated objects were determined in a GIS.

3.2.2.2 Traisen basin: HORA data base

The water depths and the floodplains for the Traisen catchment in Lower Austria were taken from the risk zoning system HORA that was completed in 2005. HORA is a joint project of the Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management and the Austrian insurance sector (BMLFUW 2006). Like in the Besòs basin digital elevation models were used to generate the geometry of the cross sections that were in turn used as a basis for the reach-wise set up of hydraulic models for one-dimensional, steady-state and gradually varied flow. These models were calibrated making use of existing models. The simulation runs were carried out for 30, 100 and 200 years return periods. The underlying runoffs were determined making use of hydrological regionalisation. The floodplain zones in the HORA system represent inundations that would occur in case of failure of the flood protection measures. In

EWASE the inundation depths at the objects within these floodplain zones were determined on the basis of these results and the digital elevation model.

3.2.3 Vulnerability Analysis

A special challenge in EWASE exposure analysis was to ensure the trans-national comparability of the results between Spain (Catalonia) and Austria. In that the approach developed in EWASE may contribute to the aims of FLOODsite task 9 which aims, among others, at proposing harmonised state-of-the-art methods and principles for flood damage analysis in EU countries (Meyer&Messner 2005 iii). Currently no standardised methodology exists which could yield trans-nationally comparable results. In some European countries certain levels of standardisation have already been developed as the following overview presents.

3.2.3.1 England and Wales

In England and Wales in almost all studies standard damage data developed by the Flood Hazard Research Centre (FHRC, Middlesex University) is used for damage evaluation. The newest and updated version of the UK methodology is presented in the Multi-Coloured Manual (Penning-Rowsell et al. 2003). In England and Wales a large range of absolute damage functions is used that indicate damage in monetary units against water depth. For residential properties damage functions indicate damage per object, for non-residential uses they reflect damage per m². Indirect losses for non-residential properties are estimated as loss of value added. These damages do occur as losses for the affected firms but mostly not for the national economy, because nearly all production losses can be transferred to other firms. Therefore, it is recommended to carry out such evaluations only if a loss of production to other countries is likely to occur (Meyer&Messner 2005:6). Two important sources exist in the UK for estimating land use for properties for large scale studies at national, regional or catchment scale: The Address Point database, which contains the indicative location of every property, and the Focus database for non-residential properties, which includes information about the type of property (for example, residential, high street shop, etc) and its rateable value. Merging these two sources Halcrow created a database which includes all properties within floodplains in England and Wales (National Property Dataset). For each property category an average ground floor area is assumed (DEFRA et al. 2004).

3.2.3.2 The Netherlands

As benefit-cost aspects gained in importance over the last years, a standard method for flood damage evaluation in all 53 Dutch dike ring areas has been developed. The current version “Standard Method 2004 – Damages and Casualties caused by Flooding” (Kok et al. 2004; Kok et al. 2002) is part of the Flood Management System (Hoogwater Informatie Systeem; HIS). Household property is evaluated per dwelling; due to the use of commercial land use data (Bridgis) five dwelling types can be distinguished. As regards companies, the number of employees in each economic sector is used to approximate the intensity of economic land use. For every damage category a maximum damage amount (i.e. the total value) for the particular unit is given, based on surveys and estimations of Briene et al. (2002). Basis for the calculation are prices of the year 2000. There is no regional differentiation made, although Briene et al. (2002) are specifying the range of the values. For the estimation of dwelling damages, median market values are used, adjusted by the approximate ground value. The value of average contents per dwelling of 70.000 EUR was derived in a study by www.ineas.nl, an insurance company (Meyer&Messner 2005:9). Indirect maximum damage amounts by business disruption are evaluated on the basis of gross value added. Eleven damage functions were derived from a study by Vrouwenfelder (1997). Basis for the development of the functions are both damage data and expert judgement. There is only a small damage database in the Netherlands due to the fact that flooding does not appear frequently. The damage functions are relative damage functions in that they give a certain percentage of the total damage amount per unit. In the primary sector, units are m², in the secondary and tertiary sector, units are employees, and in the residential sector properties are used as units.

3.2.3.3 Germany

Due to the federal structure of Germany, the approaches applied vary significantly in the different states The River Rhine study in Northrhine Westphalia estimated the maximum damage potential, i.e. the total value of assets at risk on the basis of official statistics on the level of the federal state. These values are disaggregated to the research area by the use of ATKIS land use data. Where appropriate, the location of the buildings within these ATKIS land use units was also digitised. For the estimation of the expected damages relative depth-damage functions were used. A set of about ten sectoral functions was derived from the German HOWAS-database, modified by expert judgement and by the results of a company survey (MURL 2000, Messner&Meyer 2005).

In Saxony Damage potential analyses are carried out for flood protection concepts and the prioritisation of flood protection measures. The methodology applied owes much to the approach pursued in the ICPR Rhine Atlas, which is detailed in the following. The main difference is that Saxony recommends the use of the CIR biotope-type data which differentiates urban areas into settlement and industry, which is a progress compared to the Chorine land cover (LTV 2003)

ICPR Rhine Atlas - A trans-national approach

The ICPR Rhine Atlas was the first project on trans-national evaluation and mapping of flood risk (IKSR 2001). The CORINE land use data was used as a spatial basis. Only six different land use categories were derived from this data and approximate asset values were attached to each category. The asset values have a unit of €/m² and are derived from analysis of national accounting data in Germany. These approximate asset values are derived from other more detailed damage evaluation studies in Germany. In the case of “industry” and “settlement” they are differentiated in mobile and fixed assets. For each German federal state the standard values were adjusted due to differences in land use distribution. For Switzerland, France, and the Netherlands the German values were adjusted by data on purchasing power and GDP indices. For the estimation of damages six different relative depth-damage functions are used. These were derived from the German HOWAS database.

3.2.3.4 Principles of the EWASE Approach

A wider variety of approaches towards flood damage assessment exists. But the studies cited above are enough for preparing the ground of the EWASE approach. A first decision needs to be made about absolute or relative damage functions. Even on national level there is not much economic thinking in applying an identical damage function in central London and Milford Haven (Wales) just because the property is of the same type and age. But in terms of comparability it is desirable to use the same function. This is the rational of the ICPR approach: Economies differ throughout Europe, but Physics remains unchanged. Therefore identical relative damage functions are used in all countries. For a given water level they indicate a certain percentage of damage relative to the total asset value.
But the asset values in the countries differ. And a second decision has to be made about the derivation of these asset values. It is a good idea to use high quality data free of cost. Such data is generally rare. But in macro economics national accounting delivers data which meets these demands. In the ICPR Atlas such data was used. However a first major shortcoming of the ICPR Atlas is that economic analysis for Germany was transferred to other countries on the basis of economic indicators. The reason for that might have been that no data on EU level existed in 2001 for analysing economies in the other countries. But this situation has improved.

A third decision has to be made about the indicators of value. In the ICPR Atlas certain areal entities were selected as indicators of value, derived from the CORINE land cover. This is reasonable because CORINE is still the only consistent European model of land cover (Messner et al 2007). But at the same time it is the second major shortcoming of the ICPR Atlas: It is highly questionable if a value per m² is justifiable because the size of a companies premise is a weak indicator for its value. Large areas of the premises may have fallen out of use or may have been acquired for future development and currently do not carry any value at risk of flooding.

Merz et al (2001: 21) stated that Employees could be used as indicators of value given that a fixed relation between capital stock and employees exists. The Netherlands Standard Model makes use of this economic rational (Kok et al 2004) and it is used in the EWASE approach as well. As a matter of fact capital intensity (Capital stock per employee) is a common indicator in economics, and it lends itself well for regional differentiation as will be shown in the following.

An address point data base is needed furthermore for localisation of the assets. As there is no common data base in Europe, "address points" where produced within EWASE. In a first step remote sensing imagery was used to analyse the existing land use in the flood hazard zones of the Besòs and Traisen river systems. In the second step during an in-situ survey the land use structures were classified according to the NACE-Activities and further flood damage parameters were determined. A total of 5436 structures were located in the 200 years return period floodplain and included in the computations in the Traisen, 88% of them were classified as private dwelling. For the Besòs 2987 structures in the 500 years return period floodplain were located with only 45% private dwelling, but 51% within trade and manufacturing industry, see Figure 3-4.

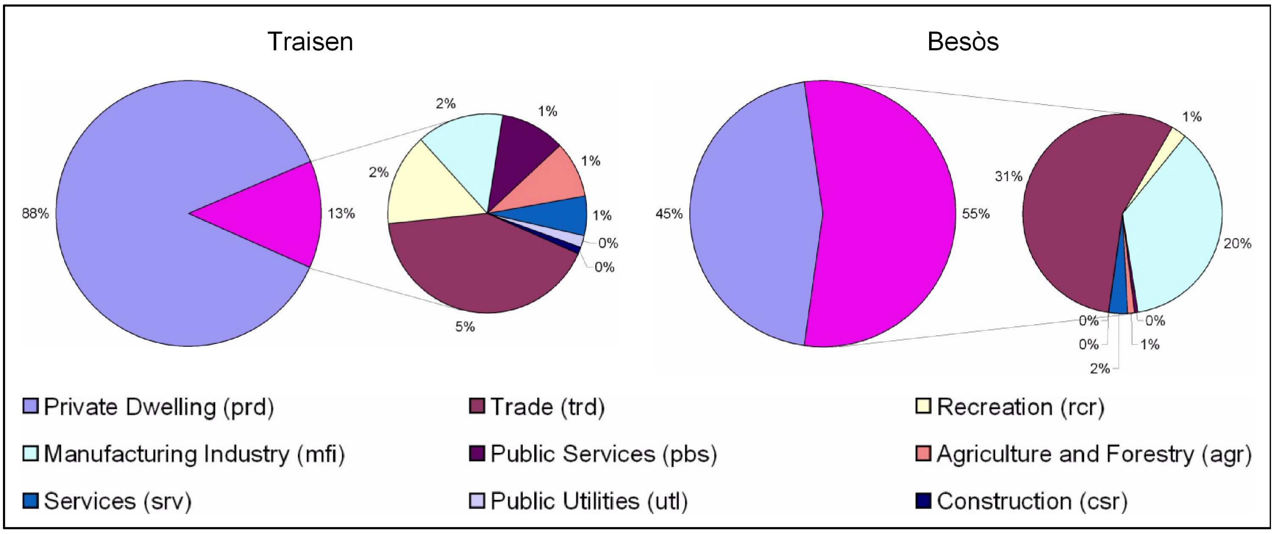


Figure 3-4: Land use distribution in the two basins

No new damage functions were developed in EWASE. Rather existing sets were used like in Saxony. The application of three different sets of damage functions from different studies indicates the uncertainty of damage estimation.

On this basis, a comparable and transparent approach was pursued in EWASE. A consistent methodology was developed that provides comparable results for both basins, because the statistical aggregates used as inputs are based on international or European standards and therefore are produced in a comparable way. It is a great achievement of the European Commission that evaluation of economic efficiency was an important part of projects receiving financial support under the FP5 INTERREG III and the FP6 ERANET framework. This enables EWASE to deliver a substantial contribution to Floodsite Work package 9.

3.2.3.5 Exposure Analysis

Indicators

Figure 3-5 provides a detailed overview over the indicators available for exposure analysis. In a utilitarian perspective the individual is seen as central for the analysis. There is no clear differentiation of a social and an economic sphere as the figure proposes. But taking it as a make-shift may facilitate the discussion. The social sphere may be divided into four main indicators: Family Structure, Education, Age and

Housing. The economic sphere may be described by Active Persons, Value Added, Capital Intensity and Industry Classification. Different purposes may employ different sets of parameters for exposure analysis. Non-economic approaches may find the main indicators in the social sphere whereas economists may prefer the indicators associated with the economic sphere. The social (blue) parameters are found in local statistics on municipality level and often exhibit a lack of trans-national comparability because they are defined to meet the local needs. It is often assumed that the social indicators add important information on susceptibility and therefore on vulnerability, but recent research suggests that the influence of age and family structure may only be important as far as emergency aid and evacuation are concerned. In exposure analysis their influence appears to be rather weak (Parker et al 2007). The economic (yellow) parameters are published on national and European level. Therefore Exposure Analysis focuses on these parameters. The following sections add information on these parameters and the concepts which provide their trans-national comparability.

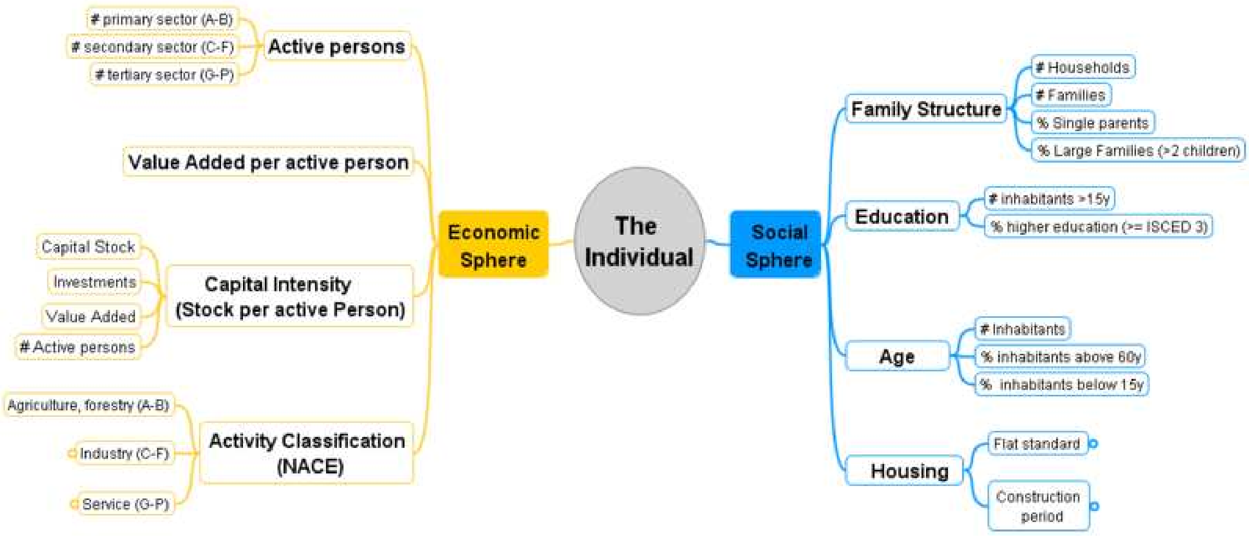


Figure 3-5: Indicators available for Exposure Analysis

National Accounting

The system of national accounting is generally a closed system of accounts showing essential macroeconomic entities as transactions or balances. It is based on the concept of an economic cycle. The United Nations System of National Accounts SNA 1993 is an international standard. On the basis of the SNA 1993 the European System of Accounting ESA 1995 was tailored to meet the demands of the European Union. Whereas SNA 1993 bears the character of a recommendation, the use of the ESA 1995 is mandatory for member states based on Council Regulation (EC) No 2223/96 within the European Union. Internationally standardized accounting has some prerequisites as regards industry and geographic classification.

Geographic Classification

The Nomenclature of Territorial Units for Statistics, 2003 (NUTS 2003) was established by Eurostat, to provide a single uniform breakdown of territorial units for the production of regional statistics for the European Union. The NUTS nomenclature serves as a reference for the collection, development and harmonization of EU regional statistics and for socio-economic analyses of the regions. For practical reasons to do with data availability and the implementation of regional policies, the NUTS nomenclature is based primarily on the institutional divisions currently in force in the Member States EC 1095/2003, Publications Office 2003).

The NUTS favours regional units of a general character. The NUTS is a five-level hierarchical classification (three regional levels and two local levels LAU, local administrative units). Since this is a hierarchical classification, the NUTS subdivides each Member State into a whole number of NUTS 1 regions, each of which is in turn subdivided into a whole number of NUTS 2 regions and so on.

At the regional level (without taking the municipalities into account), the administrative structure of the Member States generally comprises two main regional levels (Länder and Kreise in Germany, régions and départements in France, Comunidades autonomas and provincias in Spain, standard regions and counties in the United Kingdom, regioni and provincie in Italy, etc.). The grouping together of comparable units at each NUTS level involves establishing, for each Member State, an additional regional level to the two main levels referred to above. This additional level therefore corresponds to a less important or even non-existent administrative structure, and its classification level varies within the first 3 levels of the NUTS, all depending on the Member State: NUTS 1 for France, Italy, Greece, and Spain, NUTS 2 for Germany and the United Kingdom, NUTS 3 for Belgium, etc. (Eurostat 2008)

Figure 3-6: Nuts 3 Regions in the Besòs and Traisen basin, on a scale of 1:3.7 million

Figure 3-6 displays the important Nuts 3 regions for the EWASE project. The left panel shows the eastern part of Austria with its Capital Vienna. About 50km west of Vienna the Traisen basin stretches across parts of the Nuts 3 regions Niederösterreich Süd (Lower Austria South, AT122) and St. Pölten (AT123). On the right panel of the Figure the Autonomous region (or Nation) Catalonia with its capital Barcelona is shown. The Besòs basin lies fully inside the Nuts3-region Barcelona (ES511). On should always keep in mind that rather the region Barcelona than the city Barcelona is addressed in the following. No smaller Nuts regions are shown, because the resolution of statistical data available from Eurostat is generally limited to this geographic level.

Activity Classification

For comparing Industries effectively, various national and international classification schemes are in use. They can basically be differentiated into Activity and Product Classifications. In the following Activity Classifications are described in more detail. On the international level, the International Standard Industrial Classification of All Economic Activities (ISIC) was established by the United Nations (UNO). Wide use has been made of ISIC, both nationally and internationally, in classifying data according to kinds of economic activities in the fields of production, employment, gross domestic product and other statistical areas. The ISIC is a basic tool for studying economic phenomena, fostering international comparability of data, providing guidance for the development of national classifications and for promoting the development of sound national statistical systems. In the current revision 3.1 economic activities are grouped into 17 sections. On the European Community Level the “Nomenclature générale des activités économiques dans les Communautés Européennes (NACE)” or Statistical Classification of Economic Activities in the European Community was developed on the basis of the ISIC Revision 3 in 2002 (EC 1095/2003). It was implemented in 2003 and groups economic activities into 17 sections on Level 1, identified by alphabetical letters A to Q. The intermediate level has 31 sub-sections identified by two-character alphabetical codes, the Level 2 consists of 62 divisions identified by two-digit numerical codes (01 to 99), the Level 3 has 224 groups identified by three-digit numerical codes (01.1 to 99.0) and Level 4 has 514 classes identified by four-digit numerical codes (01.11 to 99.00) finally. The EWASE exposure analysis is restricted on the Level 1. Though more disaggregated than ISIC Rev.3.1, NACE Rev.1.1 is totally in line with it and can thus be regarded as its European counterpart. Its main applications are 1. Business Registers, 2. National and Regional Accounts, 3. Structural Business Statistics, 4. Industrial short-Term Indicators, 5. Labour force Survey, and 6. Other labour statistics.

Table 3-2: Sectors and Activities according to NACE Rev. 1.1

Sector	Nace Activities, Level 1	
Primary	A	Agriculture and Livestock
	B	Fishing
Secondary	C	Mining and Quarrying
	D	Manufacturing Industry
	E	Energy, Gas and Water
	F	Construction
Tertiary	G	Trade and Repair
	H	Tourism
	I	Trafic, Communication
	J	banks and insurance industry
	K	Real estate, lending, b2b services
	L	Public Administration, Defence, Social insurance
	M	Education
	N	Health
	O	Other public serivces
	P	Activities of households
	Q	Extra-territorial organizations and bodies

Table 3-2 depicts the 17 activities of the first Nace level. Traditionally they are grouped into the primary, secondary and tertiary sector according to Jean Fourastié (1954). The primary sector comprises all activities which change natural resources into primary products. The secondary sector comprises manufacturing industry. Sometimes mining and quarrying is seen as an activity of the primary sector. As the Austrian Statistics Agency Statistik Austria groups mining and quarrying into the secondary sector, this is accepted for this study. The tertiary sector comprises all private and public service activities. The NACE Rev. 1.1 Regulation allows the Member States to use a national version derived from NACE Rev. 1.1 for national purposes. Such national versions must, however, fit into the structural and hierarchical framework laid down by NACE Rev. 1.1. In Austria the Austrian Statistical Classification of Economic Activities (ÖNACE 2003) is in place since 2003. It was derived from NACE Rev. 1.1 and has many users outside the National Statistical Institute. All statistics with reference period 2003 onwards and using activity classifications build on ÖNACE 2003 (Statistik Austria 2007). In Spain the Clasificación Nacional de Actividades Económicas, 1993, Revisión 1 (CNAE-93 Rev.1) or National Classification of Economic Activities, 1993, Revision 1 is in use. It builds on NACE Rev.1.1. Every level of the international classification can be reconstructed using the national categories. It was officially first adopted in 2003. All the economic statistics and surveys use this classification when coding economic activities. In Catalonia, based on the CNAE-93 Rev.1 the Classificació Catalana d’activitats econòmiques CCAE-93 Rev.1 was developed. It is in use since 2004.

Active Persons

Employment is a major concern of politics on every geographic level. Information on employment is therefore easily accessible for every country via public sources even on the lowest geographic aggregate, on community level. For Austria regional employment statistics are published online by the Bezirksgregierung Niederösterreich (Government of Lower Austria) and Statistik Austria, for Catalonia, the regional statistical body IDESCAT as well as the national statistic agency ENA publishes the data. Table 3-3 shows Employment information as available from Eurostat on Nuts3-level for the three sectors in which the 17 level one Nace-activities are aggregated. A comparison of the figures per region reveals that the Austrian regions have still a much higher share of employment in the agricultural sector (11%) than the Barcelona region (1%). In the secondary sector (manufacturing industry) the Austrian regions are below Barcelona (25% on average compared to 35%) whereas both regions have approximately the same share of employment in the service sector (63% and 64%). As a disaggregation to the 17 level one Nace-activities was the objective of exposure analysis, employment data from the national providers had to be used. But the comparison with the Eurostat data allowed for the correction of inconsistencies. It is advantageous to use the Eurostat information rather than the regional information on the expense of regional details where ever possible.

Table 3-3: Active persons (thousands)on Nuts levels 1 to 3

NUTS regional classification	Name	Nace Activity Classification						
		a to p Total	a b primary		c to f secondary		g to p tertiary	
es	Spain	18,502.40	999.60	5%	5,461.00	30%	12,041.80	65%
es5	Este	5,675.00	160.40	3%	1,913.10	34%	3,601.50	63%
es51	Cataluña	3,310.60	82.60	2%	1,131.00	34%	2,097.00	63%
es511	Barcelona	2,449.30	28.60	1%	849.10	35%	1,571.60	64%
at	Austria	4,139.00	513.80	12%	944.20	23%	2,681.10	65%
at1	Ostösterreich	1,712.90	153.70	9%	323.70	19%	1,235.40	72%
at12	Niederösterreich	702.00	119.90	17%	167.30	24%	414.80	59%
at122	Niederösterreich-Süd	105.90	12.00	11%	31.50	30%	62.40	59%
at123	Sankt Pölten	82.00	9.30	11%	16.90	21%	55.70	68%

Value Added per Active Person

For the calculation of the average contribution to value generation of an employee, data from the national statistical agencies ENA (Spain) and Statistik Austria had to be used. Gross Value added and Employees per sector on NUTS2-level were applied. A disaggregation to NUTS3 level is possible in principle. The Eurostat data on employees were used for ensuring that Gross Value Added per active person was calculated in a comparable way. Quite often in damage potential analyses it is stated that stored inputs to production may significantly contribute to the damage potential and therefore need special treatment. Stored goods are totally neglected in EWASE because of the definition of value added: As may be taken from Eurostat (2007a) gross value added is defined as final output minus intermediate consumption. And intermediate consumption consists of the value of the goods (and services) consumed as inputs by a process of production. So if value added is included in damage estimates, additional provision for stored goods would be double counting.

Capital stock

Conceptually, there are two types of capital measures, each reflecting a different role of capital. The first type of measure looks at capital in its function as a provider of services in production (productive stock). The second major type of capital measure captures its role as a store of wealth. This measure is of interest here. The relevant aggregate is the net stock or wealth stock that captures the market value of capital goods. Unlike the productive stock, its purpose is not to track capital's role as a factor of production but to track the role of capital as a set of assets with market value – net stocks appear on balance sheets and in the context of income and wealth accounting. Although there are special cases where the net stock and the productive stock coincide, this is not generally the case because they reflect different concepts and usages. Net stock is an entity that is recognised by SNA93 and all countries that publish capital stock data publish at least a measure of the net stock. The gross stock is a special case of the net stock in that it takes retirements of assets into account, but not depreciation. A measure of the gross stock is built on the assumption that a capital good retains full productive capacity during its service life and is then retired. At the same time, when the gross stocks for different assets are aggregated, no attempt is made to introduce weights that reflect each asset's productivity. Aggregation, akin to the net stock, is on the basis of 'as new' prices. Gross capital stock is also recognised by SNA93 and is often produced and published by statistical offices (Schreyer and Webb 2006)

Capital Intensity

The statistical entity used in this context to describe exposure is capital intensity. Capital intensity is defined as capital stock per active person. Active persons are those involved in processes increasing gross domestic product GDP. Both, employed and self employed persons are included. Activities which do not directly increase GDP cannot be described via this approach. It serves well for the description of income generating activities in the primary, secondary and tertiary sector. But it fails to describe household stocks and activities in the family, e.g. private child care and education. Capital intensity is not available from the EU statistical body Eurostat on NUTS3 level. Therefore it is derived in the project. Two main inputs are necessary, capital stock and active persons, both on NUTS 3 level. Whereas statistics on active persons are available on NUTS 3 and even community level, capital stock is generally provided on higher aggregates. In Spain, the BBVA-foundation provides Capital Stock on NUTS 3 level, in Austria Capital stock is available only on National or Nuts 0 level. Therefore key parameters covering several NUTS levels were used to regionalise this information.

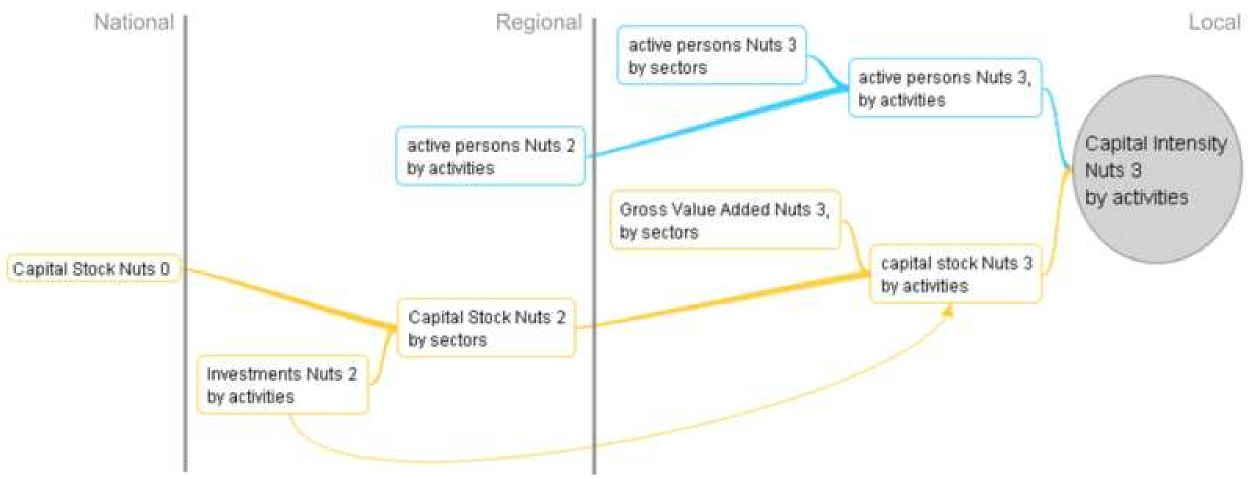


Figure 3-7: Regionalisation of Capital Intensity for Austria

For Austria, these are shown in Figure 3-7 input data are depicted in coloured boxes, derived measures are given in lined boxes. Capital stock per sector on national level is published by the national statistical body Statistik Austria for Buildings and Equipment. Two concepts are provided, the Gross Capital Stock and the Net Capital stock (Gross Capital Stock minus Depreciation). Net Capital stock is the best estimator for time value which is used as a conservative measure for exposure here. A key parameter that closely relates to Capital stock is Gross Capital Formation or investments in simple wording. For Germany both capital stock and investments are provided on NUTS 0 to NUTS 2 level. An analysis of capital stock and investments for Germany revealed a close correlation yielding a coefficient of determination R^2 of 99.8%. For Austria Investments are provided on NUTS 2 Level by activities. The larger aggregates Nuts 1 and Nuts 0 can easily be calculated. The first step leads to Capital Stock by sectors on NUTS 2 level. Unfortunately, investments are not given for Nuts 3 level in Austria. Therefore another key parameter had to be used. Gross Value added (GVA) lends itself to this purpose. For Germany a correlation of 99.6% was calculated for GVA and Capital stock. But GVA is given by sectors only. Using GVA as key parameter leads to Capital stock on NUTS 3 level by sectors. This statistical resolution is not high enough for exposure analysis, as a detailed differentiation within the secondary and tertiary sector is indispensable. Therefore the high resolution of investments by activities on NUTS 2 level was transferred to NUTS 3 level on the basis of %shares.

Private Stocks

For private stocks another approach had to be selected, because there are no or at least not enough employees in private households for deriving a meaningful ratio. Different approaches were used for estimating the value of an average private home for the Traisen and the Besòs basin. In Austria the Internet provides a sufficient source for efficiently estimating the market value of private homes. For Spain, the data quarterly published by the "Ministerio de Vivienda" were used for this purpose.

Conclusions: EU statistics as pragmatic estimators of value

It is no easy undertaking to estimate the value of a property, be it private or industrial. Everybody is very reluctant to release data on the value of his premises. There are experts that assess the value for insurance- real estate- and other purposes based on national regulations. But this expertise is time-consuming and costly. For flood risk analysis there exist data bases in different European countries, e.g. the Germany, Switzerland and the Netherlands. But the quality of the information from these data basis is highly questionable. Furthermore these data do not provide for trans-national comparability. As a result, the numbers presented in risk analysis are arbitrary for a large part. Different experts relying on own and generally secret experience may produce highly different results for the same basin under the same flooding conditions. For improving this situation, a comparable and transparent approach was developed in EWASE. Using the data provided by EU bodies as described in the above sections is a much more convenient approach than gathering data from unreliable sources or unwilling counterparts. Quality assurance of the EU Eurostat agency provides for comparability of the data. And capital intensities can be used as a proxy for the real value of a property given that the number of its employees is known. As a matter of fact most companies are pleased to inform about the number of employees. Sometimes it is not even necessary to make interviews or questionnaire based surveys for revealing the number because it is published on the company's website. For the purpose of EWASE a company's property value VP is defined as the product of its capital intensity CI and its number of employees or active persons AP:

$$VP = CP \cdot AP \quad (3)$$

VP

CP

AP

There may be significant differences between the real value of a property and the proxy above defined on the local level. But as capital intensities are calculated on Nuts 3 level and this level approximately corresponds to the basin size (see Figure: Nuts 3 Regions in the Besòs and Traisen basin, on a scale of 1:3.7 million), it may well be representative on this level.

The estimator for the creation of value in EWASE is value added per employee on Nuts level as described in section 4.2.3.1.6 Value Added per Active Person. Working days per year are estimated at 220 and the daily labour time at 8 hours. With these estimates a proxy for daily or even hourly value creation on company level can be calculated. This estimate is important for several reasons. In the risk analysis it enters the flood damage as business disruption. In the response analysis it is used as an estimator for mitigation cost. As a matter of fact not much cost of emergency response can be attributed to damage mitigation cost on an event basis. Firstly the full investment, maintenance and repair cost of disaster response falls due either there is a flood event or not. Secondly disaster response serves different purposes and it is quite arbitrary to attribute a certain portion to flood response. Therefore the only cost which can be attributed to flood response with certainty is the cost arising from employees disrupting their daily work and turning to some form of damage mitigation. Damage mitigation cost MC is conservatively estimated as the product of active persons AP and value added per active person VA on hourly or daily basis.

$$MC = VA \cdot AP \quad (4)$$

MC
VA
AP

3.2.3.6 Susceptibility Analysis

The calculation of damages makes use of flood damage functions that transpose an impact, in this case the inundation depth at an object, into a monetary damage. This is carried out for each object and for each return period; these results are then summarised to an annual risk, the expectation value of flood damages.
They are calculated applying the software HWSCalc on the basis of

- the typology of land uses
- the calculated damage extents and
- the mapping of type specific damage functions to land use

According to the basic analyses and links described above. HWSCalc is a software system of Ministry of the Environment and Conservation, Agriculture and Consumer Protection (MUNLV) of the German State of North Rhine-Westphalia to assess flood damages.

Application of HWSCalc and Methodology

A short description of the main characteristics of HWSCalc as applied and implemented in EWSAE is given below.

HWSCalc is a software system to assess flood damages. The calculation of flood damages is the basis for the economic evaluation of flood protection measures. HWSCalc calculates quantitative and monetary flood damages as well as expectation values of flood damages on the basis of land uses, flood damage functions and water surface profiles for different return periods.
The features that are relevant for water resources planning practices are the following:

- Data transfer of cadastral information according to project specific typologies
- Data transfer of water surface profiles from hydraulic models
- Definition of user-defined damage functions specific to land use types or single objects
- Linkage of land use properties with hydraulic information to calculate quantitative flood damage extents
- Linkage of flood damage functions with quantitative flood damage extents to calculate monetary flood damages
- Calculation of flood damage expectation values making use of return periods of flood events
- Aggregation of land use specific data and results under various factors for well arranged reporting of results
- Reporting and visualisation of detailed and aggregated results in tabular and graphic formats

Calculation of Flood Damages

Only damages that result from flooding due to surface inundation are considered. Damages due to confined aquifer are not considered in the calculation of potential flood damages.

Calculation of flood damages is based upon the following conditions:

- Water surface elevations for each return period are known at each land use unit that can be damaged in terms of monetary impacts.
- Each land use unit is indirectly mapped to a flood damage function through the land use category it is assigned to - providing also information on the damage type.

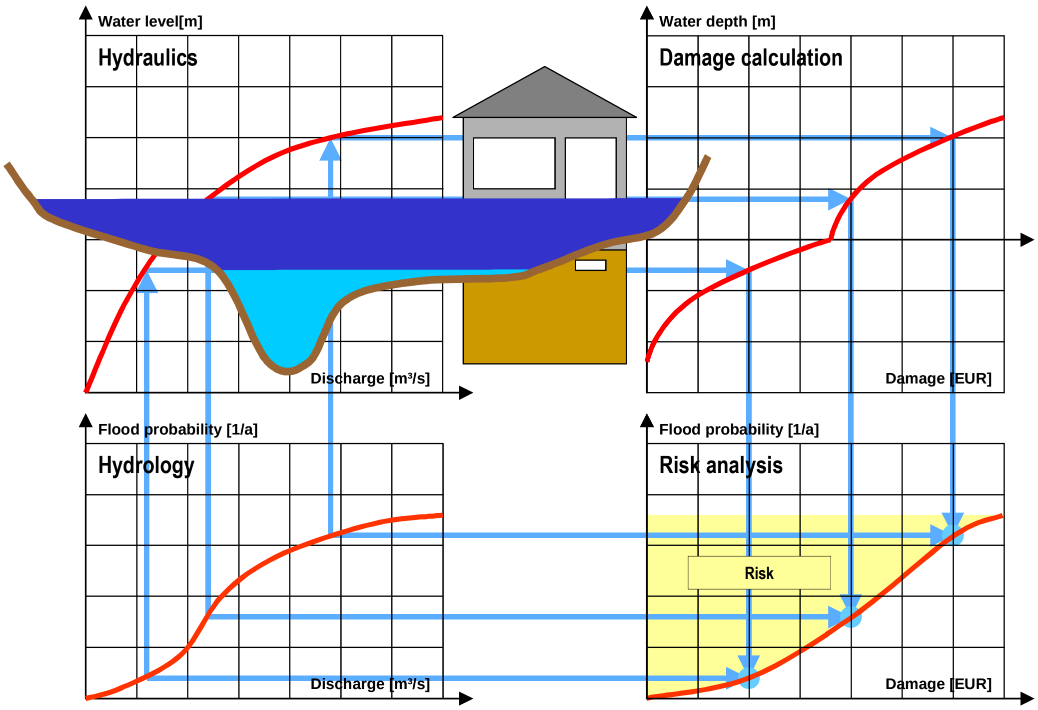


Figure 3-8: The principle of flood damage calculation

The results of the damage calculations shall be reported in an aggregated form. All calculations of flood impacts, including the monetary flood damages, are calculated for each land use unit. The documentation of the results is aggregated.

$$F = 1 - \frac{1}{T} \quad (5)$$

$$\int_0^S p(s)ds = F(S)$$

$$\mu_S = \int_0^\infty s \cdot p(s)ds$$

S	Damage
p(s)	Density function of the damage
F(s)	Distribution function of the damage
µs	Expectation value of the damage
T	Return period of the damage
	with p(s) ds = dF.

the following results: $\mu_s = \int_0^\infty s \cdot p(s)ds = \int_0^1 s(F)dF$

It is assumed that the probability of the damage is the same as the probability of the damage inducing flood discharge. Therefore the damages S_i for selected return Periods T_i are known.. Hence the distribution function F(s) is given in discrete form F_i. With this information the damage expectation value can be calculated.
Because 3 return periods are considered for each region in EWASE the distribution function to be integrated has three nodes.

- Traisen:
  - T=30 corresponds to F=0,9667
  - T=100 corresponds to F=0,9900
  - T=200 corresponds to F=0,9950
- Besòs:
  - T=50 corresponds to F=0,9800
  - T=100 corresponds to F=0,9900
  - T=500 corresponds to F=0,9980

The following is assumed for the integration:

- The upper limit of integration is T=∞. This means that risk beyond the maximum return period is not considered. Therefore an assumption has to be made on the maximum probable damage. The damage for T=∞ (F=1) is the same as the damage for T=200 and T=500 respectively.
- The lower limit for integration is determined by the return period at which the minimum damage would occur. It is assumed that this is the case when damage inducing water surface elevation is at the level of the flood threshold. Within EWASE this lower limit was assumed at the first return period, where the damage occurred.

Damage functions

The development of damage functions is a time consuming procedure. It is therefore general practice to transfer damage functions to other regions. Sometimes allowances for regional characteristics are made, sometimes not. The data samples on which damage functions are constructed generally are small and lack reliability (Messner et al. 2007). Damage functions therefore exhibit very low coefficients of determination and are for a good part arbitrary. In this light, the development of damage functions was beyond the scope of EWASE. Rather, several sets of existing damage functions were used to estimate the variability of susceptibility in the two basins. In order to be compatible with other actual flood risk studies, existing sets of damage functions were used. It serves comparability to make the same errors than others rather than introducing new errors. The following sets of flood damage functions from three different flood risk studies were applied

- Potential Flood Damages at the River Rhine in North Rhine-Westphalia (Client: Ministry of the Environment and Conservation, Agriculture and Consumer Protection (MUNLV) of the German State of North Rhine-Westphalia), 1998-2000
- Potential Flood Damages at the Danube river in Baden-Württemberg and at the rivers Breg and Brigach (Clients: River Directorates Donau/Bodensee and Südlicher Oberrhein/Hochrhein of the German State of Baden-Württemberg), 1999 – 2001
- the Rhine Atlas (Client: International Commission for the Protection of the Rhine), 2001

The purpose of the study for the River Rhine in North Rhine-Westphalia (MUNLV, 2000) was to inform the public and the relevant stakeholders about the regional levels of flood risk and, thus, to reveal the benefits and the necessity of flood protection as well as to justify investments in flood protection measures. In this study, the damage functions used for the assessment of potential flood damages were based on the HOWAS database. The HOWAS database is a collection of information on flood damages of approximately 4000 land uses in Germany, during nine flood events between 1978 and 1994 in Germany (Merz et al. 2004). The flood damages documented in HOWAS were used to develop flood damage functions for different economic sectors.

The objective of the study for the Upper Danube was to evaluate the benefits from different flood protection measures in the communities downstream of planned reservoirs for flood control (ProAqua 2001). In this study a standardised set of absolute damage functions was used for the damage calculations. Similar to the approach in EWASE, each land use object in the flood plains was identified on the basis of topographic and land register maps as well as field surveys. The flood damage functions were modified making use of the HOWAS database. This data had been reanalysed by the University of Karlsruhe (IWK 1999). The main result of the analysis is a recommendation that a root function is apparently the best estimation for the functional relationship between inundation depth and flood damage. Furthermore, flood damage data from a state insurance agency (Brandkasse Baden-Württemberg) was used to validate the maximum flood damages.

The standardised set of damage functions differentiates different economic sectors and about ten categories of residential buildings (distinguished by parameters such as type of building, age and basement use). These absolute flood damage functions were transformed into relative damage functions in EWASE.

The objective of the Rhine Atlas was to sensitise the stakeholders along the Rhine. It includes maps representing the hazard resulting from flooding and the potential flood damages in cases of extreme floods. The damage functions used in the Rhine Atlas for the assessment of the potential flood damages are again based on the HOWAS database and on studies made in the Netherlands, expert discussions as well as experience of the consortium in charge (ICPR 2001). The function set includes damage functions for immobile assets (building structures) and mobile assets (household effects, furniture, equipment and supplies). The flood damage functions for the mobile assets distinguish furthermore between residential and business use.

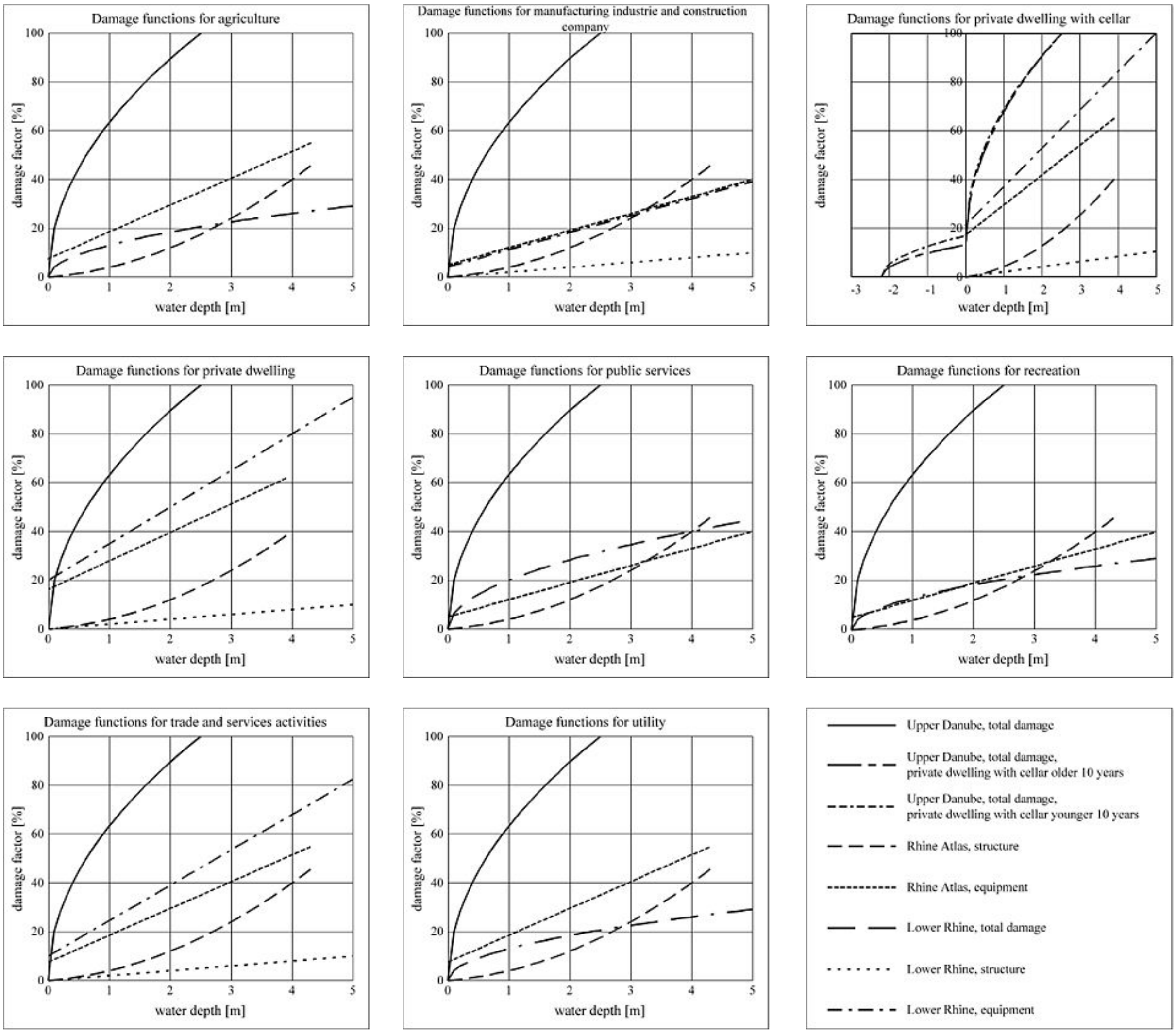


Figure 3-9: Damage functions

4 Application Examples

"In this chapter the application of the methodology developed is demonstrated within the framework of two study basins."

4.1 Traisen Basin

The Traisen Basin is located in the north eastern part of Austria (see Figure 4-1). The Traisen River is a southern tributary to the Danube and is located about 50 km east of Vienna. The entire catchment area belongs to the province of Lower Austria.

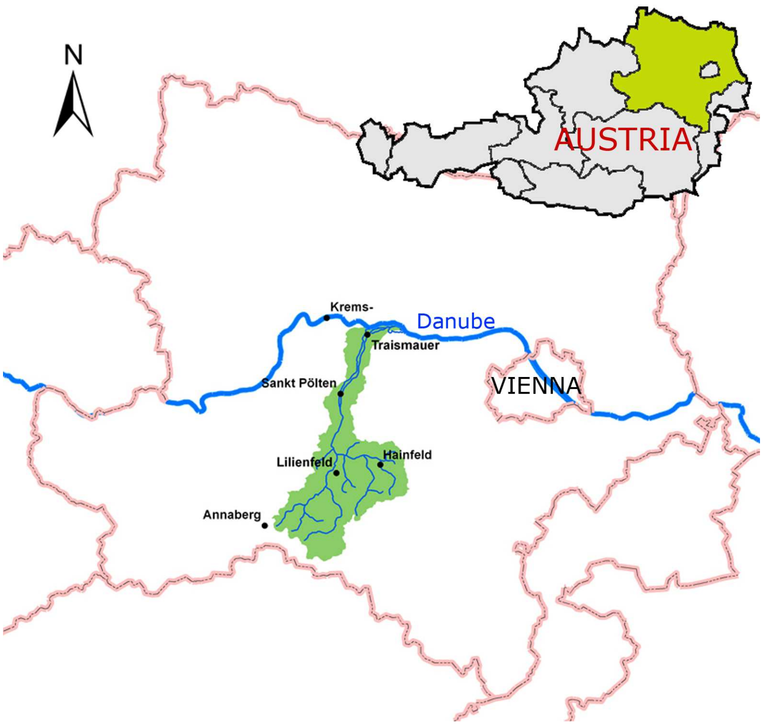


Figure 4-1: Location of Traisen Basin in Austria

4.1.1 Basin characteristics

The basin has an area of approx. 900 km². The height above sea level varies from 200 m up to alpine regions with peaks at 1800 m. The alpine part of the basin is located entirely in the northern limestone Alps. Beside that main geological zone of the catchment there are also parts within the Flysch and Molasse zone. In the lower part of the basin the river is bedded in alluvial sediments (Figure 4-3 right). The climate is alpine to sub-alpine. Precipitation ranges from 600 mm/ain the northern parts to 1500 mm/a in the southern parts of the basin. The maximum precipitation occurs in summer. High snow levels only occur in the alpine (southern) part of the catchment. Discharge shows a pluvio-nival regime where the maximum monthly discharge occurs in March and April due to snowmelt in combination with rain. Highest peak discharges occur from June until September in consequence of heavy summer precipitation. Measurement stations within the basin are 8 river gauges and 10 rain gauges (See Figure 4-2).

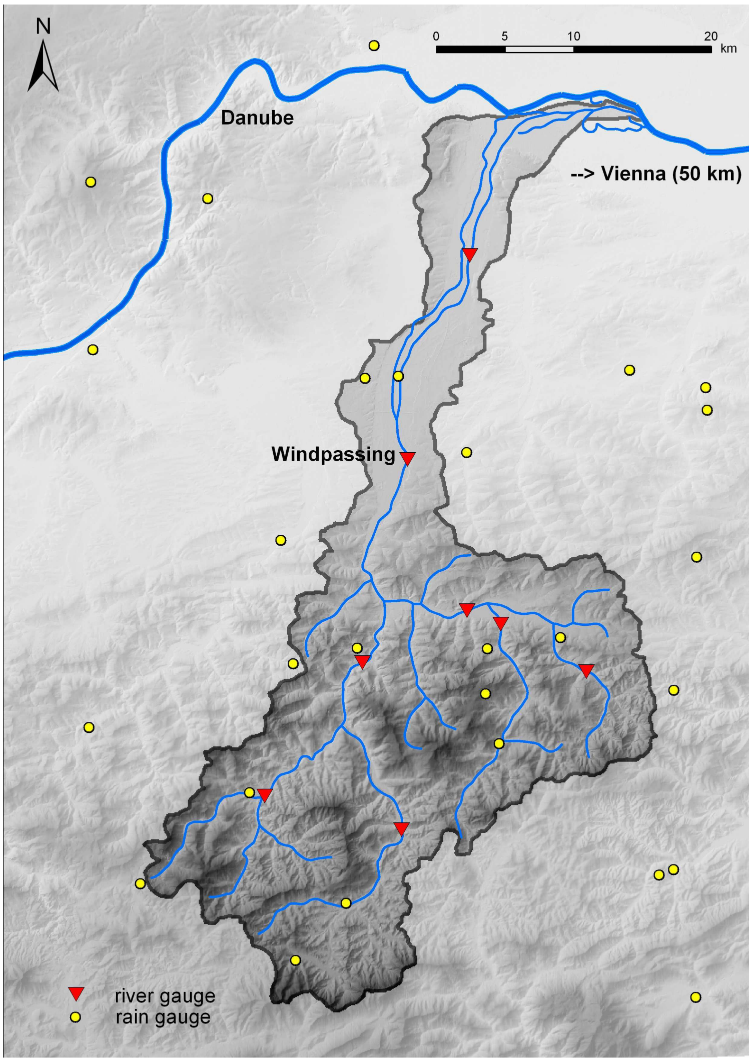


Figure 4-2: Traisen Basin and observational network

The provincial capital St. Pölten is located on the Traisen River and forms the biggest urbanised area in the catchment. In the Figure 4-3 (left) dominance of forestry in the southern areas and of agriculture in the northern areas of the basin can be seen. An impression from the upper Traisen Basin at Lilienfeld and as well a flood at the lower Basin at St.Pölten can be seen in Figure 4-4.

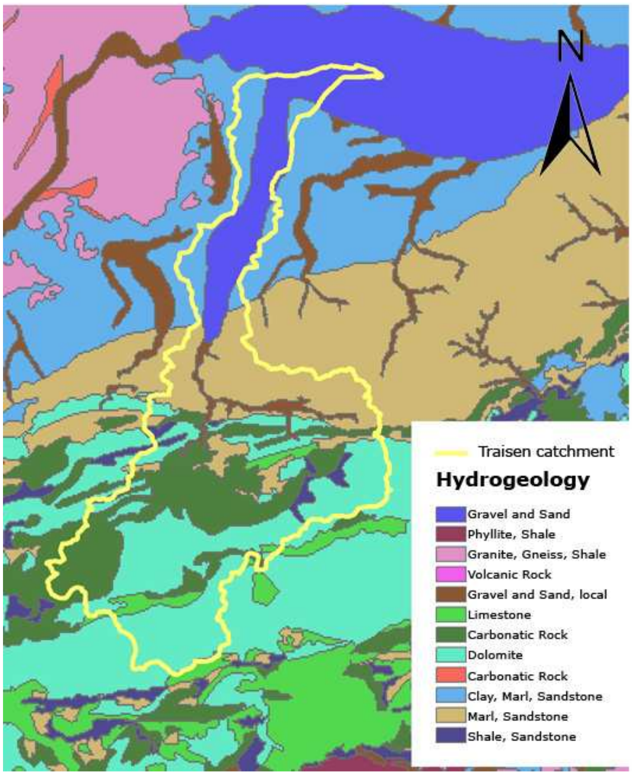


Figure 4-3: Land use and geology in the Traisen Basin

Upper part of the basin at Lilienfeld

Flood at the lower Traisen River in July 1997 at St. Pölten (app. discharge: 750 m³/s, HQ100)

Figure 4-4: Impressions from the Traisen basin

4.1.2 *Operational EWS*

In Austria civil protection and warning is structured in national, provincial, regional and local actions. The highest level for civil protection is the Federal Ministry of the Interior. Since May 2003 it is in charge for the coordination in matters of national disaster protection management, national crisis management and international disaster relief. The competence for coordinating national or international cases of emergency is now in one hand on a federal level. This should enable a better and faster reaction in crisis situations.

4.1.2.1 General concept of warning in Austria

Each province department, district commission and community has to develop a disaster protection management plan for its line of action. The disaster protection management plan shows exactly how the responsible establishment has to act in case of a disaster. Part of the disaster protection management plan is the official catalogue of hazards. In this catalogue, topics like water supply, electric power supply, transport, board and lodging of the residents are managed. The provincial authorities primarily have to inform the subordinated bodies in case of a catastrophe. Then volunteer fire brigade and other aid organizations have to be alerted. Further action is the warning of the population by sirens and loud speakers. People are advised by local organizations to prepare the required arrangements for self protection. The concept is to release a warning first to go on alert and set preventive measures. If necessary an alarm follows to set actions shortly before or in case of a disastrous event.

4.1.2.2 Flood warning in Austria

Every province has a hydrographical service that is in charge to provide a forecast in case of an approaching flood. There is a predefined system to spread information to the regional authorities and the communities. Today computer models are widely used at the hydrological services, which calculate and describe future water levels by measured and forecasted data. The intention of the computer models is to increase warning lead time. Meteorological and hydrological models are the objective base for flood warning, but still the actual warning is carried out by humans and not automatically. The hydrological service predicts tendencies (increasing, decreasing, constant) and provides data on flow rates and water levels for specific dates. Warning levels exist for rainfall and river water levels. For rainfall four warning levels are defined: no identifiable danger, attention (less than 18 times a year), greater attention (less then 4 times a year) and extreme event (less then 2 times in 3 years). The warning levels for river gauges are defined together with the communities and local companies. If no warning level is defined the responsible actors get a notification at the one year flood level.

4.1.2.3 Actors of Flood warning in the Traisen basin

The Hydrographical Service of the provincial authority of Lower Austria (Hydrographische Dienstelle des Landes Niederösterreich) is in charge for monitoring precipitation and river flow (water level and/or discharge). They are also responsible for managing and preparing hydrological forecasts. Meteorological precipitation and temperature forecasts are made externally at the ZAMG (Austrian Central Institute for Meteorology and Geodynamics). The provincial authority has to pay for that service and runs different hydrological and hydrodynamic models for the main rivers of the province with this data. In the Traisen basin the hydrological forecasting is done on a continuous basis with the model COSERO. Results from modelling are handed to the Warning Alarm Centre of Lower Austria (LWZ - Landeswarnzentrale). The LWZ then decides with predefined warning levels if an alert is necessary and is responsible for distributing warnings to the regional authorities (Bezirkshauptmannschaften). Regional authorities are in charge to arrange a team of operation controllers (Einsatzleitung). The team consists of the head of the region (Bezirkshauptmann) and members from the blue light organizations. Communities and local blue light organizations get informed and stay in continuous contact to the operation controllers. Preparations for distributing information to the residents by local fire brigade and communities are made on regional level. Residents are alerted by megaphones and sirens from local organizations or communities. For floods a special alarm plan exists and includes predefined actions for every level of responsibility. A scheme of the EWS with actors in the Traisen Basin can be seen in Figure 4-5.

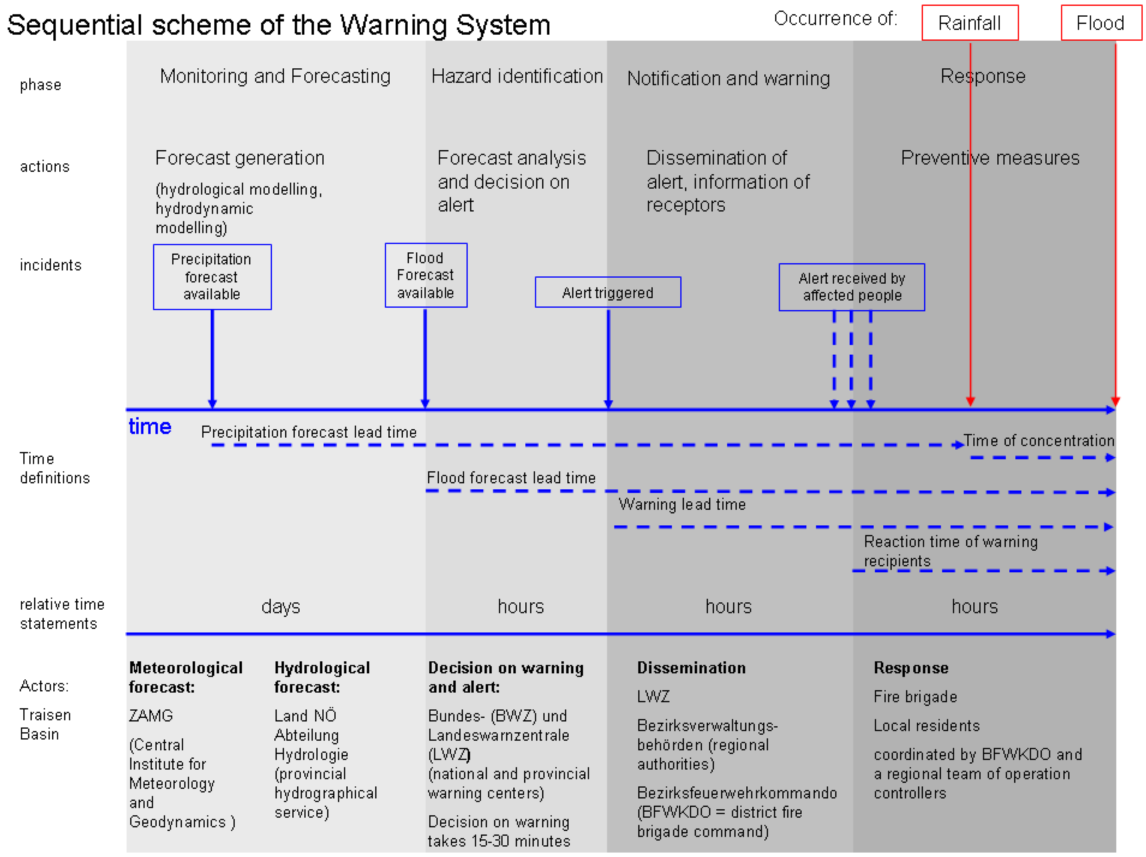


Figure 4-5: EWS time scheme with actors in the Traisen Basin

4.1.2.4 Warning levels for the gauges at river Traisen

At HQ1 level the according actors get a notification. If there is an additional warning level the according actors get a warning when discharge reaches that level. . The warning levels and one-year-flood levels can be seen in Table 4-1.

Table 4-1: Warning levels for the Traisen River (stations in alphabetic order)

Station (river)	**Warning level in alert system [W in cm]**	**One year flood level (HQ1) [W in cm]**	**Who should be informed by LWZ**
Herzogenburg (Traisen)	--	232 (115 m³/s)	BH PL
Hohenberg (Unrechttraisen)	--	160 (17 m³/s)	BH LF
Lilienfeld (Traisen)	--	266 (60 m³/s)	BH LF
Ramsau (Ramsaubach)	--	84 (10 m³/s)	BH LF
St. Veit (Gölsen)	--	261 (45 m³/s)	BH LF
Türnitz (Traisen)	200	190 (25 m³/s)	BH LF
Windpassing (Traisen)	167	156 (110 m³/s)	BH PL, Mag. St. Pölten

Source: LWZ NÖ (warning alarm centre), August 2006,
Abbreviations:
BH regional authority (Berzirkshaupmanschaft)
Mag. regional authority in big cities (Magistrat)
PL region St. Pölten Land
LF region Lilienfeld

4.1.3 Available Data base

For the project several catchment data was gathered to build and run the three hydrological models and to make the economic assessment.

The hydrological models were set up with different geographical information from the catchment like digital elevation model, river network, soil map, geological map and land use map. Calibration, validation and forecast runs were made with meteorological analysis and forecast data for precipitation and temperature from the ZAMG (Central Institute for Meteorology and Geodynamics, Vienna, Austria). The climatologic data for the Traisen Basin has a high resolution (1x1 km, 15 minutes) and is also used operational in the EWS. For calibration analysis data for precipitation and temperature from ten historic flood events between 2002 and 2007 were used. Additional for the continuous models analysis data was available from 2003-2006 constantly. Three flood events were chosen for testing precipitation ensemble forecasts to estimate the influence of meteorological uncertainty. Spatial resolution of the ensemble forecasts is with 10x10 km lower than for the analysis data. The outputs of the hydrological models were compared to the available stream flow data from the basin. Data from seven online river gauges and one offline river gauge was available for calibrating and validating the models in the Traisen Basin.

Data for economic assessment included detailed land use information (land register, orthophotos), inundation maps for floods with different return periods, digital elevation model, and data on damages from past floods and information on costs for an EWS were gathered from different authorities and interviews with companies and communities.

4.1.3.1 Catchment data Traisen

- Catchment borders: with 10 sub-catchment borders (combined and adapted to the used river gauges) Source: Hydrologischer Atlas Österreich (hydrological atlas Austria), BMLFUW (2005)

- River Network: The shape file is based on the topographic map of Austria, scale 1:1000000 Source: Hydrologischer Atlas Österreich (hydrological atlas Austria), BMLFUW (2005)

- Digital elevation model: spatial resolution 25 meters, Data source is from aerial photographs with accuracy from +/- 1 m (plane and open areas) up to +/- 20 m (mountainous and forested areas) Source: DGM (Digitales Geländehöhenmdell) Rasterweite 25m, Bundesamt für Eich- und Vermessungswesen (BEV – Federal Office for Calibration and Measurement Austria)

- Land use:

    - Land use map based on the CORINE dataset (1998), reclassified and generalised to hydrological relevant units Source: Hydrologischer Atlas Österreich (hydrological atlas Austria), BMLFUW (2005)

    - Digital Land Register: For the floodplains in urban areas a more detailed land use map was needed for risk assessment. The Digital Land Register has a resolution on building level and an accuracy of a few decimetre. Source: Digitale Katastralmappe, Amt der NÖ Landesregierung (©Land NÖ 2006 ©BEV 2006)

    - Orthophotos: For some floodplains in urban areas aerial photographs were used for risk assessment. Source: Amt der NÖ Landesregierung (©Land NÖ 2006 ©BEV 2006)

- Soil map: The map is based on an detailed Austrian soil map, the European soil map and the river network, the attributes are different soil nomenclatures: Austrian Soil Nomenclature, FAO Nomenclature, scale 1:1000000 Source: Hydrologischer Atlas Österreich (hydrological atlas Austria), BMLFUW (2005)

- Hydrogeological map: It is a generalised map of the hydrogeology of Austria and show types of aquifers on a scale 1:1000000 Source: Hydrologischer Atlas Österreich (hydrological atlas Austria), BMLFUW (2005)

- Cross sections:

    - Cross section river Gölsen (tributary to the Traisen): Cross sections fort he river Gölsen were available in digital form from the hazard zone plan for the Gölsen valley Source: Amt der NÖ Landesregierung, Gefahrenzonenplan Gölsen (2001)

    - Cross sections river Traisen: Cross sections for the river Traisen were available from hydraulic calculations in the framework of the river management plan only in hardcopy. Source: Gewässerbetreuungskonzept Traisen, Wilhelmsburg bis Donau (1999) , BMLF und Amt d. NÖ Landesregierung

    - Data for Kalinin-Miljukov calculations: For about 30 kilometres of the river Traisen between Windpassing and Traismauer Kalinin-Miljukov parameters from a retention calculation were available. Source: Gewässerbetreuungskonzept Traisen, Wilhelmsburg bis Donau (1999) , BMLF und Amt d. NÖ Landesregierung

- Inundation maps:

    - Water Provision Framework Plan (1998): inundated areas for a HQ30 and HQ100 return period based on hydraulic calculations Source: Wasserwirtschaftlicher Rahmenplan Traisental (1998), BMLF und Amt d. NÖ Landesregierung

- o HORA (HOchwasserrisikoflächen Austria) flood risk zones for Austria: Shape files with potential floodplains and water depth for return periods T=30, 100 and 200 years. The hazard zones mark the danger potential if structural flood protection measures fail. The data was collected on a scale 1:50000 and is designed for the use in regional studies but not for local projects. Source: Hochwasserrisikozonierung Austria (2006) Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft (BMLFUW)

- o Detailed inundation maps: For 3 small pilot regions (Lilienfeld, St.Pölten and Pottenbrunn) a detailed study within the flood risk project in Austria was made. Inundated areas and water depth for floods with return periods T=30, 100 and 300 years were available Source: BMLFUW, 2004. FLOODRISK – WP Naturgefahren, TP07: Raumordnung und Hochwasserschutz am Beispiel der Traisen – Siedlungsentwicklung und Schadensanalyse, Endbericht.

- Data on past damages: For three flood events (2007, 2006, 1997) data on the amount of loss from the catastrophic aid fond (Kathastrophenbeihilfenfond) was available. This fond covers damages from residents, companies and agriculture but no damages on infrastructure. Source: Amt d. NÖ Landesregierung

- EWS costs: Data on costs and effort for building up and operating an early warning system in the Traisen Basin were collected mainly by interviewing the operators forecasting system and the meteorological service of Austria. Source: Amt d. NÖ Landesregierung, ZAMG

4.1.3.2 Climatologic data Traisen

Precipitation and temperature data was used in raster format with a spatial resolution of 1x1 km (ensemble forecasts 10x10 km). The data was generated with the INCA-system (Integrated Nowcasting through Comprehensive Analysis, Haiden et al., 2007). The system uses ground measurements (rain and temperature gauges), radar information and numerical weather models (ALADIN and ECMWF) for data generation. Time step is 15 minutes. The same data is used for the operating EWS in Lower Austria. Source: ZAMG (Central Institute for Meteorology and Geodynamics).

- Analysis data (precipitation and temperature):
  Continuous data from 2003-2006 and ten selected flood events for calibration and validation were available.
  Spatial resolution: 1x1 km raster
  Temporal resolution: 15 minutes
  The INCA system is characterised by its high resolution of 1 km. Analysed meteorological fields are: temperature, humidity, wind, precipitation, cloudiness and global radiation. Input data to the system are NWP model output (ALADIN), surface station observations, radar data, satellite data and elevation data.
  The three-dimensional analysis of temperature and humidity in the INCA system starts with the ALADIN forecast as a first guess. This first guess is corrected based on differences between observation and forecast at surface station locations.
  The precipitation analysis is a synthesis of station interpolation and radar data. It is designed to combine the strengths of both methods, the accuracy of the point measurements and the spatial structure of the radar field. The radar can detect precipitating cells that do not hit a station. Pure interpolation can provide a precipitation analysis in areas not accessible to the radar beam. Naturally, the method has to deal as well with the disadvantages inherent in both datasets, namely the potentially unrepresentative locations (and low density) of stations, and the fundamental quantitative uncertainty of precipitation estimates by radar. The 1 km INCA×irregular point values are interpolated onto the regular 1 grid using distance weighting. In cases where the

radar data is missing, the final INCA precipitation analysis is simply the field of interpolated station observations as described above. The radar data, which is available at 5 minute intervals, is aggregated to 15-min precipitation amounts. Since the radar field is strongly range-dependent it must be scaled before it is used in the precipitation analysis. In a first step, a 'climatological' scaling is performed. A climatological scaling factor is calculated for each month. In order to compensate for some of the artefacts in the radar field caused by shielding of the radar beam, the interpolated scaling factor is replaced by a local scaling factor in regions where the radar beam is strongly shielded (indicated by beamlike structures with high local scaling factors). As a next step the climatologically scaled radar field is re-scaled on the basis of a comparison at analysis time of station observations and radar values at the stations. The combination of the two precipitation fields, radar and stations, is obtained through a weighting relationship

- Forecast data (precipitation):
  Data for three selected flood events was available.
  Spatial resolution: 10x10 km
  Temporal resolution: 15 minutes, forecast date: hourly, forecast horizon: 48 hours
  The ZAMG provides forecasted data from the INCA system (description see above). This is a combination of measurements, Nowcasting and NWP (numerical weather prediction). With continuous updating of the model forecast with actual measurements in the nowcasting procedure the INCA output shows better results than the direct output from ECMWF and ALADIN. The meteorological uncertainty is represented in 50 precipitation ensemble forecast. This makes it easier to handle with hydrological models (Komma et al., 2007). The ensembles are processed additionally to the deterministic forecast run within the INCA system. Nowcasting is used in the forecasting time range up to +6 h. The first 2 h of forecasts source only from nowcasting.
  The currently used method of predicting temperature in the nowcasting range has been adopted from a single-point application and treats each grid point independently. It makes certain assumptions about the persistence of the NWP forecast error, depending on stratification and cloudiness. Thus the temperature forecast consists of the observed temperature plus the temperature change predicted by the NWP forecast, multiplied by a factor which depends on the cloudiness forecast error of the NWP model. If there is no cloudiness forecast error, the predicted temperature change is equal to the one predicted by the NWP model.
  The INCA precipitation forecast consists of two components: (1) an observation-based extrapolation, and (2) an NWP model forecast. The extrapolation method is based on motion vectors determined from previous analyses. The model forecasts are output fields of the limited area model ALADIN and the global ECMWF model. Only the ECMWF model provides ensemble forecasts for the INCA-system.

4.1.3.3 Discharge data

Data from seven online river gauges and one offline river gauge from the Traisen Basin was available, see Table 4-2. The source of the data is the Hydrological Service of Lower Austria.

Table 4-2: River gauging stations in the Traisen Basin

Station name	HZB Nr.	Parameter	On/off-line	data since
Türnitz	209361	W, Q	online	1981
Hohenberg	208868	W, Q	online	2005
Lilienfeld	207894	W, Q	online	1896
Ramsau	208793	W, Q	online	2005
Haxenmühle	209445	W, Q	offline	1981
St.Veit	207902	W, Q	online	1923
Windpassing	207910	W, Q, T	online	1919
Herzogenburg	208777	W, Q	online	2005

W...water level, Q...discharge, T...water temperature
All gauges are automatically recording the water level. Two stations have ultrasonic sensors (Ramsau, Herzogenburg). Discharge is estimated from water levels with rating curves that are continuously updated.

4.1.4 *Flood Forecasting*

On the basis of the available data base the three hydrological models described in section 3.1.5.2 have been set up. Model parameters have been calibrated using the selected events given in Table 4-4. Estimation of model parameters was done according to the best practice of the modelling groups. In this context, both manual and automatic procedures have been applied. The objective of the calibration was to identify the set of parameters for each model that reproduces the observed hydrographs of all calibration events in a best possible way.

Table 4-3: Compilation of available observations for flood events in the Traisen basin

Event	Date	Return period	Event type	Available data
C1	01.06.2004 - 07.06.2004	HQ1	summer rain	P, T, Q, P-FC
C2	21.11.2004 - 24.11.2004	<HQ1	snow and rain	P, T, Q
C3	12.03.2005 - 29.03.2005	HQ2	snow melt and rain	P, T, Q
C4	04.08.2006 - 08.08.2006	HQ10-30	summer rain	P, T, Q, P-FC
C5	14.08.2005 - 23.08.2005	HQ2	summer rain	P, T, Q
V1	04.08.2002 - 16.08.2002	HQ10	summer rain	P, T, Q
V2	30.01.2004 - 05.02.2004	HQ2	snow melt	P, T, Q
V4	20.03.2006 - 30.03.2006	HQ1	snow melt and rain	P, T, Q
V5	01.06.2006 - 04.06.2006	HQ5	summer rain	P, T, Q, P-FC
V6	02.09.2007 - 10.09.2007	HQ10-30	summer rain	P, T, Q

Events marked with C are used for calibrating and events marked with V are used for validating the hydrological models
P… precipitation analysis, T… temperature analysis, Q…discharge,
P-FC…precipitation ensemble forecasts

4.1.4.1 Hydrologic modelling, model calibration and validation

The results obtained from model calibration are displayed in Figure 4-6 for each event considered. The black line shows the observed runoff at the river gauge Windpassing whereas the red, blue and green lines show the simulation results of the models WBrM, DICHITOP and COSERO for this gauge.

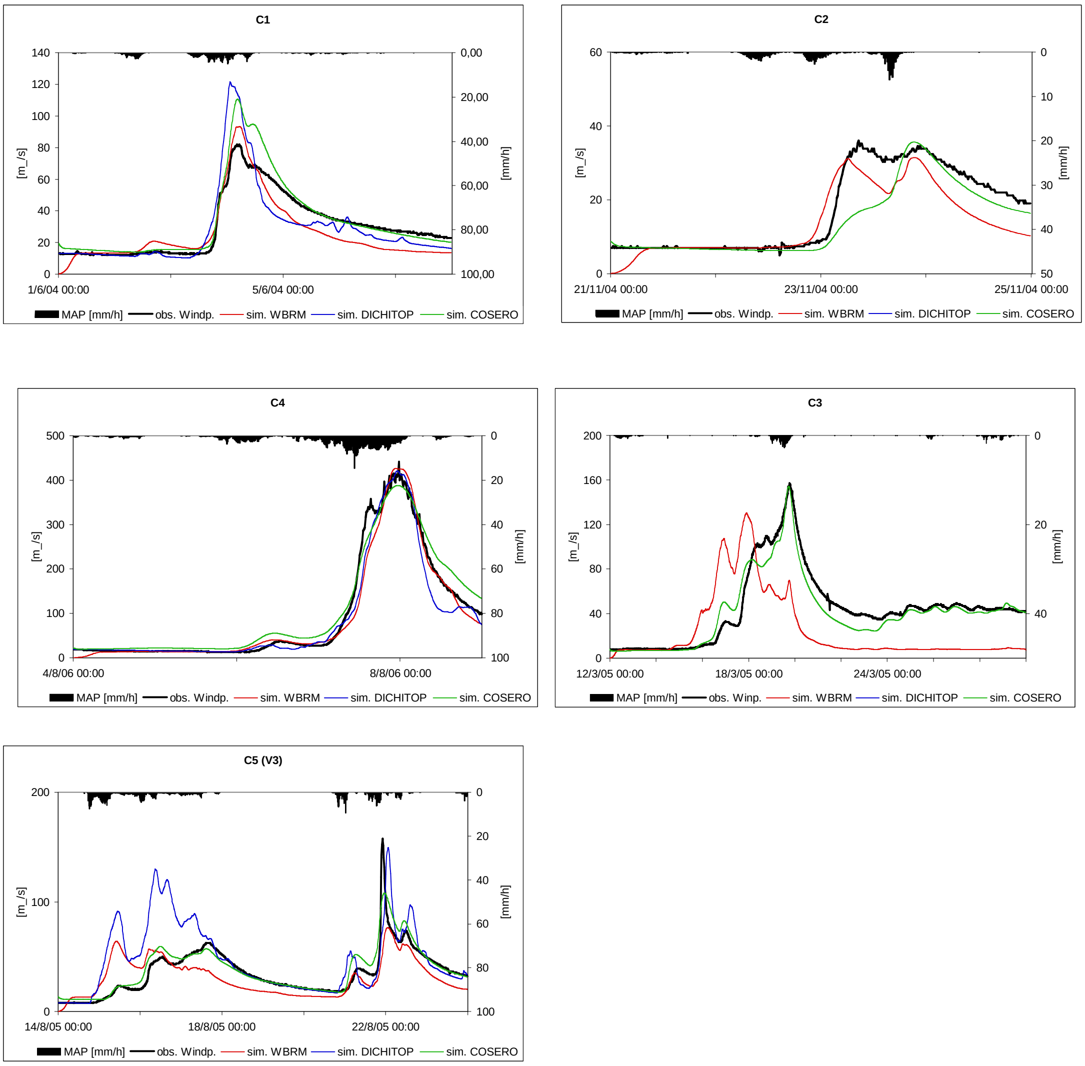


Figure 4-6: Results Model Calibration Traisen Basin

The flood events C1, C4 and C5 are generated by heavy precipitation in the summer months. The events C2 and C3 (on the right) are caused by snow melt in combination with rainfall. DICHITOP does not include procedures for the modelling of snow hydrological processes. Therefore, no results are available for these events.

The performance of the different models to reproduce the system responses is quite diverse for the different events. The models describe the dynamics of the events with regard to the initiation of the rising limp and the temporal evolution of the flood hydrograph very well. Yet, there are considerable differences between the models concerning the predicted peak flows and flow volumes.

The model COSERO performs clearly better than the WBrM with regard to the modelling of the snow melt events. In this context it has to be noted that the parameters of the snow simulation routines of WBrM have not been calibrated but standard values have been used.
An objective comparison of model performance is based on the evaluation criteria defined in Table 3-1. The resulting performance statistics of the model results for the calibration events in the Traisen basin are summarised in Table 4-4.

Table 4-4: Performance statistics model calibration Traisen

Event	Gauge	Criterion	WBRM	COSERO	DICHITOP
C1	Windpassing	E	0.68	0.82	0.59
	672	R^2	0.85	0.96	0.77
		MB	-25.29%	11.32%	-4.93%
		Peak Ratio	0.95	1.35	1.48
C2	Windpassing	E	0.72	0.72	
	384	R^2	0.81	0.80	
		MB	-0.18	-0.18	
		Peak Ratio	0.87	0.99	
C3	Windpassing	E	-0.54	0.92	
	1728	R^2	0.15	0.93	
		MB	-44.26%	-8.14%	
		Peak Ratio	0.83	0.98	
C4	Windpassing	E	0.96	0.97	0.96
	480	R^2	0.97	0.98	0.96
		MB	-6.30%	11.61%	-9.17%
		Peak Ratio	0.96	0.88	0.95
C5 - (V3)	Windpassing	E	0.34	0.87	-0.67
	960	R^2	0.41	0.89	0.40
		MB	-13.31%	6.25%	34.43%
		Peak Ratio	0.49	0.69	0.95

E: Nash-Sutcliffe Efficiency
R^2: Coefficient of determination
MB: Mass Balance
Peak Ratio: deviation from flood peak

On the basis of these results COSERO outperforms the other models in terms of model efficiency (E). As far as the mass balance and the peak ratio is concerned, in some cases the WBrM and DICHITOP provide clearly better predictions than COSERO.

After finalisation of the calibration phase the observed hydrographs for the validation events (Table 4-3) have been made available. The comparison of simulation results and observations for these events is given in Figure 4-7.

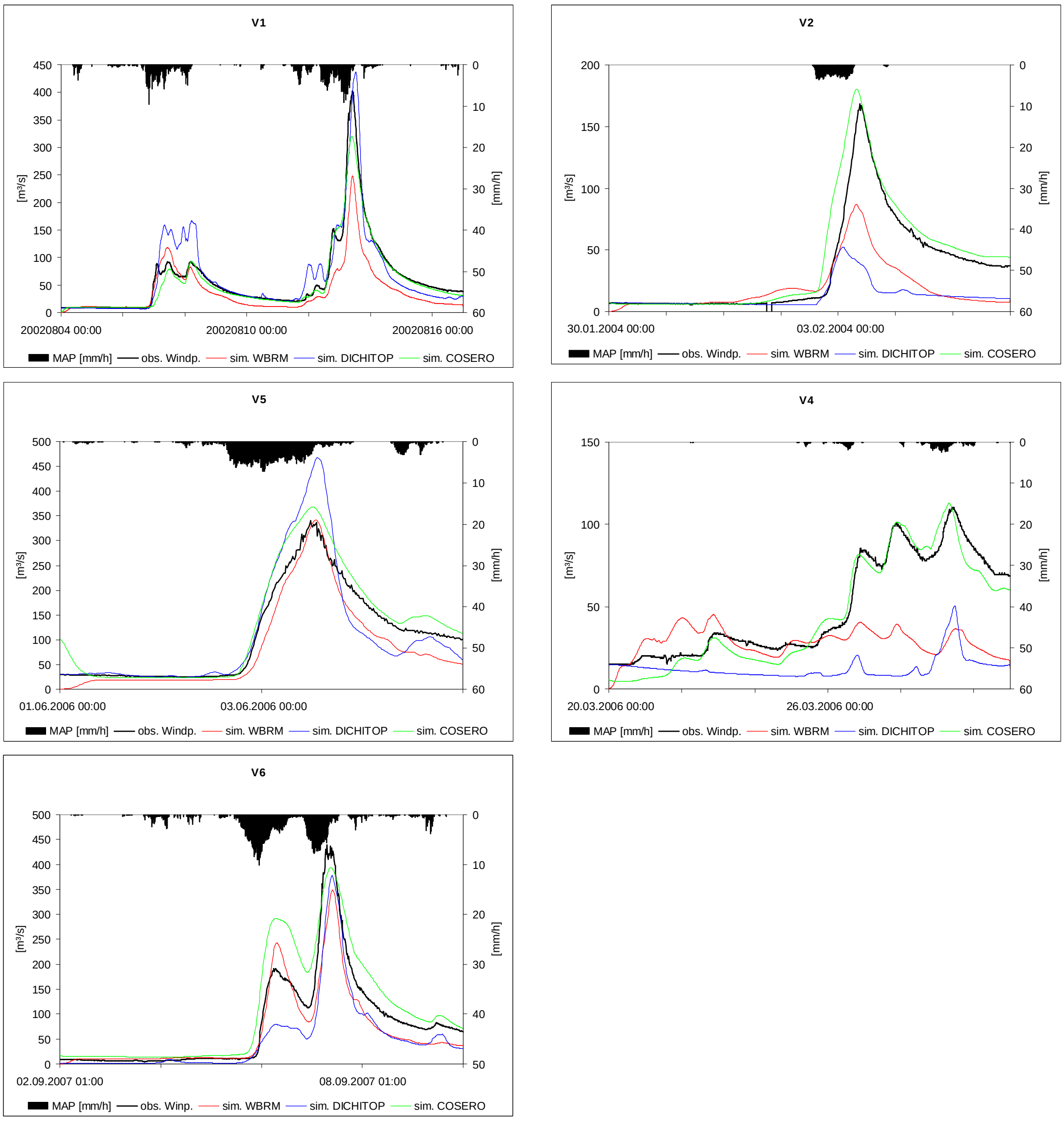


Figure 4-7: Results Model Validation Traisen Basin

Overall the results of model validation are very satisfactory. The dynamics of the flood waves are well reproduced by the simulation models. Still, with regard to predicted peak flow and flow volume there are notable differences between the simulation models. The deviation of simulation results from the observed values is considerable in some cases. For the snow melt events (V2 and V4) there is a clear difference between the models COSERO and WBrM. Probably, this can be attributed to the snow modelling procedures implemented in COSERO, which are very well adapted to the local conditions including extensive application experiences in alpine regions.
Again, the performance statistics (Table 3-1) achieved by the simulation models for the different events are summarised in Table 4-5.

Table 4-5: Performance statistics model validation Traisen

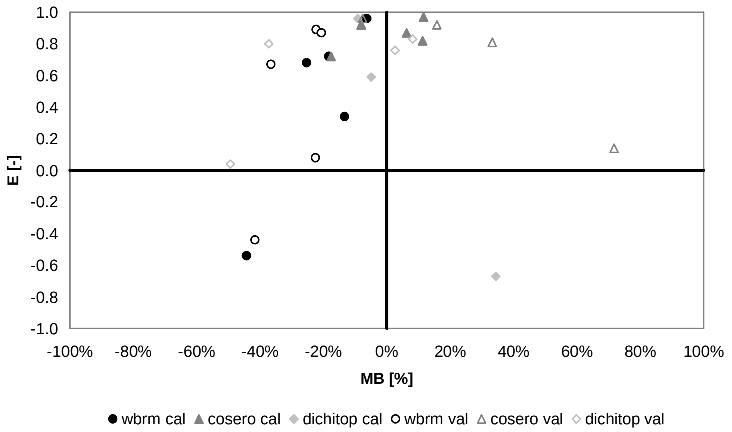
Event	Gauge	Criterion	WBRM	COSERO	DICHITOP
V1	Windpassing	E	0.67	0.96	0.83
	1248	R^2	0.88	0.97	0.87
		MB	-36.56%	-7.62%	8.23%
		Peak Ratio	0.62	0.79	1.08
V2	Windpassing	E	0.08	0.14	0.04
	672	R^2	0.11	0.16	0.11
		MB	-22.49%	71.71%	-49.38%
		Peak Ratio	0.52	1.07	0.31
V4	Windpassing	E	-0.44	0.92	-1.26
	1056	R^2	0.03	0.95	0.23
		MB	-41.57%	-7.95%	-74.02%
		Peak Ratio	0.41	1.02	0.43
V5	Windpassing	E	0.89	0.92	0.76
	384	R^2	0.96	0.99	0.88
		MB	-22.29%	15.81%	2.62%
		Peak Ratio	1.00	1.08	1.38
V6	Windpassing	E	0.87	0.81	0.80
	768	R^2	0.92	0.92	0.92
		MB	-20.61%	33.31%	-37.18%
		Peak Ratio	0.79	0.90	0.86

E: Nash-Sutcliffe Efficiency
R^2: Coefficient of determination
MB: Mass Balance
Peak Ratio: deviation from flood peak

The presented values show that no simulation model provides better predictions (in terms of the evaluation criteria) than the other models for all events. The results of the COSERO achieve better efficiency values in most cases. Yet again, separate from the events V2 and V4, either DICHITOP or WBrM provide better predictions of the peak flow and the flow volume.

Given the variation and diversity of these results it is problematic to conclusively rank the models according to their predictive performance. In fact, this heterogeneous picture of model performance emphasises the multi dimensional characteristic of the diverse aspects that have to be taken into account in flood modelling and flood forecasting.

For illustration, selected performance statistics obtained for model calibration and model validation are contrasted in Figure 4-8.



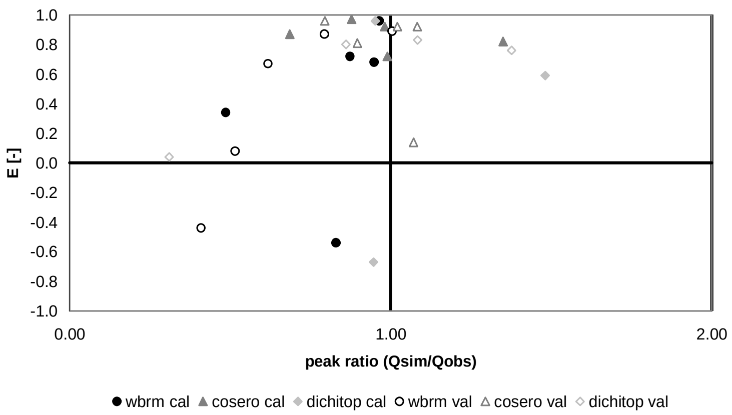


Figure 4-8: Comparison of performance criteria achieved in model calibration and validation in the Traisen basin with the different models for the events considered.

In the diagram of Figure 4-8 (top) model efficiency (vertical axis) and mass balance error (horizontal axis) are plotted. All simulation models provide results, for both calibration events (solid markings) and validation events, in the upper region of model efficiency in combination with small errors for MB. As expected the variation of results is larger for the validation events. Outliers, values for E < 0.2 and considerable MB errors, correspond to the snow melt events C2, V2 and V4.
Figure 4-8 (bottom) compares model efficiency (vertical axis) and peak ratio (horizontal). A similar picture is obtained as before. Again, the outliers correspond to the snow melt events. In addition, it has to be noted that for different validation events the best prediction of peak flow is achieved with different models, refer also to Table 4-5.

These scatter diagrams show that no clear selection can be made in favour of one simulation model. Further, there is no visible dependence between the different evaluation criteria. High efficiency values occur in combination with fair values of MB and peak ratio.

It is noticed, that there is a considerable variation of the performance criteria for the simulation results produced with different models. This gives reason to conjecture that in flood forecasting the different models will contribute complementary information to the flood forecast.

4.1.4.2 Flood forecast reliability

A total of three flood events are included in the evaluation of flood forecast reliability following the procedure detailed in 3.1. For the selected events, which are summarised in Table 4-6, deterministic QPF and ensemble QPF are available on an hourly basis.

Table 4-6: Characteristics of the events used for the evaluation of flood forecast reliability in the Traisen basin.

	Events		
Traisen	C1	C4	V5
Start	03.06.2004 00:00	07.08.2006 00:00	03.06.2006 01:00
End	05.06.2004 23:00	08.08.2006 23:00	04.06.2006 23:00
accMAP [mm]	69	164	122
Event type	Summer rain	Summer rain	Summer rain
Ini. Cond.	Dry	Wet	Wet
Runoff coef. [-]	0.16	0.22	0.25
Peak [m³/s]	82	442	340
Return period [a]	1	Okt 30	5
start Rising limp	03.06.2004 17:00	07.08.2006 03:00	02.06.2006 20:00
Time to peak [h]	11	20	16
NSE*(WBrM)	0.68	0.96	0.89
NSE*(COSERO)	0.82	0.97	0.92

*Nash-Sutcliffe-Efficiency (Nash & Sutcliffe 1970) achieved in the reproduction of the flood event with the hydrological model using observed precipitation, cf. Table 4-4 and Table 4-5.

In Figure 4-9 and Figure 4-10 flood forecasts at the gauging station of Windpassing (cf. Figure 4-2) for different points of time of the event C1 generated with WBrM and COSERO are exemplarily shown.

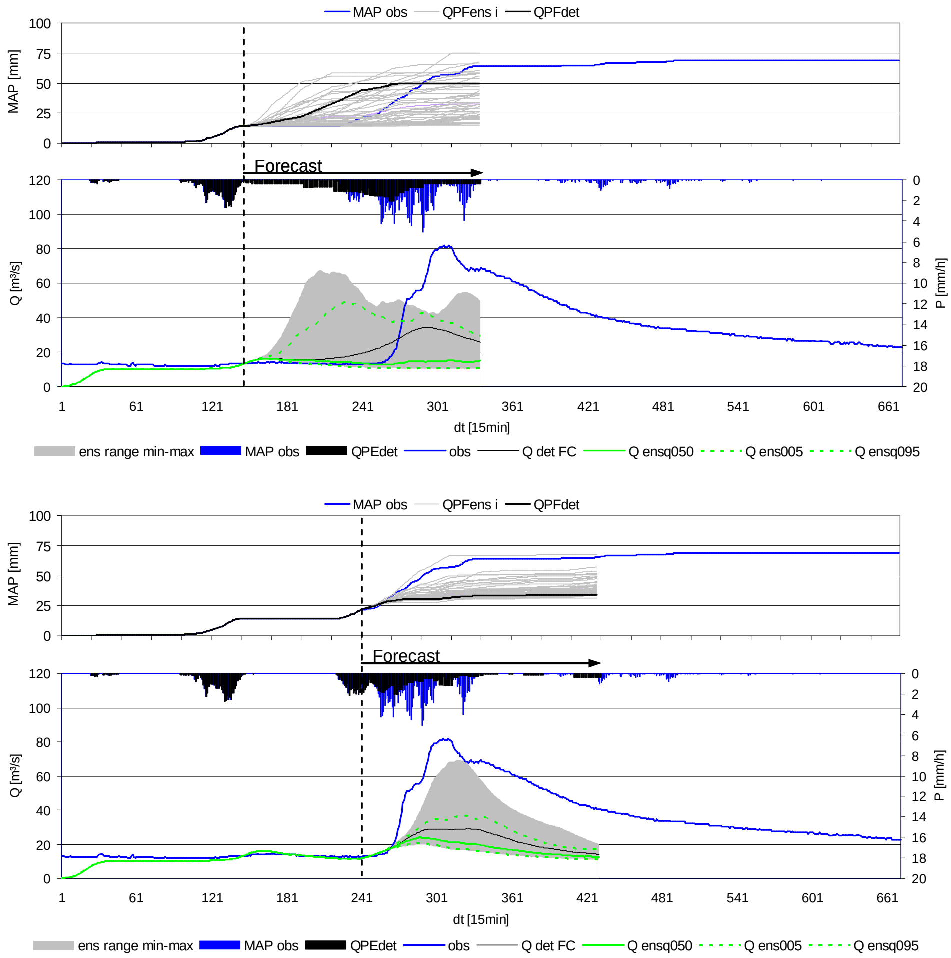


Figure 4-9: Flood forecasts at the gauging station Windpassing for the event C1 generated with WBrM using deterministic and ensemble QPF for $\tau_{max} = +48$ h. Top: forecast on 02.06.2004 12:00. Bottom: forecast on 03.06.2004 12:00.

In the upper part of the diagrams the accumulation of observed mean areal precipitation (MAPobs [mm]) throughout the event is plotted along with the accumulated mean areal precipitation according to the deterministic forecast (QPFdet [mm]) and the ensemble forecasts (QPFens [mm]). In addition, in the lower part of the figures the observed mean areal precipitation intensity (MAPobs [mm/h]) and the deterministic precipitation forecast (QPFdet [mm/h]) are shown. Further, the observed discharges (obs [m³/s]) and the flood forecasts corresponding to the deterministic QPF (Q det FC [m³/s] are displayed. The grey shaded area spans the range between the minimum and maximum ensemble flood forecast (ens range min-max). In addition, the 5%, 50% and 95% quantiles of the discharge ensemble (Qensxxx [m³/s] are indicated.

The comparison between both points of time of the flood forecast reveals that the precipitation forecast may change considerably throughout the event. At the first instant of time, at 02.06.2004 12:00 (Figure 4-9 and Figure 4-10 on top) the deterministic forecast and also several members of the ensemble forecast indicate important amounts of precipitation upcoming. Indeed the initiation of the expected precipitation is predicted to occur too early. Twenty four hours later, at the second instant of time regarded (Figure 4-9 and Figure 4-10 at the bottom) both the deterministic QPF and the bulk of the ensemble QPF predict much lower amounts of precipitation. The spread of the ensemble is much narrower and only one ensemble member indicates increased precipitation, which is however remarkably close to MAPobs.

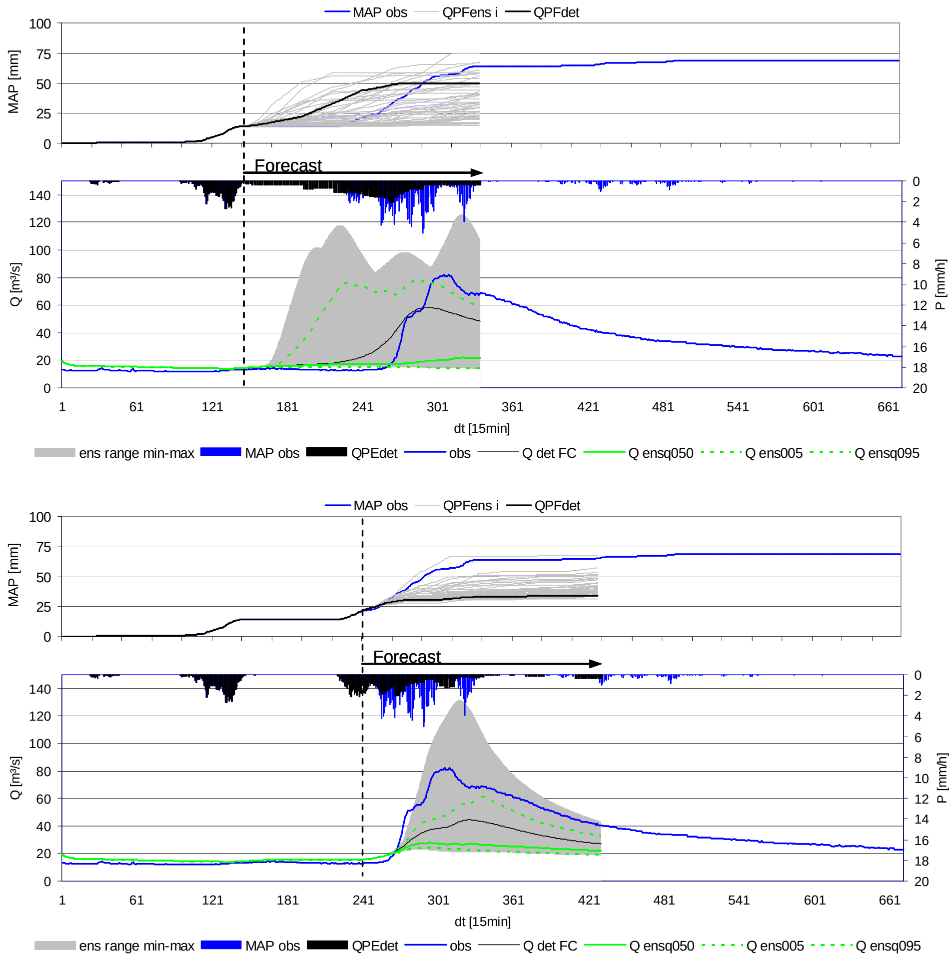
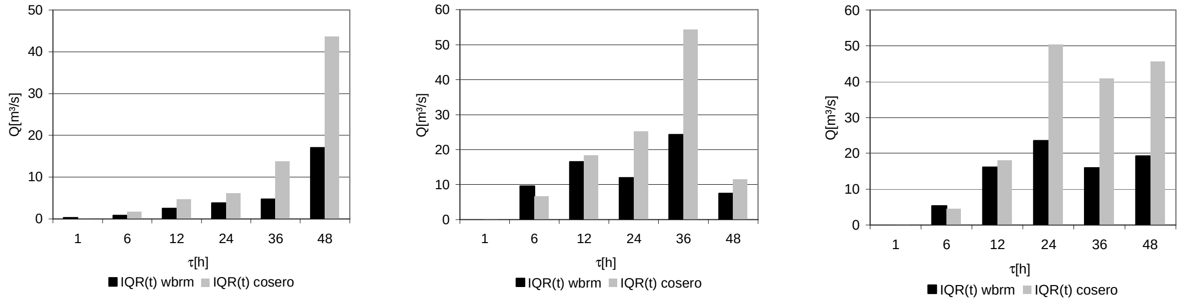


Figure 4-10: Flood forecasts at the gauging station Windpassing for the event C1 generated with COSERO using deterministic and ensemble QPF for $\tau_{max} = +48$ h. Top: forecast on 02.06.2004 12:00. Bottom: forecast on 03.06.2004 12:00.

The variability of the ensemble QPF induces significant variation of the predicted discharges. The 90% confidence interval embraced by the 5% and 95% quantile as well as the median point towards much lower upcoming discharges. The deterministic forecast is clearly above the median of the ensemble forecast.

The comparison of the flood forecasts in Figure 4-9 with Figure 4-10 shows that both simulation models generate quite different peak flows and flow volumes. From model calibration it is known that the WBrM provides a realistic estimate of the flood peak but underestimates the discharge volume for this event, see Figure 4-6. In contrast, COSERO largely overestimates the peak flow and the volume. In combination with underestimated amounts of precipitation at the second instant of time this results in higher predicted discharges which more comprehensively envelops the actual discharge values as compared to WBrM.

These findings emphasise the sensitivity of flood forecast with respect to uncertainties associated with precipitation forecasts and hydrological modelling. Furthermore, it seems that there is a complex interaction between both uncertainty sources. Figure 4-11 shows the inter quartile ranges (IQR) of ensemble flood forecasts with different lead times τ at the moment of the flood peak of the events C1, C4, and V5 using the models WBrM and COSERO.



a) Event C1 b) Event C4 c) Event V5

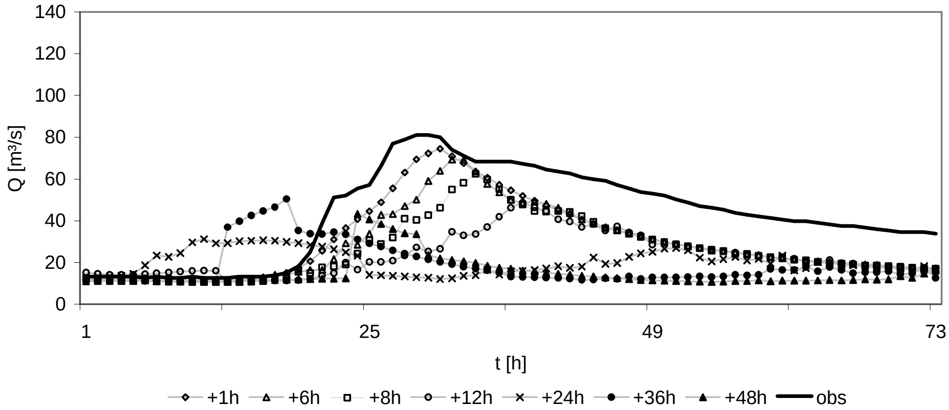
Figure 4-11: Inter quartile ranges of ensemble flood forecasts at the flood peak of the events C1, C4 and V5 for different lead times using the models WBrM and COSERO

The graphs show that the spread of the ensemble predictions increases with lead time. Apparently, using either COSERO or WBrM for processing the ensemble precipitation forecasts, results in different ranges of flood forecasts. Thus it appears that the uncertainty of the precipitation forecast is modulated in a different manner depending on the hydrological model. This confirms the requirement to take the uncertainties related to the hydrological simulation model explicitly into account in the evaluation of forecast reliability.

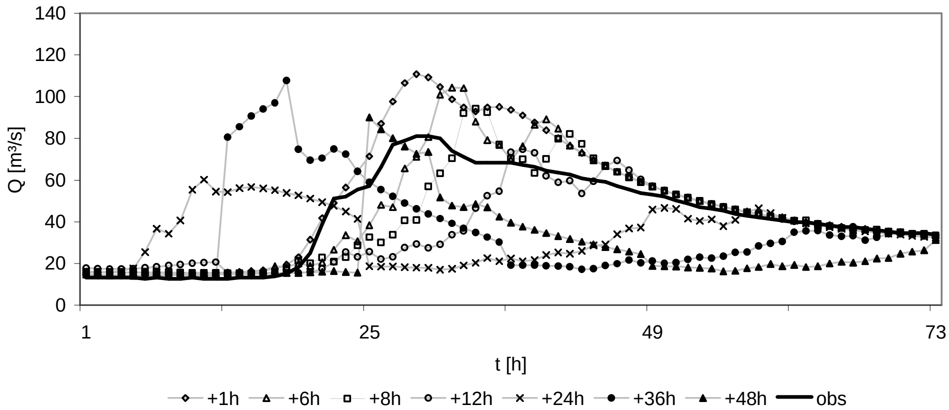
4.1.4.3 Lead time dependence of forecast reliability

For the considered events hourly precipitation forecasts are available. Accordingly, flood forecasts can be produced for each hour of the period examined with different lead times, i.e. $t_i + \tau$. For these forecasts the prediction error can be determined as per equation 1 using the discharge observations.

Figure 4-12 displays hourly values of the observed hydrographs along with the forecasts of the models WBrM and COSERO corresponding to different lead times ($\tau_=$ +1, +6, +8, +12, +24, +36, +48 using deterministic QPF. For both models an increasing deviation of the forecasts from the observations for longer lead time τ can be seen.



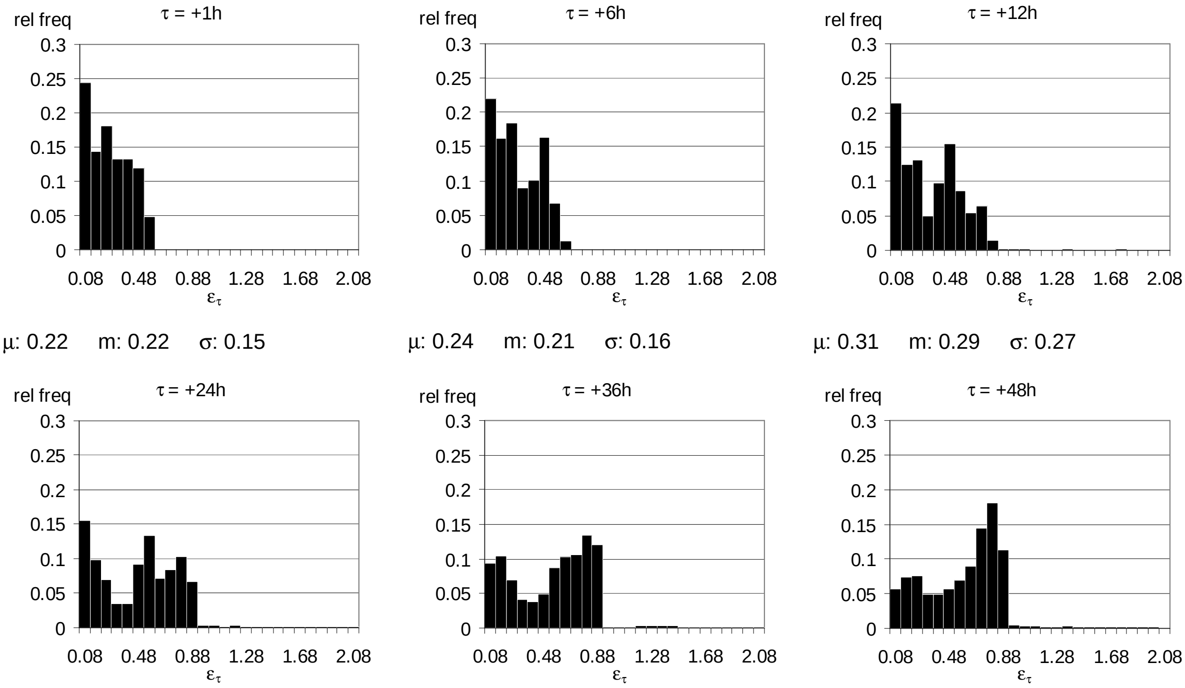
a)WBrM



b) COSERO

Figure 4-12: Hourly deterministic flood forecasts throughout the event C1 for different lead times τ [h] compared to observed discharge hydrograph. Top: flood forecasts using WBrM. Bottom: flood forecasts using COSERO.

The results from the statistical analysis of the joint sample of prediction errors $\varepsilon_{i,\tau}$ for the event C1 of both simulation models are given in Figure 4-13 in terms of histograms for the lead times $\tau =$ +1, +6, +12, +24, +36, +48.



µ: 0.55 m: 0.49 σ: 0.78 | µ: 0.61 m: 0.58 σ: 0.72 | µ: 0.60 m: 0.63 σ: 0.52

µ: mean m: median σ: standard deviation

Figure 4-13: Histograms of WBrM and COSERO prediction errors et for different lead times τ [h] for the event C1.

The diagrams show that the variation of the prediction errors ε_τ increases with lead time τ (also indicated by the standard deviation). Further, as can be observed from the mean and the median of the distributions a shift of the maximum frequencies towards larger errors can be noticed.

Figure 4-14 displays the corresponding distribution function of the prediction errors ε_τ. The increasing spread and the increment of the mean prediction errors are evident.

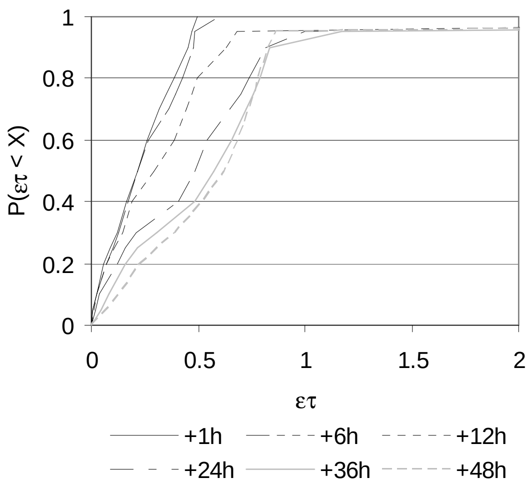


Figure 4-14: Distribution function of prediction errors for different lead times τ [h] for the event C1.

The result of the evaluation of the joint distribution of the prediction error of all events and both models in terms of forecast reliability as defined in equation 2 are given in Figure 4-15. The curve describes the evolution of forecast reliability (FR) over lead time τ at the gauging station of Windpassing. At best a forecast reliability of 66% is achieved. This level stays more or less constant for lead times up to τ = +4 h. Then a continuous decrease of FR can be observed. The intensity of this decline is most pronounced for the range between τ = +4 h and τ = +15 h lead time.

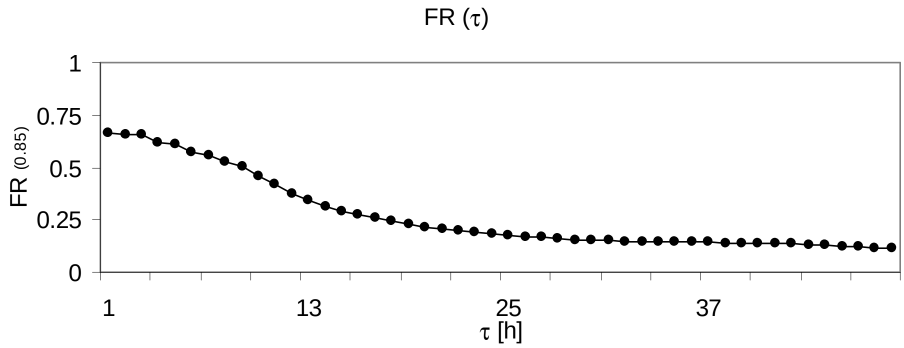


Figure 4-15: Forecast reliability (FR) as a function of lead time τ for the Traisen basin based on the distribution function of prediction errors of all events and both simulation models (WBrM and COSERO).

These results show that the predictability of floods is limited and involves a considerable degree of uncertainty that increases with lead time. A more differentiated analysis and discussion of these findings follows in section 5.1.

4.1.5 Economic evaluation

4.1.5.1 Capital Intensities

As defined in section 4.3.3.2.8 capital intensity is defined as capital stock per employee. It is used in EWASE to calculate a proxy for the value of a company. This section introduces the capital intensities for the Nuts 3 regions Niederösterreich Süd (AT122) and St. Pölten (AT123).

Table 4-7: Traisen basin, capital intensity in the primary and secondary sector, in € per active person

		Period	Primary	Secondary			
			Agriculture, Livestock and Fishing	Mining and Quarrying	Manufacturing Industry	Energy, Gas and Water	Construction
AT 122	Plant and Equipment	2002	209,954	292,358	141,468	870,096	60,662
		2003	212,191	295,473	142,975	879,366	61,308
		2004	221,464	308,386	149,224	917,797	63,988
	Buildings	2002	176,771	246,151	119,109	732,579	51,075
		2003	178,654	248,774	120,378	740,383	51,619
		2004	186,462	259,646	125,639	772,741	53,875
	Other Equipment	2002	33,183	46,207	22,359	137,517	9,588
		2003	33,536	46,699	22,597	138,982	9,690
		2004	35,002	48,740	23,585	145,056	10,113
AT123	Plant and Equipment	2002	176,430	292,644	141,607	870,948	60,722
		2003	183,984	305,173	147,669	908,236	63,321
		2004	191,192	317,130	153,455	943,822	65,802
	Buildings	2002	148,546	246,392	119,226	733,296	51,125
		2003	154,905	256,941	124,331	764,691	53,313
		2004	160,975	267,008	129,202	794,652	55,402
	Other Equipment	2002	27,884	46,252	22,381	137,652	9,597
		2003	29,078	48,232	23,339	143,545	10,008
		2004	30,218	50,122	24,253	149,169	10,400

Table 4-7 displays capital intensities for the primary and secondary sector. In the upper part of the table capital intensities for Nuts 3 Region Niederösterreich Süd (AT122) are given, the lower part of the table refers to Nuts 3 Region St. Pölten (AT 123). Values for the period 2002 to 2004 are shown. Capital Intensity is differentiated into plant and equipment, buildings, as well as other equipment. The last group mainly consists of immaterial assets, companion animals and crops where appropriate. As there is no significant fishery or fish farming in the regions, the primary sector only contains agriculture and forestry. The secondary sector is divided into four activities. All activities have the highest capital intensities in plant and equipment. It is a typical picture for Austria, that all activities show growing capital intensities over the years. Even the decreasing importance of Agriculture does not change the picture because here labor force is replaced by capital. Largest capital intensities for both regions are in the utilities (water, gas, and electricity generation) and distribution. Manufacturing Industry follows Mining and Quarrying, the lowest capital intensities exhibits the construction industry. For the secondary sector there are no significant differences in capital intensities between the regions. But in the primary sector capital intensity in Niederösterreich Süd is 20% higher than in the St. Pölten region.

Table 4-8: Traisen Basin, capital intensities in the tertiary sector, in € per active person

		Period	Tertiary								
			Trade and Repair	Tourism	Trafic, Communication	banks and insurance industry	Real estate, lending, b2b services	Public Administration, Defence, Social insurance	Educa-tion	Health	Other public serivces
AT 122	Plant and Equipment	2002	67,532	51,572	371,527	155,010	1,054,913	153,695	40,785	50,534	215,781
		2003	68,252	52,121	375,484	156,662	1,066,151	155,332	41,220	51,072	218,080
		2004	71,234	54,399	391,895	163,508	1,112,746	162,121	43,021	53,304	227,611
	Buildings	2002	56,859	43,421	312,807	130,511	888,186	129,404	34,339	42,547	181,678
		2003	57,465	43,884	316,140	131,901	897,648	130,782	34,705	43,000	183,613
		2004	59,976	45,801	329,956	137,666	936,878	136,498	36,222	44,879	191,638
	Other	2002	10,673	8,151	58,719	24,499	166,727	24,291	6,446	7,987	34,104
		2003	10,787	8,238	59,345	24,760	168,503	24,550	6,515	8,072	34,467
		2004	11,258	8,598	61,938	25,842	175,868	25,623	6,799	8,425	35,974
AT123	Plant and Equipment	2002	79,026	60,349	434,760	181,393	1,234,459	179,854	47,727	59,134	252,507
		2003	82,410	62,933	453,374	189,159	1,287,310	187,554	49,770	61,666	263,318
		2004	85,638	65,399	471,137	196,570	1,337,747	194,902	51,720	64,082	273,635
	Buildings	2002	66,536	50,811	366,047	152,724	1,039,354	151,428	40,184	49,788	212,599
		2003	69,385	52,987	381,719	159,263	1,083,853	157,911	41,904	51,920	221,701
		2004	72,103	55,063	396,675	165,503	1,126,319	164,098	43,546	53,954	230,387
	Other Equipment	2002	12,490	9,538	68,713	28,669	195,104	28,426	7,543	9,346	39,908
		2003	13,025	9,946	71,655	29,896	203,457	29,643	7,866	9,746	41,617
		2004	13,535	10,336	74,462	31,068	211,429	30,804	8,174	10,128	43,248

Quite a different picture gives capital intensity in the tertiary sector which is shown in Table 4-8. The largest capital intensity of all 17 NACE activities is in the real estate and lending activities. Again the equipment takes the largest share. The second largest capital intensity is in traffic and communication followed by other public services. This activity summarises sewage and refuse disposal, sanitation and recreational, cultural and sporting activities. Very close to banks and insurance industry is capital intensity in public administration. Trade and repair as well as tourism, health and education exhibit much lower capital intensities which clearly show the higher labor intensities in these sectors. The comparison between the regions for the tertiary sector shows a different picture than in the primary and secondary sector. In Niederösterreich Süd capital intensities in the tertiary sector reach roughly 80% of the St. Pölten region. Niederösterreich Süd shows still a more agricultural imprint, whereas the region St. Pölten, driven by the dynamic Capital of Lower Austria (AT 12), St. Pölten, has made larger progress on its way into the service society.

4.1.5.2 Added Value

As a second economic indicator gross value added (GVA) is used for taking into account indirect losses. Firstly business disruption occurs when a company suffers direct flood damage. There is an ongoing debate if these damages should be included or not, dependant upon the perspective of the decision maker. With a regional perspective, value added may be included because it is lost to the region whereas on a national level value added may be excluded because it is only shifted to other regions of the nation (Meyer et al 2005, Messner et al. 2007). As the EU generally takes a regional perspective, value added is included in this study. Secondly business disruption occurs in case of a flood warning when employees of a company stop their productive work and turn to any kind of damage mitigation actions, be it carrying sandbags, moving cars into safety, installing mobile flood protection or speeding home to take care of private belongings. EWASE is the first study to include mitigation cost into economic analysis on the very pragmatic basis of lost value added. As a measure for indirect losses value added is used on a daily basis. It is calculated on the basis of national data from Statistic Austria (Traisen) and Instituto Nacional de Estadistica (INE) (Besòs). Gross value added per activity is divided by active persons per activity on NUTS2 level. The annual values are broken down to daily values on the assumption that average working days per year are 220 and average working hours per day are 8. As was shown for the capital intensities a regionalisation to NUTS3-level is possible in principle. GVA is shown for the primary and secondary sector in Table 4-9 and for the tertiary sector in Table 4-10.

Table 4-9: Gross Value Added per year and active person in the primary and secondary sector in Lower Austria (AT12) [€], 2000 - 2004

	Primary	Secondary			
Period	Agriculture, Livestock and Fishing	Mining and Quarrying	Manufacturing Industry	Energy, Gas and Water	Construc-tion
2000	23,770	60,000	62,774	165,556	49,903
2001	25,900	90,000	63,158	168,049	51,283
2002	25,010	94,545	64,948	175,897	55,350
2003	24,077	106,667	66,297	168,837	56,823
2004	25,132	143,704	68,962	165,000	59,836

It is not surprising that there is a strong correlation between capital intensities and gross value added. High investments per active persons lead to high GVA. Therefore the highest GVA are in the utilities activities (Energy, Gas, and Water) whereas lowest GVA is in the tourist industry. The growth in GVA is very modest generally. Only mining and quarrying exhibited significant growth over the time series (26%). In the other activities growth was very low or moved around zero in small positive or negative percentage values. Tourism had 6% and construction industry had 5% growth rates on average, the other activities grew between 1% and 2% on average.

Table 4-10: Gross Value Added per year and active person in the tertiary sector in Lower Austria (AT12) [€] 2000 - 2004

	Tertiary								
Period	Trade and Repair	Tourism	Trafic, Communication	banks and insurance industry	Real estate, lending, b2b services	Public Administration, Defence, Social insurance	Education	Health	Other public serivces
2000	34,264	26,797	54,497	82,826	75,741	43,679	48,788	32,422	30,332
2001	33,859	29,470	53,326	81,898	78,843	44,764	50,836	32,797	30,580
2002	34,982	30,386	54,570	77,681	81,237	43,624	50,814	33,787	30,255
2003	35,663	32,230	54,079	82,446	82,684	45,011	51,037	33,124	32,065
2004	37,160	33,495	53,817	89,281	86,324	46,265	50,200	33,791	34,176

4.1.5.3 Residential Exposure

An economic assessment should build on undistorted market prices where ever possible, because prices on perfect markets are efficient allocations. A market price reflects an allocation, where nobody can be made better off without making somebody else worse off. That means that prices on perfect markets represent a Pareto-efficient allocation or a Pareto optimum (Perman et al. 2003). Perfect markets do not exist in reality. But Internet-markets potentially exhibit new degrees of “next-to-perfect” market conditions, at least with respect to perfect information: Every customer can easily gather comprehensive market overview with respect to supply and prices. These principles of utilitarian economics enabled us to overcome a weakness of the approach in the private sector. Capital stock information includes private dwellings – at least where they are rented – in NACE-activity K: Real estate, renting and business activities. But the few active persons in this activity are weak indicators for distribution of private stocks. Therefore online-real estate markets were checked for availability of house-prices.

Table 4-11: House prices in the Traisen basin

	Municipality	sample	price [€]	land [m²]	living space [m²]
Houses, land included	Herzogenburg	46	183,220	2,017	190
	St Pölten	60	211,274	2,178	192
	Lilienfeld	43	201,625	1,942	186
	total	149			price [€/m²]
Land	Herzogenburg	60	75,035	1,963	38.22
	St Pölten	80	156,814	2,798	56.04
	Lilienfeld	33	50,717	1,546	32.80
	total	173			
Houses, land excluded	Herzogenburg		106,109		
	St Pölten		89,204		
	Lilienfeld		137,919		
	Average price		111,077		

Table 4-11 presents the data used to calculate the average value of a private home in the Traisen basin. For the three larges municipalities in the basin, samples of above 40 members where selected from www.immobilien.net. Herzogenburg and St. Pölten – the capital of Lower Austria - are the main municipalities in the lower basin. Lilienfeld is the largest community in the upper basin. Houses are generally sold with the land they are built on. Therefore the net value of a house was calculated from the difference of a sample of houses (land included) and a sample of land (ready for construction). Larger samples would have produced safer results. As a result of the survey the average private home in the Traisen basin has a living area of 189 m² and an average net value of € 111,077. For taking the quality of the houses into consideration, a factor called "grade" between 0.8 and 1.2 was introduced and applied on the basis of visual inspection.
Compared to the € 70.000 used in the Netherlands as average value of content per dwelling (Meyer et al 2005), a very conservative estimate of € 29.500 per house was selected in EWASE based on considerations of Pro Aqua (et al. 2001). The same standard value was used for both basins. The product of a building's grade and the standard inventory value of € 29.500 was taken as the time value of household inventory.

4.1.5.4 Damage and Risk

The successful accomplishment of the vulnerability Analysis enabled us to calculate damages for the Traisen basins. These results are given in Figure 4-16.

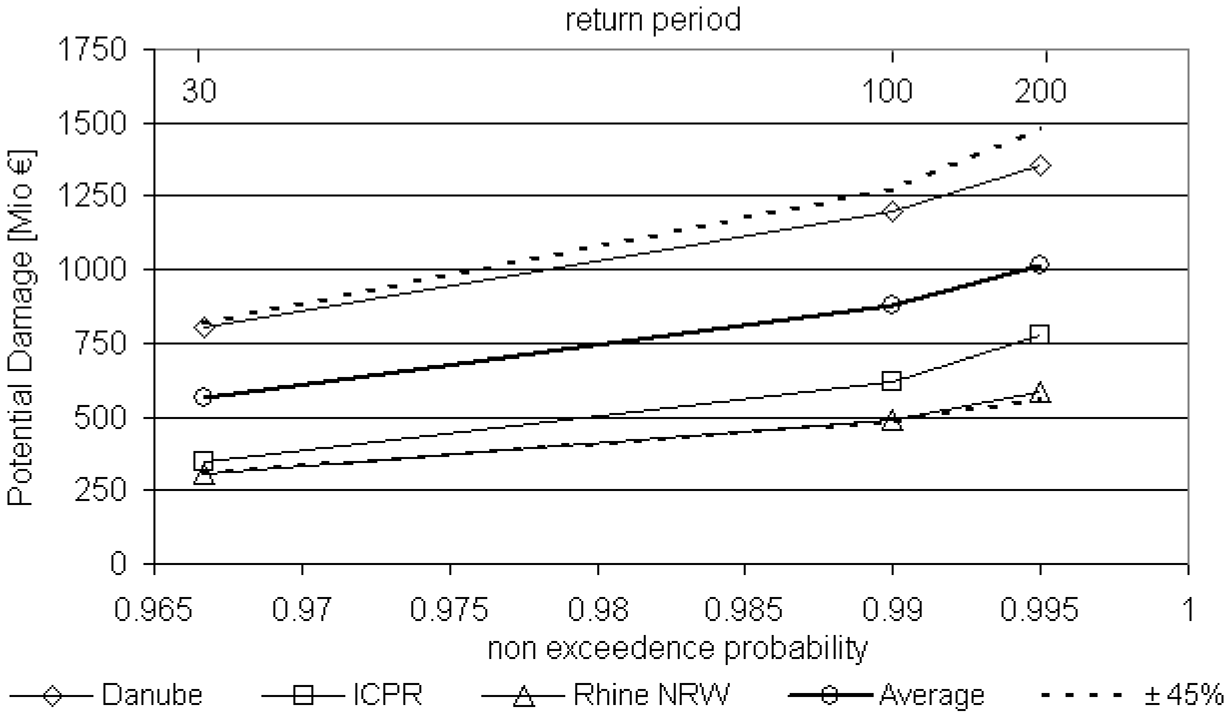


Figure 4-16: Calculated Damages in the Traisen Basin

Three sets of damage functions where used to frame the uncertainty inherent in damage estimates. The highest values are calculated with the damage functions set from the upper Danube study (Pro Aqua et al 2001). These functions where designed for single buildings and therefore conceptually meet best the demand of the EWASE approach. The ICPR damage function set, designed for larger land use units, delivers the second highest values (ICPR 2001). Again a set designed for the use on land use units is the set developed for the lower Rhine in Northrhine-Westphalia (MUNLV 2000). It delivers the lowest values. The bold line in the figure represents a weighted average calculated from these results, the weights being fixed by expert judgement at 0,5 for the Danube functions and 0,25 for the ICPR and MUNLV-functions respectively. Uncertainty bounds of around ±45% can be drawn to include all calculated values.

Damages of € 563 mn were calculated for the one in 30 years event, € 877 mn for the 100 years event and € 1,0 bn for the 300 years event for the weighted average. These results are clearly too high because there is a 100 years flood protection in place in large parts of the basin. The HORA flood plains neglect the damage reducing effect of structural flood protection at and below the design event. This is probably the main source for the very high potential damages in the Traisen basin.

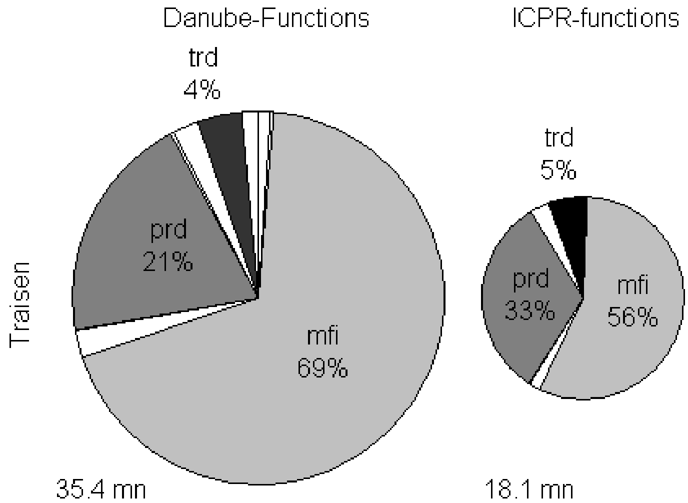


Figure 4-17: Distribution of risk over the main sectors for the Danube and ICPR-functions

Figure 4-17 displays the distribution of the risk over the main activities in the Traisen basin. The left pie in Figure 4-17 represents the results of the Danube functions whereas the right pie refers to the ICPR functions. The largest share of the risk 69% (mfi, Danube-functions) and 56% (IPCR-functions) is in the manufacturing industry, followed by private dwelling (prd, 21% and 33%) and trade (trd, 4% and 5%). These three activities account for 93% and 94% of the total risk in the Traisen basin.
As mentioned above damages in the Traisen basin are clearly overestimated, because the flood plains available from the HORA project do not account for structural flood protection. In a detailed risk analysis for a small basin, Gocht (2003) analysed the distribution of risk over total probability density. The results are given in Figure 4-18. According to this analysis, up to 90% of the total flood risk comes from relatively frequent flood events (return periods up to 100 years). The largest share of this risk (67%) can be mitigated by local measures (embankments, walls etc.). In the absence of a more detailed analysis for the Traisen basin it was therefore assumed, that only 20% of the calculated damage would occur because of structural measures in place in the Traisen basin.

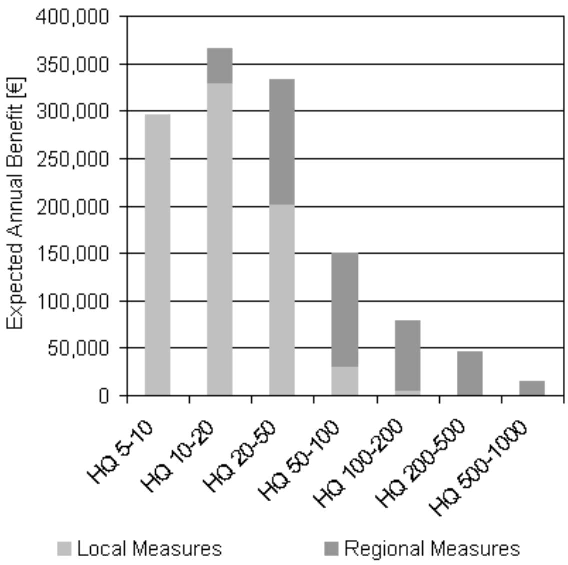


Figure 4-18: Distribution of risk over probability density in a small river basin, grouped by return periods (Gocht 2003)

4.2 Besòs Basin

The region of Catalunya, located at the North-East of the Iberian Peninsula, occupies around 32000 km^2, and it is structured by three mountainous ranges: the Pyrenees, with summits above 3000 m a.s.l. and the Prelittoral (around 1000 m high) and the Littoral ranges (around 500 m high), both roughly parallel to the coast, see Figure 4-19. At different scale, each of these mountainous ranges acts as natural barriers to the air coming from the sea (warm and wet), thus favouring the geneses of convective processes and intense rainfalls. Climatologically heterogeneous, this region shows yearly average rainfalls typically ranging between 400 and 1200 mm/year, but the maximal precipitation can be more than 1200 mm in one day. With these parameters in mind, the 10-year return period of daily precipitation commonly exceeds 100 mm, and in an attempt to illustrate this phenomena, accumulated rainfall over 200 mm in one day is seen at least once per year somewhere in the Spanish Mediterranean coast.

Between the Littoral and Prelittoral mountain ranges, the land surface is consequence of sedimentary basins subjected to fractures and other tectonic pressures, shaping also a hilly terrain. Hydrology has modelled this heterogeneous land, shaping developed drainage networks, but only in few cases they have got a mature state. Thus, while river slopes are really important in the mountainous areas, they remain high in most of the river profiles (more than 1% is widely present). These factors imply short catchment response times, and as heavy rainfall over short periods are frequent, flash floods are a common fact. These problems are enhanced by the human activity and the urbanisation of flood plains. Moreover, several ephemeral streams have become streets in many towns (very common near the coast), which are oftentimes affected by minor but risky floods.

After the floods that affected Catalunya in 1982 and the Basque Country in 1983, the Spanish government decided to invest in a real-time network of rain gauges and stage sensors that would be managed by different water basin authorities (the SAIH system). Some years later, a weather radar network was installed, managed by the Spanish Meteorological Agency (INM, now AEMET). And with the reappearance of the Catalan Meteorological Service (SMC) after 60 years, an impulse was made to suitably manage different local rain gauge networks and to create a dense weather radar network (up to 4 C-band radars).

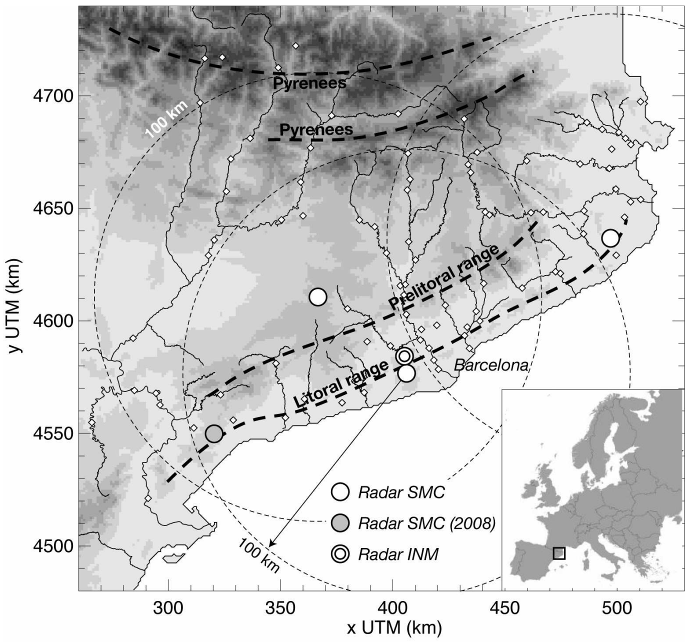


Figure 4-19: The Hydrological Observatory of Catalunya (Spain), with the radar network and the river stage sensor deployment (for the sake of clarity the rain gauge network is not shown).

4.2.1 Basin characteristics

The Besòs catchment (1020 km^2) is located between the Prelittoral and the Littoral mountain ranges, crossing the latter by the strait of Montcada. Downstream, a delta was formed to the Mediterranean Sea, shaping part of Barcelona's plane. The drainage network has a basic structure of different rivers coming from North to South, draining to the main river (the Besòs itself) in the down part of the catchment, see Figure 4-20. The main river is around 17.7 km length, from the intersection between Mogent and Congost rivers, finishing at Sant Adrià de Besòs city. Main tributaries from East to West are Mogent, Congost, Tenes, riera de Caldes and Ripoll. These rivers show a torrential behaviour, since they are almost dry most of the year, but they can experience suddenly important floods, with important amounts of sediment transport due to the high slopes of the river beds (around 5 per 1000 in the lower part, around 10 per 1000 upstream).
Important summits in the catchment are El Sui at Pla de la Calma (1322 m), Puigfred at Cingles de Bertí (947), La Mola at Sant Llorenç del Munt (1104 m), Tibidabo at Collserola (512 m) and Corredor (657 m).
As indicated by topography the geology of the basin is differentiated between the mountain ranges, mainly composed of granites, shale, limestone and sandstone, and the central valley where deposits of clay, sand and conglomerate dominate, see Figure 4-21.

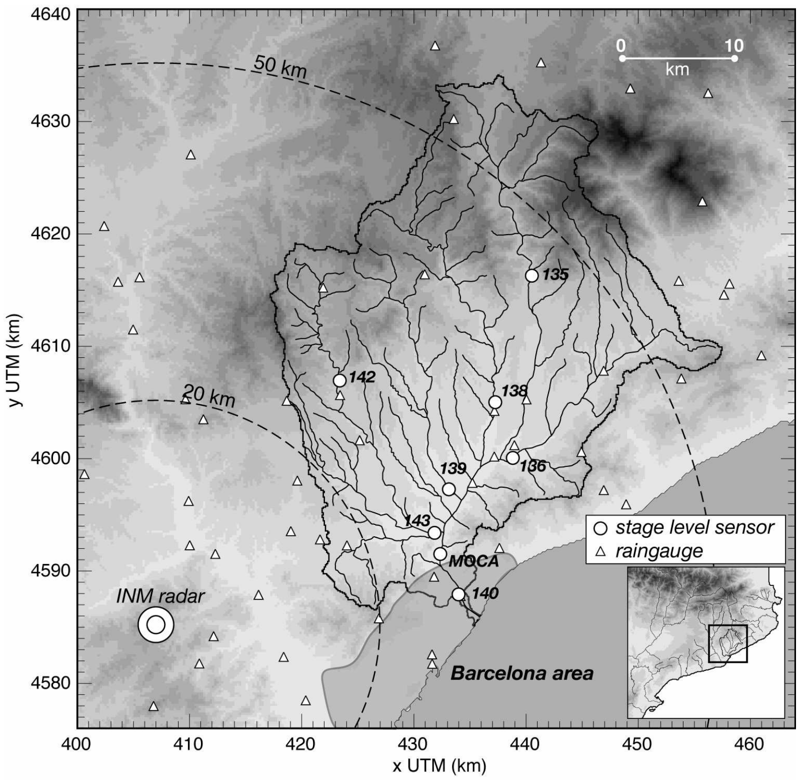


Figure 4-20: Besòs basin, topography and observational network. Data from the PRS1 gauge level has been used instead of the 140 gauge in this project.

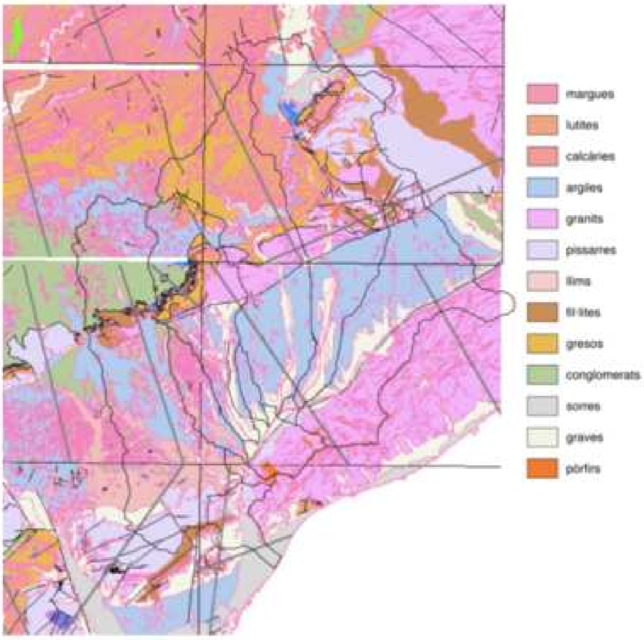


Figure 4-21: Geologic Map of the Besòs Basin

Climatic conditions on the catchment are typically Mediterranean, with fluctuations on different areas influenced by orography. This climate produces typically short but intense rain events. Mean annual precipitation in the Besòs basin is about 661mm. Potential evapotranspiration is bigger than mean annual precipitation (about 776 mm), but considering that measured runoff is 129 Hm^3 (127mm) then real evapotranspiration estimation is about 534 mm.

Land use is changing quite rapidly, and while in the mountainous zones the forest is increasing (with preponderance of pines and evergreen oaks), in the plane zones the agricultural uses are integrated by the urban expansion of towns, see Figure 4-22.

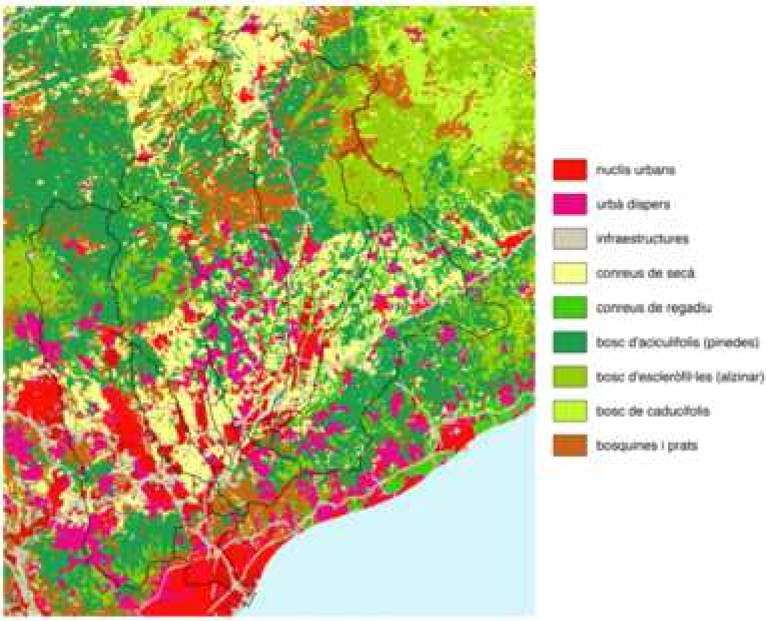


Figure 4-22: Land use Map for the Besòs Basin (1997 published data)

In fact, most of these towns are now integrated into the metropolitan area of Barcelona (one of the socio-economic important centres in Europe), and more than one million people live inside the catchment.
In 50 years, this area has experienced a fast and many times chaotic industrial and urban growth that can be considered harmful from the point of view of hydrological risk. Sometimes looking for the cheapest terrain, sometimes searching for a place with facilities to remove wastewater, in general having a good link with road transportation lines, many of the industries are located up to the river limits. Moreover, during this period the land planning tendencies have consolidated a spread urban area, with a lot of buildings and houses close to a variety of minor rivers and creeks that are also prone to torrential flash floods.
The continuous displacement from agriculture to industry, as well as an intensification of contaminants in agriculture, has been also harmful from the point of view of the river environment. There are many kinds of industries along the river course, chemical companies, plastics, building materials, leather, paper, etc. In many cases, the concentration of industrial activity is located on the floodplains. In Figure 4-23 some views of the course of the river are shown.

As a consequence of this development the Besòs river had the dubious honour of being considered one of the most contaminated rivers in Europe during the 1970s and 1980s. Since the mid-1990s, local authorities and collectives have raised the social sensitivity towards the recovering and improvement of the riverine environment. This social pressure led to a recovering planning for the Besòs river, and the first action was the construction of the fluvial park in the lower reach of the river. The Fòrum Universal de les Cultures (which took place in Barcelona during 2004) and other synergies allowed the creation of a recreation area in the last stretch of the river called Parc Fluvial del Besòs, between the cities of Barcelona, Santa Coloma de Gramanet and Sant Adrià de Besòs.
The catchment is quite well instrumented, with several river stage sensors gauging the main rivers (managed by the ACA), and there are also other stage sensors along the Besòs Fluvial Park in the last stretch of the river (managed by CLABSA).

Besòs River in the middle reach

Besòs River in the low reach (Sant Adrià)

Besòs River in the middle reach (Granollers)

Figure 4-23: Views of the Besòs river

4.2.2 Operational EWS

4.2.2.1 SAHBE Early Warning System for the Besòs river park

The construction of the fluvial park in the downstream reach of Besós river for local recreation (see Figure 4-24) required the implementation of an early warning system for floods in order to warn and evacuate the area during floods.

The aim of the Early Warning System is to inform people inside the fluvial park about the level of risk due to flooding. When the risk becomes high, the system is prepared to evacuate the park and keep it totally closed. The warning system includes different modules: real time monitoring system, a continuous, numerical forecast of the flood in the affected area and, finally, a warning system in the park in order to give information and alerts to the users.

Citizens using the fluvial park as a green zone.

View of the previous canalisation in the low Besòs river (Santa Coloma de Gramanet)

Figure 4-24: View of the Besòs river in the fluvial park

The Besòs river acts as physical barrier between important cities and urban areas located along the water course. These cities and towns present a lack of green areas and parks and the citizens live apart of the river due to its man-made degradation. So, in the last years, local authorities and collectives have raised the social sensitivity towards the recovering and improvement of the riverine environment. This social pressure leaded to a recovering planning for the Besòs river, and the first action was the construction of the fluvial park in the lower reach of the river.

The aim of the Early Warning System is to inform people inside the fluvial park about the level of risk due to flooding. When the risk becomes high, the system is prepared to evacuate the park and keep it totally close. The high risk level definition includes not only flooding periods (water depth and flow are significant in the channel and banks) but periods with an immediate forecasted flow. The reaction time for the civil services is rather low, due to the combination of flash flood regime in the area and the morphology of the Besòs watershed.

4.2.2.2 Sensors and Monitoring System

The early warning system is connected to a real-time monitoring network which includes information from:

- Rain gauges.
- River level gauges.
- Weather radar information.
- Data from the General Agency of Emergency and Civil Security.

All these information are input automatically for the hydrologic numerical models in order to forecast the flood levels in some critical points along the park. These forecasting models are simple enough to be run in real–time, but users are quite confident with them.

4.2.2.3 Warning System Outputs

The system is designed to start the warning protocol when one of the following criteria is satisfied:

- The rainfall monitoring system measures a rainfall accumulation above a critical threshold.
- The estimated cumulated precipitation based on the radar rainfield confirms an actual or nowcasted exceedance of a critical threshold.
- The Civil Services informs about an imminent risk period.
- The hydrologic models forecast floods in the fluvial park.

The warning protocol includes the next elements for the warning chain:

- Acoustic signals in the fluvial park.
- Lights signals in the fluvial park.
- Information boards.
- Warnings to the different administrations.

These warnings inform the user about evacuation and/or the prohibition to access the fluvial park.

4.2.3 Available Data base

The catchment data available to implement the hydrological models are:

- Digital Elevation Model: Spatial resolution of 45 m. Data source from aerial photographs with accuracy +/- 1 m. Source: Institut Cartogràfic de Catalunya (ICC), Generalitat de Catalunya.
- Land use: Raster information (Spatial resolution of 45 m) of land use classification over Catalunya in 2002. 22 categories from LANDSAT-TM images. Source: Departament de Medi Ambient i Habitatge, Generalitat de Catalunya.
- Soil type: Vectorial information. Source: FAO soil map for Europe. Also the Geologic Map at a scale of 1:50.000 (BC50-M). Source: Institut Cartogràfic de Catalunya (ICC), Generalitat de Catalunya.

Regarding the hydrological data, the following data sources have been available:

- Rain gauge data: From the SAIH system (managed by the ACA).
- Radar data: From the Corbera C-band radar, managed by the Spanish Weather Agency (AEMET, formerly INM). Volumetric raw radar data (3-D information).
- Climatological data (temperature, potential evapotranspiration): From the XEMEC network (managed by the Meteorological Service of Catalunya, SMC).
- Level river data come from two sources: The SAIH system (managed by the ACA) provides river data for all the sub-catchments and also for the outlet. However, during the period 2002-2003 the sensor at the basin outlet was not operational (145 gauge has been substituted by the 140 gauge). During this period (the whole period considered in EWASE project), level river data from the Besòs Riverside Park (managed by Clavegueram de Barcelona, CLABSA), is used to complete hydrological data in the last stretch of the Besòs river (corresponding approximately to the river outlet).

Several flow events have been observed in the period 2000-2003 with significant peak flows. The selection of the events suitable for this study was led by the important restriction to have volumetric radar data (3-D information) available in adequate quality. The events identified for use within this study are compiled in Table 4-12.

Table 4-12: Compilation of observed flood events in the Besòs basin

	Event	Time period	Peak flow [m³/s]	Return period [a]	accMAP [mm]
c	A	22.12.2000 - 26.12.2000	87.7 (MOCA)	-	79.3
c	B	19.07.2001 - 20.07.2001	77.9 (MOCA)	-	29.1
c	C	13.04.2002 - 15.04.2002	100.9 (MOCA)	-	16.5
c	D	08.10.2002 - 12.10.2002	101.5 (MOCA)	-	94.2
c	E	17.02.2003 - 02.03.2003	345.0 (PRS1)	5	121.6
c	F	07.09.2003 - 09.09.2003	131.6 (PRS1)	2	34.2
c	G	15.10.2003 - 23.10.2003	82.9 (PRS1)	-	82.1
v	H	15.01.2001 - 17.01.2001	102.7 (MOCA)	-	47.4
v	I	15.11.2001 - 19.11.2001	116.9 (MOCA)	-	61.5
v	J	09.12.2002 - 16.12.2002	145.0 (MOCA)	2	73.7
c	K	17.08.2003 - 19.08.2003	131.0 (PRS1)	2	32.3
v	L	01.12.2003 - 13.12.2003	60.7 (MOCA)	-	45.7

accMAP: accumulated Mean areal Precipiation

c: event used for calibration

v: event used for validation

For these events radar data come from the Corbera C-band radar, managed by the Spanish Weather Agency (AEMET, formerly INM). These data have been processed in order to achieve an improved rainfall field, following these steps:

- Identification and correction of the under-detected precipitation zones caused by beam blocking. From the application of a technique of ground clutter simulation using topographic information (Delrieu & Creutin, 1995), beam-blocking (as the energy lost due to radar interception with ground) is estimated and corrected in the shadow affected zones (behind zones affected by ground clutter).
- Ground clutter correction. Ground-clutter affected zones are identified previously from pictures without rain. Reflectivity values in these affected bins are recovered by interpolation using reflectivity values of the non-affected neighbour bins. The substitution is made differently in convective zones (vertical substitution) than in the rest (horizontal substitution) using a first classification of the rainfall type (Sánchez-Diezma, 2001).
- Application of a Z-R relationship to transform reflectivity into rain intensity (mm/h), applying a different relationship depending on the precipitation type (stratiform or convective).
- Computation of accumulated rainfall fields from the instantaneous radar fields. The used procedure (Bellon & Zawadzki, 1994) applies a tracking algorithm, assuming that the precipitation field moves at constant velocity between consecutive radar scans. A motion field is obtained by correlation and it is used to advect radar rainfall fields from one scan to the next (time interval of one minute), interpolating rainfall values linearly. From this information, the 10-min radar rainfall accumulation is obtained.
- Bias correction of radar rainfall using rain gauge information. At each time step, a correction factor is obtained comparing rain gauge values against radar values in these rain gauge locations. This factor is applied globally to the radar rainfall.

4.2.4 *Flood Forecasting*

On the basis of the data described above, the hydrological models have been set-up in the study basin. Model parameters have been calibrated using the events labelled ‘c’ in the first column of Table 4-12. Estimation of model parameters was done according to the best practice of the modelling groups. In this context, both manual and automatic procedures have been applied. The objective of the calibration was to identify the set of parameter for each model that reproduces the hydrographs of all calibration events in a best possible way.

4.2.4.1 Hydrologic modelling, model calibration and validation

The results obtained from calibration of the hydrological models are displayed in Figure 4-25 for each event considered. The black line shows the observed discharge at the river gauge MOCA or PRS1 (140), depending on the availability of the data records. The red, blue and green lines show the simulation results of the models WBrM, DICHITOP and COSERO for this gauge.

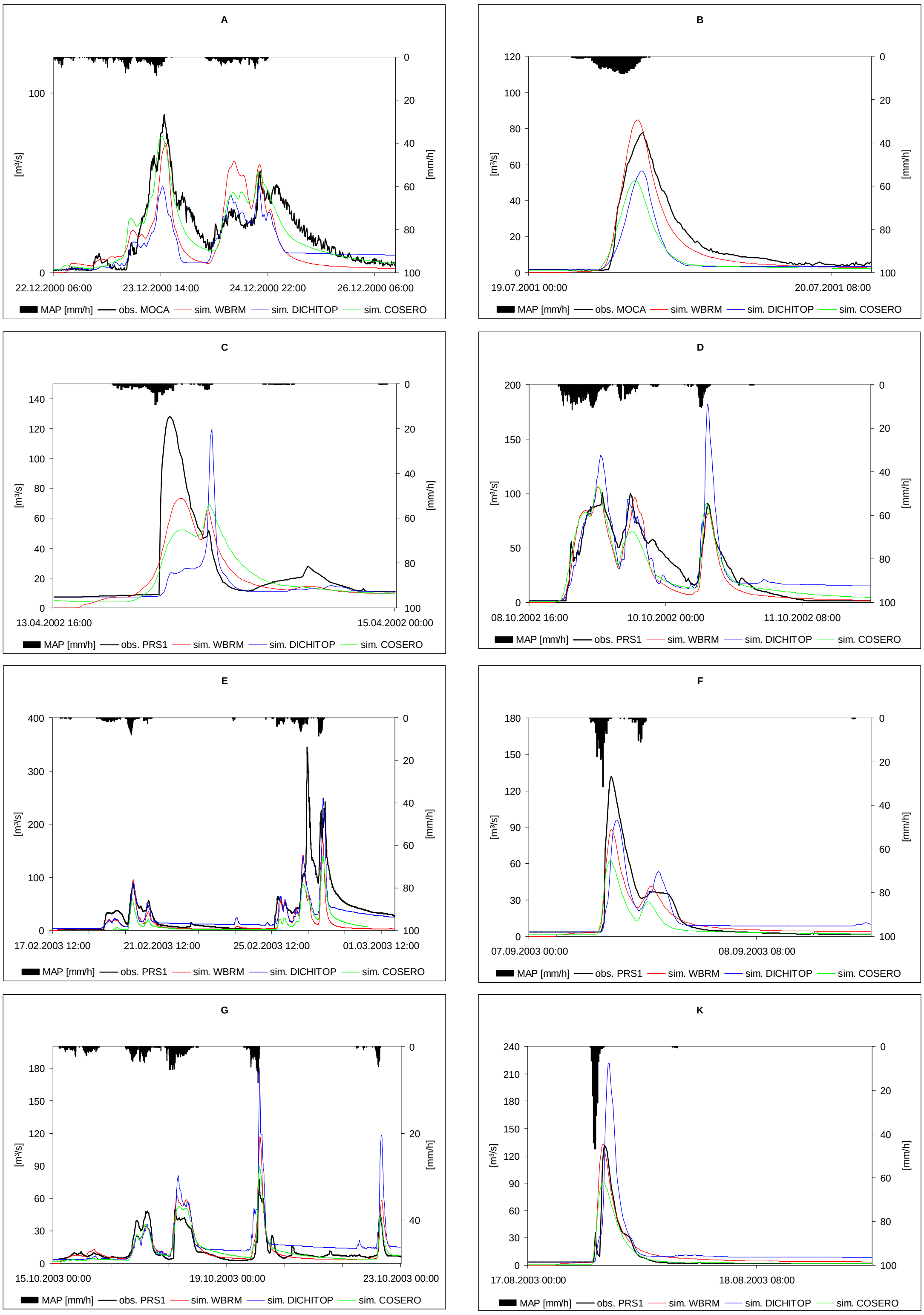


Figure 4-25 Results model calibration Besòs basin

The observed hydrographs illustrate that the flood events in the Besòs are characterised by a rapid increase of discharges from low flow conditions to peak flow within few hours. The pronounced dynamic of these flash flood events are quiet well reproduced by the hydrological models as can be seen from the rising limps of the events B, D, F and H, whereby the response of DICHITOP tends to be slower than the other models. In contrast, for the event C COSERO and WBrM indicate the initiation of the rising limp of the flood wave too early and the sharp increase of discharges is not reflected in the modelling results. DICHITOP does not represent the flood peak at all but shows a sensitive response during the second burst of the event. A comparable behaviour can be observed for the event E. The largest peak is underestimated by all models, whereas the magnitude of the second peak is better reproduced, in particular by the model DICHITOP. Further, it is noticed that DICHITOP largely overestimates the peak flow of some events (D, G and K). The peak flows simulated with COSERO and WBrM are closer to the observations in these cases. Another important difference between the results of the hydrological models is related to the flow volume, which shows a considerable variability for the different models.

Apart from that, it is problematic to identify a clear pattern of differences in the simulation results provided by the models considered. Therefore, for an objective comparison of model performance the simulation results are evaluated in terms of the criteria defined in Table 3 1. The resulting performance statistics for the calibration events in the Besòs basin are summarised in Table 4-13.

Table 4-13: Performance statistics model calibration Besòs

Event	Gauge	Criterion	WBRM	COSERO	DICHITOP
A	MOCA	E	0.41	0.81	0.4
		R^2	0.54	0.82	0.56
		MB	-23.54%	-4.85%	-33.56%
		Peak Ratio	0.82	0.86	0.55
B	MOCA	E	0.94	0.62	0.66
		R^2	0.96	0.86	0.89
		MB	-12.84%	-48.71%	-47.21%
		Peak Ratio	1.09	0.66	0.72
C	140	E	0.68	0.44	0.00
		R^2	0.74	0.47	0.13
		MB	-18.87%	-17.88%	-37.75%
		Peak Ratio	0.57	0.54	0.93
D	140	E	0.83	0.85	0.64
		R^2	0.86	0.86	0.76
		MB	-16.11%	-7.28%	15.04%
		Peak Ratio	1.06	1.06	1.81
E	140	E	0.25	0.31	0.55
		R^2	0.45	0.72	0.61
		MB	-55.25%	-63.59%	-24.58%
		Peak Ratio	0.50	0.40	0.72
F	140	E	0.83	0.59	0.02
		R^2	0.94	0.89	0.27
		MB	-17.19%	-47.56%	17.85%
		Peak Ratio	0.67	0.48	0.73
G	140	E	0.62	0.81	-0.37
		R^2	0.8	0.84	0.65
		MB	8.19%	0.99%	54.40%
		Peak Ratio	1.52	1.17	2.35
K	140	E	0.79	0.83	0.24
		R^2	0.83	0.85	0.79
		MB	34.70%	-8.48%	88.32%
		Peak Ratio	1.02	0.70	1.69

E: Nash-Sutcliffe Efficiency
R^2: Coefficient of determination
MB: Mass Balance
Peak Ratio: deviation from flood peak

The performance of the simulation models varies considerably between the events with regard to the different metrics. There is no indication for the superiority of one specific model. With respect to model efficiency (E) COSERO and WBrM achieve better scores than DICHITOP, except for the event E. Yet, concerning the MB and the peak ratio DICHITOP provides comparable or better results than the other models.

After finalisation of the calibration phase the observed hydrographs for the validation events labelled ‘v’ in the first column of Table 4-12 have been made available. The comparison of simulation results and observations for these events is given in Figure 4-26.

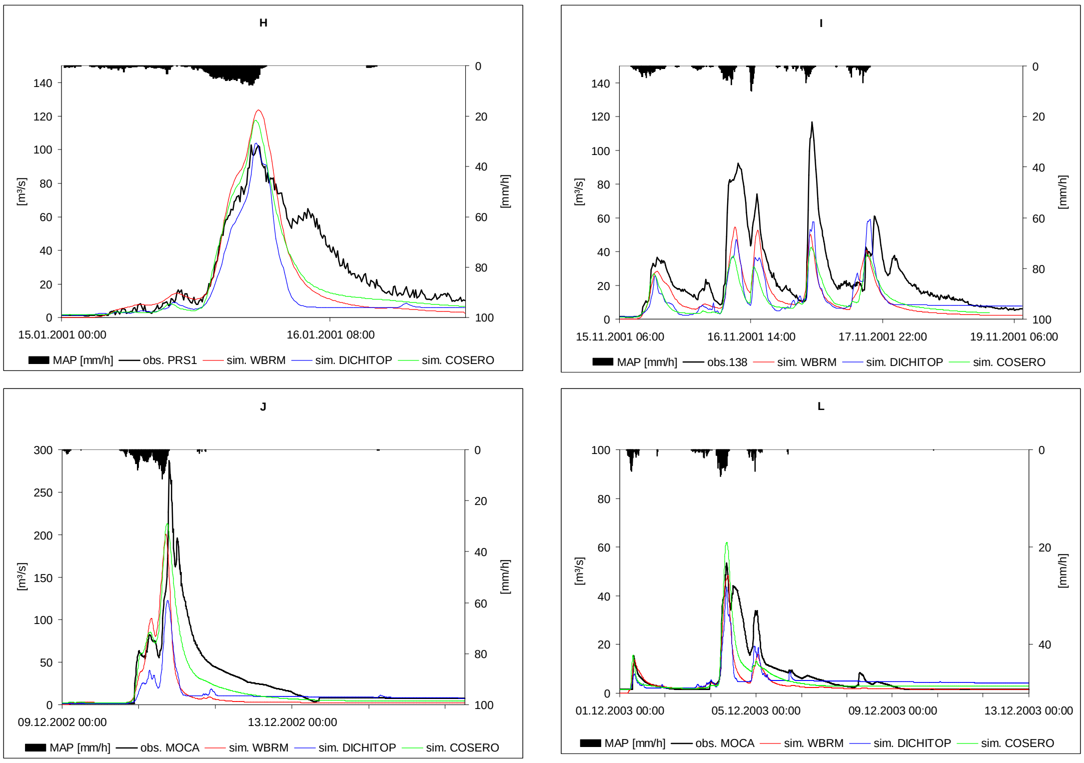


Figure 4-26 Results model Validation Besòs basin

Overall, the results of model validation are satisfactory. The dynamic of the flood waves with regard to the initiation of the rising limp and the development of the flood peak are well reproduced by the simulation models. Still, there are clear differences concerning the predictions of the peak flow and the flow volume. As distinct from the calibration results, the deviation of the simulated hydrographs from the observations is more similar for the different models. The three models clearly underestimate the peak flow and flow volumes of the event I. For the events H and L all simulation results lack some smaller peaks that are indicated by the observed hydrographs. Possibly this is caused by a lack of information in the QPE data.

Again, the performance of the simulation models is evaluated in terms of the statistics defined in Table 3-1. The values achieved by the simulation models for the different events are summarised in Table 4-14.

Table 4-14: Performance statistics model validation Besòs

Event	Gauge	Criterion	WBRM	COSERO	DICHITOP
H	MOCA	E	0.67	0.76	0.49
		R^2	0.78	0.83	0.69
		MB	-21.94%	-22.98%	-44.34%
		Peak Ratio	1.20	1.14	1.01
J	140	E	0.31	0.77	0.33
		R^2	0.44	0.81	0.65
		MB	-54.68%	-28.00%	-56.95%
		Peak Ratio	0.70	0.74	0.43
I	MOCA	E	0.3	0.07	0.22
		R^2	0.72	0.7	0.61
		MB	-51.12%	-57.50%	-50.26%
		Peak Ratio	0.47	0.36	0.51
L	140	E	0.55	0.71	0.48
		R^2	0.65	0.73	0.57
		MB	-39.94%	-18.47%	-19.31%
		Peak Ratio	0.90	1.16	0.81

E: Nash-Sutcliffe Efficiency
R^2: Coefficient of determination
MB: Mass Balance
Peak Ratio: deviation from flood peak

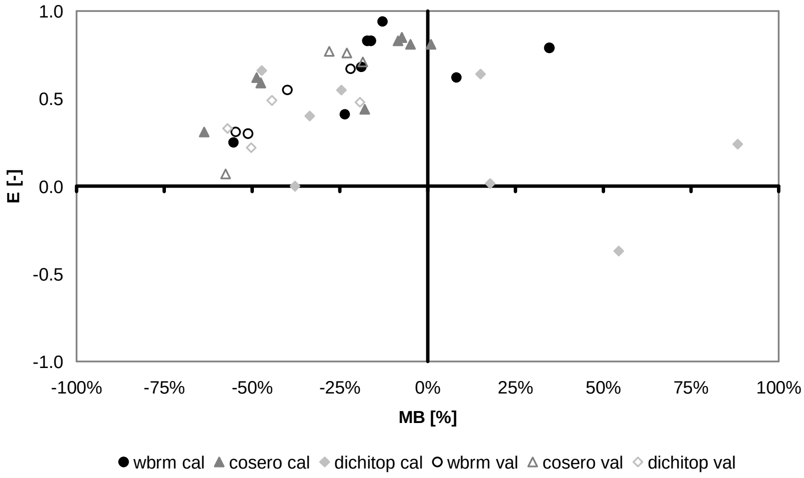
The presented values show that no simulation model provides better predictions for all events (in terms of all evaluation criteria) than the other models. The results of COSERO achieve best efficiency values (E) in most cases. Yet, separate from the events J either DICHITOP or WBrM provide better predictions of the peak flow and the flow volume.

Given the variation and diversity of these results it is problematic to conclusively rank the models according to their predictive performance. In fact, this heterogeneous picture of model performance emphasises the multi dimensional characteristic of the diverse aspects that have to be taken into account in flood modelling and flood forecasting.

For illustration, selected performance statistics obtained for model calibration and model validation are contrasted in Figure 4-27.

The diagram in Figure 4-27 on top plots model efficiency on the vertical axis and mass balance error on the horizontal axis. COSERO and WBrM produce the most part of model predictions, which are found in the upper range of model efficiency values in combination with mass balance errors smaller than 25% including both calibration events (solid markings) and validation events. Apart from few outliers, the graph reflects the tendency towards an underestimation of discharge volumes in runoff simulation. The outliers are mainly associated with calibration results of the model DICHITOP (cf. Table 4-13). Otherwise, the results for the validation events are inferior to the calibration events. As can be seen by comparison to the values given in Table 4-14 the best performance of each model in terms of the selected criteria is achieved for different events.

Figure 4-27 (bottom) compares model efficiency (vertical axis) and peak ratio (horizontal axis). Overall, a similar picture is obtained as for the previous graph. All models demonstrate, at least for some events, the capability to predict peak flows with an acceptable level of accuracy. The best absolute values of the peak ratio for the different events are achieved with different simulation models. By reference to Table 4-14 it is worth noting that the best values for this metric are obtained for the same events as for model efficiency.



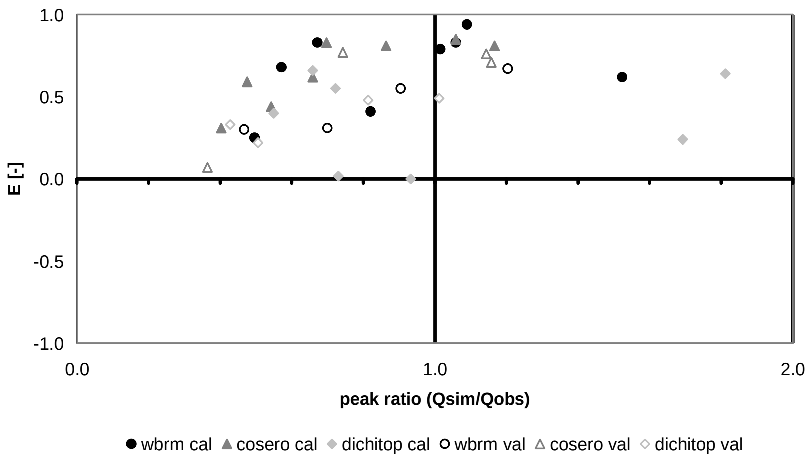


Figure 4-27: Comparison of performance criteria achieved in model calibration and validation in the Besòs basin with the different models for the events considered.

Altogether, these findings indicate a dependence of model predictive performance on the flood event considered. In this context, the information content of the observed precipitation data seems to have an overriding influence on the reproduction of the system response by the hydrological models. Yet, for each event the best performance with regard to the various performance criteria is achieved by different simulation models. Hence, it is problematic to make a clear selection in favour of one simulation model. Instead, it is expected that the different simulation models contribute complementary information to the flood forecast, whereby the quality of these predictions is strongly impacted by the completeness of the precipitation input data.

4.2.4.2 Flood forecast reliability

The evaluation of flood forecast reliability in the Besòs basin following the procedure detailed in section 3.1 is exemplified on the basis of two flood events. As a major difference to the general outline of the procedure the operational EWS in the Besòs basin and in the fluvial park do not include QPF information. Therefore, the data used for flood forecasting are quantitative precipitation estimates (QPE) available in real as detailed in section 4.2.3.

The flood forecast horizon examined has been limited to τ_{max} = +5 h which covers the response time of the basin. Prediction errors $\varepsilon_{i,\tau}$ are evaluated at the gauging MOCA (Figure 4-20) for 10 minute intervals throughout the events B and H which are summarised in Table 4-15. Within the framework of the EWASE project, only the results of the model WBrM are included in the analysis.

Table 4-15: Selection of Events used for the evaluation of flood forecast reliability in the Besòs basin

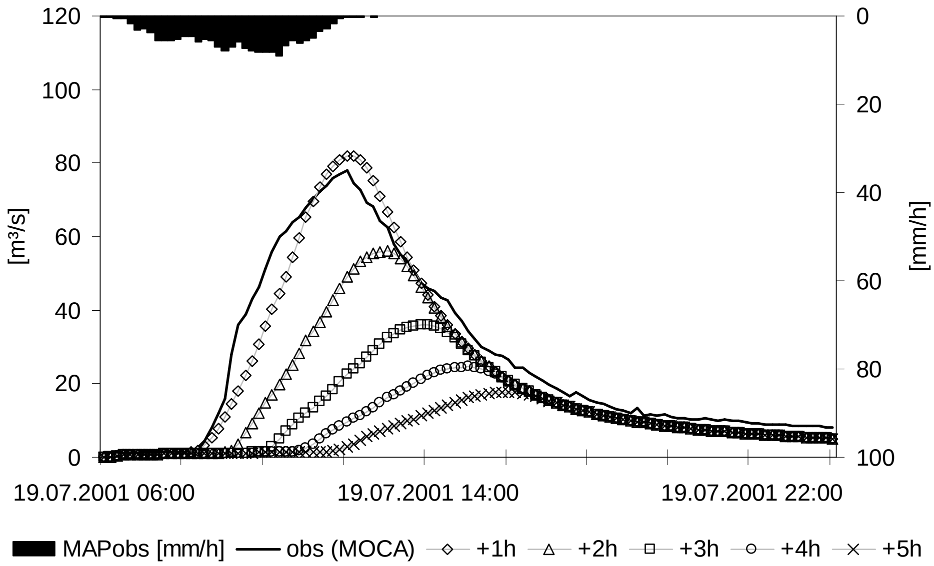
	Events	
Besòs	B	H
Start	19.07.2001 05:00	15.01.2001 05:00
End	20.07.2001 12:00	16.01.2001 12:00
accMAP [mm]	21	43
Event type	Conv./Strat	Strat.
Ini. cond.	Dry	Wet
Runoff coef. [-]	0.06	0.11
Peak [m³/s]	78	103
start Rising limp	19.07.2001 08:00	15.01.2001 17:00
Time to peak [h]	4	6
NSE*	0.94	0.67

*Nash-Sutcliffe-Efficiency (Nash & Sutcliffe 1970) achieved in the reproduction of the flood event with the hydrological model using observed precipitation

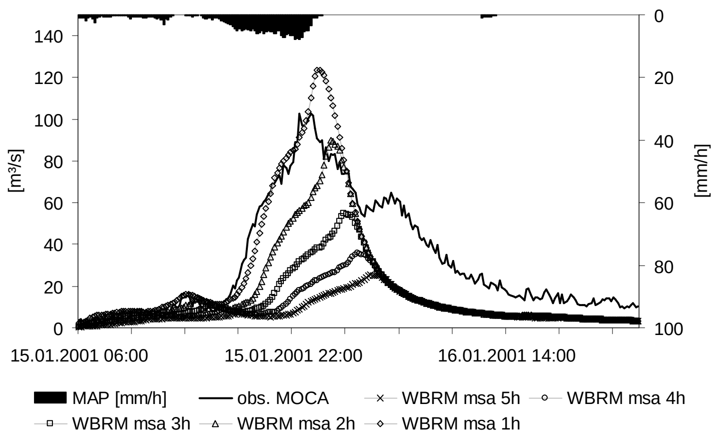
4.2.4.3 Lead time dependence of forecast reliability

For the considered events QPE are available every 10 minutes. Accordingly, flood forecasts can be produced in 10 minute intervals throughout the period examined with different lead times $t_i + \tau$ using the available QPE until t_ι and assuming no further rainfall for the future. For these flood forecasts the prediction error can be determined as per equation 1 using the observed discharge.

In Figure 4-28 the forecasted discharge values corresponding to the different lead times (τ = +1, +2, +3, +4, +5are displayed at each point of time t_i of the event along with the observed hydrographs. From both graphs it can be seen that the forecasted values increasingly deviate from the observations as lead time is extended. Basically, this deviation becomes manifest in a reduction of discharge predictions.
This characteristic points up that rainfall observed at the current time t_i is only of limited use for the prediction of runoff because of the finite persistence of this information depending on the response time of the catchment.



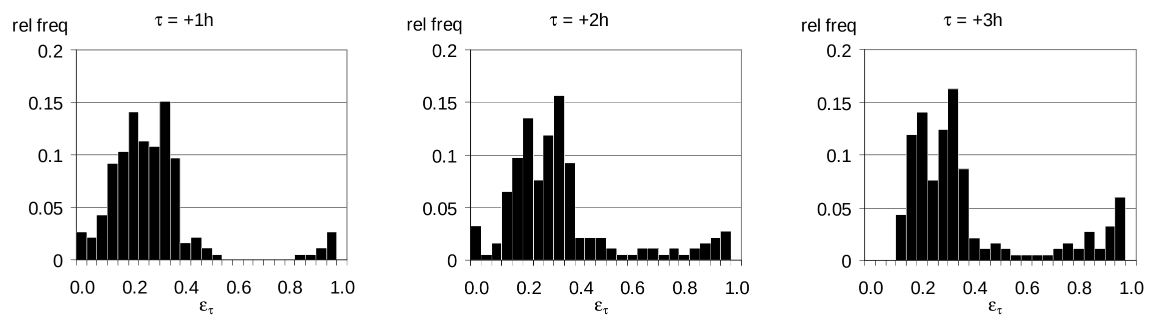
Event B



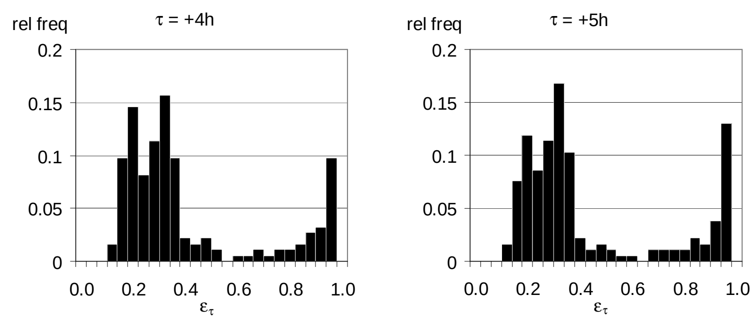
Event H

Figure 4-28: Flood forecasts throughout the events B (top) and H (bottom) using real time available QPE for different lead times τ [h] compared to the observed discharge hydrograph.

The results from the statistical analysis of the sample of prediction errors $\varepsilon_{i,\tau}$ of the event B are given in Figure 4-29 in terms of histograms for the lead times τ = +1, +2, +3, +4, +5. For comparison, the according histograms of prediction error sample $\varepsilon_{i,\tau}$ of event H are displayed in Figure 4-30.



μ:0.28 m:0.26 σ: 0.18 μ:0.33 m:0.29 σ: 0.22 μ:0.39 m:0.31 σ: 0.24



μ:0.42 m:0.32 σ: 0.26 μ:0.45 m:0.36 σ: 0.28

μ: mean m: median σ: standard deviation

Figure 4-29: Histograms and distribution characteristics of prediction errors for different lead times τ [h] for the event B using WBrM.

The diagrams clearly show that the distribution of the prediction errors ε_τ changes for different lead times τ. Also, a general tendency towards larger errors for increasing lead times τ can be observed and is reflected in increasing mean and median of the distribution. The shape of the distributions is quite different for both events.

For event B a bimodal distribution appears having a first cumulation of errors around $\varepsilon_\tau = 0.3$ and a second accumulation around $\varepsilon_\tau = 0.9$. The latter cluster becomes more pronounced for larger lead times. Accordingly, the variation of the errors increases as can be seen from the values of the standard deviation.

The distribution of event H is less diversified. The maximum accumulation of prediction errors around $\varepsilon_\tau = 0.65$ remains more or less constant for the different lead times. For larger lead times the number of smaller errors decreases, which is also indicated by the decreasing variation in terms of the standard deviation and an increase of the mean and median.

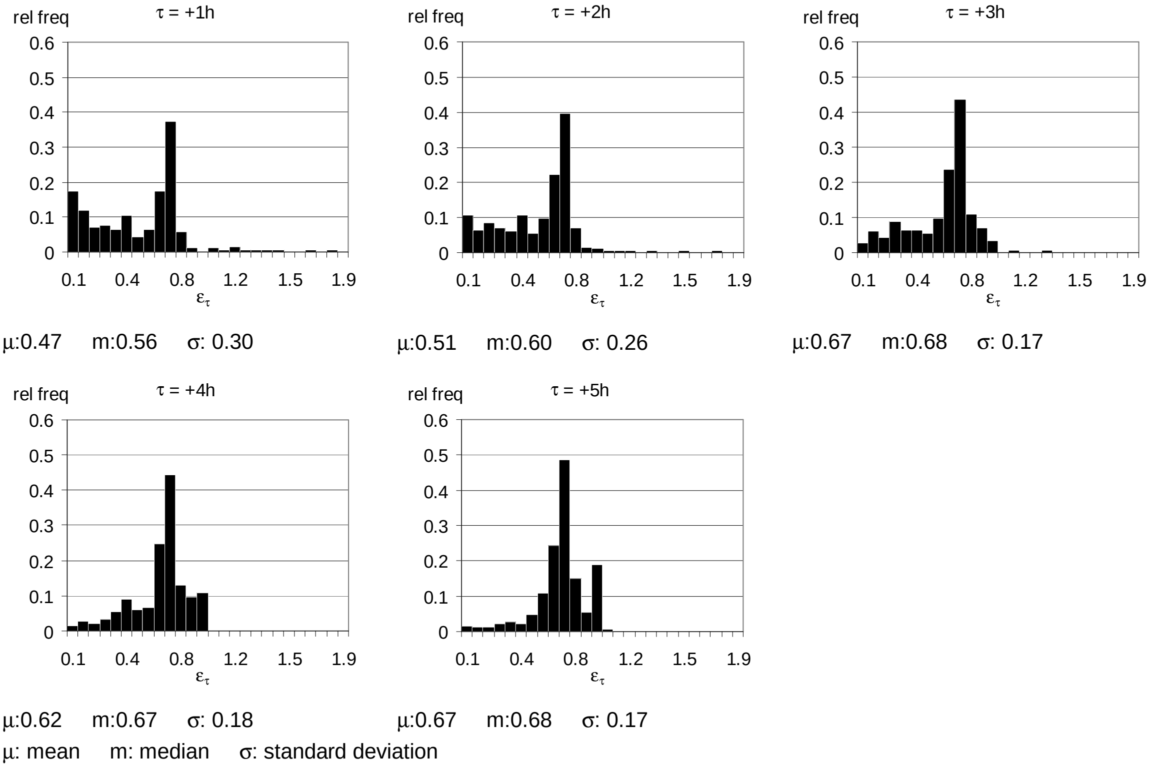


Figure 4-30: Histograms and distribution characteristics of prediction errors for different lead times τ [h] for the event H using WBrM.

Figure 4-14 displays the distribution functions of the prediction errors ε_τ corresponding to both events. The increasing spread and the increment of the mean are evident.

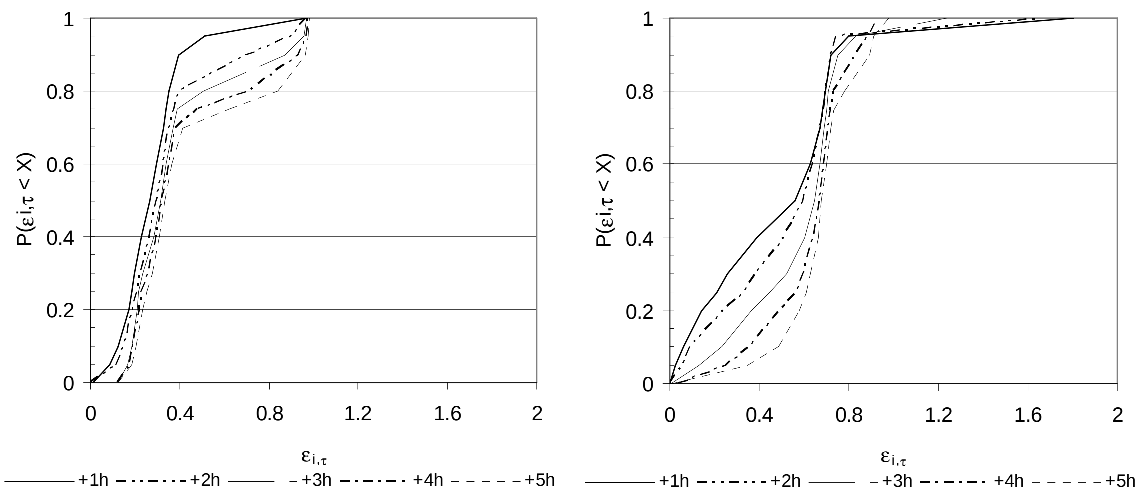


Figure 4-31: Distribution function of prediction errors for different lead times τ [h] for the event B (left) and event H (right)

The outcome of the evaluation of these distribution functions in terms of forecast reliability as defined in equation 2 is given in Figure 4-32. The curve describes the development of forecast reliability (FR) with lead time τ at the gauging station MOCA. The results obtained show an articulate dependence of FR(τ) on the event.
In the case of event B forecast reliability (FR) is clearly superior for lead-times τ < +3 h as compared to event H. From the above discussion of model calibration and validation results it is known that the performance of the simulation model to reproduce the observed hydrographs of the flood events, e.g. in terms of the Nash-Sutcliffe-Efficiency (Table 4-15), is better for event B than for H.
In addition, in Figure 4-32 the FR curve resulting from the combined analysis of both events which is based on the joint distribution of prediction errors is shown. The corresponding forecast reliability curve closely follows the curve of event H indicating low reliability of flood forecasts for the Besòs basin even for short lead times τ < + 3h. A more detailed discussion follows in section 5.1.

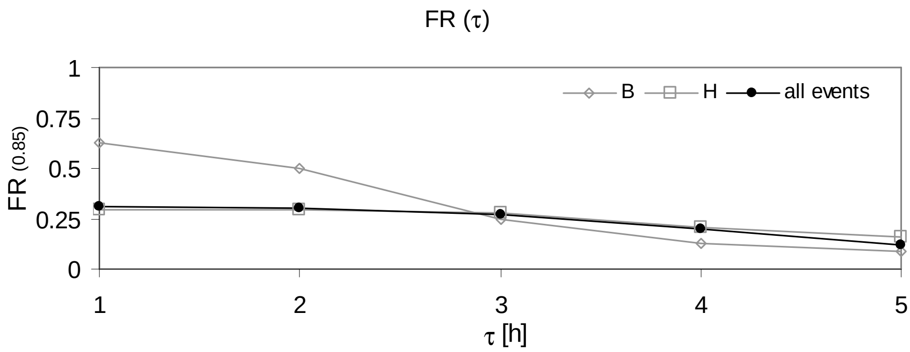


Figure 4-32: Forecast reliability as a function of lead time τ for the Besòs basin

4.2.5 *Economic evaluation*

4.2.5.1 Capital Intensities in the Besòs basin

This section introduces the capital intensities for the Nuts 3 region Barcelona (ES511). Table 4-16 shows capital intensities for the primary and secondary sector. Values for the period 2002 to 2004 are shown. Capital Intensity is differentiated into plant and equipment, buildings, as well as other equipment.

The last group mainly consists of immaterial assets, companion animals and crops where appropriate. As there is no significant fishery or fish farming in the regions, the primary sector only contains agriculture and forestry. The secondary sector is divided into four activities. All activities have the highest capital intensities in buildings. In the first and secondary sector all activities exhibit decreasing capital intensities from 2002 to 2004. Largest capital intensities of all 17 Nace activities are in the utilities sector(water, gas, and electricity generation and distribution). Manufacturing Industry follows Mining and Quarrying, the lowest capital intensities exhibits the construction industry.

Table 4-16: Selection of Events used for the evaluation of flood forecast reliability in the Besòs basin

	Period	Primary	Secondary			
		Agriculture, Livestock and Fishing	Mining and Quarrying	Manufact. Industry	Energy, Gas and Water	Construction
Buildings	2002	133,344	618,021	90,905	1,204,810	47,161
	2003	126,600	554,635	84,883	1,083,905	46,503
	2004	119,575	448,211	80,839	916,298	44,707
Plant and Equipment	2002	21,407	99,216	14,594	193,418	7,571
	2003	20,784	91,057	13,936	177,949	7,635
	2004	19,652	73,663	13,286	150,593	7,348
Other Equipment	2002	1,022	4,735	696	9,231	361
	2003	1,039	4,550	696	8,893	382
	2004	1,044	3,913	706	8,000	390

Table 4-17: Besòs basin, capital intensity in the tertiary sector

	Period	Tertiary								
		Trade and Repair	Tourism	Trafic, Communi-cation	Banks and insurance industry	Real estate, lending, b2b services	Public Administration, Defence, Social	Education	Health	Other public serivces
Buildings	2002	65,242	60,470	284,518	86,014	502,602	243,913	59,852	45,297	151,552
	2003	64,162	64,450	268,939	107,475	503,294	259,627	57,477	41,628	144,752
	2004	63,508	67,929	264,945	133,728	496,364	281,935	55,444	41,224	153,268
Plant and Equipment	2002	10,474	9,708	45,676	13,809	80,687	39,157	9,608	7,272	24,330
	2003	10,534	10,581	44,153	17,645	82,628	42,624	9,436	6,834	23,764
	2004	10,437	11,164	43,543	21,978	81,577	46,336	9,112	6,775	25,189
Other Equipment	2002	500	463	2,180	659	3,851	1,869	459	347	1,161
	2003	526	529	2,206	882	4,129	2,130	472	342	1,188
	2004	554	593	2,313	1,167	4,333	2,461	484	360	1,338

Another picture gives capital intensity in the tertiary sector which is shown in Table 4-17. The largest capital intensities are in the real estate and lending activities. But the values are roughly 50% of those in the utilities activities. Again real estate takes the largest share. The second largest capital intensity is in traffic and communication followed by public administration. Other public services (sewage and refuse disposal, sanitation and recreational, cultural and sporting activities) are well above banks and insurance industry. Trade and repair as well as tourism, health and education exhibit much lower capital intensities which clearly show the higher labour intensities in these sectors. Development of capital intensities between 2002 and 2004 was quite heterogeneous in the activities of the tertiary sector. Whereas Public Administration (8%), Tourism (6%)and Banks and Insurance (3%) show significant positive annual growth rates, capital intensity is decreasing in Traffic and Communication (-3%), education (-4%) and health (-4%). Given the short time series one should not overhasty jump to conclusions.

4.2.5.2 Added Value

There is also a strong correlation between capital intensities and gross value added in Catalonia. High investments per active persons lead to high GVA. Therefore the highest GVA are in the utilities activities (Energy, Gas, and Water) whereas lowest GVA is in education. The growth in GVA is very modest generally. The construction industry exhibited significant growth over the time series (11%) followed by agriculture (8%). Mining and Quarrying lost 3%. In the other activities growth was low and grew in small positive percentage values. Banks had 9% and public administration had 6% growth rates on average, the other activities grew between 2% and 4% on average.

Table 4-18: Gross Value Added per year and active person in the primary and secondary sector in Catalonia (ES51) [€], 2000 - 2004

Period	Primary	Secondary			
	Agriculture, Livestock and Fishing	Mining and Quarrying	Manufacturing Industry	Energy, Gas and Water	Construction
2000	25,142	156,145	42,779	172,614	29,567
2001	28,144	169,414	44,942	177,744	32,004
2002	29,308	157,571	46,071	190,061	35,939
2003	30,737	151,814	46,962	194,200	40,252
2004	34,575	138,200	48,010	186,459	44,257

Table 4-19: Gross Value Added per year and active person in the tertiary sector in Catalonia (ES51) [€], 2000 - 2004

Period	Tertiary								
	Trade and Repair	Tourism	Trafic, Communication	banks and insurance industry	Real estate, lending, b2b services	Public Administration, Defence, Social	Education	Health	Other public serivces
2000	31,837	50,737	55,915	82,181	69,270	44,150	34,828	36,389	35,182
2001	33,987	50,985	58,687	94,573	72,436	46,049	35,392	38,022	37,468
2002	36,722	52,729	58,471	102,162	76,841	49,339	36,416	39,204	38,985
2003	37,104	54,734	59,856	106,769	80,188	53,987	38,304	39,870	38,574
2004	37,125	55,443	62,535	114,057	80,788	56,736	40,412	40,629	39,547

4.2.5.3 Residential Exposure

Whereas gathering market values for buildings from the Internet was successful an approach for Austria, we decided against using the information available for Spain: Real estate prices in Catalonia appeared inflated by a bias towards tourist and holyday properties. But even the resort to official construction cost estimates, published four times a year by the Spanish ministry of living “Ministerio di Vivienda”, revealed a tremendous disparity between Spanish and Austrian real estate prices. In Spain, the real estate market exhibited some of the characteristics of the American market in recent years. The “Ministerio di Vivienda” releases information on house prices quarterly at www.mviv.es/es/. House prices where highly volatile but steadily increasing since 2000. Between 2000 and 2005 the price increase was 15% or three percent per year. In 2006 the increase was tremendous 14% in one year, and 2007 added another 5 % to the 2007 prices. For 2008 growth is expected to slow down, even a turnaround of the trend is possible. Such price developments are no sign of an efficient market. External influences seem to exert tremendous pressure on the prices. We therefore used the average prices of the time series 2000 to 2007 as a basis for the damage calculation. These prices are given in Table 4-20 House prices in the Besòs basin for the municipalities of the basin. The cost of a private house averages at € 247,689. A grade again was calculated as deviation from the average cost for every municipality. Highest prices are to be found in Sant Cugat del Valles, lowest prices are in Martorell. The numbers reflect prices for newly erected and older buildings and therefore appear to reflect time value. The average cost per home was calculated on the basis of a GIS evaluation of satellite images that revealed an average floor space of 108 m² calculated from a sample of 285 buildings.

Table 4-20: House prices in the Besòs basin

Municipality	cost [€/m²]	grade	floor space [m²]
Granollers	2,198	0.96	
Martorell	1,991	0.87	
Mollet del Vallès	2,173	0.95	
Montcada i Reixac	2,177	0.95	
Ripollet	2,227	0.97	
Sabadell	2,209	0.96	
Sant Adrià de Besòs	2,363	1.03	
Sant Cugat del Vallès	3,018	1.32	
Cerdanyola del Vallès	2,417	1.05	
Terrassa	2,160	0.94	
Average cost per m²	2,293	1.00	108
Average House cost	247,689		

4.2.5.4 Damage and Risk

The successful accomplishment of the vulnerability Analysis enabled us to calculate damages for the Besòs basins. These results are given in Figure 4-33.

Again three sets of damage functions where used to frame the uncertainty inherent in damage estimates. The highest values are calculated with the damage functions set from the upper Danube study (Pro Aqua et al 2001). These functions where designed for single buildings and therefore conceptually meet best the demand of the EWASE approach. The ICPR damage function set, designed for larger land use units, delivers values very close to those of the MUNLV-set (ICPR 2001). The MUNLV-set (Rhine, NRW, MUNLV 2000) delivers the lowest values. The bold line in the figure represents a weighted average calculated from these results, the weights being fixed by expert judgement at 0,5 for the Danube functions and 0,25 for the ICPR and MUNLV-functions respectively. Uncertainty bounds of around ±45% can be drawn to include all calculated values.

Damages of € 117 mn were calculated for the one in 50 years event, € 200 mn for the 100 years event and € 452 mn for the 500 years event for the weighted average. These results appear as a reasonable estimate of potential damages.

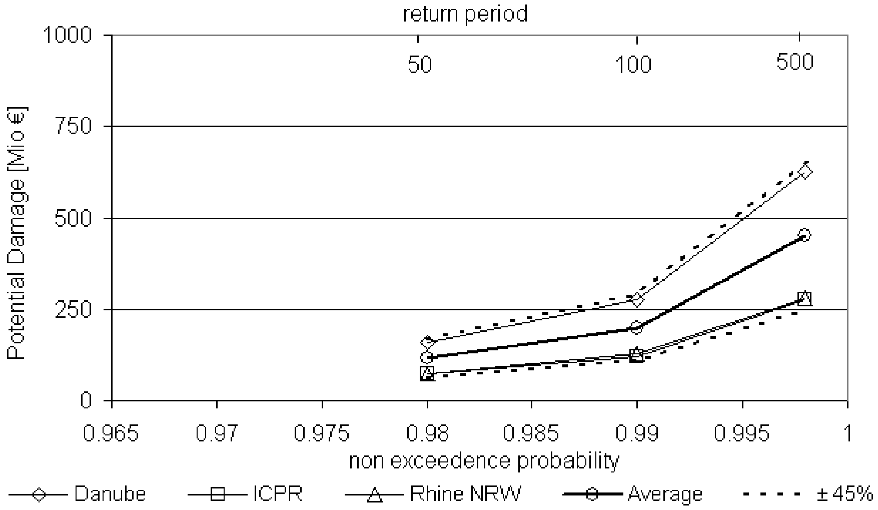


Figure 4-33: Calculated Damages in the Besòs basin

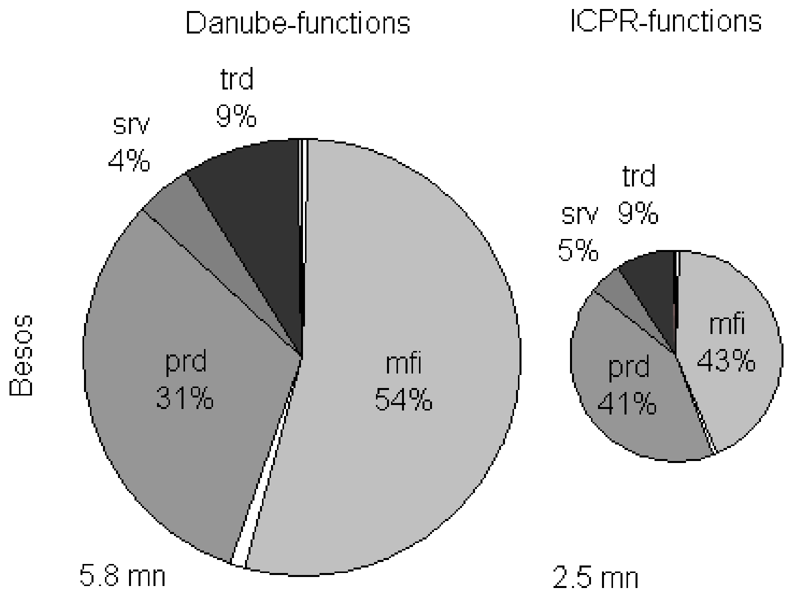


Figure 4-34: Distribution of risk over the main sectors for the Danube and ICPR-functions

Figure 4-34 displays the distribution of the risk over the main activities in the Besòs basin. The left pie in Figure 4-34 represents the results of the Danube functions whereas the right pie refers to the ICPR functions. The largest share of the risk 45% (mfi, Danube-functions) and 43% (IPCR-functions) is in the manufacturing industry, followed by private dwelling (prd, 31% and 41%) and trade (trd, both 9%). For the Besòs basin there is another considerable source of risk in the Service sector (4% and 5%) These four activities account for 98% (Danube-functions) and 97% (ICPR-functions) of the total risk in the Traisen basin.

5 Discussion of results

"In this chapter the findings from the study basins are summarised. This includes a comparison of similarities and disparities of both case studies, as well as a discussion of the results obtained in order to provide a general overview of the project success."

5.1 Flood forecast reliability

The evaluation of forecast reliability for the EWS in the study basins has shown that the predictability of floods is limited and involves a considerable degree of uncertainty that increases with lead time. Yet, the results presented in the sections 4.1.3.1 and 4.2.4 are the outcome of an aggregated evaluation on the basis of several events. For the appraisal of the generality of the findings and for the interpretation with regard to the effectiveness a more differentiated analysis is useful.

For this purpose, the dependence of forecast reliability on the different events is examined in detail. Further the relevance of the various components of the forecasting chain deserves a closer study. In this context, using the results obtained for the Traisen study basin the implications of explicitly taking into account the uncertainties associated with QPF and the hydrological model are discussed.

5.1.1 Event dependence of forecast reliability

Figure 5-1 shows FR(τ) for the individual events considered in both study basins.

For the Traisen (Figure 5-1 top) there is a visible pattern of FR(τ) development in accordance with the findings discussed in relation to Figure 4-15. However, it can be noted that FR varies for each event, e.g. FR(+1 h) = 0.57 for event C1 and FR(+1 h) = 0.72 for event V5. Also the decrease of FR with lead time is distinct for each event. As can be observed for event C1, the relative differences of FR between the events change with the lead time.

The results obtained for the Besòs basin (Figure 5-1 bottom) show an articulate dependence of FR(τ) on the event considered. In the case of event B FR is clearly superior for lead times τ < +3 h as compared to event H. From model calibration and validation it is known that the performance of the simulation model to reproduce the observed hydrographs of the flood events, e.g. in terms of the Nash-Sutcliffe-Efficiency (Table 4-15), is better for event B than for event H.

It seems that for the event B the observations of system input better capture the relevant information and that the hydrological model does better represent the induced response of the system.

It is noticeable that the FR(τ) curve for all events tends towards the lower FR values associated with event H. In this context it is of interest to examine the underlying CDF of ε_τ in detail. In Figure 5-2 and Figure 5-3 respectively the distribution of the individual events are compared against the CDF of the joint sample of ε_τ for a specific lead time in each basin.

In case of the Besòs Figure 5-2 at the up-per and lower bounds the CDF(τ =+2 h) for the events B and H are very close. However, there are clear differences concerning the shape and in relation to the median of the distributions. These differences are reflected in the CDF for all events. At first, for quantiles smaller than 0.2, the joint CDF follows the error distribution of event B. Following, there is a transition area towards the CDF of event H. Apparently the distribution of the joint sample of ε_τ is determined by the prediction errors of event B in the lower part and by the prediction errors of event H in the upper range. Accordingly, the evaluation of the ε_τ at the 0.85 quantile is dominated by the prediction errors of event H.

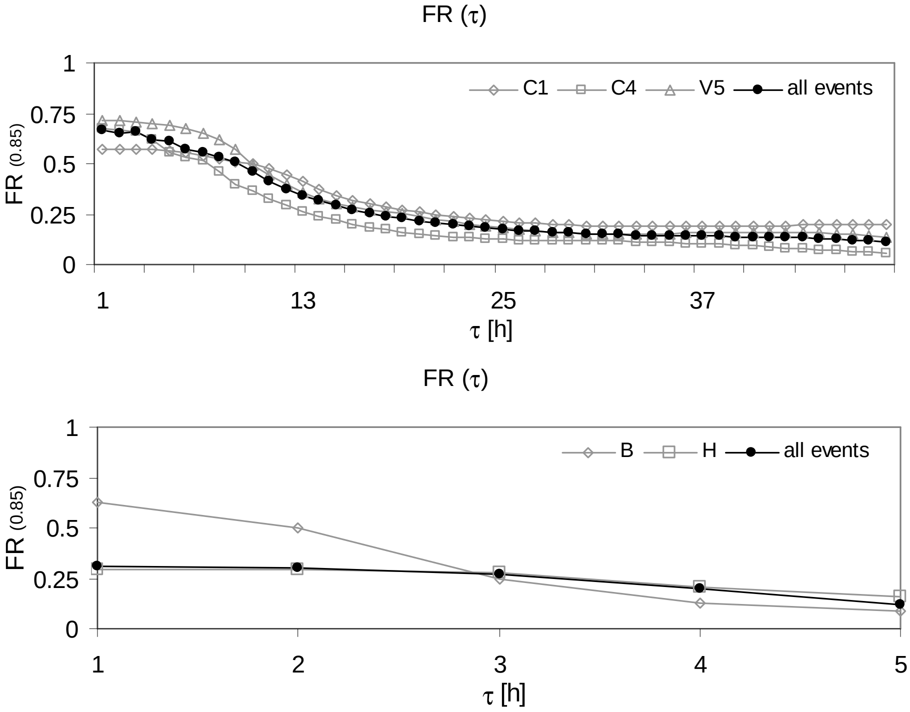


Figure 5-1: Forecast reliability as a function of lead time τ for the Traisen basin (above) and the Besòs basin (below). FR is differentiated for the events considered.

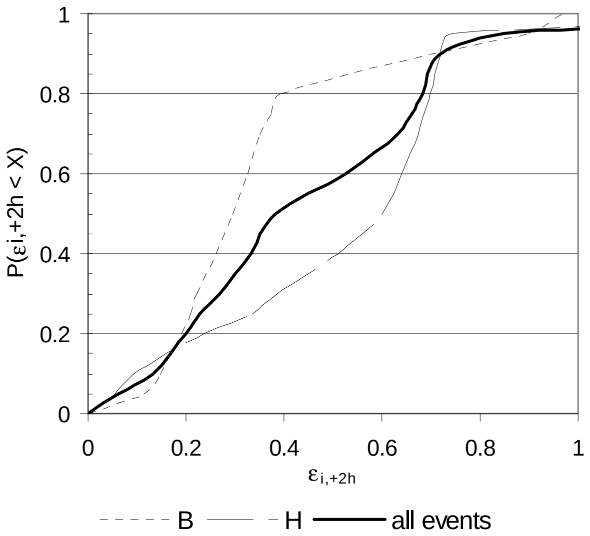


Figure 5-2: CDF of ε_τ for individual events compared to CDF(τ = +2h) of ε_τ for all events considered in the Besòs basin.

For the Traisen basin (Figure 5-3) the CDF(τ < +6 h) for the joint sample of ε_τ and the individual events are more homogeneous. The curves diverge for quantiles above the 0.6 quantile. Still, the joint CDF at the 0.85 quantile is well centred in relation to the individual distributions. Comparable results have been found for CDF corresponding to other lead times.

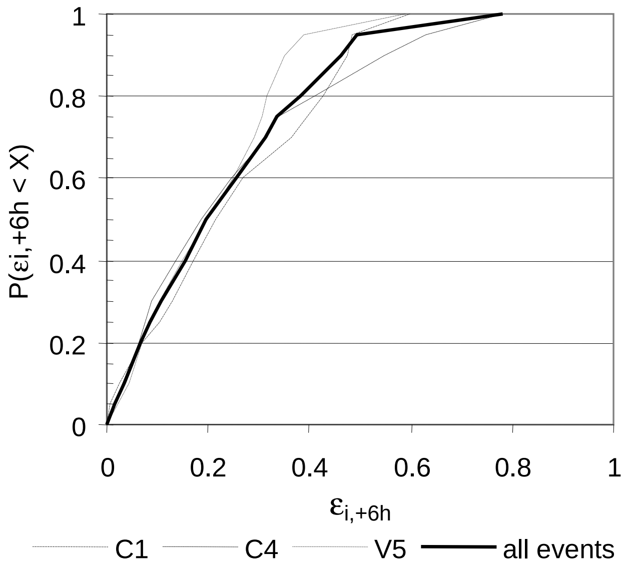


Figure 5-3: CDF of ε_τ for individual events compared to CDF(τ = +6h) of ε_τ for all events considered in the Traisen basin.

5.1.2 Implications of QPF uncertainty

The implication of precipitation forecast uncertainty on FR is studied by the comparison of using either ensemble QPF or deterministic QPF. In Figure 5-4 the FR(τ) curves corresponding to an evaluation of the ε_τ samples based on both QPF methods are shown.

Overall the development of both curves is very similar. For lead times τ < +10 h no difference can be observed between the graphs. In this context it has to be kept in mind that according to the underlying procedure of QPF ensemble generation the spread of the ensemble develops progressively with lead time. For lead times τ < +2 h all ensemble members are identical.

Beyond τ > +10 h FR is reduced when QPF related uncertainty is taken into account in terms of the ensemble QPF. Otherwise FR tends to be slightly overestimated.

Apparently, the prediction errors resulting from the ensemble QPF are at large very similarly distributed as the error sample obtained by the use of the deterministic QPF, see Figure 5-5. For larger lead times the shape of the distribution remains similar but the magnitude of the errors associated with ensemble QPF increases, see Figure 5-5 (on the right). Recalling the predictive performance of deterministic and ensemble QPF exemplified in Figure 4-9 and Figure 4-10 it is comprehensible that in total the ensemble predictions come along with larger errors.

Therefore, within the context of this study the reliability of the flood forecast does not seem to be improved by the use of the ensemble QPF. These findings are consistent also for a separated analysis of the individual events considered.

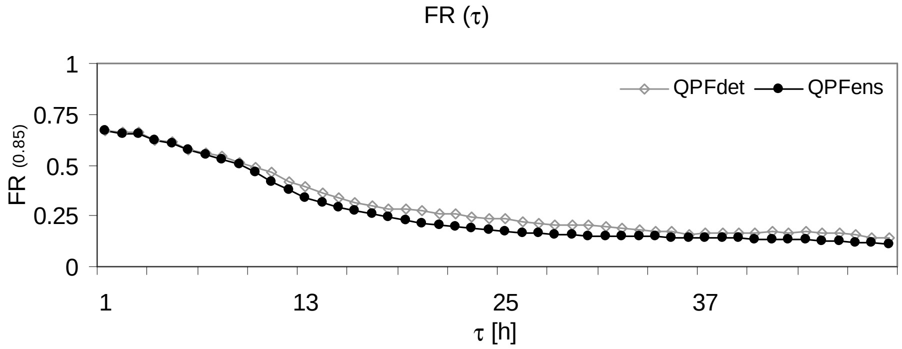


Figure 5-4: Forecast reliability as a function of lead time τ in the Traisen basin using either deterministic QPF (QPFdet) or ensemble QPF (QPFens).

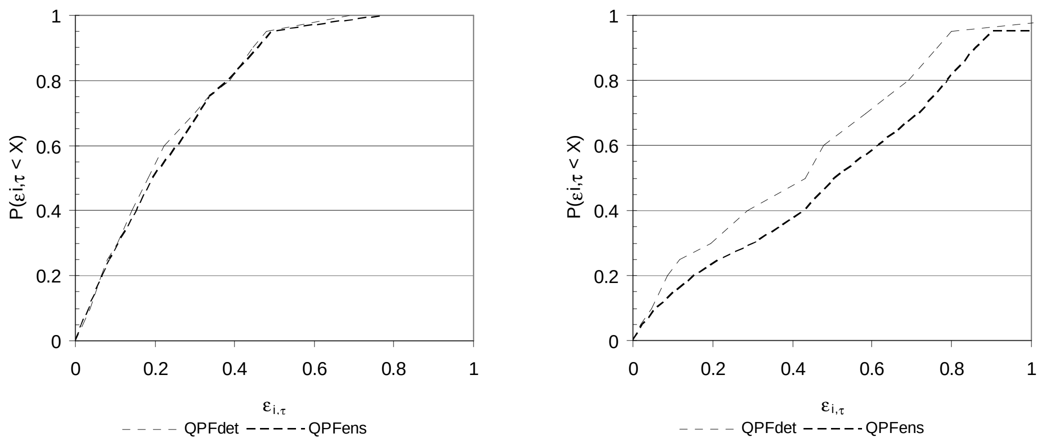


Figure 5-5: CDF of ε_τ for deterministic QPF and ensemble QPF for all events considered in the Traisen basin. Left: (τ = +6 h). Right: (τ = +24 h).

5.1.3 Implications of hydrological model uncertainty

As discussed above, FR is related to the basic capability of the hydrological model to reproduce the dynamics of a specific flood event. The application of multiple hydrological models allows for a glimpse on the dependence of FR(τ) on the hydrological simulation model used. In Figure 5-6 the FR(τ) curve is broken down with respect to the models COSERO and WBrM.

The graphs for the evaluation of FR based on all events (Figure 5-6) shows a systematic deviation between the models. These findings correspond to the differences in the basic model performance discussed in 4.1.4.1. This indicates that FR is conditioned by the capability of the simulation model to reproduce the dynamic behaviour of the hydrological system and the characteristics of the flood event.

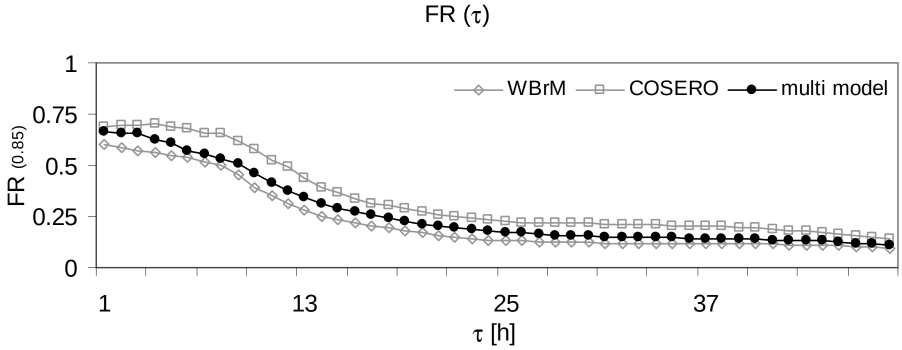


Figure 5-6: Forecast reliability as a function of lead time τ in the Traisen basin using different hydrological models based on all events.

However, the diagram in Figure 5-7, which shows FR(τ) for the event C4 using different models does not confirm this relation. For τ = +1 h WBrM provides more reliable predictions than COSERO. Making reference to the criteria for the evaluation of predictive performance listed in Table 4-4 it is noted that for this event the WBrM achieves a better reproduction of the peak flow and the flow volume than COSERO. However, with increasing τ both curves intersect at τ = +4 h and the relation between both models is reversed. This example demonstrates clearly that the modulation of QPF input information depends on the hydrological model. So, it seems that there is a complex interaction between QPF input data and other factors included in the simulation model.

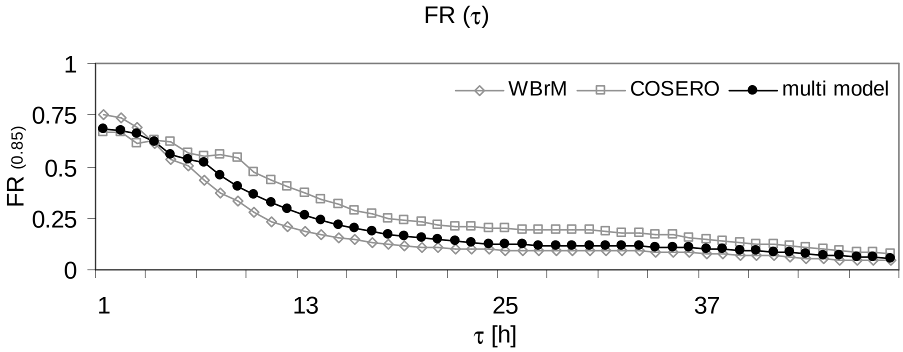


Figure 5-7: Forecast reliability as a function of lead time τ in the Traisen basin using different hydrological models based on event C4.

5.1.4 *Appraisal of the approach to evaluate forecast reliability*

The methodology proposed allows for the evaluation of flood forecast reliability as a function of lead time. Forecast reliability is quantified on the basis of a straightforward interpretation of the cumulative distribution function of a sample of prediction errors, which is derived from the comparison of predicted and observed discharges of past flood events.

The results of the exemplary analysis of forecast reliability within the framework of two operational EWS demonstrate the potential to produce flood forecasts with an adequate level of reliability. However, it became also apparent that the predictability of floods is limited and involves a considerable degree of uncertainty that increases with lead time. Within the approach it is possible to take different sources of uncertainty about the flood forecast and the warning explicitly into account by means of ensemble techniques.

The decrease of FR with increasing lead time can be principally attributed to the capability of the QPF method to anticipate future rainfall. However, the basic level of FR is determined by the performance of the hydrological model to reproduce the dynamic behaviour of the hydrological system. In this respect, it has been shown that the uncertainty of the precipitation forecast is modulated in a different manner depending on the hydrological model. Hence, the responses of multiple hydrological models add complementary information to the forecasting process and provide a means to frame the related uncertainty. However, compared to QPF related uncertainty the importance of the hydrological model performance for the reliability of the flood forecasts decreases as lead time is extended. For illustration in Figure 5-8 the absolute changes of forecast reliability (ΔFR) in reference to the initial level of forecast reliability are compared to the changes in forecast reliability in consequence of the consideration of different sources of uncertainty. As can be seen from this graph the model related differences of FR increase until lead times of approx. τ = +10 h and then decrease continuously. From this point onwards the deterioration of FR can be attributed to the performance of the QPF method. The changes in FR owing to the consideration of ensemble QPF are comparably small.

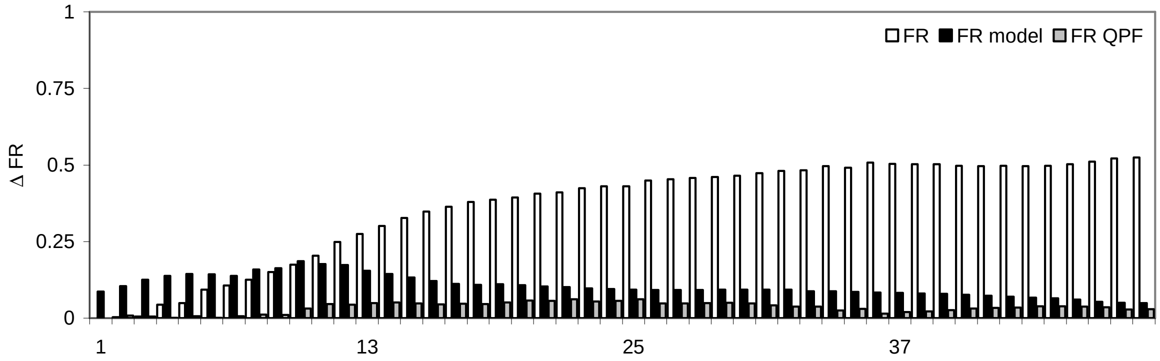


Figure 5-8: Changes in FR due to ensemble QPF (grey), different hydrological models (black) in comparison to the overall decrease of FR (in white) in the Traisen basin.

Furthermore, the results of the Traisen basin (see Figure 4-15) indicate that the model related level of FR is constant for lead times of approximately +4 h. For this forecast horizon, the information coming from rainfall observations seems to persist. Beyond this point, the importance of comparatively uncertain rainfall forecasts increases continuously with lead time and deteriorates FR.
The results for the Besòs illustrate (see Figure 4-32) that input information based on QPE is useful for the prediction of floods at best for a forecast horizon of +2 h. The lead time of approx. τ = +4 h to +6 h in the Traisen and approx. τ = +2 h in the Besòs are within the range of the response time in each basin.

In comparison to this, the effect of explicitly quantified QPF related uncertainty in terms of ensemble QPF is of secondary order, as also illustrated in Figure 5-8. However, it has to be noted that the applied method for the analysis of prediction errors integrates the forecasts of all ensemble members in a joint distribution, thus obscuring the predictive performance of individual ensemble members. In this context, a differentiated analysis of the variation of forecast reliability associated with the individual ensemble members is of interest.

Furthermore, it has been shown that FR is dependent on individual events. As can be observed from the Besòs case study, the evaluation of FR is highly influenced by the distributions' shapes and the ranges of prediction errors of the particular events. These results are derived on the basis of relatively small sample sizes of the prediction error. For a general interpretation and to decide whether or not the EWS in the study basins are effective, it is required to include more events in the analysis. Also it will be necessary to carry out the analysis of forecast reliability at different susceptible locations inside the study basin.

The question whether reliable flood forecasts are available with sufficient lead time requires taking a look at the preventive measures to be completed. Also, it has to be taken into consideration that the decision about a flood alert is very complex and involves the trade-off between numerous aspects. Therefore, the reliability of the flood forecast has to be assessed in the context of the potential damages and the consequences of an alert. In this regard, the EWASE approach proposes to combine the FR(τ) curves presented with a benefit function that quantifies the (socio-) economic consequences of a decision by stating the potential damages to be avoided and the damages a false alert might cause due to unnecessary precautionary measures (see section 5.3.1).

5.2 Comparative Risk Analysis

5.2.1 Industrial Exposure

The plausibility of the exposure analysis results on the regional level can be demonstrated by comparison with the EU regional statistical data. The overall comparison in terms of GPP depicts Table 5-1. Regional GDP per inhabitant provide measures of the total economic activity in a region. Whereas it serves for comparing the degree of economic development of regions, it does not measure the income ultimately available to private households. The PPS (purchasing power standard) is an artificial currency that takes into account differences in national price levels. This unit allows meaningful volume comparisons of economic indicators over countries. Aggregates expressed in PPS are derived by dividing aggregates in current prices and national currency by the respective Purchasing Power Parity (PPP). (Eurostat 2005).

Table 5-1: Regional GDP in the EU27 member states 2004

Region NUTS 2003	GDP Mio €	GDP per Inh. €	GDP Mio PPS	GDP per Inh. PPS	GDP per Inh. PPS
Eu 27	10,529,351	21,503	10,529,351	21,503	100.0%
Spain	840,106	19,678	924,629	21,658	100.7%
Este	260,805	21,527	287,044	23,693	110.2%
Cataluna	**157,922**	**23,533**	**173,811**	**25,900**	**120.5%**
Valenciana	81,781	18,340	90,009	20,185	93.9%
Illes Balears	21,101	22,332	23,224	24,579	114.3%
Austria	235,819	28,847	226,163	27,666	128.7%
Ostöstereich	107,133	31,019	102,747	29,749	138.3%
Burgenland	5,585	20,129	5,357	19,305	89.8%
Niederösterreich	**36,583**	**23,397**	**35,085**	**22,439**	**103.3%**
Wien	64,965	40,281	62,305	38,632	179.7%

The table presents the NUTS 2 regions in a national and trans-national context. Compared to the EU27, inhabitants in Catalonia (120.5%) are better of than the EU average (100%) and than inhabitants in Lower Austria (103.3%). The GDP per inhabitant is higher in Catalonia but differs only by 136 €. On this level great differences in the structure of regional economies are not to be expected.

Table 5-2: Indicators on the national level, 2004

		Austria	Spain	Spain/Austr.
Stock	[Mio €]	836,723	2,818,379	3.37
GDP	[Mio €]	235,819	840,106	3.56
Active Persons	[Mio]	4.1	18.5	4.47
Capital Intensity	[€/AP]	202,156	152,325	0.75
GDP/Act Person	[€/AP]	56,975	45,405	0.80

Another picture appears when Stocks and Employees are compared on the national level as in

Table 5-2. The table compares the Capital Stock data from BBVA foundation and Statistik Austria respectively with the employment data from Eurostat. It appears that Spain has 3 times the capital stock of Austria and 4 times the active persons. From that we can calculate that the average capital intensity in Spain is only 75% of the Austrian capital intensity. Because there is a higher stock per active person in Austria (more and better equipment per employee), the productivity in Austria is higher than in Spain, the Spanish GDP per active person is 80% of the Austrian.
If the reader carefully compares the tables on Lower Austrian (section 5.1.5.1) and Barcelonan (section 5.2.5.1) capital intensities, he will detect that in Austria, Plant and Equipment accounts for the larges part of the capital stock whereas in Barcelona, buildings contribute the major share. It is a problem that capital stock data are not available from Eurostat and therefore a comparison builds on the national data. For Barcelona a detailed analysis of the stock was provided from BBVA foundation whereas only aggregate data were available for Austria. “Buildings” is the term selected by the author for the Spanish infrastructures. The contradiction may therefore build on a misnomer. However, as total capital intensities enter the damage calculation this potential error does not affect the results.

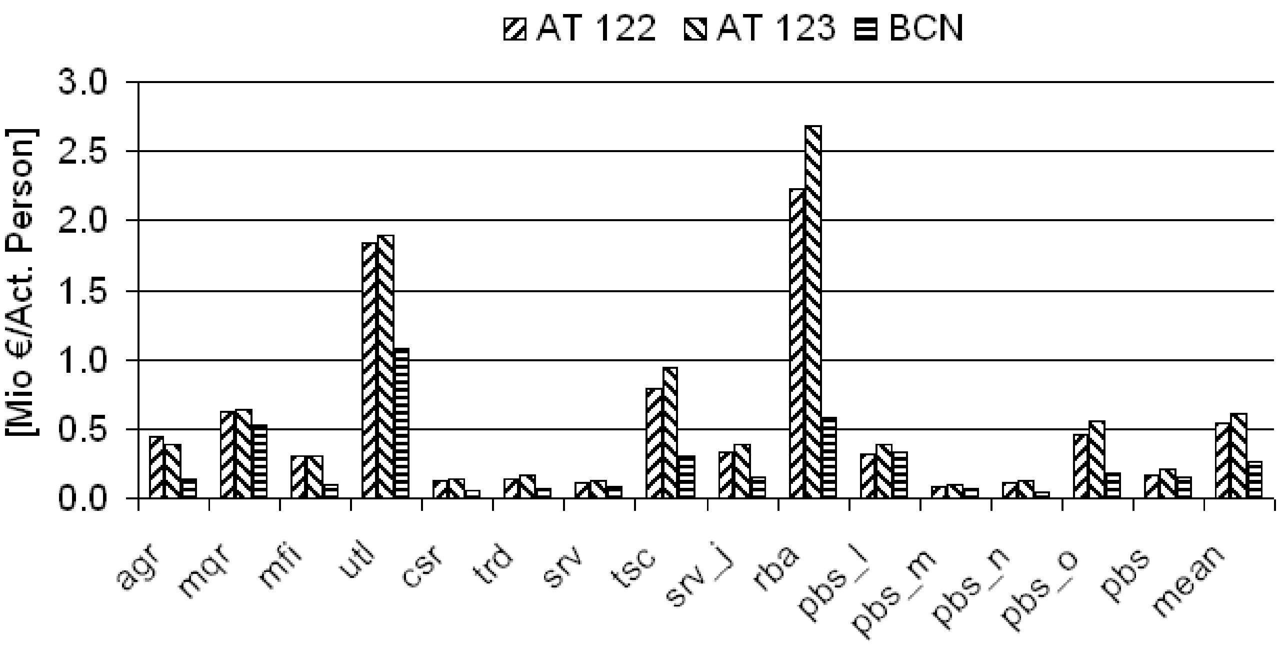


Figure 5-9: Comparison of Capital Intensities in the NUTS3 regions, 2004

Other striking differences in the capital intensities are shown in Figure 5-9 as well as Table 5-3. Both the figure and the table present the same data.

The Austrian NUTS3 regions Niederösterreich Süd (AT122) and St.Pölten (AT123) are presented besides the region Barcelona (ES511). Firstly significant differences can be found in the Austrian capital intensities. These are detailed in section 5.1.5.1. Secondly the trans-national comparison clearly shows that industrialisation in Austria has a longer tradition than in Spain: Nowhere are capital intensities in Spain higher than in Austria. The last column in the table presents the quotient of the Barcelonan capital intensities and the average Austrian capital intensities per activity (BCN/((AT122+AT123)*0,5). In some sectors like in Public Administration (93%) or Mining and Quarrying (84%) Barcelonan capital intensities nearly reach the Austrian level, in most sectors they are below 50% as may be taken from the last column of the table. On average, barcelonian capital intensities are 50% of the Austrian.

Table 5-3: Comparison of Capital Intensities in the NUTS3 regions, 2004

Nace Activity				Austria		Barcelona	Spain
	Code	Abbr.	Description	AT122	AT123	ES511	Austria
Primary	A	agr	Agricult., Liveststock	442,929 €	382,385 €	140,271 €	34%
	B		Fishing				
Secondary	C	mqr	Mining, Quarrying	616,772 €	634,260 €	525,787 €	84%
	D	mfi	Manufact. Industry	298,448 €	306,910 €	94,831 €	31%
	E	utl	Energy, Gas, Water	1,835,594 €	1,887,643 €	1,074,891 €	58%
	F	csr	Construction	127,976 €	131,605 €	52,445 €	40%
Tertiary	G	trd	Trade and Repair	142,469 €	171,277 €	74,499 €	47%
	H	srv	Tourism	108,798 €	130,798 €	79,686 €	67%
	I	tsc	Trafic, Communic.	783,789 €	942,274 €	310,802 €	36%
	J	srv_j	banks, insurance	327,016 €	393,140 €	156,874 €	44%
	K	rba	Real est., lending, ...	2,225,492 €	2,675,495 €	582,275 €	24%
	L	pbs_l	Publ. Admin.	324,241 €	389,804 €	330,732 €	93%
	M	pbs_m	Education	86,042 €	103,441 €	65,040 €	69%
	N	pbs_n	Health	106,608 €	128,165 €	48,360 €	41%
	O	pbs_o	Other publ. serv.	455,222 €	547,270 €	179,795 €	36%

Comparing the tables on Lower Austrian (section 5.1.5.1) and Barcelonan (section 5.2.5.1) capital intensities reveals the following: Whereas Austrian capital intensities showed constant growth between 2002 and 2004 for all activities, the picture is quit different for Spain. The primary and secondary sector is decreasing at significant rates: 2% in the construction industry, 5% in manufacturing industry and agriculture, 13% in the utilities and 15% in Mining and quarrying. The tertiary sector exhibits a mixed picture: Whereas Public Administration (8%), Tourism (6%)and Banks and Insurance (3%) show significant positive annual growth rates, capital intensity is decreasing in Traffic and Communication (-3%), education (-4%) and health (-4%). Given the short time series one should not overhasty jump to conclusions. But the comparison between the countries opposes a positive development in Lower Austria to a mixed picture in Barcelona on the regional level.

As discussed in section 4.1.5.2 indirect losses are taken into account in two ways in EWASE. Firstly business disruption occurs when a company suffers direct flood damage. Secondly business disruption occurs in case of a flood warning when employees of a company stop their productive work and turn to any kind of damage mitigation actions, be it carrying sand-bags, moving cars into safety, installing mobile flood protection or speeding home to care for private belongings. EWASE is the first study to include mitigation cost into economic analysis on the very pragmatic basis of lost value added.

As a measure for indirect losses value added per active person is used on a daily basis. It is calculated on the basis of national data from Statistic Austria and Instituto Nacional de Estadistica (INE). Gross Value added per activity is divided by active persons per activity on NUTS2 level. The annual values are broken down to daily values on the assumption that average working days per year are 220. Average working hours per day are assumed to amount to 8 for further disaggregation. A spatial disaggregation to NUTS 3 is possible in principle. The results are displayed in Table 5-4.

Table 5-4: Gross Value added per activity in Spain and Austria, 2004.

Nace Activity	Code	Abbr.	Description	Lw. Austria AT12	Catalonia ES51	Spain Austria
Primary	A	agr	Agricult., Liveststock	114 €/d	157 €/d	138%
	B		Fishing			
Secondary	C	mqr	Mining, Quarrying	653 €/d	628 €/d	96%
	D	mfi	Manufact. Industry	313 €/d	218 €/d	70%
	E	utl	Energy, Gas, Water	750 €/d	848 €/d	113%
	F	csr	Construction	272 €/d	201 €/d	74%
Tertiary	G	trd	Trade and Repair	169 €/d	169 €/d	100%
	H	srv	Tourism	152 €/d	252 €/d	166%
	I	tsc	Trafic, Communic.	245 €/d	284 €/d	116%
	J	srv_j	banks, insurance	406 €/d	518 €/d	128%
	K	rba	Real est., lending, ...	392 €/d	367 €/d	94%
	L	pbs_l	Publ. Admin.	210 €/d	258 €/d	123%
	M	pbs_m	Education	228 €/d	184 €/d	81%
	N	pbs_n	Health	154 €/d	185 €/d	120%
	O	pbs_o	Other publ. serv.	155 €/d	180 €/d	116%

A comparison of the data with the conclusions drawn on the basis of

Table 5-2 reveals that disaggregation is necessary to prevent major errors. Firstly, Catalonia is no smaller average part of Spain, and secondly, high capital intensities do not automatically translate into high output. Table 5-4 showed that Barcelonian are 50% of Austrian capital intensities on average. The Table 5-4 shows, that gross value added is higher in Spain for most activities. Catalonian Value added is 109% of Lower Austrian in relation to Employees on average. There is no clear pattern between capital intensities and value added between the countries and activities. A detailed analysis per activity may clarify the issue. Reasons may be found in higher environmental regulation and better or safer infrastructure and equipment in Austria. But the disparity between capital intensities and value added in Catalonia reconciles the result with the values of the introductory Table 5-1. Only if Catalonian Employees generate higher value added with lower capital intensities, Catalonian inhabitants can enjoy a higher per capita GDP.

5.2.1.1 Damage and Risk in the study basins

The successful accomplishment of the Vulnerability Analysis enabled us to calculate damages for the basins. As the establishment of flood plains for both basins was not within the scope of EWASE, we had to use existing studies which are not consistent with regard to the return periods. For the Traisen basin we had floodplains for the 30, 100 and 200 year return period, for the Besòs basin they were available for the 50, 100 and 500 year return periods. This difference is presented in Table 5-5.

Table 5-5: Average Damage and Risk in the study basins

	Damage [€ mn]					Risk [€/a]
Return period	30	50	100	200	500	-
Traisen	563		877	1,017		25,795,784
Besos		117	200		452	4,165,846

The table lists average damages calculated for the basins ranging from € 560 million to € 1 billion in the Traisen and from € 117 million to € 452 mn in the Besòs basin. For the 100 years flood damages in the Besòs are 55% of the Traisen damages. Accidentally this is nearly the same ratio as for the capital intensities. But along with the lower capital intensities there are other reasons for the high Austrian values. Neglecting the damage reducing effect of structural flood protection at the design event - as in the HORA data - is probably the main source for the very high damages in the Traisen basin. The same facts reflect the annual expected damages in the right column of the table. An unaccounted flood protection for a 100 years event leads to a risk of 26 million €/a in the Traisen basin compared to a risk of 4,2 million €/a in the Besòs basin. But even 4,2 million € per year is a significant figure which may easily allow for significant investment in flood protection.

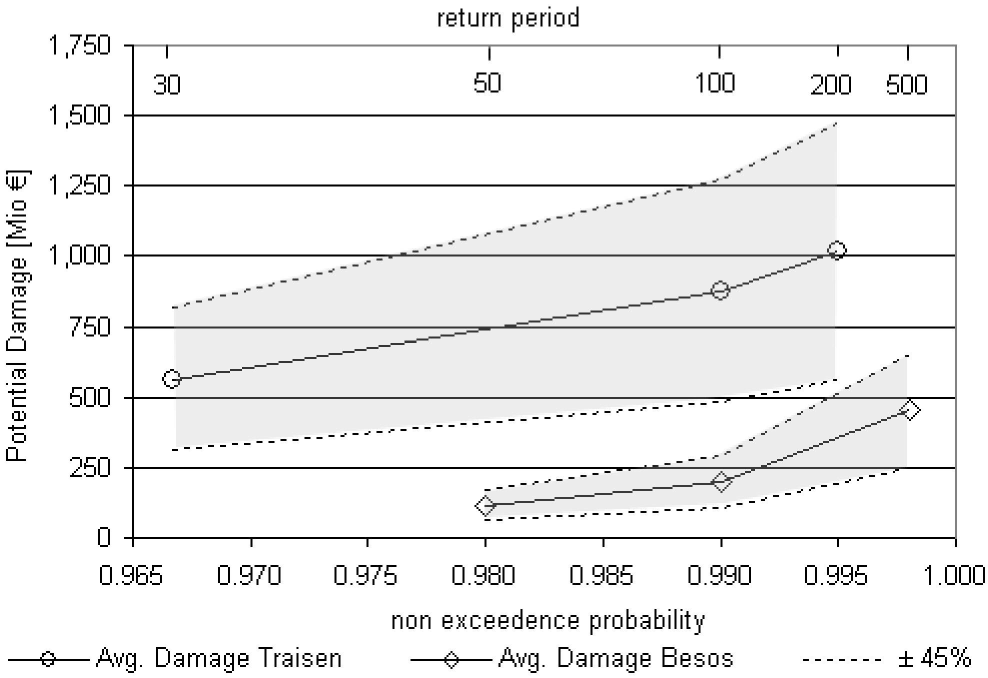


Figure 5-10: Potential Damages in the study basins

Figure 5-10 summarises the information on damages detailed in sections 4.1.1.4 and 4.2.1.4. A weighted average was calculated from the results of three different sets of damage functions and is represented as a line for each basin in the figure. These average values are given in Table 5-5. The grey area represents the uncertainty of around ±45% if all calculated values are included.

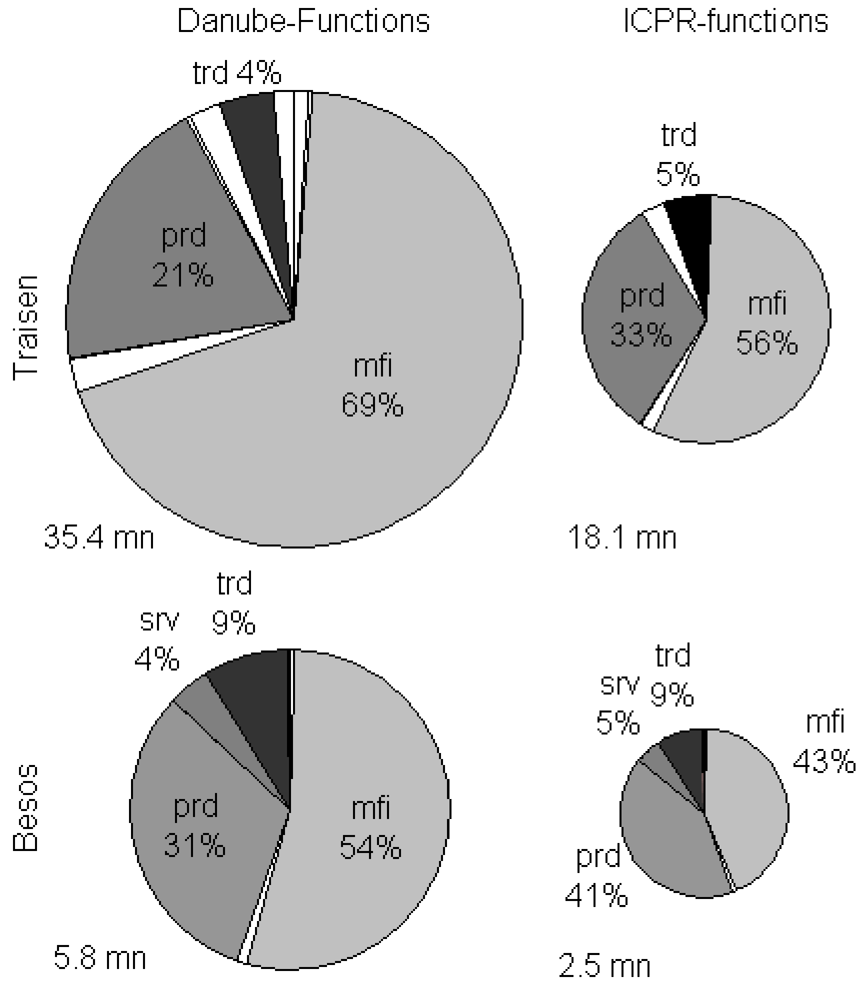


Figure 5-11: Distribution of risk over the activities for both basins. Results from two sets of damage functions given to represent variability of susceptibility (see Table 5-5 for legend)

Figure 5-11 displays the distribution of the risk over the main activities affected. The values calculated for the Danube- and ICPR-functions are shown at the right and left side of the figure for the Traisen (top) and the Besòs basin (bottom). The distribution is slightly different for the damage function sets. The largest share in both basins comes from manufacturing industry (mfi) with 69% and 54% respectively, for the Danube functions, the ICPR-functions delivering 56% and 43%. On the second place private dwelling is found with 21% for the Traisen and 31% for the Besòs basin (ICPR: 33% and 41%). The third place goes to trade (trd) with shares of 4% and 9%. In the Besòs basin service industry adds another share of 4 to 5% to the risk. These three activities in the Traisen and four activities in the Besòs basin account for above 90% of the risk for both sets of damage functions, leaving very small shares to the other activities in the basins. On the lower right side of every pie chart, the total risk is indicated. It ranges from € 18.1 mn to € 35.4 mn for the Traisen (structural flood protection neglected) and from € 2.5 mn to € 5.8 mn for the Besòs basin.

In order to know the sensitivity of the damage and risk calculation, theoretical calculations were carried out for the concerned structures in the Besòs and the Traisen basin. The water-level was reduced and increased by 5 and 10 centimetres. With these changed water-levels new damage calculation were carried out. The results are shown in the following Figure 5-12. A change of 5 centimetres in the water level leads to a change of the risk by approx. 2%.

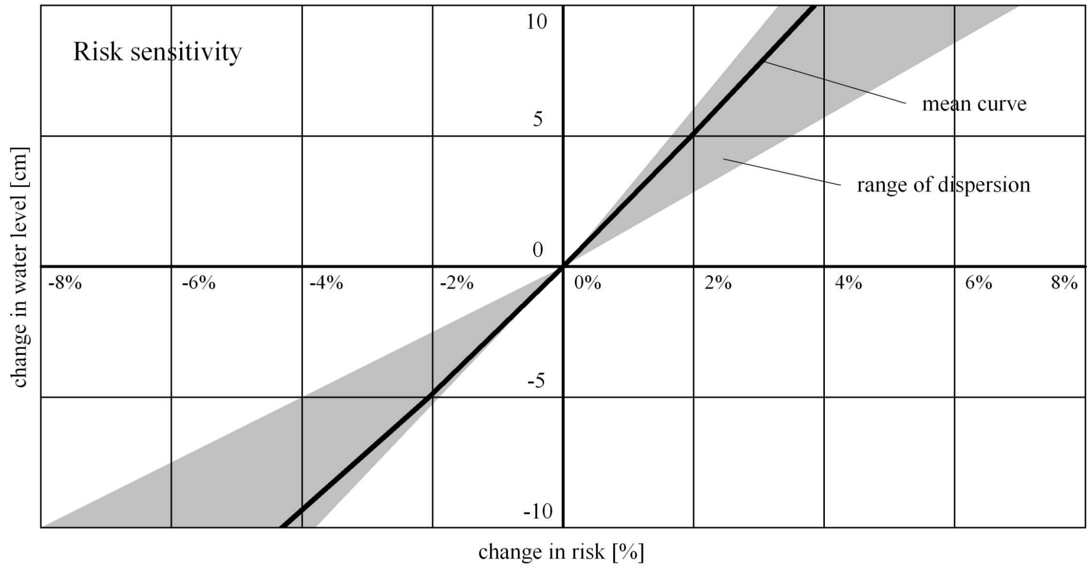


Figure 5-12: Risk sensitivity

5.3 EWS Assessment

5.3.1 Event-dependent Evaluation

Any investment project in natural hazards protection must successfully pass an event-dependent as well as an event-independent evaluation for showing its viability. Usually there is a greater probability for successfully passing the event dependent evaluation. An event dependent evaluation focuses on the flood event, leaving all issues which do not directly relate to the flood aside. Therefore, an event dependent evaluation does not include investments etc. In economic terms, investments are treated as sunk costs, e.g. as costs which cannot be recovered by a decision about an alert.

5.3.1.1 Response analysis in the industry sectors

For determining the ability of the companies to react in case of a flood warning, a questionnaire based survey was carried out. A questionnaire in the national languages (Catalonian for Catalonia and German for Austria) was sent via the national project partners (UPC for Catalonia and BOKU for Austria) to the larger flood affected companies in both basins. Although we tried to pursue an approach with close stakeholder involvement, the response was unexpectedly low. From 20 questionnaires posted in the Traisen basin we received 8 (40%) completed, and from 100 questionnaires posted in the Besòs basin we received 4 (4%) respectively. A local approach should yield better results. The most important question for assessing the benefit of an alert was the question number eleven: “supposed you receive an alert some time before a flash flood, by which percentage could you reduce flood damage”? Respondents were asked to tick their estimate on a matrix as given in Table 5-6.

Table 5-6: Question 11 of the EWASE questionnaire

11	a) How long do you need to make your company flood safe?				
	☐ 1 hour	☐ 1 day	☐ 1 week	☐ __________	
	b) Supposed you receive an alert some time before a flash flood. By which percentage could you reduce flood damage?				
	Lead time	Damage reduction			
	1 day (12hrs)	☐ 100 %	☐ 80 %	☐ 50 %	☐ 20 % ☐ 10 %
	6 hours	☐ 100 %	☐ 80 %	☐ 50 %	☐ 20 % ☐ 10 %
	3 hours	☐ 100 %	☐ 80 %	☐ 50 %	☐ 20 % ☐ 10 %
	1 hour	☐ 100 %	☐ 80 %	☐ 50 %	☐ 20 % ☐ 10 %

Question 11a provided us with information on preparedness of the respondents. In question 11b respondents could indicate an estimate of their damage reduction capability by reasonably ticking four boxes. One ticked 5, some rejected to answer the question, therefore the question 11b yielded 35 answers in total. From these results we computed the damage mitigation function presented in Figure 5-13.

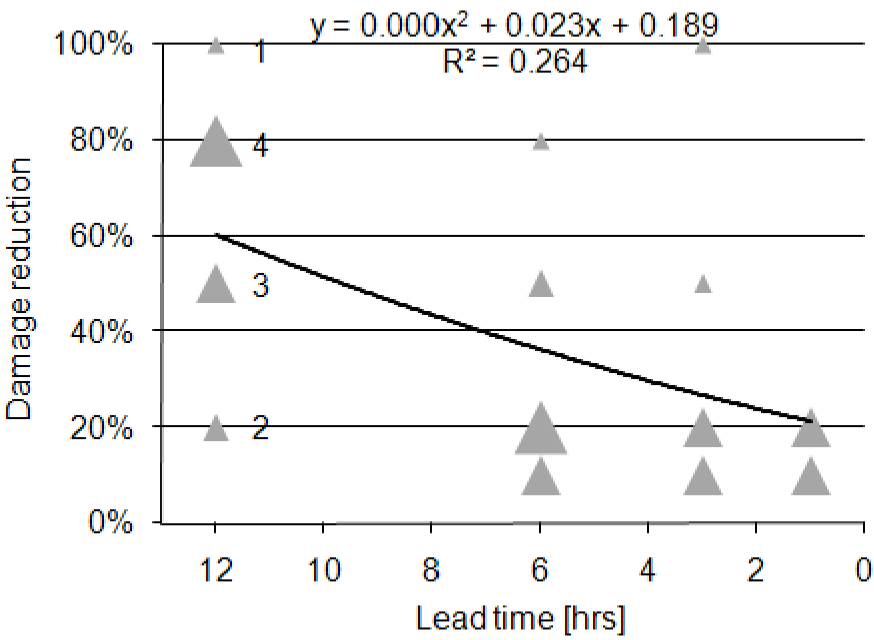


Figure 5-13: Damage reduction as a function of lead time in the industry sectors.

The answers to the questions are presented as black triangles. The size of the triangles is a measure for the frequency of a certain answer, ranging between 4 and 1. Four respondents estimated, that they could reduce their flood damage by 80% if they would receive a warning 12 hours before a flood. Equally four estimated, that they could achieve 20% in case of a 6 hours lead time. Three respondents estimated a reduction by 50% for a 12 hours lead time. 20% reductions were estimated at lead times of 6, 3 and 1 hours by three respondents each. Two estimated that even a lead time of 12 hours would not enable them

to achieve more than a 20% reduction of damages. Twenty one answers are at and below 20%, fourteen answers are at or above 50%. Very clearly there is a strong correlation between preparedness and effectiveness of mitigation measures. We had two respondents estimating a damage reduction of 100% for a lead time of 12 and 3 hours respectively. This assumedly is an indication of the synergies between temporary / demountable protection measures and early warning (Kathibi et al. 2003).
A non-linear regression as indicated in Figure 5-13 delivered a coefficient of determination of 0.26 which is more than we expected given the small sample size.

The Damage reduction function allows for the calculation of an event dependent benefit because the potential damage for the event is known from the risk analysis. The benefit of the warning is the portion of damage avoided as indicated by the respondents.

5.3.1.2 Response analysis in the private sector

We assessed the potential reduction of damage to household inventory on the basis of a UK-study on the response ability of households to flooding situations in England and Wales (Parker et al 2007). Parker estimated based on a comprehensive questionnaire based telephone survey that approximately 40% of the household inventory is moveable and therefore can be put into safety during floods. Based on this result we calculated the time value of movable inventory as 40% of € 29,500 = € 11,800.

Furthermore Parker established a relationship between effectiveness of damage mitigation and lead time. As a result of his study 55% of moveable household inventory can be saved for lead-times below 8 hours and 71% for lead-times above 8 hours if 100% of households receive a warning. In EWASE this translates into a damage reduction of 21% of the total household inventory for lead-times below 8 hours and 27% for lead times above. Fixing the lower estimate (21%) at 4 and the higher estimate (27%) at 12 hours enabled us to establish a linear relationship between lead time and avoidable damage as given in Figure 5-14.

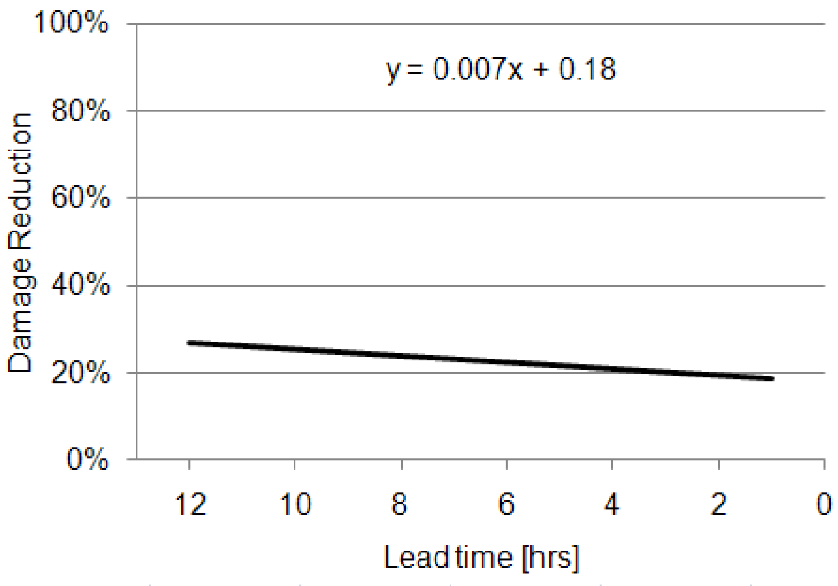


Figure 5-14: Damage reduction as a function of lead time in the private sector.

According to this rough estimate the influence of lead time on damage reduction in the private sector is pretty low. Even for no formal flood warning there is a damage reduction of 18%. A lead time of 12 hours increases damage reduction only by 15 percentage-points. A detailed discussion is given in Parker et al. 2007.

5.3.1.3 Optimal Alert

This section integrates all the results of EWASE into a pragmatic tool for decision support. Generally we assume that the reliability of a warning is independent from the return period of the event. This assumption allows for the combination of reliability curves from frequent events with damages from rare events. All figures below refer to the one in hundred years event. For the Besòs basin it is assumed that a warning system as installed in the Besòs fluvial park is available on basin level, for the Traisen basin, the existing system is evaluated.

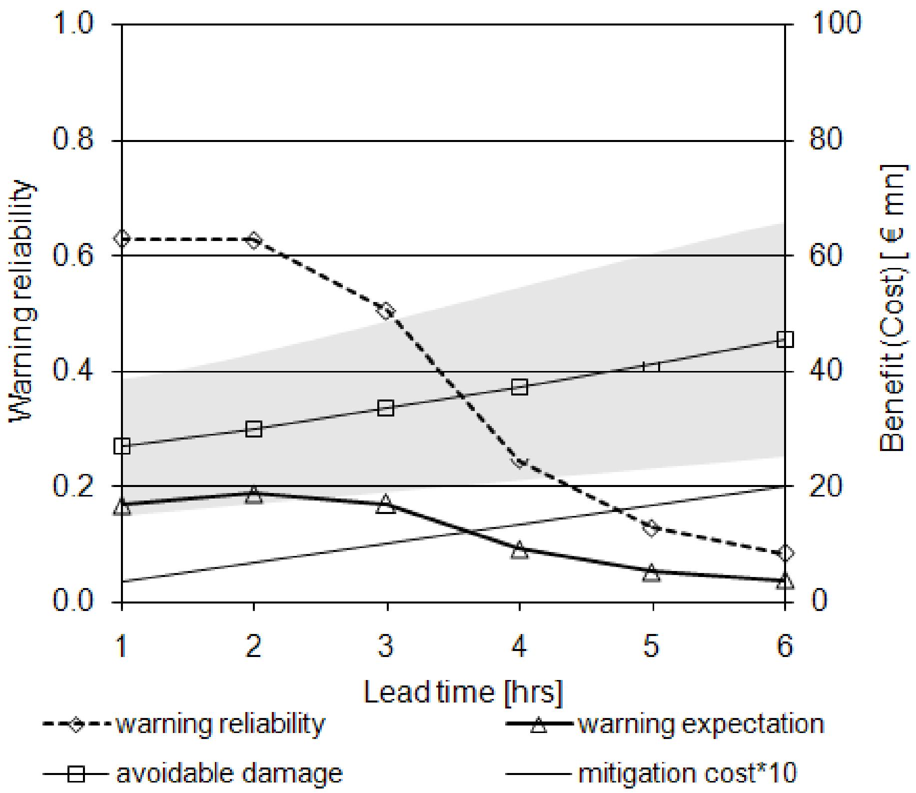


Figure 5-15: Warning expectation for the industrial sectors in the Besòs basin for the 100 years event.

Figure 5-15 presents the results of the synopsis for the Besòs basin for the one in hundred years event. With respect to the left axis, warning reliability as calculated for the event B is drawn. It is important to note that according to the evaluation of forecast reliability detailed in 5.1 this specific warning reliability curve depends on the analysed event and the configuration of the operational warning system. The curve starts at 62%, levels until a lead time of 2 hours, and then sharply turns into a progressive decrease to values around 20% for 4 hours, from which point the decrease of reliability becomes degressive. Avoidable damage as calculated from Figure 5-10 and Figure 5-13 for the one in hundred years event is drawn with respect to the right axis, starting at a value of € 45.31 mn for a lead time of 6 hours and continually decreasing to € 26.75 mn at a lead time of one hour. These are large numbers building on the assumption that every company in the study basin realises damage reductions as indicated in Figure 5-13. It is therefore an optimal reaction which might not be reached during emergencies. As a grey shadow the area between upper and lower boundary of potential damage is drawn. At the lower part of the figure mitigation cost is indicated and multiplied by 10 for better representation in the figure.

Mitigation cost indicate that a cost of € 331,000 per hour arises if the estimated 12.500 active persons in the flood prone areas of the Besòs basin stop their productive work, generating a gross value added GVA of € 26 per hour and active person on average and turn to preventive measures. Given the high associated costs of the alert in terms of GVA-losses, there is good reason to reflect carefully about triggering an alert for a flood event which is uncertain to happen. It is a main objective of EWASE to deliver decision support to this end.

Very generally, an expectation is defined as the product of probability and consequences. Analogously we define the expectation of an alert as a product of its reliability and the avoidable damage. Its unit is € per alert, and its curve is given as a bold line in Figure 5-15. Unsurprisingly, warning expectation is not a constant but changes over lead time. Low values of reliability affect it in the same way as low values of avoidable damage. The maximum of the warning expectation, for the Besòs basin reached at a lead time of 2 hours, is the optimal point in time for releasing an alert with respect to reliability and consequences. The avoidable damage is € 30 mn, the damage mitigation cost amounts to € 662,000.- or 2% of the avoidable damage.

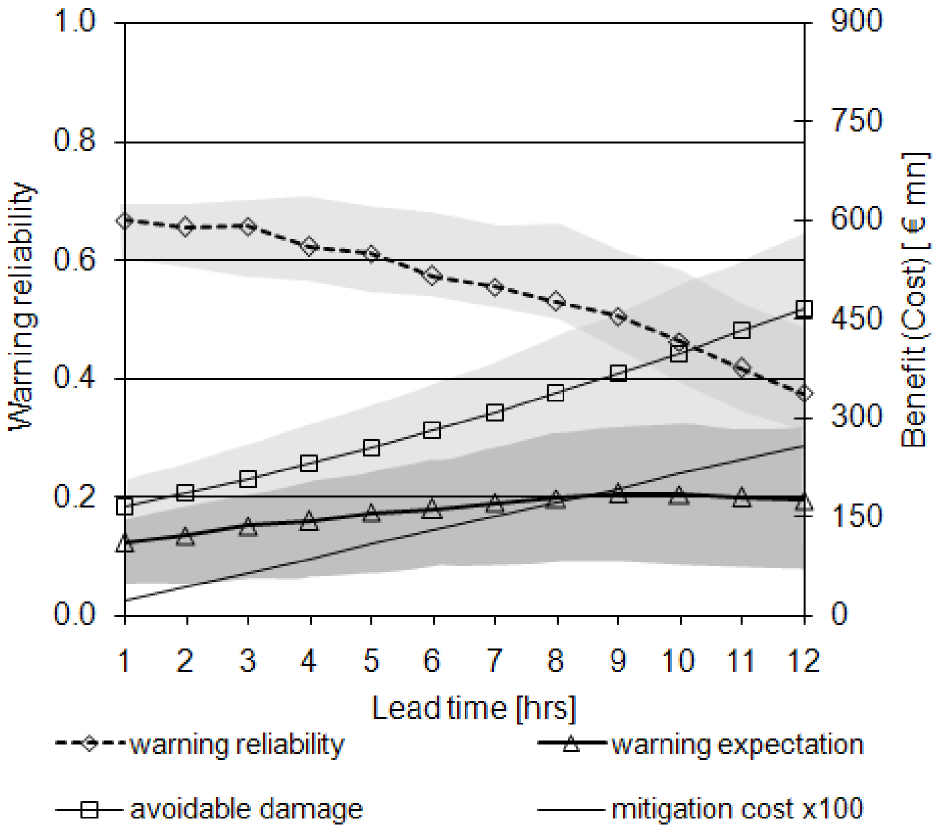


Figure 5-16: Warning expectation for the industrial sectors in the Traisen basin for the 100 years event.

Principally the same issues are depicted in Figure 5-16 for the Traisen basin for the one in hundred years event. But as the information available on the reliability of the forecast is more comprehensive, the figure is more complex. The reliability curve for all events (C1, C4 and V5) starts at 67% at a lead time of 1 hour and decreases more or less continually until 9 hours is reached. There, the intensity of the decrease grows. For the Traisen basin an estimate of the uncertainty associated with reliability is available, it is drawn as a grey shade behind the warning reliability curve. The avoidable damage of the one in hundred years event starts at € 401 mn for 12 hours and decreases continually to € 143 mn for one hour (structural flood protection neglected). The uncertainty of the avoidable damage is indicated as grey shadow again. Warning expectation is drawn in the foreground with a darker shadow indicating its uncertainty, combined from the uncertainties of reliability and avoidable damage.

As the persistence of high values of forecast reliability in the Traisen basin is much longer than in the Besòs basin, the maximum of the warning expectation allows for an earlier warning. The optimal point in time for releasing the alert is reached at 9 hours.

The estimated 6,364 active persons in the flood prone areas of the Traisen basin generate a total GVA of € 214,116 per hour. If they lay down their work 9 hours before a flood event occurs and invest their time in preventive measures, they incur a GVA loss of € 1.9 mn and avoid a damage of € 316 mn in principle (structural flood protection neglected). The warning reliability at 9 hours is 50%. Under the assumption that 80% of the calculated flood damage is avoided through structural measures, there remains an avoidable damage of € 63 mn[1]. The mitigation cost is then 3% of avoidable damage.

In the private sector damage reductions through early warning are also achievable, but on a lower level than in the industry sectors. This may mainly be owed to the fact that people are often not at home during floods and therefore not able to put preventive measures into place (Parker et al. 2007).

Figure 5-17 displays the warning expectation for the private sector in the Besòs basin for the one in hundred years event. The result is quite similar to warning expectation for the industry sector. Due to the strong curvature of the reliability curve the Optimum of the warning expectation is again reached for a lead time of 2 hours. For this lead time a benefit from mitigated inventory damage of € 14.7 mn can be achieved.

A different result delivers warning expectation for the private sector in the Traisen basin as shown in Figure 5-18. Because the curvature of the reliability function is less strong than in the Besòs basin, its small irregularities combined with the weak gradient of the avoidable damage shift the optimum of warning expectation to a three hours lead time. If the warning reliability function were smooth, the optimum would only shift to 5 hours. The warning expectation forms a very smooth bow with a feeble maximum at three hours. In other words, because the impact of the lead time on avoidable damage is low (cf. Figure 5-14), the warning expectation is indifferent for lead times between three and nine hours. This indicates that the preparedness of the warned people is of paramount importance for the efficiency of an early warning system.

[1] The assumption of an 80% damage reduction for the 100 years event is not fully consistent with the assumption of a 80% reduction of total risk, but it is made here for the convenience of the reader.

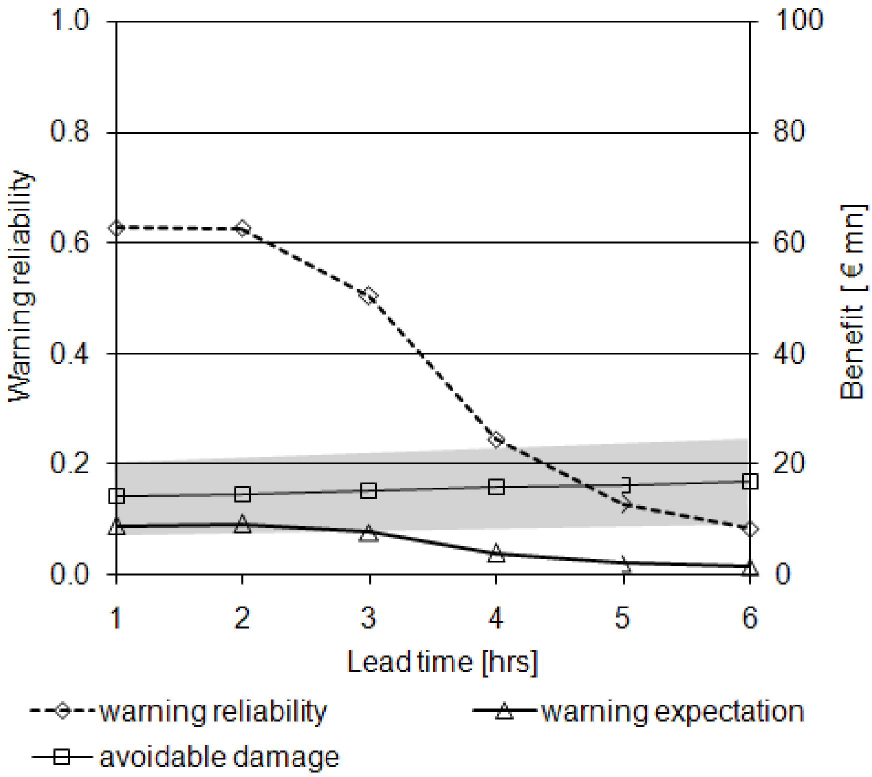


Figure 5-17: Warning expectation for the private sector in the Besòs basin for the 100 years event.

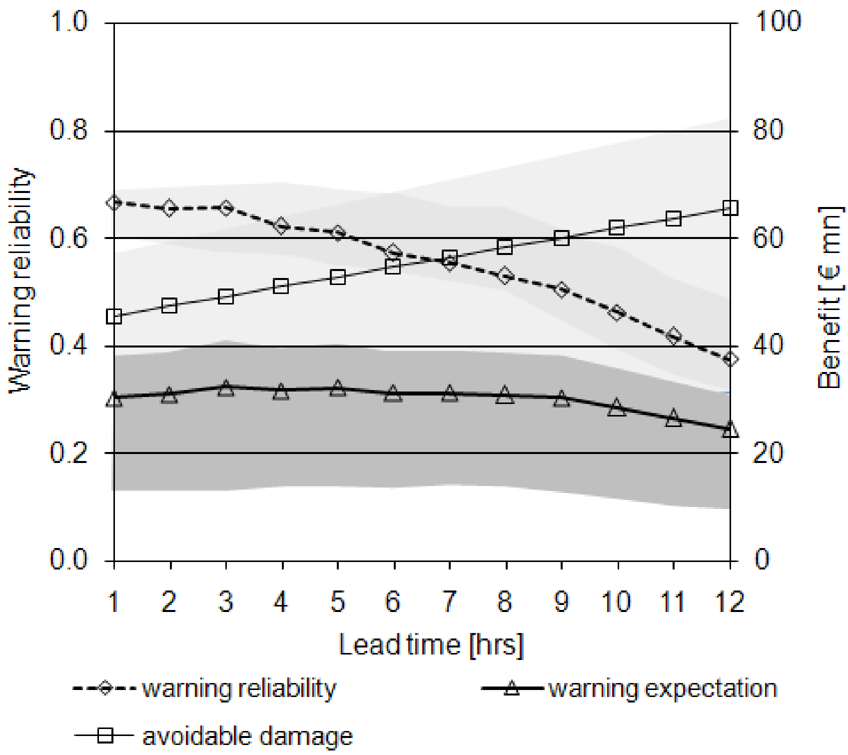


Figure 5-18: Warning expectation for the private sector in the Traisen basin for the 100 years event

5.3.2 *Event-independent evaluation*

An event-independent evaluation is consistent with a traditional benefit cost analysis. Total benefit from the systems is compared with total cost for the systems. The total benefit of an early warning system (and any other flood protection system) consists of mitigated flood risk. The risk comprises the total probability density of flood damages, and therefore is independent from a single flood event. Most costs for the system are not correlated with the flood events, but occur in times without floods. The construction and maintenance of the early warning system will not take place during a flood event but well before or after. The operation cost of the early warning system arises during flood events as well as during normal conditions.

5.3.2.1 Benefit of Early Warning

With the results of the event-dependent evaluation we calculate the benefit of the early warning system as shown in Table 5-7. The upper part presents the damages calculated for the events considered. The middle part shows the avoidable damages. We assume that the EWS perform in the same manner, and that the companies (and the population) show the same level of response for all events.

Table 5-7: Benefit of the Early warning systems in the Traisen and Besòs basin

	Ret. Prd.	Traisen		Besos	
Damage distribution [%]		industry 76%	private 24%	industry 62%	private 38%
Potential	30	428.0	135.2		
Damage	50			72.3	44.3
[€ mn]	100	666.7	210.5	124.1	76.1
	200	772.8	244.0		
	500			280.2	171.7
Avoidable	30	203.0	27.2		
Damage	50			17.5	8.5
[€ mn]	100	316.3	42.3	30.0	14.7
	200	366.6	49.1		
	500			67.8	33.1
Avoidable Damage [%]		47%	20%	24%	19%
Potential Risk	[€ mn/a]	19.61	6.19	2.59	1.58
Avoided Risk	[€ mn/a]	9.28	1.24	0.62	0.31
Residual Risk	[€ mn/a]	10.33	4.95	1.96	1.28
Benefit, 20a, 3%		138.07	18.42	9.24	4.55
Total benefit	[€mn/a]	156.49		13.79	
-struct. protection		31.30		13.79	

Therefore the avoided damage per event is a constant percentage, In the Traisen basin it is 47% in the industrial sectors and 20% in the private sector. In the Besòs basin it is 24% for the industrial sectors and 19% for the private sector. Because damage and risk are direct proportional, we can conclude that a damage reduction of 47% (24%) translates into a risk reduction of 47% (24%). Therefore the risk avoided for the Traisen basin is estimated at 9.28+1.24 = € 10.52 mn per year (structural flood protection neglected). The risk avoided in the Besòs basin is estimated at 0.62+0.31= € 0.93 mn per year. There remains a considerable residual risk in both basins (€ 15.28 and 3.24 mn) which could further be mitigated by enhanced preventive measures through the affected companies and population. From the avoidable risk of € 10.52 mn (€ 0.93 mn) a present value of € 156.5 mn (€ 13.8 mn) is calculated for a useful life of 20 years at a discount rate of 3%.

In a detailed risk analysis for a small basin, Gocht (2003) analysed the distribution of risk over total probability density and determined that up to 80% of the risk from frequent events up to a return period of 100 years is prevented by structural measures. In the absence of a more detailed analysis for the Traisen basin it was therefore assumed, that only 20% of the calculated damage would occur because of structural measures in place in the Traisen basin. Therefore only € 31.30 mn, the 20% share of the calculated benefit, enter the benefit cost analysis for the Traisen basin.

5.3.2.2 Cost of Early Warning

For estimating the cost of an early warning system, interviews where carried out in the Traisen and the Besòs basin. Furthermore cost statements from EU-wide biddings for planned EWS were used. Therefore the cost information should be taken as an average estimate for an EWS in the European Union.

5.3.2.2.1 Cost of a Radar

The cost for an X-band radar suitable for quantitative precipitation forecast (QPF) is estimated at € 500.000 (Krämer, Leibniz-Universität Hannover, personal communication). In the case of the Catalonian radars, the 2002 contract of acquisition and installation of 2 radars included, apart from the radars themselves, spare parts, installation cost, testing, secondary systems and maintenance and monitoring services. The cost of each radar was € 1.75 Million. Typically, the "useful life" of a radar is 10 to 20 years. But in this period reinvestments have to be made for spare parts.

Operation of the three Catalonian radars involves two high grade engineers. They also support related projects, e.g. the installation of new radar. The personnel responsible for maintenance and repair consist of:

- 1 high grade engineer (full time)
- 1 medium grade engineer (full time)
- 1 technician (full time)
- Some technicians in part time for supporting, very local activities in the radars

(Bech, Servei Meteorologic de Catalunya (SMC), personal communication).

Radar serves several purposes. In Catalonia the main users are:

- Forecasting and vigilance team in the SMC,
- Civil Protection in the Catalonian Government,
- Catalonian Water Agency (ACA)
- Press, and Regional TV 3 (Televisió de Catalunya)

In Austria the radar at the Vienna airport in Schwechat is used for aviation and QPF as well.
Estimating the gross annual salary of an engineer at € 60.000 and of a technician at € 40.000, a present value of operation, maintenance, and repair costs for the Catalonian Meteorological Service of € 2.97 million for a useful life of 20 years at a discount rate of 3% can be calculated. The total cost of a radar, covering an area of 125.000 km² (radius r = 90 km) totals at a present value of € 2.75 million (€ 1.75 million investments + 2.97/3 Million maintenance and repair).

The construction cost for a one km stretch of dike at the German Elbe river is estimated at € 1.5 million on average (minimum € 1.2 million and maximum € 2 million, Simon, ICPE, personal communication). Maintenance for a river dike is approximately € 7,000 per km and year (Gocht 2004). The useful life of a dike is estimated at 100 years. A cost comparison for a useful life of 100 years at a discount rate of 3% leads to an annuity for the radar of € 186,000 per year and of € 54,400 for the dike. In other words, the total investment in a Radar equals the total investment in a 4 km stretch of river dike.

5.3.2.2.2 Cost of an Early Warning System

5.3.2.2.2.1 Data

As radars are multi-purpose instruments, it is advantageous to exclude their investment and operation cost from the cost assessment and use a rate for the service provided instead. For the Traisen basin, the government of Lower Austria acquires precipitation and temperature forecasts from Austrian Central Institute for Meteorology and Geodynamics (ZAMG). The regular rate is 22,700 €/a for an area of 5,500 km². Public authorities like the regional authority of Lower Austria usually receive discounts. These are treated as a subsidy and excluded from the cost assessment. The forecast area is approximately six times larger than the Traisen basin, because data for a rectangular area completely containing the basin have to be bought.

5.3.2.2.2.2 Personnel

At the government of Lower Austria in St. Pölten, two high grade engineers regularly operate the early warning system, supported by up to 15 engineers during emergencies for 24/7 operation. Emergency operation is necessary at estimated 42 days per year. At the Catalan Water Agency ACA in Barcelona, two engineers are present 24/7 for water management system operation. They are supported by project people on 22 hours per day. As a matter of fact, both agencies serve for their respective region, Lower Austria and Catalonia, rather than the Traisen and the Besòs basin. Secondly they have more obligations than emergency management. The ACA in particular collects significant benefits from synergies between emergency management and water quality monitoring. Therefore an estimated third of personnel costs, calculated with the salaries mentioned above is attributed to early warning in the Traisen and the Besòs basin respectively. The Traisen basin (921 km²) accounts for 5% of Lower Austria (19,178 km²) and the Besòs basin (1,024 km²) for 3,2% of Catalonia (32,091 km²). It is inappropriate to use these spatial relations for attribution of personnel costs, because only few areas need flash flood forecasts and only few services are as costly as early warning. These relations would lead to much lower personnel costs. An attribution of 33% of the total personnel cost is clearly no underestimation of the necessary effort.

5.3.2.2.2.3 Structures

River gauges are the structures adding the largest share of costs to an early warning system. In the Traisen basin the investment in a river gauge is estimated at € 30,000, remote data transmission adds another € 7,500 (± € 2,500) Investment per gauge, reinvestments are estimated at low 20% every five years. In the Traisen basin, ten technicians are involved in maintaining the gauges 52 days per year. The Traisen basin has 7 Gauges. In the Besòs basin, station data are often acquired from service providers at a rate of € 800 per gauge and year. 7 gauges feed data into the Besòs early warning system. As the Besòs information leads to very low data costs, only the Traisen data was used for the cost assessment.

5.3.2.2.2.4 Software system

Development of the software system adds a significant portion of the total cost of the early warning systems. From two Austrian systems cost data was available. For the benefit of the reader the cost information is expressed as percentage of total software system cost and as amounts normalised to a 1,000 km² river basin. The data is presented in Table 5-8. The models account for roughly 57% of the total cost, leaving a share of 43% for peripheral devices, implementation and project management. Reinvestments are not included in the table. They are estimated at 20% of investments every five years and included in total system cost.

Table 5-8: Cost for the software system of an EWS, as percentage of the total software system cost and as cost for a 1,000 km² river basin

item	share	cost
Data base	3%	6,146 €
Meteorological Forecast Model Hydrological Forecast Model	34%	67,602 €
Hydraulic Model on existing data Economic Model	23%	46,430 €
interfaces	2%	3,780 €
control and visualisation	4%	8,758 €
Hardware Upgrade	12%	23,968 €
Start of operation	15%	29,960 €
Project Management and Controlling	6%	12,967 €
Total cost	100%	199,609 €

The available cost information for the software system indicates significant economies of scale. Assuming a standard parabolic cost function leads to the results given in Figure 5-19.

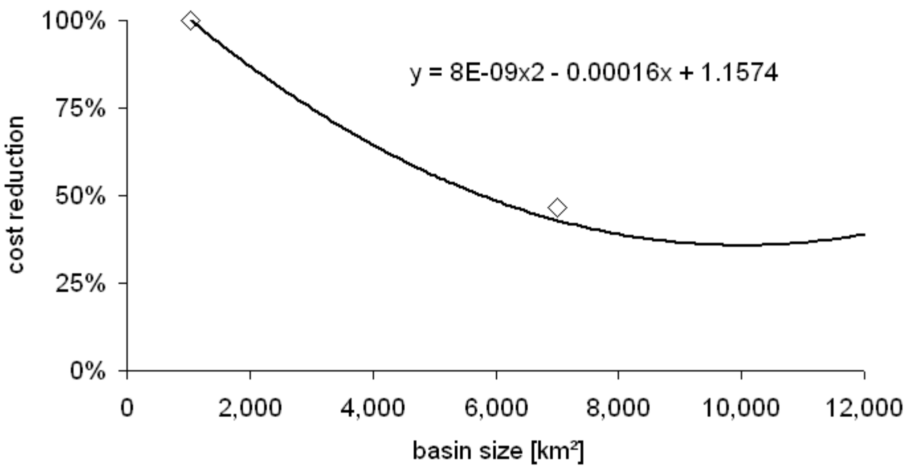


Figure 5-19: Cost reduction for the software system in larger river basins

5.3.2.2.2.5 Total system cost

Table 5-9 summarises the cost information. Present values are given in the table for a useful life of 20 years at a discount rate of 3%. Reinvestments are estimated at 20% of investments, every 5 years. Costs are presented in €/km². For a first estimate of total system cost for a certain river basin, the values from Table 5-9 may be multiplied by the basins size, the software system cost should then be reduced by the value derived from Figure 5-19. For a 1,000 km² river basin the present value of total cost would approximately amount at € 2.9 Million. 79% of the total cost is data and personnel cost, leaving 15% for investment and 7% for reinvestments. Table 5-9 summarises the cost information. Only present values are given in the table for a time series of 20 years at a discount rate of 3%. For enhancing transferability of the cost information, all costs are divided by basin size. Therefore the unit of the data shown is €/km². For a 1,000 km² river basin the present value of total cost would approximately amount at € 2.9 million. 79% of the total costs are data and personnel costs, leaving 15% to investments and 7% to reinvestments.

Table 5-9: Cost of an early warning system, present value per km² in €

		operation	investment	reinvestment
Input data		338		
Personnel for EWS Operation		1,570		
Structures	Gauges	382	180	101
	Data transmission		45	
Software system cost			200	90
Subtotals		2,290	425	191
Total PV (20a,3%)		2,905		

The total system cost for a EWS in a 1,000 km² river basin amounts at a present value of € 81.64 million for an operation time of 20 years at a discount rate of 3%. The annuity is € 2.58 million, corresponding to the annuity for a 54 km stretch of river dike.

5.3.3 Benefit Cost Ratio and Net Present Value

Table 5-10 presents the results of the event independent evaluation. For the Traisen (top) and the Besòs basin (bottom) benefits, costs, benefit cost ratios and net present values are given. Sensitivity of the result is tested by varying benefits and costs. Benefits are varied for ±40% and costs for ±20%. The lower benefit is compared to the higher cost and vice versa.

The result for the Traisen basin is tremendous and should therefore be treated very carefully. Average benefits and costs translate into a benefit cost ratio of 11.7 and a net present value of € 28.6 mn, even at a benefit reduced by 80% for taking into account structural flood protection measures. That would mean that early warning yields return on investments sufficient for commercial exploitation. Even an extreme increase of costs by 20% and decrease of benefit by 40% does not force the benefit cost ratio into shiftiness. It still maintains a value of 5.85 which means a net benefit of € 15.57 mn. It has to be questioned if a natural hazards protection measure can ever reach such degrees of profitability.

Table 5-10: Comparison and Sensitivity analysis of the EWS for a useful life of 20 years at a discount rate of 3%)

Basin/size	Benefit [€ mn]		Cost [€ mn]		BCR [-]	NPV [€ mn]	
Traisen	-40%	18.78	+20%	3.21	5.85	min	15.57
	Avg	31.30	Avg	2.68	11.70	mean	28.62
921 km²	+40%	43.82	-20%	2.14	20.47	max	41.68
Besos	-40%	8.27	+20%	3.21	2.58	min	5.06
	Avg	13.79	Avg	2.98	4.63	mean	10.81
1024 km²	+40%	19.30	-20%	2.14	9.02	max	17.16

Equally for the Besòs basin, the benefit cost analysis presents impressive results: The average benefit of € 13.8 mn and cost of € 3 mn yield a benefit cost ratio of 4.6 and a net present value of close to € 11 mn. Increasing the cost and lowering the benefit as above lowers the benefit cost ratio to a still very comfortable 2.6 and creates a net benefit of € 5.06 mn. It may be repeated that these degrees of efficiency are unexpectedly high. Therefore further investigations should be made. Different causes can lead to distortions of system efficiency:

- There is a high probability that the damage functions do not appropriately reflect the conditions in the study basins. Being designed for the underflow of large rivers we used them for flash flood regions. It was initially planned to include functions from the German RIMAX-project MEDIS, but these were not available during the EWASE project term.

- Not all costs are considered, but only those to be covered by public spending. Companies and population will have to make investments to improve their damage mitigation abilities.

In the light of these potential sources of errors, the lower values for the benefit cost ratio and the net present values should be used as an orientation

5.3.3.1.1.1 Comparison of the efficiency of structural and non structural flood protection measures

It needs considering that EWASE aimed at a consistent strategy for EWS assessment rather than for statistically sound results. The comparison presented here is therefore indicative, and needs further research to gain significance

Table 5-11: Comparison of the efficiency of structural and non structural flood protection measures

Measure	Benefit-Cost Ratio			Source
	min	mean	max	
Polder use	2.20	4.00	5.80	Förster et al. 2005
Polder invest		0.10		Gocht 2004
FRBs		0.50		Merz & Gocht 2001
Local measures		5.20		
EWS	**2.60**	**4.60**	**9.00**	**EWASE**
Insurance		0.80		Gocht 2003
Derivatives		0.90		

Table 5-11 compares the EWASE result for the Besòs basin to research work of the authors from the last years. A study on Polder use and construction at Elbe and Odra revealed the use of the Havel polders to be very beneficial in an event dependant assessment (Förster et al. 2005). The erection of a Polder under less favourable conditions at Odra river turned out to deliver no economic benefit (Gocht 2004). Whereas local protection measures showed significant benefit in a micro scale BCA, flood retention basins (FRBs) failed to meet the economic criterion of a BCR of at least one (Merz & Gocht 2001). A theoretical work on flood insurance and flood protection via precipitation derivatives resulted in BCRs near but below one. Because the expectation is the fair insurance premium and insurances aim at creating positive returns in the long run, the total cost (risk plus premium) needs to be higher than the total benefit. Precipitation derivatives potentially offer the same benefit as insurance at lower transaction costs and are economically more viable.

In the light of current knowledge no flood protection strategy appears to offer higher efficiency than the combination of local protection measures and early warning.

5.3.4 Qualitative Multi-Criteria Assessment

We did not expect to be able to monetarise all aspects of early warning in the basin, therefore we discuss such intangible damages in a qualitative multi-criteria assessment. Generally there is a close relationship between the outcome of the economic analysis and the extent of qualitative assessment of intangible issues. If the economic viability of a project is questionable, large effort is invested in finding intangible reasons which suggest realisation of the project. In the case of an economically feasible project the discussion of intangibles is usually short. This is the case for the EWASE project.

5.3.4.1 Assessment Criteria

For the determination of assessment criteria a questionnaire based survey was carried out at the ERA NET CRUE Lyon Workshop in October 2007. From 50 questionnaires handed out we received 25 or 50%

back. Respondents were asked to indicate their estimate of relative importance for certain criteria with respect to flood protection on a scale from 1 (unimportant) to 5 (very important). The results are presented in Figure 5-19.

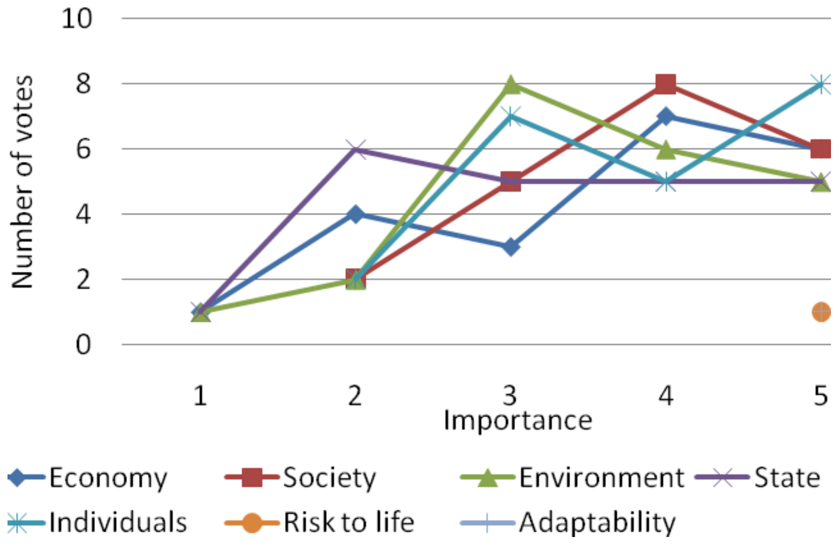


Figure 5-20: Distribution of the results for the criteria evaluated at the ERANET-CRUE Workshop in Lyon, October 2007

Generally all participants tended to select high values to the proposed criteria, a strong indicator for the importance of all the criteria with respect to flood protection. The maximum number of ticks for voting a criterion in the first place ranged from 6 to 8. The role of the state in flood protection was estimated to be of low importance (2) by a weak majority of 6 participants. There were 5 participants choosing 3, 4 and 5 respectively for the role of the state. Impacts on environment were estimated as an issue of average importance by 8 participants. Again 8 voted for an important role of the society as a whole in flood protection, including intangible issues as protection of the weak and cultural heritage. Seven participants estimated economic issues to be important in flood protection, and 8 decided the individuals as protectors of themselves to be very important in flood protection. There was one suggestion to include risk to life and adaptability as important items to the list of criteria.

The results of our survey highlight that there is another perspective in expert circles as e.g. CRUE participants than in population at large (DKKV, 2003). In the general perception of the population, protection against natural hazards is seen as an important task of the state with low responsibility of f the individuals for self protection. As this protection is a matter of general interest (Daseinsvorsorge), economic issues are usually considered to be of minor importance.

5.3.4.2 The role of the state

Early warning exhibits a significant potential for transferring responsibility from the state to the individual. In the framework of EWASE it offers strong incentives for individuals to care about their maximum benefit from early warning, whereby the responsibility for warning generation and distribution remains with the state. If the EWASE approach is fully developed on company level, the responsibility for releasing the alert is shifted from the administrative level to the realm of companies. A role of average importance for the state is well in line with early warning as treated in EWASE. There remains reason for public authorities to maintain the role of generating and distributing the warning. But the approach is open towards the inclusion of independent or private bodies as service providers as e.g. the Schwechat airport radar in the Traisen basin or the input data providers in the Besòs basin. The high potential profitability of early warning even opens the ground for private generation and distribution of early warning. In terms of EWASE Early warning therefore supports the shift from a security-paradigm to a risk-awareness paradigm.

5.3.4.3 Environmental Impact

The public as well as the experts accept considerable environmental degradations that follow the implementation of structural flood protection. Until recently, environmentalists found it difficult to address degeneration of environment as a source of concern in flood protection. The design and implementation of the Water Framework Directive changed this. It does not need deliberate arguing to convince experts as well as the public that non-structural protection measures like early warning have a very low detrimental effect on natural environment. In fact it may be hard to find any. Therefore the implementation of early warning is a good opportunity to reconcile the Water Framework Directive and the Floods Directive.

5.3.4.4 Society as a whole

How is the effect of early warning on the society as a whole? It was repeatedly mentioned that the benefit of early warning does urgently depend on preparedness of the population. Without deliberate measures for rising awareness among the population – be it private or commercial – benefits of early warning cannot tap there full potential.

The protection of the aged and infirm is well in line with early warning. In fact timely warning may be the only possibility to move the elderly in Wilhelmsburg, the children in Traisen and the pupils in Lilienfeld from their resorts, kindergartens and schools. Particularly in the Traisen basin a considerable number of public facilities for the weak was found in the unprotected flood plains, because the valleys does not provide enough space for structural protection measures. The distribution of the warning can be organised in a way that it is accessible to the society as a whole. The warning expectation as introduced in EWASE is an easily comprehensible tool for communicating the meaning of a warning and its associated uncertainty to those who are not experts. Risk to life and adaptability are issues to be discusses under the headline of society as a whole.

5.3.4.5 Economy

Chapter 5.3 comprehensively treats economic and efficiency aspects of early warning. The largest share of costs comes from personnel, but large synergies can be collected here from jointly operating water quality and flood protection tasks. It may be sufficient here to recall, that early warning systems for river basins of about 1,000 km² size as discussed in EWASE bear a total cost of about € 3 million in their useful life of 20 years and may well generate a net benefit of € 15 million or a benefit-cost ratio of 5. In the light of current knowledge, no flood risk management strategy appears to offer higher degrees of efficiency than the combination of early warning and temporary flood protection measures.

5.3.4.6 The role of the individual

Early warning as discussed in EWASE transfers important tasks to the individuals. The high economic efficiency of the early warning system partly stems from the fact that the cost of local temporary flood protection measures remains unaccounted for. It is the task of the individuals to erect the necessary walls around their premises and to acquire and maintain the stop logs which need to be put in place in emergencies. Of course are there synergies from such walls in terms of potential amenity and general security enhancements. Nevertheless it remains to be decided by local authorities to which part investors may be offset for their investments in local temporary flood protection measures.

The extent to which individuals are enabled to care for their safety and to optimise their benefit from the warning depends to a large part on the distributive depth of the warning. Particularly in the economic sectors high potential benefits can be realised, because of the ongoing presence of people at least during the day. The same fact limits the potential benefit in the private sector: If nobody is present to receive a warning, protective measures cannot be put in place. It should be recalled here that 60 to 70% of the risk arise in the economic sectors and are non-private therefore. This reveals the high potential of early warning, if high distributive depth is achieved. Today the distribution of a warning in the commercial sectors is possible at very low cost because of the widespread use of the Internet. The limited access of parts of the society because of the digital divide is no issue here as long emphasis is put on the industry sectors, where computers and online access are ubiquitous. It is therefore highly interesting to think about the implementation of an EWS on the company level that informs the company about the flood hazard in its sub-basin and informs the decision makers on company level about their potential benefit from taking preventive measures and supports their decision trough the company-specific warning expectation.

6 Implications for Stakeholders

"This chapter summarises the basic principles of the methodology developed for the assessment of early warning systems effectiveness and efficiency and subsumes the key findings of the project work."

The overall objective of EWASE, the evaluation of the effectiveness and efficiency of early warning systems for medium sized river basins prone to flash floods was well met in the project term. The uncertainty of flood forecasts was translated into a reliability curve as an indicator for the effectiveness of the Early Warning System. The socioeconomic analysis of the river basins allowed for the determination of avoidable damage as a function of lead time. The combination of reliability and economic information into the warning expectation (reliability · avoidable damage) delivers a pragmatic Decision Support which enables decision makers to trigger an economically optimal alert.

The efficiency of the system was assessed on a time horizon of 20 years. Benefit Cost ratios around 5 for an early warning system with a total system cost (investment, maintenance …) of around € 3 million are a conservative estimate of the project results. Stakeholder awareness has a high impact on the efficiency of the system. High levels of preparedness to put temporary measures into work can lead to higher system efficiencies. The cost of the erection of temporary flood protection measures is included on the basis of lost gross value added per employee. It is in the range of only 2% to 5% of the avoidable damage but amounts up to € 2 million, a considerable cost in the case of a false alert.

It needs consideration that EWASE aimed at a consistent strategy for EWS assessment rather than for statistically sound results. In view of the short project duration the comparison of structural and non-structural measures presented in EWASE can only be indicative and needs further research for gaining statistical significance. Still, in the light of current knowledge, given the assumptions and region of investigation of this study, no flood risk management strategy appears to offer higher levels of efficiency than the combination of local flood protection measures and early warning.

An important outcome of the project is the deliberate and proved concept for the assessment of EWS.

Forecast reliability is an important issue for the responsible authorities in concrete decision situations about an alert. EWASE proposes a pragmatic method to evaluate the reliability of flood forecasts as a function of lead time. The approach is based on a straightforward interpretation of prediction errors which are obtained from the analysis of past flood events. The method allows for the quantification and explicit consideration of different sources of uncertainty effective in the forecasting chain. In this way the implications of these uncertainty sources can be examined and compared, which in turn allows for the identification of promising directions for improving the early warning system.

The exemplary application within the framework of two operational EWS indicates that the capability to anticipate upcoming rainfall is the decisive source of information to generate flood forecasts with lead times beyond the response time of the basin. The performance of the hydrological simulation governs the achievable level of forecast reliability. In view of complex interactions between quantitative precipitation forecasts and hydrological modelling, the application of alternative simulation models provides complementary information to the flood forecast.

The newly developed concept for exposure analysis based on EU statistical concepts assures comparability of the results on the trans-national level. It enables interesting insights in the economic structure of regions, their similarities and differences. Further application of the approach will lead to refinements particularly in the capital stock analysis.

It is a well known fact that damage functions lack statistically sound foundation and it was no aim of EWASE to dedicate work on this. Instead, the use of several well established sets of damage functions assures the comparability of the results to other studies on the efficiency of flood protection measures and informs about uncertainty of damage and risk which amount to ±45%.

The ability of the warned people to reduce flood damage was assessed by means of a survey which delivered indicative results for the industry sectors. Even under the current state of awareness and in the absence of programmes for enhancement of preparedness the ability to reduce damage is considerable and reaches 60% for lead-times of 12 hours. For the private sector a model proposed by Parker et al (2007) proved its applicability. Potential damage mitigation is lower in this sector, but damage mitigation of around 20% is achievable without special training programmes.

The industrial focus of the EWASE risk assessment turned out to be well justified: on the one hand a reliable concepts for evaluation of flood damages to industry was proposed to the scientific community, on the other hand it was shown that such concepts are important in the light of the distribution of risk with about 70% in the industry sectors and about 30% in the private sector in the study basins.

7 Recommendations for future Work

"Based on the findings of the project work this chapter identifies promising lines of further research work."

7.1 Policy maker issues: Capitalising on EWASE

The implementation of the EU floods directive foresees flood risk management plans which entail risk maps. These maps should be developed in a participative approach in accordance to Articles 6 and 7 of the directive.

As the EWASE risk analysis was accomplished on basin scale, all data necessary for the establishment of flood risk maps in the Traisen and the Besòs basin are available. As a first step in a participatory process such maps could be used for the information of the public about the flood risk. Hot spots could be determined for which more detailed risk mapping could be taken into consideration. Preconditions for such a participatory process are good, because the products for the communication of risk as well as expertise in creating these products are available from the EWASE partners at reasonable cost.

7.2 Scientific Issues: Dynamic Modelling on the local scale in view of uncertainty

EWASE products currently are presented on basin level. An additional spatial component to the alarm on sub-basin level would prevent the affected population from taking unnecessary preventive measures, as flash floods are most often localised phenomena and thus affect only parts of the basins. It is interesting to adapt the analysis to local places, making use of all the capabilities provided by distributed modelling in minor rivers. In this context, it is important to investigate to which extent the efficiency of EWS could be improved by more detailed flood and inundation forecasts also including computationally fast hydraulic models.

The EU floods directive requires a three-step method for the assessment and the management of flood risks. A more detailed data base is recommended for the preparation of flood hazard maps and flood risk maps. On the one hand, vulnerability analysis of the economic activities should be improved. Building on the results of EWASE a more detailed enterprise data collection should be carried out. The contacts to the local industry and authorities established within EWASE offer an ideal starting point. On the other hand this requires a higher precision of the hydraulic information. The straightforward representation of hydraulics within the hydrological models currently applied in the Traisen and the Besòs can be supplemented by more detailed models with a focus on the damage hot spots. The high quality digital terrain models permit the construction and operation of fast two-dimensional hydraulic models. The coupling of these models with the available forecast systems will result in real time inundation modelling. This information is important for the management of flood risks.

Further, improving QPF methods and constraining the related uncertainty is a key challenge for progress in flood forecasting. In the context of flash-flood forecasting this applies first and foremost to short term QPF and radar nowcasting methods. The quantification of flood forecast uncertainty has to be addressed in consideration of the interactions between the different sources of uncertainty inherent to the flood forecasting chain. This uncertainty needs to be coherently estimated from a comparison with measured discharge data, and has to be extrapolated in space to ungauged sites, e.g. internal locations of the river basin. Furthermore, the uncertainty also needs to be coherently estimated at the temporal scale, since both hydrological simulation models and rainfall forecasts uncertainty are related to the return period, particularly for low frequency events.

As warning expectation, defined as the product of the warning reliability and the avoidable damage, is dependent on rainfall forecasts lead time and accuracy, it is interesting to detail this analysis with regard to the characteristics of this dependency. An adequate integration of radar nowcasting (short lead times) and numerical weather prediction models (larger lead times) will offer the basis for this analysis and will provide valuable information about the dependency of the spatial scale also at local ungauged sites.

7.3 Practitioner Issues: Creating Value from Uncertainty Estimates

The Warning Expectation as a new approach to create additional information out of uncertainty estimates in form of the optimal alert should be introduced and discussed to decision makers and practitioners on the local level. A new form of public private partnership in early warning could develop on this basis, leaving the responsibility of warning production and distribution with the public authorities but transferring the responsibility for triggering the alert to decision makers on company level.

7.4 Data Related Issues: EU Statistics as Warranty of Reliability

The concept of using regional data sources from Eurostat and national statistics for creating a proxy for value on company level appears promising. On the one hand this approach frees value estimates from arbitrary assessments of individuals. On the other hand the results may be published as average estimate, which allows for realistic aggregates on the basin level. An extended offer of regional data from Eurostat would further facilitate the procedure.

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Project Summary

Joint project title	**Effectiveness and Efficiency of Early Warning Systems for Flash-Floods (EWASE)**
CRUE Project No.:	I-5
Project partner #1 (Co-ordinator):	Kai Schröter, Manfred Ostrowski
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Project website:	http://www.ewase.net
Objectives	The main objective of EWASE is to develop a practical methodology for the evaluation of early warning systems effectiveness and efficiency. This involves two central questions that have to be addressed. With regard to effectiveness this relates to the question whether an imminent flood is forecasted reliably and allows for a warning with sufficient lead time to avoid damages. The question concerning the efficiency is whether the benefit and the cost of this warning are at a reasonable ratio in the long term. Therefore, in detail • a practicable approach to assess flood forecast reliability as a function of forecast lead time in view of different sources of uncertainty is developed, • a relationship between lead time and avoided damage expressed through a damage reduction function is established, • a benefit cost ratio comparing the Present Values of the EWS and the Present Value of Risk as Expected Annual Damage mitigated in the basins by EWS is determined.
Background	Flood alerts provided by early warning systems are an important element of comprehensive flood risk management strategies. The purpose of EWS is to provide information on expected flows and water levels prior to the actual occurrence of a flood peak and to generate alerts in order to take preventive measures for avoiding damages. The potential benefit from the anticipation of imminent floods is unquestioned. Nonetheless, reliable forecasts are a basic requirement for warning system operators and responsible authorities to take robust decisions. Especially in river basins prone to flash-floods, critical situations develop quickly and make high demands on the warning lead time. However, uncertainties with regard to the formation and evolution of forthcoming storms as well as uncertainties inherent to the mathematical modelling of rainfall-runoff processes reduce the reliability of flood forecasts with increasing lead time. The evaluation of the effectiveness of an EWS is basically related to the question whether a reliable alert can be set off with sufficient lead time to complete preventive measures. For the EWS to be efficient, the decision about a flood alert has to trade off the prolongation of the warning lead time and the decrease of forecast reliability. In this context, it is important to bear in mind that a successful warning will bring about (socio-) economic benefit whereas a false alert leads to (socio-) economic loss.
Research	EWASE evaluates the efficiency and the effectiveness of early warning systems in small river basins that have short hydrological response times. EWASE adopts a pragmatic method to evaluate the reliability of flood forecasts as a function of lead time. The approach is based on a

	straightforward interpretation of prediction errors which are obtained from the analysis of past flood events. EWASE provides information for optimal alerts through the analysis of the trade-off between the benefit of an increased lead time and the simultaneous decrease of warning reliability. Two study basins in Austria and Spain are presented to illustrate the application of the methodology proposed and to identify the key information required to integrate this approach into comprehensive flood risk management strategies. In this way EWASE synthesises data and experiences to help flood managers in finding better solutions for the operation of early warning systems.
Findings ◄	Warning reliability is introduced as an indicator for the uncertainty of early warning system outputs dependent on the forecast lead time. In combination with damage reductions as a function of lead time the warning expectation is derived as an indicator for an optimal alert. The comparison of the benefit cost ratio of early warning systems with other structural and non-structural flood protection strategies shows the potential of early warning. In the light of current knowledge given the assumptions and region of investigation of this study, no flood risk management strategy appears to offer higher efficiency than the combination of local protection measures and early warning.
Implications (Outcome) ◄	The uncertainty of flood forecasts is translated into a reliability curve as an indicator for the effectiveness of the Early Warning System. The socioeconomic analysis of the river basins allowed for the determination of avoidable damage as a function of lead time. The combination of reliability and economic information into the warning expectation (reliability x avoidable damage) delivers a pragmatic Decision Support which enables decision makers to trigger an economically optimal alert. The capability to anticipate upcoming rainfall is the decisive source of information to generate flood forecasts with lead times beyond the response time of the basin. In view of complex interactions between quantitative precipitation forecasts and hydrological modelling, the application of alternative simulation models provides complementary information to the flood forecast. Stakeholder awareness has a high impact on the efficiency of the system. High levels of preparedness to put temporary measures into work can lead to higher system efficiencies.
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