HOW TO ASSESS THE BENEFITS FROM EARLY FLOOD WARNING SYSTEMS?

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ABSTRACT: The objective of this paper is to assess the reliability and the efficiency of early flood warning systems (EWS) in small river basins exhibiting short hydrological response times. The reliability expresses the hydrological quality of the forecasts for different lead times. The efficiency evaluates the socio-economic benefits from a forecasting system characterised by the ratio of reduced damages dependent on lead time and the costs of the early warning system. The assessment is performed in two steps: first the reliability of early warning system is evaluated by analysing the performance of an EWS over several years and by considering true and false alarms. Second, the economic effectiveness 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.

EWS as a non-structural protection measure induce very low detrimental effects on the natural environment and can be quickly implemented. Here, experiences from an Austrian case study from a pre-alpine catchment are described demonstrating the application of the proposed methodology.

Key Words: Hydrological forecasting, reliability, risk assessment, flood risk management, efficiency measures

1. INTRODUCTION

River floods are considered as the most frequent and costly natural hazard, affecting the majority of the world's countries on a regular basis (Jongman et al., 2012; UNISDR, 2011). At the global scale (Kundzewicz, 2010) it is estimated that, on average, floods affect more than 115 million people worldwide each year, and the respective economic damages are about $19 billion. Between 1998 and 2009, Europe suffered over 213 major damaging floods (Kryzanowski et al., 2014), including the catastrophic floods along the Danube and Elbe rivers in summer 2002. These floods caused 1126 human fatalities, the displacement of about half a million people and at least 52 billion in insured economic losses (EEA, 2010). The total (CEA, 2007) estimated flood damages are about 100 billion € of economic losses only over the period 1986–2006 and thus floods are considered as one of the most important natural disasters in Europe. The economic damage from flood events have increased during the past few decades in most regions of the world (de Moel et al., 2009, Barredo, 2009; Bouwer et al., 2010; Kreft, 2011; UNISDR, 2011). These facts are surprising because many countries, especially in Europe, have annually invested over the last decades substantial amounts in physical flood protection measures, such as levees, dykes and flood detention reservoirs. These measures proved to be successful in reducing the number of fatalities but they did not result in significant reduction of damages.

Considering that in the coming decades more severe floods are likely to occur and greater economic damages are to be expected a revision of the traditional flood protection strategies was initiated. A shift in flood policy in Europe from the old concept of ''flood protection'' or ''flood defence'' to the new paradigm of ''flood risk management'' can be recognized (Meyer et al., 2009; Schanze, 2006; Nachtnebel and Faber, 2009). This concept of flood risk management is also reflected in the new European Union ''directive on the assessment and management of flood risk'' (Directive 2007/60/EC). The flood risk directive (FRD) prescribes risk assessment and its underlying principles such as mapping of areas exposed to inundation with different recurrence intervals, the estimation of the damage potential and the identification of areas of potential significant flood risk (APSFR). The directive also states that, if appropriate, non-structural measures should be considered to reduce the likelihood of flooding and the respective damages.

Early warning systems (EWS) are among these non-structural measures that gained in the last years increasing attention (Penning-Rowsell et al., 2004; Environment Agency, 2003; Tunstall et al., 2005; Parker et al., 2007; Schröter et al., 2008). EWS as a non-structural protection measure induce very low detrimental effects on the natural environment and can be quickly implemented. Based on warnings preventive measures can be taken to reduce health risk and flood damages.

The objective of this paper is to present a methodology to assess the economic benefits of EWS in small river basins exhibiting short hydrological response times. The paper is organised in four chapters. After an introduction (chapter 1) the methodology for the assessment of EWS is presented (chapter 2). Then a revised concept that is based on the reliability of hydrological forecasts and the benefits of forecasts dependent on the lead time is applied to an Austrian catchment (chapter 3). Benefits are classified as avoided damages due to a reliable forecast. Obviously, the longer the lead time the larger are the benefits but also the uncertainty of the forecasts is increasing. The combination of reliability and avoided damages leads to the warning expectation as an indicator for the optimal alert. Finally, after a short summary conclusions are drawn (chapter 4).

2. METHODOLOGICAL FRAMEWORK

Various measures exist to manage flood risk ranging from physical alternatives to control the flooding probability to actions which reduce the vulnerability of objects such as flood proofing of exposed objects. EWS will not change the flooding probability at all but it provides some information about a coming hazardous event usually described by its magnitude and the respective arrival time of the peak. Provided that this information is reliable precautionary measures can be taken to reduce economic losses and to evacuate endangered people timely. Penning-Rowsell et. al., 2004 conclude that the increasing number of EWS in EU-river basins and their improved reliability could be the explanation of a negative correlation between flood incidence and loss of life in Europe over the past three decades.

A good example demonstrating the reduction of flood losses by non-structural measures refers to two flood events in the Rhine basin which occurred in winter in 1993 and 1995. The reported flood damages in the German part of the basin added up to 615 Mio € in 1993 while the respective damages in 1995 were 255 Mio €. Both floods were of similar magnitude, corresponding to about a 100 years flood event, and both occurred in winter. Although the 1995 flood event exhibited even a larger flood peak in Cologne and downstream the total damages were only about 50 % of the previous event (Engel et al., 1999). The reason is that people were still aware of the previous flood and the warnings were issued readily.

Not too many papers on the economic assessment of EWS exist. Tunstall et al. (2005) and Parker et al. (2005) analysed the socio-economic benefits of flood forecasting systems. The Environment Agency (2003) estimated a benefit-cost ratio of 4,8 that could be reached by implementing an efficient EWS for England and Wales over a period of 10 years.

2.1 Early warning systems (EWS)

Within the EWASE project (Schröter et al., 2008) EWS were analysed in several European catchments. The reliability of forecasts was combined with the damage reduction potential, both dependent on the lead time τ. In Schröter et al. (2009) the reliability of EWS was assessed considering different lead times while in Gocht et al. (2009) the economic viability of EWS was analysed. The reliability of forecasts was described by a probability function dependent on the lead time. Secondly, the damage potential was assessed for the flood plain and thirdly the response capability of the people and of small scale industries, typical for the region, was identified on the basis of a questionnaire and individual interviews. Finally, the reliability of forecasts was multiplied with the damage reduction potential to obtain the expectation value of damage reduction.

The forecasts from EWS are online available and are directly communicated to emergency teams in the region. Here, we neglect the reliability of the communication lines and the capability of people to understand the warnings and to take appropriate actions. Some information can be derived from the questionnaire (see chapter 3.4).

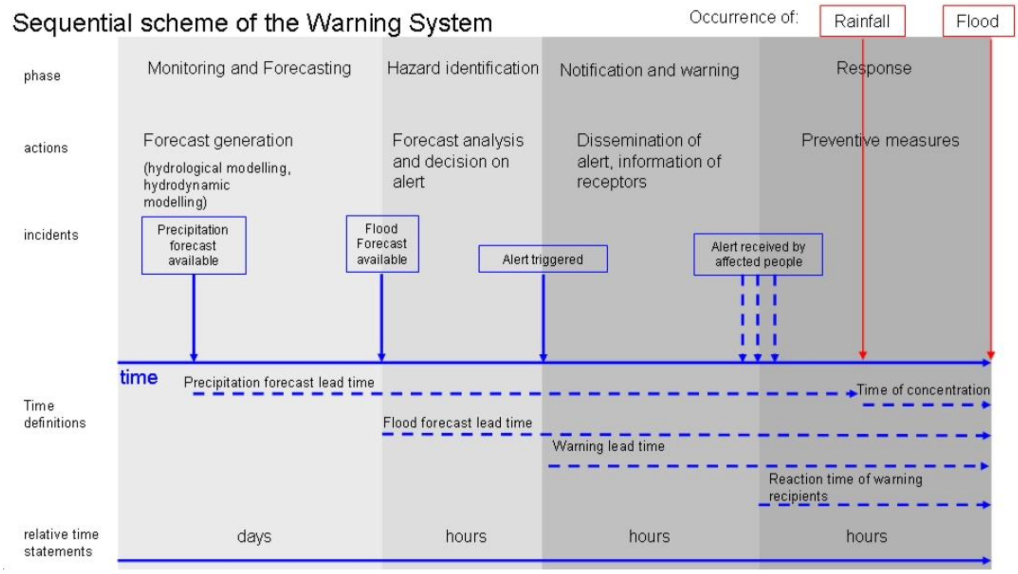


Figure 1: Sequential scheme of an EWS

Obviously, for individuals it is the warning lead time that determines the time slot for taking counter measures while for organisation an internal alert time has to be additionally considered that finally the reaction time remains.

2.2 Reliability of EWS

EWS are based on hydrological models which use meteorological forecasts as an input to extend the lead time τ beyond the concentration time T_c in a catchment. The increase in lead time may provide valuable time for the completion of preventive measures, whereas the decrease of warning reliability will reduce potential benefits and may also cause economic losses due to a false alert.

Flood forecasting involves a considerable degree of uncertainty inherent to the future development of meteorological conditions and the pre-flood state of the catchment. In general the predictive uncertainty of meteorological forecasts is larger than that of hydrological models. This means that for short concentration time in a catchment the meteorological uncertainty is dominating.

The relative forecast error $\varepsilon_{i,\tau}$ is defined according to (1) by comparing observed runoff $Qobs_i$ with forecasted $Qsim_{i,\tau}$ at lead time τ. Usually, only the predictive errors of large events are interesting, for instance, those discharges that exceed a certain threshold level indicating the begin of major inundations.

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

Assuming that the errors stem from the same population an overall probability density function (PDF) or a cumulative distribution function (CDF) can be derived. Based on the CDF an estimate of the magnitude of the prediction error can be derived for any confidence interval. In (Merz et al., 2004) the error was selected at the 85% percentile of the CDF ($\varepsilon_{i,\tau}$ at 85%) to provide an appropriate estimate of forecast reliability $FR(\tau)$. As reliability is usually defined on a scale between zero (unreliable) and one (reliable) it is defined as

$$0.85 = P(\varepsilon_{i,\tau} \le \varepsilon^*_\tau)$$

$$FR(\tau) = 1 - \varepsilon_{\tau}^{*} \qquad (2)$$

This procedure can be repeated for several lead times and as a consequence the reliability function of the forecasts can be established. Obviously, the reliability will decrease with increasing lead time.

Wrong alerts have to be separately considered. They refer to an issued alert although the observed peak remains below the critical threshold Qcrit P_1 and in the second case no alert is issued while the observed flood peak is above the critical level P_2.

$$P_1 = P(Qsim_i > Qcrit \mid Qobs_i < Qcrit)$$

$$P_2 = P(Qobs_i > Qcrit \mid Qsim_i < Qcrit) \qquad (3)$$

2.3 Vulnerability analysis and damage potential

Vulnerability analysis is based on two elements: exposure and susceptibility. The estimation of these two quantities depends on the scale of the analysis (Hall et al. 2003).

Based on inundation and land use maps, which are available together with the delineated areas of potential significant flood risk (APSFR regions) (UBA, 2012) by the end of 2013 for EU country, exposed objects and residential areas can be identified and number of people in the flood plain can be estimated. The number of exposed residents can be derived from residential registries at the district level by estimating the percentage of inundated residential area. For a detailed analysis digital terrain information, land use maps and cadastral information have to be combined with 2-D hydraulic model to identify inundated areas (Nachtnebel et al., 2005), number of objects at risk and number of endangered people. According to Smith and Ward (1998) and Messner et al. (2007) flood losses can be classified into direct and indirect damages which are subdivided into tangible and intangible damages (Table 1).

Table 1: Types of flood damages

		TANGIBLE DAMAGES	INTANGIBLE DAMAGES
TYPES OF DAMAGES	DIRECT	Physical damage to assets Buildings Contents of buildings Infrastructural damages Losses in agriculture	Losses of life Health effects Losses of cultural heritage Losses in ecological goods
	INDIRECT	Production losses Traffic and transportation losses Emergency costs Increase in insurance costs Potential risks of future production contracts	Inconvenience of post flood recovery Increased vulnerability of survivors

At the local scale estimates of damages to objects can be obtained from compensation payments from catastrophic funds after the last floods from census data of population and inventory of buildings (Nachtnebel et al., 2009, Nachtnebel and Neuhold, 2012; Merz et al., 2007) and on the basis of the regional market values of different classes of objects. The percentage of damages to moveable inventory was estimated by Merz et al. (2004) by more than 50 % in the service sector and about 75% in the manufacturing sector. The respective percentage for private houses is about 30 % and 10-15% for public infrastructure.

The damage potential of industrial companies and of infrastructure (tangible direct damages) at the regional level (Schröter et al., 2008) can be obtained from NUTS3 data (Council Regulation, 2003) which provide standardised information about production sectors in territorial units. Regional data on capital stock, active persons, investments and value added pursuing to these standards are available for EU countries from Eurostat and national statistical agencies. These data are sometimes only available at a larger scale and may require downscaling. Merz and Gocht (2001) found a strong correlation among capital stock, which is a measure of stored wealth, and the number of employees in a given production sector. The number of active persons per company is in most cases easily accessible and can be obtained from the municipal office because some local taxes are allocated per employee to the municipality. Based on this information the capital intensity (€/employee) can be derived for each production sector and then downscaled to each company.

Several sets of damage functions are available for different objects, basins, countries and production sectors from various risk assessment studies (BUWAL, 1999; MUNLV, 2000; ICPR, 2001; Pro Aqua et al., 2001; Merz et al., 2004; Nachtnebel and Neuhold, 2012). Utilising a relative damage function, relating inundation depth with percentage of potential damages of an object, an estimate of the damage can be derived for a specific flood event and the respective inundation depth at each individual object. Summing up over the whole flood plain an estimate of direct damages can be obtained. Of course, many other factors such as flow velocity, duration of inundation, sediment load and diluted chemicals may aggravate the damages.

Indirect damages are often dominating the direct impacts of a flood. The gross value added (GVA), which exhibits a strong correlation with capital stock, can be used as an indicator for indirect damages (Gocht et al., 2009, Schröter et al., 2009). GVA data describing the average contribution to value generation in a production sector (NACE, 2008) are widely available from national statistical agencies. In combination with the number of active persons in the respective production sectors (Schröter et al., 2008) GVA per person, activity and day can be derived.

2.4 Potential of damage reduction

The benefits from EWS depend on the reliability of forecasts and the respective lead time. Additionally they depend on the awareness and preparedness of the population and of the responsible managers in companies Parker et al. (2005). Benefits originate from reduced damages due to temporary flood protection measures, either by mobile walls to protect larger areas or by local flood proofing of objects. Further, the contents of objects as well as cars etc. could be removed out from the flood plain and susceptible people could be transferred to saver places.

In Table 1 the largest economic benefits from EWS are seen with respect to the content of buildings and mitigation of production losses. The mitigation potential can be estimated similar to the damage potential (Gocht et al., 2009). This figure gives an upper bound for the benefits of EWS that may be reached under optimal conditions, such as availability of precise long term forecasts and well prepared and informed people and communities. Interviews with local emergency managers and representatives of companies will assist in improving the estimation of mitigation potential. Additionally, conclusions could be drawn with respect to required lead time for mitigation measures.

In a UK-study on the response ability of households to flooding situations in England and Wales (Parker et al 2007) is analysed. As a result of this study 55% of moveable household inventory can be saved for lead-times below 8 hours and 71% for warning lead-times above 8 hours.

Information about the damage mitigation potential in companies and enterprises could be obtained from a questionnaire (Neuhold and Nachtnebel, 2009; Gocht et al., 2009) completed by emergency managers of these companies or officials from regional flood alert centers. Such questionnaires will help in revealing the ability of the people at risk to respond to the hazard (see chapter 3.4).

2.5 Efficiency of EWS

To analyse the economic efficiency of the EWS the expectation value of avoided damages per year has to be compared with the total annual cost of EWS. The costs of EWS include the implementation of the EWS together with costs for the provision of required input data including the monitoring system. Further costs elements are in staff costs and training, software development and maintenance.

Additionally labour costs and production losses during a flood event have to be considered because voluntary emergency teams and staff from companies take local flood protection actions. These costs will also accrue in case of a false alarm. The probability of false alarms can be obtained by equation (3). In the case of a missing alarm the damages could be estimated on the basis of a damage function as indicated in chapter 2.2 while in the case of issuing a false alarm only labour costs and production losses would have to be considered.

According to Gocht et al., (2009) an event independent evaluation translates the avoided damages into a reduction of risk and compares the costs of the EWS with the benefits. Having estimated the cost elements a benefit cost ratio can be derived for the evaluation of EWS and for assessing the efficiency of EWS.

3. APPLICATION TO AN AUSTRIAN CATCHMENT (TRAISEN BASIN)

Here, the performance of EWS in a smaller river basin (< 1000 km^2) will be demonstrated. After a brief description of the physical structure of the catchment the hydrological reliability will be assessed. Then the damage potential and the benefits of EWS will be analysed.

3.1 Physical features of the catchment and description of the EWS

The Traisen basin is located about 50 km West of Vienna and discharges to the Danube river The size of the catchment is 921 km² and elevations range from 200 m in the North to 1800 m a.s.l. in the South (Schröter et al., 2008; Nachtnebel and Kahl, 2007). Mean annual precipitation ranges from 600 to 1500 mm/a with high precipitation amounts in summer, mostly in the alpine part. In spring snow driven floods occur often in combination with rainfall. In summer flood events usually are caused by heavy rainfall. In particular the summer flood events are characterized by response times of 8 to 24 hours.

The EWS for the Traisen catchment (Nachtnebel and Kahl, 2007) was developed between 2004 and 2005 and subsequently updated. The operational warning system for the Traisen is based on the spatially distributed continuous hydrological model COSERO (Kahl and Nachtnebel, 2009) and it incorporates quantitative precipitation forecasts (QPF) by the Central Institute for Meteorology and Geodynamics (ZAMG). For flood warning additional information is provided by the hydrological services' observation network which consists of ten rain gauges and seven online river gauges. While the deterministic precipitation forecast exhibits a high spatio-temporal resolution (1x1 km, 15 minutes) the ensemble forecasts are available at a 10 km grid scale and are updated every hour. The data provided for this study comprise the deterministic QPF and ensemble QPF with 50 members for a maximum lead time of τ_{max} = +48 h. The outcomes of the flood forecasting system are passed on to the Warning Alert Centre (LWZ) which decides about an alert on the basis of predefined warning levels corresponding to thresholds of discharge values (see Figure 1).

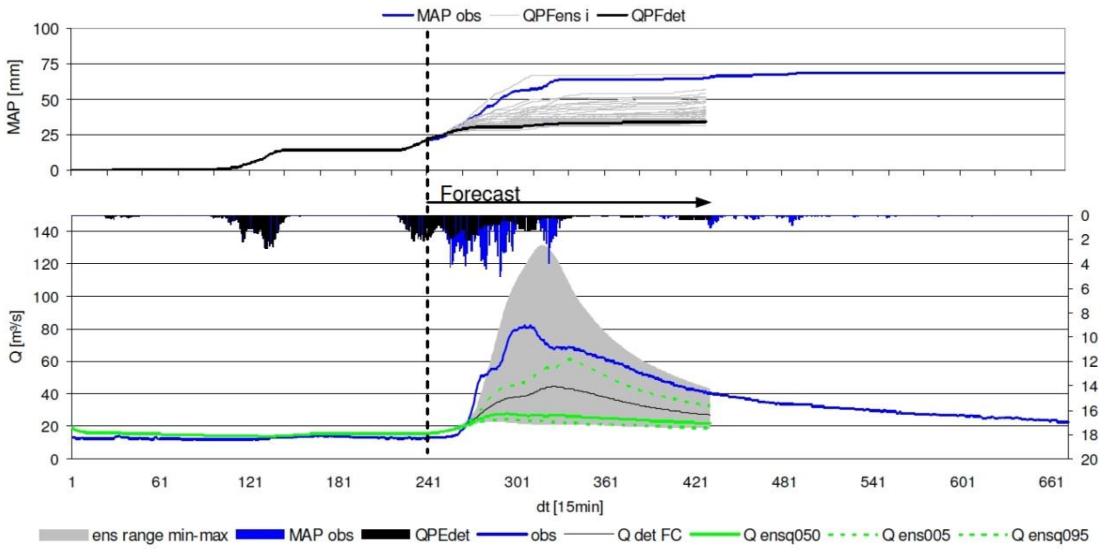
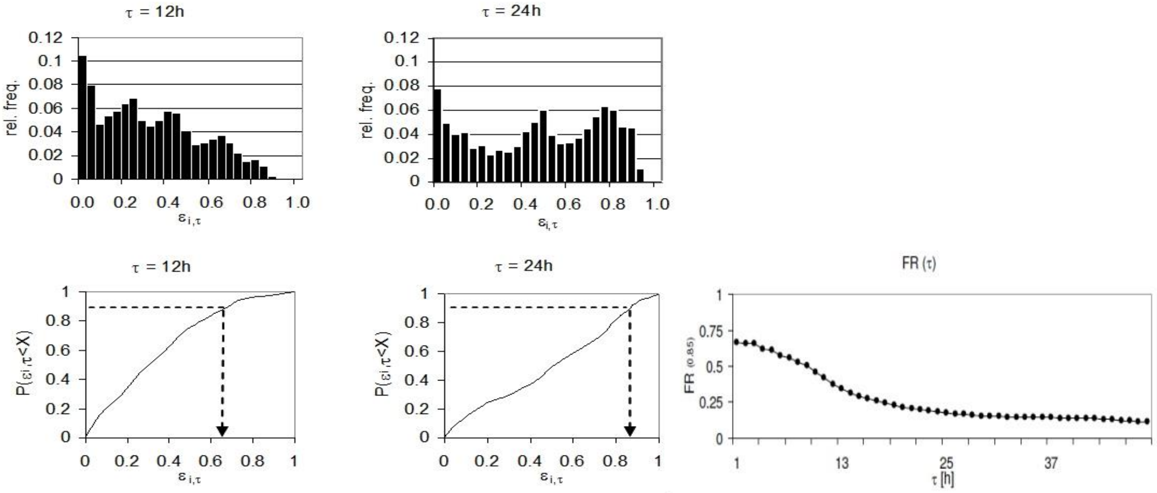


Figure 2: Observed, simulated and uncertainty range of forecasted mean areal precipitation (MAP) and respective hydrographs.
The vertical dotted line indicates the beginning of the forecasting period.
blue: observed mean areal precipitation and runoff
black: deterministic forecasted mean areal precipitation and runoff
grey: ensemble forecasts of precipitation and runoff
green: range of ensemble simulation of runoff within 5% and 95 %

This event (Figure 2) exhibits the large uncertainty in the ensemble forecasts of precipitation. The deterministic precipitation forecast underestimates the rainfall event and thus the simulated flood peak is also underestimated (black line). One of the reasons is in the reliability of small scale precipitation forecasts in a hilly terrain.

3.2 Reliability of EWS

Utilising equation (1) and (2) and executing an ex-post analysis of all the major flood events during the period from 2002 to 2012 a probability distribution function together with a CDF can be established and finally a reliability function of flood forecast (FR) can be obtained (Figure 3)



$$FR = 1 - \varepsilon_{i,\tau}(85\%) \quad : FR \geq 0$$

Figure 3: histograms of relative forecast errors for two different lead times τ and reliability function FR(τ) (Schröter et al., 2008)

3.3 Estimation of potential damages

This step requires the identification of endangered objects, a relative depth-damage function expressing the percentage of potential damages. The water depths and the flood plains for the Traisen catchment were taken from the risk zoning system HORA (BMLFUW, 2006). HORA provides inundation maps together with water depths for return periods of 30, 100 and 200 years without consideration of any flood protection measures. This implies that the inundated area would be overestimated in case of medium sized floods while it would yield a realistic flood area for extreme events exceeding the design values which usually refer to a hundred years flood.

Especially the lower part of the Traisen catchment is intensively populated and industrialized. About 5436 physical objects were identified within the 200 years flood plain area. 87 % of them are private dwellings, 1% is public utilities, 2 % refer to industrial use, 5% to trade, 2% to recreation and 1% serves agriculture. Detailed information about production sector and the number of active persons was collected from 22 companies on the basis of public available statistical data. According to Merz and Gocht (2001) the derived capital intensity would provide useful information about damage potential of the firms in the flood plain. The monetary value at risk was estimated on the basis of capital stock per employee in the primary, secondary and tertiary sectors for all the NACE (2008) activities. In the established data set the capital stock of each NUTS3 region discriminated among the value of plant and equipment, buildings, and other equipment, such as stocks of crops and animals among others. A standardised set of damage functions utilising data from the Rhine (MUNLV, 2000; ICPR, 2001, Pro Aqua et al., 2001) and flood damage studies from Austria (Nachtnebel and Neuhold, 2012) assisted to differentiate among different economic sectors and categories of residential buildings. Based on inundation depth and damage function the damage potential could be derived for each return period.

The gross value added (€ per sector, person and day) was estimated based on the NUTS3 regional data to take into account indirect damages.

Table 2: Potential damage and risk in the study basins (Gocht et al., 2009)

Return period (years)	30	100	200
Damage (mn €)	563	877	1017

The mean annual risk has been estimated at 25,89 mn €/a. Obviously, these figures are quite high. The main reason for this high risk is the neglect of the existing structural flood protection measures in the HORA study. Another factor could be in the derived damage functions. The largest share of damage potential comes from manufacturing industry with 56-69 %, private dwelling contribute 21-33% and 4-5 % originate from the trading and repair activities. The range is explained by applying different depth-damage functions.

3.4 Estimation of damage mitigation

To estimate the mitigation potential originating from an EWS a questionnaire was distributed among the 20 companies from which 8 responded. Respondents were asked to tick their estimate on a matrix with rows for a given lead time and columns indicating the damage reduction. Based on these answers the damage reduction function presented in Figure 4 was fitted. 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.

Table 3: Excerpt of the questionnaire (Schröter et al., 2008)

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 %

To give an example, five respondents estimated, that they could reduce their flood damage by at least 80% if they would receive a warning 12 hours before a flood. In total, 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 but it should be kept in mind that the sample size is rather small.

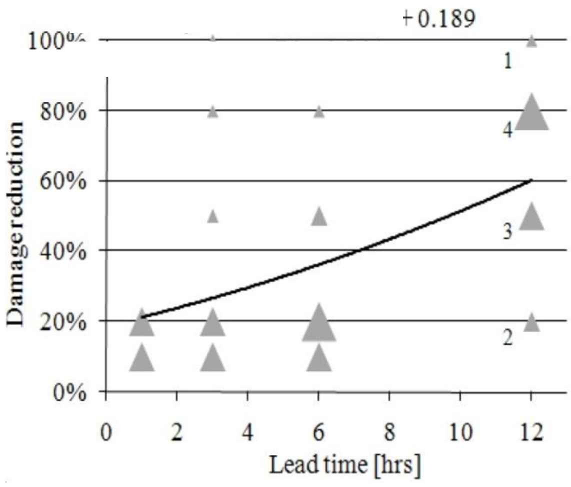


Figure 4: Damage reduction as a function of lead time τ (Gocht et al. 2009) (based on company responses to questionnaire) in industrial/commercial sectors. The size of the triangle corresponds to the number of responses.

Following the findings of Parker et al. (2007) about 40 % of household inventory can be theoretically removed from the flood plain. This would result in a respective value of movable inventory of 40 % of € 29,500 per household in the Traisen basin corresponding to € 11,800 per household. Utilising the percentage of inventory that can be really removed (Parker et al., 2007), dependent on the lead time τ, a damage reduction of 21% of the total household inventory for lead-times of two hours and 27% for lead times above 8 hours would be realistic. The influence of the lead time is quite low.

3.5 Efficiency of EWS

Similarly to the standard risk definition (Duckstein and Plate, 1987; Smith and Ward, 1998) expectation values of avoidable damages are defined as the product of forecasting reliability and avoidable damages for a given lead time. Based on this information a graph could be established relating reduced damages and total costs with reliability function. Based on the questionnaire and the information about the potential damages the expected avoidable damage is obtained by multiplying the reliability (a probability measure) with the potential avoidable damage (Figure 5). The maximum of the warning expectation could be reached at a lead time of about 9-10 hours but even between 7 and 12 hours lead time the benefits are almost the same. This implies that the time lag between the flood warning time and the arrival of the alert at the final recipient is not that relevant as expected, as long this time lag remains within 1-3 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 million € in principle. 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 million €. The mitigation cost is then 3% of avoidable damage and is included in Figure 5 as a linear function increasing with time.

The uncertainty in the warning efficiency can be calculated on the basis of a statistical analysis of past flood events. The uncertainty in estimating the damage potential was obtained by applying different depth-damage functions. The range of the percentage of avoidable damages could be obtained from the questionnaire. Finally, these uncertainties are represented by the shaded areas in Figure 5. Of course, there are additional uncertainties which have not been considered here.

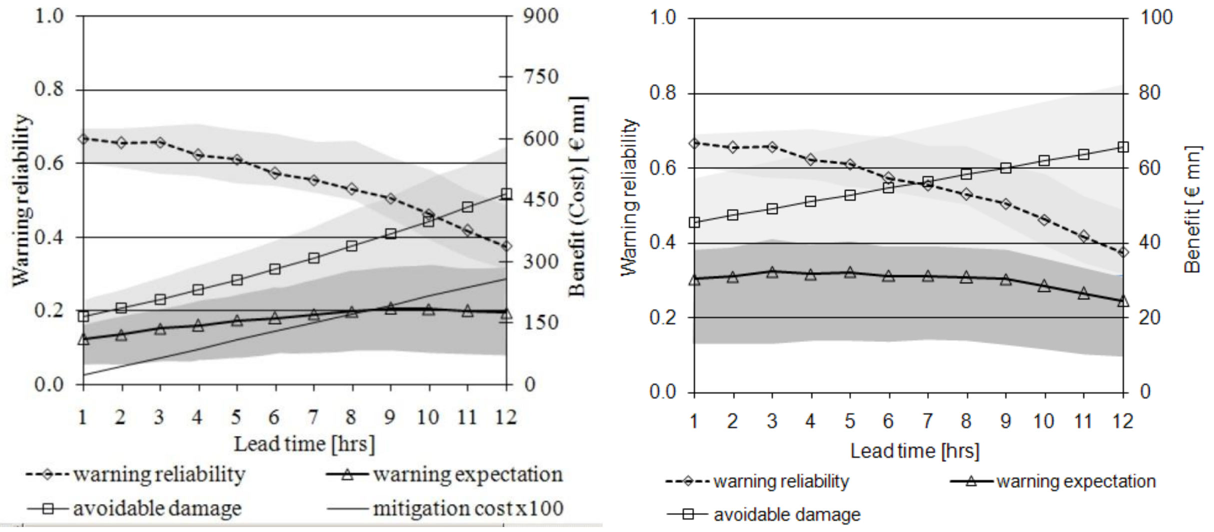


Figure 5. Damage reduction of in the Traisen basin as a function lead time (Schröter et al., 2008) Left whole industrial sector right: private sector

In the private sector damage reductions through early warning are also achievable, but on a lower level than in the industrial sectors. This can be explained by 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). We used same percentages of saved private household values.

The costs of EWS were obtained by interviews with EWS responsibles and from cost statements from EU-biddings for planned EWS. The total system costs for an EWS of about 1000 km^2 were estimated at a present value of 81,6 mio. € over 20 years at a discount rate of 3%. This corresponds to annuity costs of 2.58 mio. €.

Table 4: potential damages and mitigated damages

Damages	Return period (years)	Industries	Private sector
Potential damages (mn €)	30	428.0	135.2
	100	666.7	210.5
	200	772.8	244.0
Avoidable damages (mn €)	30	203.0	27.2
	100	316.3	42.3
	200	366.6	49.1
Potential risk (mn €/a)		19.61	6.19
Damage distribution (%)		76 %	24 %
Avoided risk (mn €/a)		9.28	1.24
Avoided damages (%)		47%	20%
Remaining risk (mn €/a)		10.33	4.95

Average benefits and costs translate into a benefit cost ratio of 11.70 and a net present value of € 28.62 mn, even at a benefit reduced by 80%. Even an increase of costs by 20% and decrease of benefit by 40% would not force the benefit cost ratio into shiftiness. It still maintains a value of 5.9 which means a net benefit of € 15.6 mn. The result for the Traisen basin is tremendous and should be treated very carefully therefore. In this case study EWS exceed the efficiency of alternative flood protection measures, such as flood retention basins or dykes, by far.

4. SUMMARY AND CONCLUSIONS

Early Warning systems are gaining increasing attention. In this paper the results from an economic analysis of an EWS in Austria were presented. Based on the reliability of the forecasts and the mitigation potential of flood damages, which depends on the lead time, the economic efficiency of EWS was estimated. It can be concluded that EWS systems are economically highly attractive, compared to other flood damage mitigation measures, such as technical systems. Particularly in the industrial sectors, which contribute about 70% to the risk, high potential benefits can be realised.

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, given high levels of preparedness are maintained in the affected population.

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