ABSTRACTS

OF

Oral and Poster Contributions to the International CHR-Workshop

'Advances in Flood Forecasting and the Implications for Risk Management'

Alkmaar, The Netherlands, 25 and 26 May 2010

KHR
CHR

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German
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Centre for Water

Hydrologische Wissenschaften
Fachgemeinschaft in der DWA
(German Association of Hydrological Sciences)

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BACKGROUND

Floods are major natural hazards affecting large areas and millions of people world-wide every year. They are a regularly recurring phenomenon with strong environmental and socio-economic impacts. Flood prevention and protection will be one of the most important challenges for all parties involved in flood risk management in the coming decades. It will be a continuous task of governmental bodies and scientific institutes, in close cooperation with society and business, to look for innovative methods for flood protection and prevention, especially in a transboundary context.

Recent developments in flood forecasting allow for better quantification of uncertainties that come with flood forecasting modelling. Information about uncertainties must be communicated to decision makers as well as to the general public. The change from pure deterministic to more probabilistic forecasts is a challenge for all stages of flood risk management.

The workshop will present recent developments, look for knowledge gaps and discuss new perspectives.

OBJECTIVES

- To introduce new approaches in hydrological and meteorological forecasting
- To discuss ways of assessing, communicating and accepting uncertainty
- To improve practical decision making based on a better understanding of theory
- To foster integrated approaches (model chain, risk assessment, decision and communication)
- To explore ways of integrating predictive uncertainty into decision making processes
- To address the benefits of forecasting systems

STRUCTURE AND WORKSHOP THEMES

The workshop is divided in three plenary working sessions:

Theme 1: New approaches to flood forecasting

Keywords:
Forecasting systems (Hydrology, Meteorology)
Quantification of uncertainty
Ensemble and probabilistic forecasting

Theme 2: Aspects of decision making for flood damage prevention

Keywords:
Understanding and enhancing public's behavioural response to flood warning information
General principles of theory - versus actual practice
Boundary conditions and drivers of decision making (economy)
Integrated decision support systems (DSS)
Decision making under known uncertainty (risk informed decision making)

Theme 3: Acceptance and communication of flood warnings

Keywords:
Verification of forecast and warning
Assessment of predictive uncertainty
Communication of uncertainty
Communication systems
Human factor (psychological aspects of forecasting and warning)
Common language
Role of media/competing services
Training/preparedness

PROGRAMME AND TIME TABLE

Day 1 – 25th May 2010

Registration – from 08.30 a.m.

09.00	Welcome by Manfred Spreafico, president of CHR
09.15	Welcome by Roeland Allewijn, Director Division Water and Use, Centre for Water Management
09.30	Keynote by Günter Blöschl – Technical University of Vienna
Theme block 1 – New approaches to flood forecasting	
Chair: Johannes Cullmann / Rapporteur: Eric Sprokkereef	
10.15 – 10.45	Advances in flood forecasting with Delft-FEWS – Martin Ebel, Deltares
10.45 – 11.15	Tea/Coffee – Posters
11.15 – 11.45	Meteorological Ensemble Forecasting – Paul Becker, German Weather Service
11.45 – 12.15	Quantification of uncertainty using Bayesian approaches – Ezio Todini, University of Bologna
12.15 – 13.15	Lunch
13.15 – 13.45	The COST731 Action - Propagation of uncertainty from meteorology into hydrological models – Massimiliano Zappa, Swiss Federal Research Institute WSL Birmensdorf
13.45 – 14.15	Anomalies in the Meuse behaviour and how to model flood events – Hubert H.G. Savenije, Delft University of Technology
14.15 – 14.35	Two strategies for the quantification of uncertainty in the European Flood Alert System – Peter Salamon, Joint Research Centre, Ispra
14.35 – 15.05	Discussion of theme 1
15.05 – 15.30	2 min. oral poster presentations
15.30 – 16.00	Tea/Coffee – Posters
Theme block 2 – Aspects of decision making for flood damage prevention	
Chair: Günter Blöschl / Rapporteur: Sebastian Kofalk	
16.00 – 16.30	Decision support systems and decision making under known uncertainty - Jörg Dietrich, Leibnitz University Hannover
16.30 – 17.00	Disaster management and dealing with the response on flooding – Kees van Ruiten, Deltares
17.00 – 17.30	More information is not always better: Coping with uncertainty in adaptive water management, Marcela Brugnach, University of Twente
17.30 – 18.00	Quantification of uncertainty in flood risk assessments - Bruno Merz, GFZ German Research Centre for Geosciences
18.00 – 18.30	Discussion of theme 2
19.30	Participants' dinner

Day 2 – 26th May 2010

Theme block 3 – Acceptance and communication of flood warnings	
Chair: Michael Bruen / Rapporteur: Peter Krahe	
09.00 – 09.30	On the way to ensemble hydrological forecasts: Lessons learned from MAP D-PHASE – André Walser, MeteoSwiss
09.30 – 10.00	Meet the press! Nobody cares about flood prevention – Joachim Mahrholdt, ZDF German Television
10.00 – 10.30	Warning communication, communication warning - Dominique Bérod, Swiss Federal Office for the Environment
10.30 – 11.00	Tea/Coffee – Posters
11.00 – 11.30	The media do not report on forecasts, they report on events – Michael Schanne, Zurich University of Applied Sciences
11.30 – 12.00	The role of affect in communicating flood risks – Heinz Gutscher, University of Zürich
12.00 – 12.30	Discussion of theme 3
12.30 – 13.00	Summary and conclusions of the workshop
13.00	Closing of the workshop

LANGUAGE

Working language of the workshop will be English

VENUE

Café Restaurant 'De Notaris', Houttil 18, 1811 JM Alkmaar, The Netherlands.

ORGANISERS

The invitation to the event is issued by the International Commission for the Hydrology of the Rhine Basin (CHR) in cooperation with the COST731 Action, the Swiss Federal Office for the Environment, the German Federal Institute for Hydrology, the German IHP/HWRP Secretariat, the German Association of Hydrological Sciences, the Netherlands National Committee IHP-HWRP, and the Dutch Rijkswaterstaat. For further information about CHR and about the workshop, please visit our website at www.chr-khr.org

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ABSTRACTS OF ORAL PRESENTATIONS

ADVANCES IN FLOOD FORECASTING AND IMPLICATIONS FOR RISK MANAGEMENT

Günter Blöschl

Institute of Hydraulics and Water Resources Engineering Technical University of Vienna

As a result of major floods, flood forecasting has received increased impetus in the recent years. There is now a need to make forecasts for smaller catchments than before which implies short travel times. Also runoff data are often not available for calibration. Forecasts are needed for longer lead times than before which requires quantitative precipitation forecasts. In order to cope with the increased uncertainty, ensemble flood forecasts are increasingly used. New technologies such as highly detailed models and satellite data are at the verge of outperforming the more traditional technologies. Here the challenge is to estimate parameters in a reliable and robust way to minimise bias. This presentation will discuss recent advances in flood forecasting with respect to these issues for the example of flood forecasting in the Danube basin. For example, to increase the accuracy of the runoff model an Ensemble Kalman filter is used that back-calculates the soil moisture state of the catchments from real time runoff. The estimated soil moisture is then used as the initial condition of the forecasts. As the future rainfall estimates are associated with considerable uncertainty, ensemble forecasts are performed based on the ensembles of the ECMWF forecasts and used for early warning purposes. Results will be given on what forecast accuracy can be achieved as a function of lead time, data availability and hydrological setting of the catchments. The advances in flood forecasting will be put into the context of risk management. Specifically, the role of local versus global information will be discussed. Communication and the credibility of warnings may be strongly enhanced by local human forecasters that are familiar both with the model and the flood situation in the area of interest. It is argued that credibility is the main goal of the forecasts in a flood risk management context.

ADVANCES IN FLOOD FORECASTING WITH DELFT-FEWS

Martin Ebel

DELTARES – WL | Delft Hydraulics, Delft, Netherlands

1. INTRODUCTION

Many of the operational forecasting systems that are in use today have been built around the application of hydrological and/or hydraulic routing models. These systems and the required data streams have been tailored to provide a close-knit interaction with their underlying modelling components. This model centred approach, which concentrates on the model rather than on the data process, can be quite successful and lead to a rapid development of an operational system in the beginning.

Over time, it does have some disadvantages, though. When faced with changing requirements, it may be easy to adjust the system to minor changes. However, major changes may be difficult to implement into such a grown model centred system. Extension of required lead times, introducing new or alternative models and concepts, introduction of operational real time control or new approaches in uncertainty estimation may require drastic changes in the concept and design of the existing system.

Besides this, the increasing availability of input data such as weather radar and weather forecast products or real time satellite data require to focus more on the effective integration and handling of these new sources of information. Data handling and evaluation become major factors in the chain of detection, forecasting, warning and response.

Furthermore, as time progresses it becomes a challenge to integrate new technologies into these model centric operational systems. The software used to develop these systems may be out of date, or the original designers of these systems often are no longer available. Changing the underlying models or adding new models to the existing system may require extensive effort.

2. OPEN MODEL INTEGRATION WITH THE DELFT-FEWS FORECASTING SHELL

One approach to reducing the effort required in integrating new models and data sources is through an open interface architecture, and through the use of defined interfaces and standards in data exchange. This approach is taken by the Delft-FEWS operational forecasting shell, which has now been applied in some 40 operational forecasting centres across the world.

Delft-FEWS has been developed as a data management platform and is equipped with a user-friendly GIS based interface. It includes a time series viewer and editor, and a wide range of tools for data conversion, visualization, analysis, validation and error correction as well as dissemination of forecasting results (Werner et al. (2004), Werner and Heynert (2006). Current developments include an interactive forecast display, which enables the forecaster to spread the Delft-FEWS display over several screens, and which allows to see and start connected model runs and workflows in a topology display.

The Delft-FEWS framework provides several interfaces that allow models and data in differing formats to be flexibly integrated with the system. More than 90 standardised data formats such as GRIB and NetCDF-CF are supported at present. The Delft-FEWS database model is inherently ensemble aware, and supports specifically the import of ensemble data (e.g. ECMWF, COSMO-LEPS), model runs for ensemble members, display, statistical summary and verification of ensemble forecasts.

Thanks to this open infrastructure, new models can easily be incorporated into an operational system without having to change the operational process. All model formats introduced to the Delft-FEWS framework are in principle available to the Delft-FEWS community (subject to the licence conditions of the model supplier). A wide range of models has been integrated and is being used operationally: Mike 11, HEC-RAS & HEC-RESSIM, HBV, MODFLOW, SOBEK, and more. In this way Delft-FEWS not only provides a modelling interface but also a platform for model inter-comparison or multi-model ensembles. As a knowledge interface it allows forecasters throughout the world to exchange their ideas on operational forecasting and to profit from new developments implemented into it and made available to all users.

This way the forecaster can effectively to focus on the operational forecasting and warning tasks instead of having to worry about model details and data formats.

The Delft-FEWS shell handles all data flows, prepares the data needed for a specific model, runs the connected model, retrieves and eventually processes and evaluates the model output. Despite this close interaction with the model, it is entirely independent of it. Delft-FEWS therefore is not only used for the purpose of forecasting of floods or low flow situations in rivers. Its architecture proves to be highly suitable for simulation purposes, hindcast analysis, and climate change studies, and is used as an instrument for applications such as ground water modelling, coastal forecasting and integrated water resources studies.

Currently Delft-FEWS is used to operationalise the Dutch National Hydrological Instrument (NHI). The NHI combines a nationwide distribution model and surface water model coupled with a high resolution MODFLOW-METASWAP model of the saturated-unsaturated zone of the whole of the Netherlands. It is driven by measured and forecasted precipitation and evaporation data (ECMWF-DET and -EPS). It runs on a daily time step and is used to obtain insight into the actual and forecasted states of the surface, ground and soil water in the Netherlands. The NHI will be used by Dutch authorities to support decisions on the allocation of available surface water during periods of droughts in the Netherlands. It provides real-time information on the availability of surface water, groundwater levels, saturation of the root zone, etc. and gives insight into the actual and forecasted water demands of different actors (http://www.nhi.nu).

3. DATools: A GENERIC DATA ASSIMILATION SOFTWARE FOR FLOOD FORECASTING PURPOSES

Error correction methods by means of data assimilation can be regarded as an essential element in operational flood forecasting and are included in most real time forecasting models. The primary goal of data assimilation is to guarantee an up to date representation of the state variables in model terms, making use of most recent available measurement information. This state is then used as an initial state for subsequent forecasts.

Delft-FEWS includes an error correction module for output correction (Broersen and Weerts, 2005). A more sophisticated form of data assimilation is sequential data assimilation, in which the states of the process models are conditioned using the information on the current state of the modelled system. These process models can be considered as a set of equations containing parameters and state variables, in which state variables are transient in time, and the parameters are generally held constant at some value determined in the calibration of the model prior to application in the real time environment.

Most implementations of these sequential data assimilation methods are custom implementations specially designed for and integrated in the code of a particular model. This makes it difficult and very time consuming, if not impossible to use them with other models.

Therefore, a generic sequential data assimilation module (DATools) for use within Delft-FEWS has been developed, which can also be used standalone. (El Serafy et al. 2007). DATools, which is completely configurable via XML configuration, is built up of three components: a Filter, a Stochastic Modeller, and a Stochastic Observer (Figure 2). At present two data assimilation filters are available within DATools: (a) ensemble Kalman Filter and (b) the residual resampling filter.

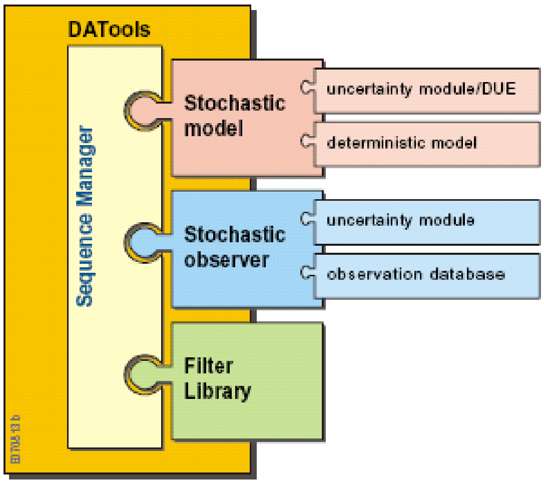

Figure 1: Structure and components of DATools

Results of a twin experiment with both filters with DATtools show similar results as a previous study performed with custom implementations (Weerts et al. 2010). Applying EnKF to a 1D hydrodynamic SOBEK-RE model of the river Rhine within the operational system FEWS-NL for Rhine and Meuse improves the forecasts at the Lobith gauging station and downstream of Lobith.

DATools has been coupled with the HBV-96, SOBEK, and REW models and will be coupled to MODFLOW, Delft-3D, and the geotechnical model MSetlle in the near future. Uncertainty analysis with this tool is also possible and calibration will be added.

4. POST-PROCESSING OF ENSEMBLE HYDROLOGICAL FORECASTS USING QUANTILE REGRESSION

Quantile regression is a method for estimating conditional quantiles. The aim of the error quantile regression is to estimate the cumulative distribution function of forecast error conditioned by the value of the contemporary simulated river levels. As such, given a value of model forecast, the error distribution around this value can be estimated. The conditional probability distribution is expressed in terms of the error estimate and the associated quantiles.

Besides other approaches this method has been integrated in Delft-FEWS and tested within the project 'Risk-based Probabilistic Fluvial Flood Forecasting for Integrated Catchment Models', which aim was to develop and test practical probabilistic methods to quantify and reduce uncertainties in fluvial flood forecasts. (Environment Agency 2009).

The quantile regression approach aims at capturing the uncertainty due to errors in initial conditions, modelling errors, and Numerical Weather Forecasts. It has been developed in R, and is easy to implement in Delft-FEWS. The method is calibrated off-line. For reliable results, long calibration time series are necessary. The calibrated conditional quantiles (on the forecasted water level or discharge) are then used online, which makes the method computationally very attractive.

The results of case studies indicate that the quantile regression method offers a real possibility to derive probabilities of forecast water levels (and discharges). The method has been tested and validated for various forecast locations and catchment sizes. For most locations, the forecasted probabilities match reasonably well with the observed probabilities.

5. REAL-TIME DECISION-SUPPORT IN FORECASTING SYSTEMS

Real Time Control Tools (RTCTools) is a novel framework in Delft-FEWS for supporting real-time control. Originally it was set-up for simulating and evaluating the optimum control of hydraulic structures in the forecast horizon and supporting stakeholders in taking optimum decisions. The framework includes a collection of operating rules mainly for reservoirs, simple reactive controllers for hydraulic structures in rivers such as the PID-controller. Furthermore, it contains more sophisticated model predictive controllers of various types including a set of internal models for pool routing in reservoirs, flood routing in rivers and the embedded hydraulic structures. Logical rules can be simulated for activating or deactivating certain sets of rules / controllers.

An ongoing project aims at the integration of RTCTools in SOBEK / Delft3D via OpenMI[1]. In this context, it will replace and extend the existing functionality of the SOBEK RTC Module. The overall architecture of the tools is presented in Figure 2.

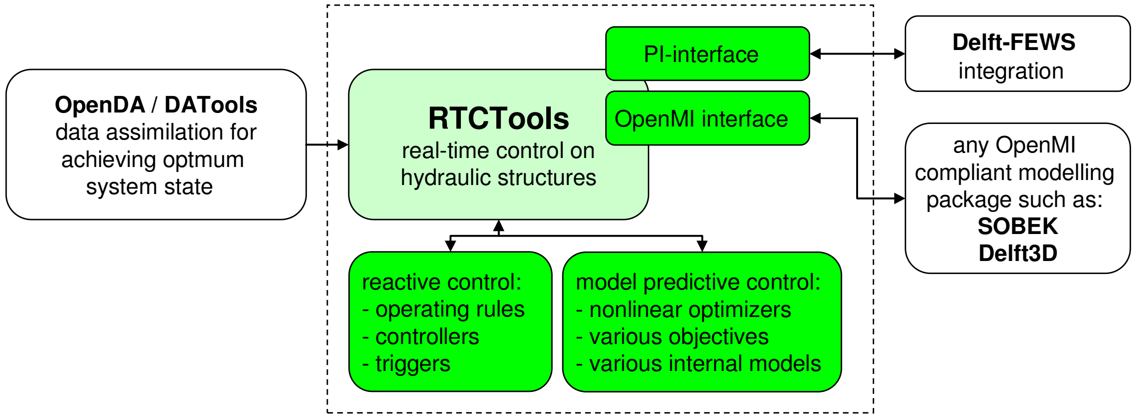

Figure 2: Architecture of RTCTools

A demonstration of the tool is based on an application of a nonlinear model predictive controller on the control of a river weir and two virtual flood detention basins along the bifurcation points of the river Rhine in the Netherlands (Figure 3). This part of the river system is the key to the discharge distribution along the different Dutch river Rhine branches and therefore has a major impact on the water management in The Netherlands. The discharge distribution affects various aspects such as the allocation of drinking water, irrigation, salt intrusion, navigation, and flood protection. The control of the discharge distribution has been the focus of several recent publications such as Schielen et al. (2008).

The scheme controls the discharge distribution at the bifurcation points at low and medium flows by control of a hydraulic structure at Driel (S01). Furthermore, it operates five inlet and outlet structures (S02-S06) of two virtual flood detention basins for dampening flood peaks during flood events.

[1] OpenMI provides a standard interface, which allows models to exchange data with each other or modelling tools on a time step by time step basis as they run (www.openmi.org).

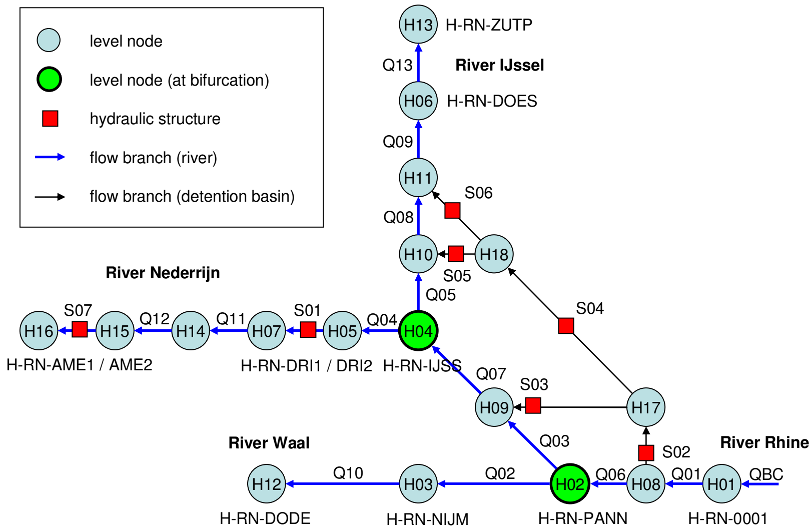

Figure 3: Layout of internal model of predictive controller (kinematic wave model): schematic overview about nodes and flow branches and hydraulic structure branches

Figure 4 presents some results of the controller running in a closed loop setting using a kinematic wave model also as a replacement of the actual system and perfect predictions of the disturbance. We intend to repeat the exercise in the near future using a full hydraulic model and predicted disturbance.

In the left figure, the regime is gradually shifting from low flow (1) for which the set point is not maintained even with fully closed gates, to (2) medium flow for which the set point is well maintained, to (3) a higher flow regime with gates completely opened and balanced water levels upstream and downstream of the gate. The right figure presents the dampening of a small flood wave. In phase (1) the inlet structures of the detention basins are still inactive. They start discharging the water during phase (2) for keeping the desired water level at Lobith at a level of 12.75 m a.s.l. Inlet gates are closed again in phase (3) till the water is released from the detention basins through the outlet structures in phase (4). A more detailed description of the control scheme and the results of the test case can be found in Schwanenberg et al. (2010).

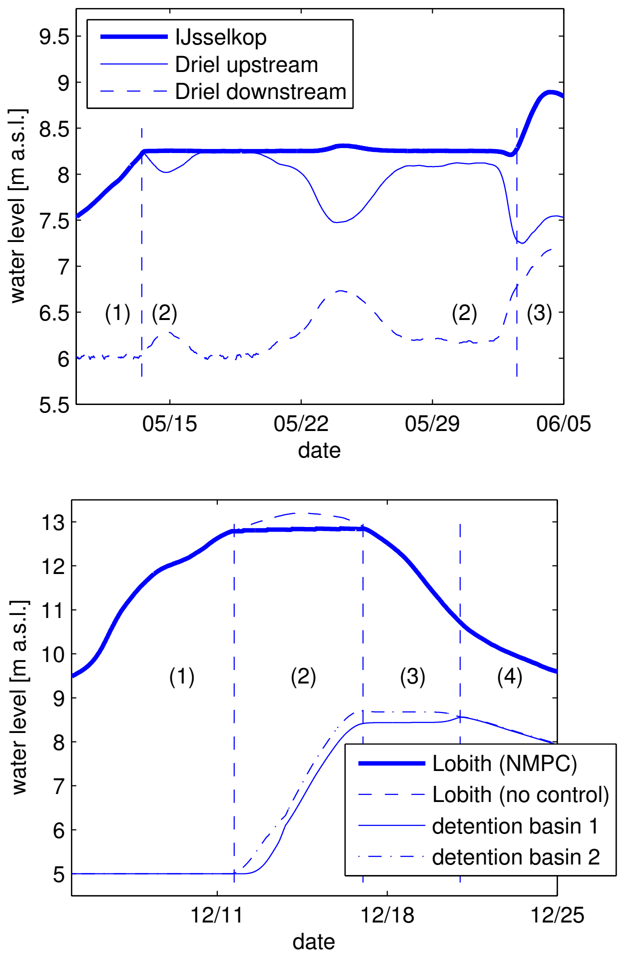

Figure 4: a) water level control at Driel during low - medium flow regime in May 2007 with water level set point of 8.25 m a.s.l. at gauge IJsselkop,
b) damping of small flood peak above 12.75 m a.s.l. in December 2007 at gauge Lobith by control of detention basins 1 and 2

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METEOROLOGICAL ENSEMBLE FORECASTING

Paul Becker

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1. INTRODUCTION

A weather forecast always contains uncertainties. Since the degree of uncertainty can be highly variable, the specification of forecast uncertainty is a fundamental information. Therefore ensemble prediction systems (EPS) have become a standard method in estimating forecast uncertainties and producing probabilistic forecasts in nearly all major weather centres. In the model chain at DWD the spatial resolution ranges from grid sizes of 30 km of the global model (GME) and 7 km for the area of Europe (COSMO-EU) down to a grid box size of 2.8 km for the area of Central Europe (Fig. 1). On this last-mentioned spatial grid size the model is called COSMO-DE, which was developed to simulate deep convection systems explicitly.

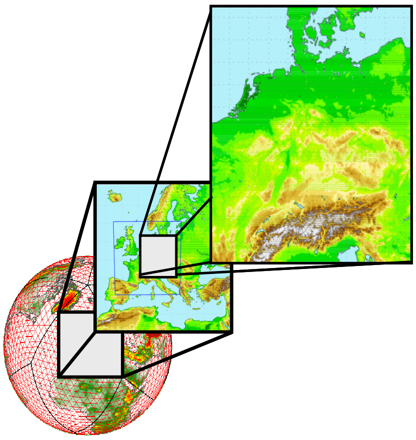

Figure 1: DWD model-chain (GME - COSMO-EU - COSMO-DE)

2. ENSEMBLE PREDICTION SYSTEMS AT DWD

An advantage of COSMO-DE is therefore to avoid the parameterisation of deep convection. From this improvement one can not expect a better forecast of precipitation in a deterministic sense, e.g. the "exact" location of convective cells in space and time, based on a single simulation (Fig. 2). With a focus on the grid size scale quite the contrary is expected: the uncertainty of the forecasts will augment (Mass et.al., 2002). This is caused by the non-linear error growth of processes like deep convection. On the other hand the simulation of deep convection allows a more realistic forecast of the statistical characteristics of the precipitation fields particularly with regard to precipitation extremes. This advantage can be made visible if a probabilistic approach is used, realized by an ensemble prediction system.

Currently, within a developing and built-up phase of a real EPS for this quite highly resolved spatial scale and representing the forecast time-scale from 2 up to 21 hours, the ensemble is generated by perturbations of model-physics and lateral boundary conditions (Gebhardt et.al., 2010; Gebhardt et.al., 2008). The next step is to introduce perturbations of initial conditions. It is scheduled that the COSMO-DE-EPS will become pre-operational in 2010 and operational in 2012.

For regional forecasts from 12 to 72 hours, the ensemble prediction system COSMO-LEPS (Limited-Area EPS) is operationally available, based on dynamical downscaling of the ECMWF EPS, using the COSMO model with a grid size of 7 km. In addition an operational "poor man"-EPS (PEPS) has been developed within the framework of EUMETNET (Heizenreder et.al., 2006). The PEPS forecasts are provided by DWD on the basis of available forecasts from national weather centres within Europe (recently up to 23 models).

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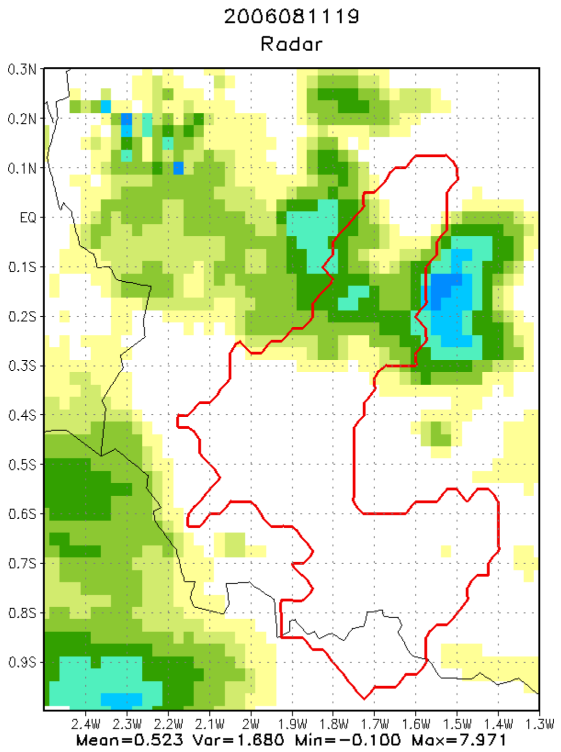


Figure 2a

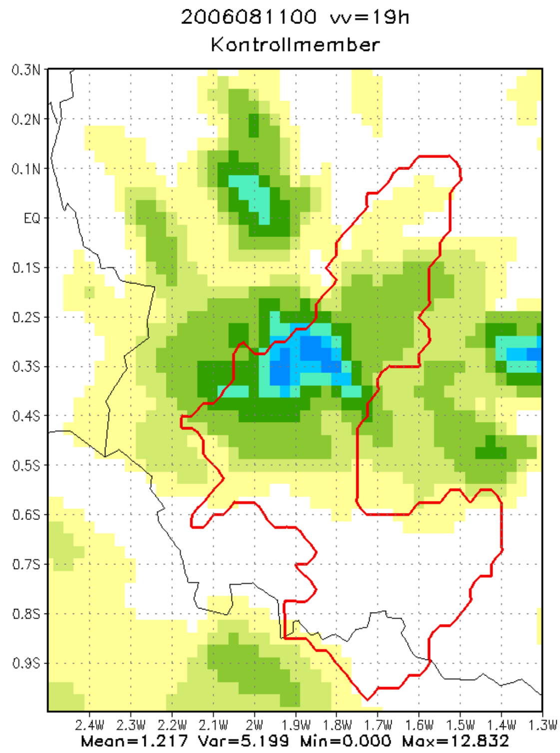
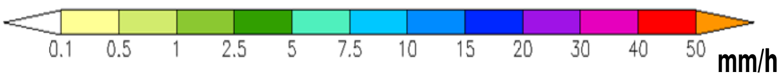


Figure 2b



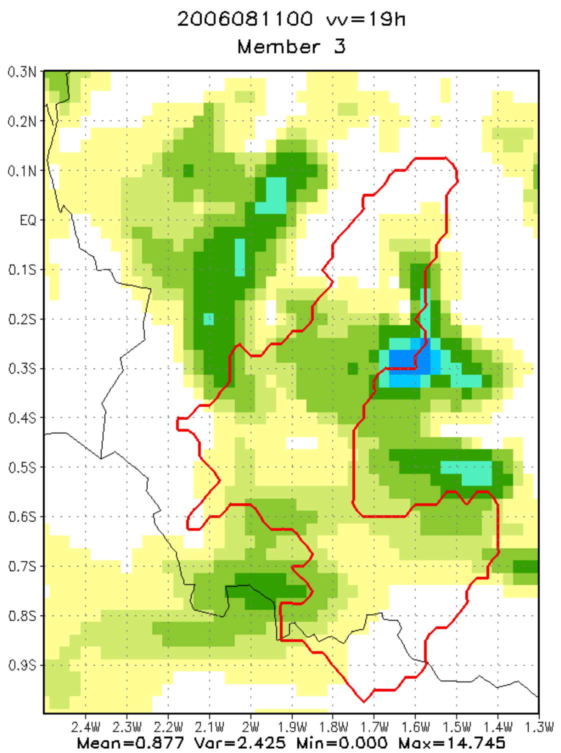


Figure 2c

Figure 2a: Precipitation field given by radar.

Figure 2b,c: Two members of a COSMO-DE forecast ensemble.

The red line is the joint catchment area of the rivers Blies and Prims. The black lines are parts of the western borders of Germany to Luxembourg and France.

QUANTIFICATION OF UNCERTAINTY USING BAYESIAN APPROACHES

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1. INTRODUCTION: THE DEFINITION OF PREDICTIVE UNCERTAINTY

In water resources management, and more specifically in flood emergency management, decisions, which may generate dramatic social and economical consequences, must be taken on the basis of variables such as water stages, discharges, runoff volumes, etc. without perfect knowledge of the future evolution of the hydro-meteorological phenomena. This lack of knowledge or uncertainty on future occurrences is commonly called "predictive uncertainty".

The state of knowledge of a decision maker may be assumed to be a mixture of "what he knows", or better "what he believes he knows" (in the sense that he may be wrong), which is a "subjective state of mind" and what he learns from observations (which includes data and models), which can be considered as "objective". Therefore, following Rougier (2007), a possible definition of predictive uncertainty is:

Predictive uncertainty is the expression of a subjective assessment of the probability of occurrence a future (real) event conditional upon all the knowledge available up to the present (the prior knowledge) and the information that can be acquired through a learning inferential process.

From this definition, the need emerges for using hydrological model forecasts in order to reduce the predictive uncertainty, usually expressed in terms of a probability density (or probability distribution) function, "conditional" upon the available observations and hydrological model forecasts, which are now seen as the available, although uncertain, extensions into the future of observations. In other words, hydrological model forecasts are a way to complement the prior belief of the decision maker in order to reduce "his" prior uncertainty within the frame of the decision making process. This way of looking at hydrological model forecasts is the opposite of current operational practice where (explicitly or implicitly) models are assumed to provide deterministic (and therefore "certain") forecasts such as future levels, flows, etc.. Krzysztofowicz (1999), was the first to clarify, within the hydrological context, that the objective of forecasting is the assessment of the probability that future values of water stage, discharge, runoff volume, etc. will be smaller, grater or equal to given values (generally threshold values, such as for instance the elevation of the dykes), rather than the estimation of the uncertainty of the same quantities forecasted by hydrological models.

2. COMBINING MEASUREMENTS AND MODELS TO IMPROVE PREDICTABILITY

As previously stated, hydrological prediction must aim at the reduction of the uncertainty on the future occurrence of quantities such as future water levels, discharges or water volumes, that will be called "predictands" in the sequel. To do so, the decision maker generally starts from his prior belief. For instance, he can use the climatological distribution of extreme discharge occurrence to describe his prior belief on the possibility of flooding, but In general, the relevant probability density function is very flat and is not sufficiently dense around some specific value to allow reliable decisions, such as issuing a flood alert. Therefore it is necessary to gather additional information, additional measurements or to generate future scenarios by means of one or more forecasting models.

There is no substantial difference between a measurement or a modelled quantity apart from the type of errors affecting them. Measurements, although affected by measurement errors, can be reasonably accurate. But if these measurements are indirect measures of the predictand, they become "predictors", which implies that they will also be affected by modelling errors, similarly to "model predictions". Modelled quantities incorporate both measurement errors and model errors, that can be large if the model is not very accurate. Nonetheless, models become essential when dealing with "forecasting", because measurements are not available at any future time, therefore one can only use modelled quantities in order to increase insight into the future, and consequently reduce uncertainty.

The forecasting problem can be usually tackled on the basis of two different approaches, depending on its nature and on the decision problem to be solved. The first approach relates to cases where only the total probability (namely the integral of the predictive density) above or below a threshold is needed. This is the case for instance when one has to decide whether a landslide will or won't occur on the basis of one or more sensors or models. The second approach relates to continuous processes, requiring the estimation of the entire predictive probability function: for instance when dealing with flood damages, which vary with the water level. In this case decisions tend to be taken on the basis of the expected damages, which can only be estimated if the full probability density of future water levels is available.

2.1 Discrete probability problems: the binary response approaches

When dealing with discrete probability problems, the predictive problem is generally simpler when both the predictand and the predictors are binary functions such as rain/no-rain, flooding/no-flooding, landslides/no-landslides. Unfortunately several problems, generally referred to as "binary response" have binary predictands but continuous predictors. In this case the problem can be quite complex due to the need for converting the continuous into binary functions.

Let us consider a binary response variable, the predictand, y taking values of 1 or 0, and a vector of m explanatory variable $\mathbf{x} \triangleq [x_1, x_2, \ldots, x_m]$, the predictors. The most commonly used statistical models for this type of data are the generalized linear models:

$$g(\pi_i) = \beta_0 + \sum_{j=1}^{m} \beta_j x_{i,j} \qquad (1)$$

where $\pi_i = Prob\{y_i = 1\}$ is the probability of positive response, namely y_i taking the value 1 when the x value is x_i, while g is the link function (McCullagh and Nelder, 1989; Nelder and Wedderburn, 1972).

Logistic and probit functions are two commonly used link functions. The logistic function, defined as:

$$g(\pi) = ln\left(\frac{\pi}{1-\pi}\right) \qquad (2)$$

while the probit function is the inverse of a Normal cumulative density function:

$$g(\pi) = N^{-1}(\pi) \qquad (3)$$

Regardless of the link function used, the parameters of the model of Eqn. 1 (the betas of Eq. 1) are usually estimated by the maximum likelihood approach through an iteratively re-weighted least-squares method. More in general, a binary response linear or non-linear regression model can be summarized as:

$$\pi = F[\gamma(\mathbf{x})] \qquad (4)$$

where F represents a cdf and $\gamma(\mathbf{x})$ represents a linear or non-linear function of the explanatory variables.

Alternative approaches, based on purely binary probability schemes, can also be used when the predictors are also binary functions. These approaches, such as for instance the Bayesian Multivariate Binary Predictor (BMBP) (Todini et al., 2009), allow to derive the probability of the predictand y being above a threshold value y^* conditional to the knowledge that a number of predictors x_j is above or below their respective thresholds x_j^*. In this approach the parameters are the unknown threshold values x_j^* , which can be estimated by maximising a Likelihood function (Todini et al., 2009).

2.2 Continuous probability problems: the Bayesian uncertainty processors

When the problem requires the assessment of the full predictive distribution, namely the probability distribution of the predictand given the predictors, one must first derive the predictand-predictors multivariate joint probability. Since most of the multivariate distributions cannot be analytically formulated or effectively treated, Krzysztofowicz (1999) suggested to transform observations and modelled forecasts in a multi-Gaussian or multi-Normal space via a non-parametric transformation known as the Normal Quantile Transform (NQT) (Van der Waerden, 1952, 1953a,b).

2.2.1 The Hydrological Uncertainty Processor

Krzysztofowicz (1999) introduced a Bayesian processor, the Hydrological Uncertainty Processor (HUP) which aims at estimating the predictive uncertainty given a set of historical observations and a hydrological model prediction. The HUP was developed around the idea of converting both observations and model predictions into a Normal space by means of the NQT in order to derive the joint distribution and the predictive conditional distribution from a treatable multivariate distribution. In practice, as described in Krzysztofowicz (1999), after converting the observations and the model forecasts available for the historical period into the Normal space, the HUP combines the prior predictive uncertainty (in this case derived using an autoregressive model) with a Likelihood function in order to obtain the posterior density of the predictand conditional to the model forecasts. From the Normal space this conditional density is finally re-converted into the real space in order to provide the predictive probability density.

The introduction of HUP generated a positive impact into the hydrological community, because it was the first time that predicting uncertainty was correctly formulated and used in hydrological forecasting. Nonetheless, HUP has three major limitations. The first one relates to the fact that only one model at a time can be used in HUP, which is hardly extendable to multi model forecasts. Moreover the used prior autoregressive (AR) model frequently tends to be inadequate to represent the predictand, as for instance in the case of a flood routing problem where the AR model is adequate for representing the recession but not the rising limb of the flood wave. Finally, the HUP procedure implies the independence of the AR model errors from those deriving from the used prediction model, which is not guaranteed due to the fact that both models tend to be highly correlated to the observations, which inevitably induces a level of correlation among them.

2.2.2 The Bayesian Model Averaging Processor

Introduced by Raftery (1993), Bayesian Model Averaging (BMA) has gained a certain popularity in the latest years. The scope of Bayesian Model Averaging is correctly formulated in that it aims at assessing the mean and variance of any future value of the predictand conditional upon several model forecasts. Differently from the HUP assumptions, in BMA all the models (including the AR prior model) are similarly considered as “alternative models”. Raftery et al. (2003) developed the approach on the assumption that the predictand as well as the model forecasts were approximately Normally distributed, while Vrugt and Robinson (2007) relaxed this hypothesis and showed how to apply the BMA to Log-normal and Gamma distributed variables. In practice the Bayesian Inference problem, namely the need for estimating a posterior density for the parameters, is overcome in the BMA by estimating a number of weights via a constrained optimization problem. Once the weights have been estimated, BMA allows to estimate the mean and the variance of the predictand conditional upon several models at the same time.

The original BMA, as introduced by Raftery (1993), has shown several problems. First of all, as pointed out by Vrugt and Robinson (2007), the original assumption of approximately Normally distributed errors, is not appropriate for representing highly skewed quantities such as water discharges or water levels in rivers. Therefore one must either relax this hypothesis, as done by Vrugt and Robinson (2007) who applied the BMA to Log-normal and Gamma distributed variables or to convert the original in the Normal space once again using the NQT, as done in Todini (2008). Another problem, which emerges from the application of BMA is the use of the "expectation-maximization" (EM) algorithm Dempster et al. (1977) proposed by Raftery et al. (2003), which was not found to properly converge to the maximum of the likelihood. To overcome this problem, one can either use sophisticated, complex optimization tools such as the SCEM-UA (Vrugt et al., 2003) or, as proposed by Todini (2008), a simple and original constrained Newton-Raphson approach, which converges in a very limited number of iterations.

2.2.3 The Model Conditional Processor

The analysis of the two previously described approaches, together with the convenient properties of the multivariate Normal distribution, generated the idea of generalizing the use of the NQT to derive what was called the Model Conditional Processor (MCP) Todini (2008). MCP allows to directly assess the density of the predictand y_t conditional upon all the m model forecasts $\hat{y}^{(1)}_{t|t_0}, \hat{y}^{(2)}_{t|t_0}, \cdots, \hat{y}^{(m)}_{t|t_0}$ issued at time t_0, namely $f_{t|t_0}\left(y_t \mid \hat{y}^{(1)}_{t|t_0}, \hat{y}^{(2)}_{t|t_0}, \cdots, \hat{y}^{(m)}_{t|t_0}\right)$. This conditional density can be found by converting y_t and $\hat{y}^{(1)}_{t|t_0}, \hat{y}^{(2)}_{t|t_0}, \cdots, \hat{y}^{(m)}_{t|t_0}$ into their corresponding Normal space images η_t and $\hat{\eta}^{(1)}_{t|t_0}, \hat{\eta}^{(2)}_{t|t_0}, \cdots, \hat{\eta}^{(m)}_{t|t_0}$, via the NQT as described in Krzysztofowicz (1999) and by assuming the joint distribution to be approximately multivariate Normal. The degree of approximation in the assumption of multi Normality lies in the actual linearity of the statistical dependence among the variables and it is similar to the one used in the linear regression advocated by Krzysztofowicz and Kelly (2000) for the HUP or by Raftery et al. (2005) for the BMA.

In the multivariate Normal case, following Mardia et al. (1979), it is then possible to analytically define the joint distribution of $\boldsymbol{\eta}^T = \left[\eta_t^{(1)}, \eta_t^{(2)}, \cdots, \eta_t^{(r)}\right]$ and $\hat{\boldsymbol{\eta}}^T = \left[\hat{\eta}^{(1)}_{t|t_0}, \hat{\eta}^{(2)}_{t|t_0}, \cdots, \hat{\eta}^{(m)}_{t|t_0}\right]$, where $\boldsymbol{\eta}$ is the r-dimensional image, in the normal space, of the predictand vector (with $r = 1$ if only one predictand is used), and $\hat{\boldsymbol{\eta}}$ is the m-dimensional normal space image of all the used model forecasts. If all these quantities have marginal standard Normal distributions (which is guaranteed by the NQT) and are linearly related (which is assumed), their joint distribution is the multivariate normal distribution:

$$\begin{bmatrix} \boldsymbol{\eta} \\ \cdots \\ \hat{\boldsymbol{\eta}} \end{bmatrix} \approx \mathrm{N}\left(\begin{bmatrix} 0 \\ \cdots \\ 0 \end{bmatrix}, \begin{bmatrix} \boldsymbol{\Sigma}_{\eta\eta} & \vdots & \boldsymbol{\Sigma}_{\eta\hat{\eta}} \\ \cdots & \cdots & \cdots \\ \boldsymbol{\Sigma}_{\hat{\eta}\eta} & \vdots & \boldsymbol{\Sigma}_{\hat{\eta}\hat{\eta}} \end{bmatrix} \right) \qquad (5)$$

Where $\boldsymbol{\Sigma}_{\eta\eta}$ is the $[r, r]$ correlation matrix of the image of observations; $\boldsymbol{\Sigma}_{\hat{\eta}\hat{\eta}}$ is the $[m, m]$ correlation matrix of the image of the model forecasts; $\boldsymbol{\Sigma}_{\eta\hat{\eta}} = \boldsymbol{\Sigma}^T_{\hat{\eta}\eta}$ is the $[r, m]$ cross correlation matrix between the images of observations and forecasts.

Given that the joint probability distribution is multivariate Normal, one can directly derive the distribution of the predictand normal image $\boldsymbol{\eta}$ conditional on $\hat{\boldsymbol{\eta}}$, as the multivariate Normal distribution $\mathrm{N}\left(\boldsymbol{\mu}_{\eta|\hat{\eta}}, \boldsymbol{\Sigma}_{\eta\eta|\hat{\eta}}\right)$ with mean:

$$\boldsymbol{\mu}_{\eta|\hat{\eta}} = \boldsymbol{\Sigma}_{\eta\hat{\eta}}\, \boldsymbol{\Sigma}^{-1}_{\hat{\eta}\hat{\eta}}\, \hat{\boldsymbol{\eta}} \qquad (6)$$

and variance-covariance:

$$\boldsymbol{\Sigma}_{\eta\eta|\hat{\eta}} = \boldsymbol{\Sigma}_{\eta\eta} - \boldsymbol{\Sigma}_{\eta\hat{\eta}}\, \boldsymbol{\Sigma}^{-1}_{\hat{\eta}\hat{\eta}}\, \boldsymbol{\Sigma}_{\hat{\eta}\eta} \qquad (7)$$

As one can see this result is fairly general and can be applied to one or more predictands at the same time (for instance the water stages in successive cross sections along a river or water stage and discharge) as well as conditioned to several model forecasts.

With respect to HUP, the proposed MCP approach, similarly to BMA, may then lead to interesting generalizations. First of all it is no more limited to the choice of a lag-1 Markov process as in Krzysztofowicz and Kelly, (2000), but can be extended to additional physically based models or other types of data driven or Artificial Neural Network models. Moreover, given the very general matrix formulation, the approach is no more limited to the choice of only one additional model, but, similarly to BMA, MCP can be extended to a larger number of models and can be applied using a number of predictands (such as water stage, discharge, water volume, etc.) in one or more sites (for instance different water level gauges along a river) at successive time-steps taking advantage of the spatial and temporal dependence.

3. USING PREDICTIVE UNCERTAINTY IN OPERATIONAL FLOOD WARNING: AN EXAMPLE

The Po river is the largest Italian river with its length of length 650 km and a catchment area of approximately 70,000 km^2, covering most of Northern Italy. The river originates in the North-West of Italy, near the border with France at an altitude of 2000 m and flows Easterly into the Adriatic Sea after crossing four of the most industrialized and populated Italian regions. There are several river sections where flood forecasts are issued, but the most important one is the ending section of the river prior to its delta where the level gauging station of Pontelagoscuro is located. Flood forecasting in Pontelagoscuro is an exceedingly important issue because the river is here characterized by a suspended bed over a flat plain only protected by high earth dykes, which failure could cause extremely dramatic consequences. Presently a flood forecasting system, based on a hydraulic model (PAB - Todini and Bossi, 1986) is operational with forecasting horizons of 12, 24 and 36 hours in advance. The data used in the present work are the measured water levels at Pontelagoscuro, which are automatically collected in real time since 1993 by a network of telemetering gauges.

Figure 1 shows interesting results highlighting the improvements due to the use of the MCP processor instead of the direct use of the model forecasts. Figure 1 (left) illustrates a case when the actual model forecast (dotted line) does not reach the threshold: if the forecast is directly compared to the threshold level y_T the decision maker will not issue an alert, as he should. On the contrary, the decision maker would correctly issue an alert when using, as the triggering quantity, the predictive probability of the real level being above the threshold level y_T. In Figure 1 (upper left) one can see that the $Prob(y_t \geq y_T \mid \hat{y}_t, t_0)$ (the dotted line), stays for several hours above 0.5 and the alert triggering, represented by the dashed line, closely reproduces what actually occurs (solid line). The same correct result is obtained in terms of false alarms rate. Figure 1 (upper right) shows in fact a case when the direct model forecasts would induce to issue an alert, while the probability of overtopping the threshold constantly remains below 0.5.

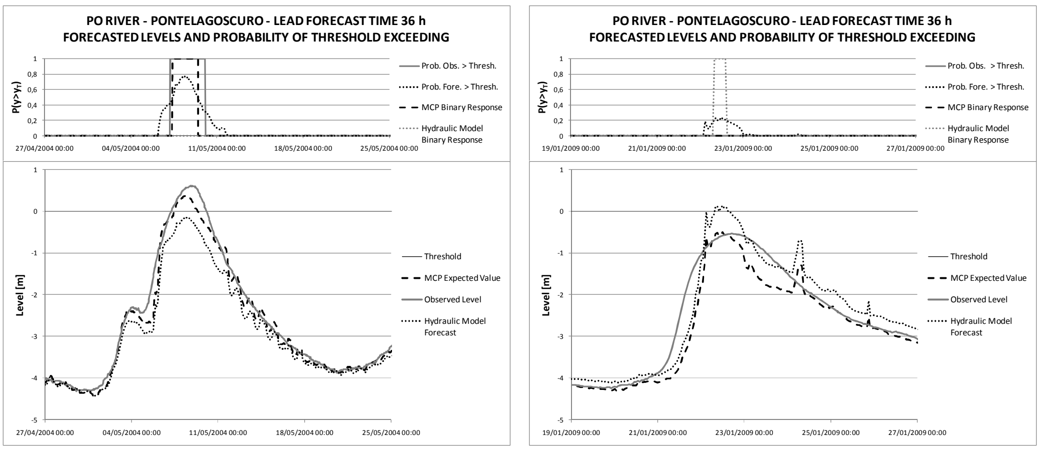

Figure 1: Use of hydrological uncertainty processors in operational flood warning: improvements in terms of missed alarm (left) and false alarm (right)

4. CONCLUSIONS

While the problem of assessing predictive uncertainty in flood forecasting has been introduced and discussed in this paper, a number of issues, such as handling non-stationarity, using predicted inputs instead of the measured ones or using meteorological ensembles, still remain open. Two discrete and three continuous probability approaches to the assessment of predictive uncertainty, have been presented. In particular, the MCP approach can be extremely useful in the assessment and the reduction of predictive uncertainty. Assessment is achieved by formulating in the Normal space the joint probability distribution of predictand and predictors, from which the conditional distribution is then obtained. Reduction can finally be obtained by merging together several forecasting models of different nature and characteristics, such as physically based and data driven hydrological models.

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THE COST731 ACTION- PROPAGATION OF UNCERTAINTY FROM METEOROLOGY INTO HYDROLOGICAL MODELS

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1. SUMMARY

Quantifying uncertainty in flood forecasting is a difficult task, given the multiple and strongly non-linear model components involved in such a system. Much effort has been and is being invested in the quest of dealing with uncertain precipitation observations and forecasts and the propagation of such uncertainties through hydrological and hydraulic models predicting river discharges and risk for inundation. The COST 731 Action is one of these and constitutes a European initiative which deals with the quantification of forecast uncertainty in hydro-meteorological forecast systems (Rossa et al., 2010b). COST 731 addresses three major lines of development: (1) combining meteorological and hydrological models to form a forecast chain, (2) propagating uncertainty information through this chain and make it available to end users in a suitable form, (3) advancing high-resolution numerical weather prediction precipitation forecasts by using non-conventional observations from, for instance, radar to determine details in the initial conditions on scales smaller than what can be resolved by conventional observing systems. Recognizing the interdisciplinarity of the challenge COST 731 has organized its work forming Working Groups at the interfaces between the different scientific disciplines involved, i.e. between observation and atmospheric (and hydrological) modelling (WG-1, Rossa et al., 2010a), between atmospheric and hydrologic modelling (WG-2, Zappa et al., 2010) and between hydrologic modelling and end-users (WG-3, Bruen et al., 2010).

2. THE COST731 ACTION IN BULLETS

2.1 General Framework

COST is an intergovernmental framework for European Cooperation in Science and Technology, allowing the coordination of nationally-funded research on a European level. COST contributes to reducing the fragmentation in European research investments and opens the European Research Area to worldwide cooperation, thus ensuring that Europe holds a strong position in the field of scientific and technical research for peaceful purposes, by increasing European cooperation and interaction in nine key domains, one of which is the Earth System Science and Environmental Management (ESSEM, see www.cost.esf.org).

The COST 731 Action was launched mid 2005 for a five-year period as an offspring of a series of COST Actions related to radar meteorology. To date 22 countries joined the action: Australia, Belgium, Cyprus, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Luxembourg, Netherlands, Norway, Poland, Portugal, Romania, Spain, Sweden, Switzerland, United Kingdom.

Numerous contributors of COST 731 have been and are also involved in MAP D-PHASE and HEPEX, two large initiatives on demonstrating the potential of hydrological ensemble prediction systems. The following section gives a short overview on these two projects.

“MAP D-PHASE” is an acronym for Mesoscale Alpine Program Demonstration of Probabilistic Hydrological and Atmospheric Simulation of flood Events in the Alps (Zappa et al., 2008). MAP D-

PHASE was an important element of the COST 731 Action, right from its initial planning. This WWRP (World Weather Research Programme)-approved Forecast Demonstration Project (FDP) D-PHASE was a follow-on project of the Mesoscale Alpine Programme (MAP) to demonstrate the societal impact of MAP by showcasing the progress achieved in high-resolution and probabilistic numerical weather prediction in complex terrain, along with the consequent benefits for hydrological forecasting.

The Hydrological Ensemble Prediction Experiment (HEPEX). was launched as a bottom-up process by scientists and users at an ECMWF workshop in 2004. This international research activity is designed to address questions related to end-to-end forecast systems in order to build useful systems and to promote their rapid development and deployment. Schaake et al. (2007) present some of the key scientific questions associated with the major components of a probabilistic hydrological forecast system, including calibration and downscaling of ensemble weather and climate forecasts, hydrological data assimilation, and user issues.

COST 731 joined with both the MAP D-PHASE (Bologna, 2008) and HEPEX (Toulouse, 2009) communities for common workshops with the goal of sharing expertise and establishing scientific collaboration.

2.2 Objectives

The main objective of the Action is to address issues intimately associated with the quality and uncertainty of meteorological observations from remote sensing and other potentially valuable instrumentation, along with their impacts on hydro-meteorological outputs from advanced forecast systems. This will be achieved through specific objectives which can be summarized as follows:

- Radar data assimilation in NWP: provide radar data errors in a form suitable for assimilation schemes, and compare different assimilation techniques for the cloud resolving scale, including nudging, 3- and 4-dimensional variational assimilation and the ensemble Kalman filter techniques and establish their sensitivity to the specification of radar uncertainty.
- Radar data quality description: the NWP user requirement for radar data to assist operational data providers.
- Radar ensembles: Investigate methods for generation of ensembles based on uncertainty in radar observations.
- Understand Uncertainty: clarify and understand the meaning of uncertainty and to establish and agree upon ways to measure and express them.
- Use of uncertainty in hydrological models: establish a standard methodology which has the potential to be a reference in the future, and to provide feed back for improvement of meteorological input data.
- Methodology transfer: explore the potential of techniques used to quantify uncertainty commonly used in meteorology applied to hydrology, and promote them to end users.
- Test beds as proof of concept: set up a European test bed(s) in which to run a demonstration project as a proof of concept for probabilistic flood forecasting systems. Test beds integrate observation and forecast uncertainty into a hydrological forecast to provide warning uncertainty. A “simulation package” including a hydrological model and all aspects of decision making can be used for presentation, education and training as well as to perform sensitivity studies.

2.3 Working Group 1: Propagation of uncertainty from observing systems (radars) into NWP

The COST 731 WG1 is progressing in the three distinct, yet interlinked, areas of radar data quality description, radar data assimilation in high-resolution NWP, and high-resolution ensemble forecasting. Salient issues on a European level concern:

- Radar data quality description:

- intercompare best practices in the different countries and the advices provided by COST to the end-users, e.g. supporting the transfer of latest research to operational solutions;
- establish links to the WMO RQQI initiative;
- intensify links to NWP (and hydrological) modellers in order to provide adequate formulations and study impact of errors.
- intercomparison of data assimilation schemes using data from the Convective and Orographically-induced Precipitation Study (COPS; Wulfmeyer et al. 2008).
- Explore the potential of radar data and other observation uncertainty for ensemble generation;

The most significant progresses are shown in more detail in Rossa et al., (2010a).

2.4 Working Group 2: Propagation of uncertainty from observing systems and NWP into hydrological models

WG-2 co-ordinates research efforts on the propagation of uncertainty from observing systems and NWP into hydrological models. Five main objectives have been defined when designing WG-2:

- Understand and evaluate the uncertainty associated with different observed or forecast variables for which different methodologies may be used;
- Explore and design methodologies for the estimation and propagation of uncertainty in hydrological models and try to establish a standard methodology or guidelines for good practice to be a reference in the future;
- Explore and design methodologies for assessing the hydrological impact of the different sources of observation and forecast uncertainty in order to give a feedback to the data providers;
- Explore the transfer of verification methodologies commonly used in meteorology for hydrological purposes;
- Set up a European test-bed in which to run a demonstration project as a proof of concept to the hydrological community, not yet used to dealing with uncertainties in operational forecasting chains.

Specific outcomes from WG2 are presented in Zappa et al. (2010).

2.5 Working Group 3: Use of uncertainty in warnings and decision making

At present quite a substantial gap seems to exist between the forecast information possibly available from the chain atmospheric modelling / hydrological modelling or observation / hydrological modelling (see Fig. 1) and the information that is actually used by the authorities or end-users. This is believed to be on the one hand due to this information not being communicated to (nor requested by) the end users and, on the other hand, due to a failure of the scientists to communicate the possible uses of this information and to provide practical tools for their use. The overall goal of WG 3 is therefore to bridge this gap between the available forecast information and that actually used for hydrology related warnings and decisions. WG3 examined how uncertainty is communicated to end-users and held a special workshop in Dublin in November 2008 which demonstrated a number of internet-based platforms, most operational and many using some form of Ensemble Prediction System (EPS), for delivering both the flood forecast and also uncertainty information to the user. There was a wide variety of approaches to presenting uncertainty information to the end-user. Most approaches accept that the “spaghetti plots” generated from EPS are not appropriate, but each differs in how to represent and communicate the probabilistic information they contain. The opinions of the Workshop participants on the platforms presented and on the communication of uncertainty information was sought at round table discussions following the formal presentations and formed part of the meeting report. The variety of approaches and some of the platforms are described in detail in Bruen et al., (2010).

3. EMERGING RESULTS AND TRENDS:

COST 731 can be seen as a timely European initiative to make concerted progress in the field of probabilistic flood forecasting with a particular emphasis on operational applications. The most significant emerging results and trends can be summarized as follows:

- One of the most innovative developments emerging from the COST 731 Action is related to probabilistic quantitative precipitation estimation (QPE) from radar. Three different contributors from Switzerland (Figure 1), Spain, and Poland implemented slightly differing methodologies based on a quality description of the precipitation estimates. It is to be seen as a sign of good progress that all of these probabilistic QPE methods are being used in combination with hydrological models for simulation of small river catchments (Zappa et al., 2010).
- An increasing number of hydrological models are now using EPS QPF for operational medium- to long-range forecasts for river flow forecasting and water management purposes (Cloke and Pappenberger, 2009; Zappa et al., 2010; Bruen et al., 2010).

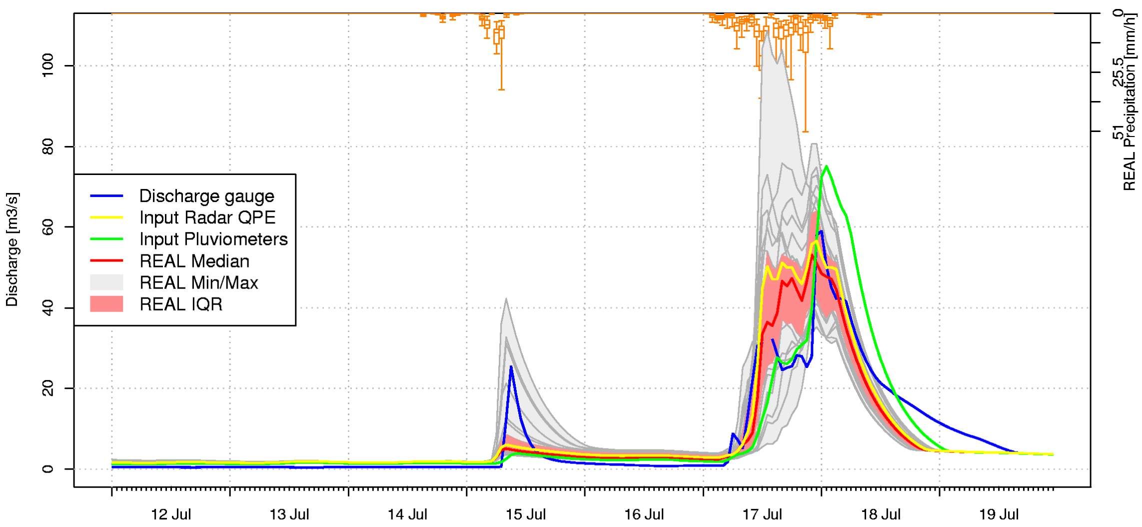

Figure 1: Operational hydrological ensemble nowcasting with ensemble radar information (REAL), starting on 12 July 2009 for the Pincascia basin in southern Switzerland (44.4 km^2). The 25 members from REAL (light grey) are shown with corresponding interquartile range (REAL IQR, red area) and the median (red line). Additionally, two deterministic runs are shown: deterministic radar QPE (yellow line) and forcing with interpolated pluviometer data (green line). The observed runoff is shown in blue.

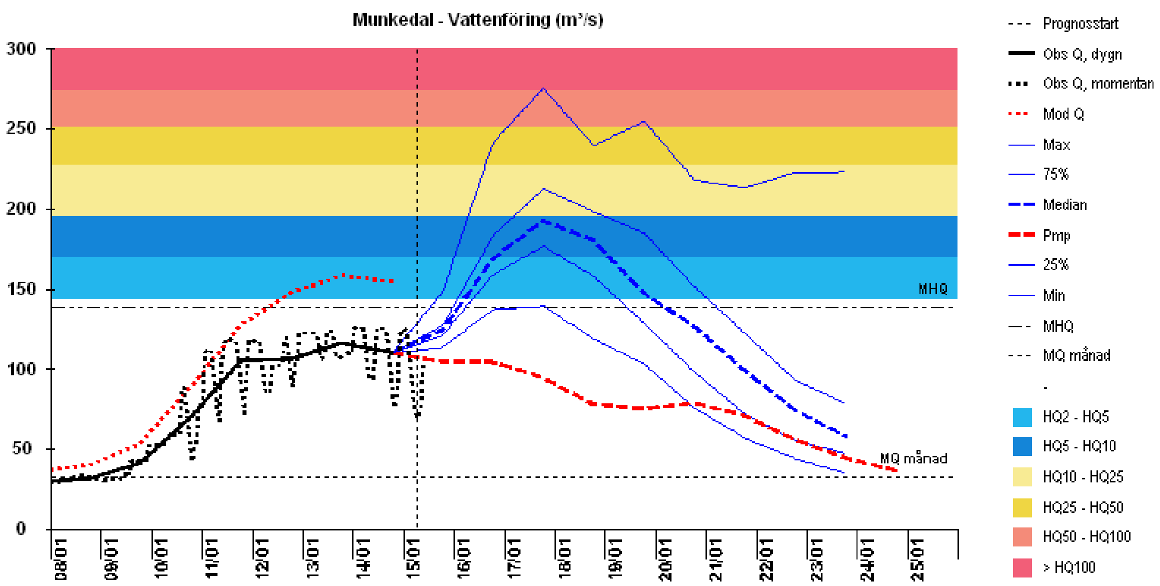

Figure 2. Examples of graphical ensemble forecast products in WebHyPro (Swedish EPS Platform) as : ensemble quantiles for a single catchment (a)

- A large number of testbeds have been implemented in quasi operational mode, especially during the MAP D-PHASE Operations Phase (Rotach et al. 2009), some of them have been online for the duration of MAP D-PHASE in 2007 only, some systems are still providing results in real time.
- A recommendation has been made to include a systematic radar data description for European radar data exchange.
- Progress has been made on the convective-scale NWP by radar data assimilation. This is particularly relevant for flash flood prediction in small river catchments where extending the warning lead time is crucial.
- A set of demonstration platforms and tools for communicating uncertainty (Figure 2) to the end-users have been identified (Bruen et al., 2010).

4. CLOSING REMARKS

The potential value of improved flood forecasting capabilities is beyond controversy. The meetings and joint efforts of the COST731 contributors and of participants to other initiatives such as MAP D-PHASE and HEPEX testifies to the great effort which is being invested in this field in Europe and elsewhere, both by the research as well as by the operational community. The fact that forecasts of this kind are inherently uncertain, a characteristic that will not change even in the future, seems to be increasingly appreciated, as is the need to adequately quantify and formulate this uncertainty and to make proper use of this information in a decision making context. The COST 731 Action ‘Propagation of Uncertainty in Advanced Meteo-Hydrological Forecast Systems’ is an expression of and contributes to this trend. A particularly positive aspect hereby is that the meteorological and hydrological community, traditionally quite separate, have increased their cooperation in a very significant way.

Avenues of improvement of flood forecasting include the respective improvement of the individual system components, as well as establishing improved combined systems and promote the interpretation of the system output, notably:

- improving radar quantitative precipitation estimation for small- to medium-scale river catchments;
- improving short-range NWP quantitative precipitation forecasts by making better use of radar and other non-conventional meteorological information, especially at the convection scale;
- improving observations and use of snow cover and soil moisture, both in meteorological and hydrological models;
- Extending limited area EPS to forecast ranges of 7-8 days for water management;
- Increasing spatial resolution of NWP EPSs, e.g. at convection scale with radar precipitation and wind assimilation;
- Implementing and extending to wider areas existing test bed implementations, e.g. to cover the entire Alpine range;
- Enhancing end user and decision maker involvement and training in using probabilistic forecast systems;
- Establishing Economic-Value Issues as a tool for tailored decision making.

The COST 731 will end mid 2010 but the work will continue on, especially in the scientific networks that have formed as a result of the Action.

5. ACKNOWLEDGEMENTS

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ANOMALIES IN THE MEUSE BEHAVIOUR AND HOW TO MODEL FLOOD EVENTS

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Hydrological records in the Meuse stretch over about a hundred years of data, starting in 1911. Although world-wide this is a respectable period, it is still a very short period to test long-term hydrological trends. Changes that we consider a significant trend over a period of several decades may very well turn out to be cyclic over longer periods of time. More difficult even is it to observe significant trends as a result of human activities, and to separate them from natural fluctuations. During the period of observation, the Meuse catchment has undergone significant modifications. In this paper we investigate the significance of structural changes in the catchment through the use of a conceptual model. Changes in model structure and changes in model parameters are indications for structural, man-induced, changes in the catchment, irrespective of variability in the climatic drivers. Hence, we investigated the time variability of catchment characteristics in the Meuse basin through its effect on catchment response.

The approach makes use of a physically based conceptual model to represent rainfall-runoff behaviour to evaluate possible time-dependence of model parameters. The main hypothesis is that conceptual model parameters, although not measurable quantities, are representative of specific catchment attributes (e.g. geology, land-use, land management, topography). Hence, we assume that eventual trends in model parameters are representative of catchment attributes that may have changed over time. However, these catchment structural modifications, although documented, are not available as 'hard-data'. Hence, our results should be considered as 'plausible hypotheses'. The main motivation of this work is the 'anomaly' found in the rainfall runoff behaviour of the Meuse basin, where ninety years of rainfall-runoff simulations show a consistent overestimation of the runoff in the period between 1930 and 1965.

Different authors have debated possible causes for the 'anomaly', including climatic variability, land-use change and data errors. However, none of the authors considered the way in which the land is used by agricultural and forestry practices as a possible cause. In order to test this hypothesis, the model structure and equations were modified so as to be able to account for different evaporation demand of growing forest. As a result of our analysis, we conclude that the lag time of the catchment decreased significantly over the last decades, which we attribute to more intensive drainage (e.g. by road infrastructure, agricultural drainage and urbanization) and river training works. Furthermore, we found out that forest rotation may have a significant impact on the evaporation of the catchment. These results contrast with previous studies, where the effect of land-use change on the hydrological behaviour of the Meuse catchment was considered negligible, mainly because there was not sufficient change in land cover to account for it. Here we hypothesise that in the Meuse it was not the change of land cover that was responsible for hydrological change, but rather the way the land was managed. In Figure 1, the traditional HBV model (FLEX Uncorrected) is compared to the new FLEX model that includes these new time-dependent characteristics. Already with two additional parameters, reflecting the travel time and the dependency of evaporation to management, the 'anomaly' disappeared. Of course this is not proof, but it is an indication of a significant effect of human interference which needs to be further looked into.

In order to further develop a more physically based yet parsimonious semi-distributed model of the Meuse (FLEX-TOPO) that incorporates the correct and dominant runoff generating mechanisms and that is capable of reliably forecasting flood events, we are in the process of setting up a new modelling framework that takes account of the topography, the geology and the dominant rainfall-runoff mechanisms associated to these land forms. This new approach has been developed in various sub-catchments in Luxembourg and is going to be tested in the different sub-catchments of the Meuse.

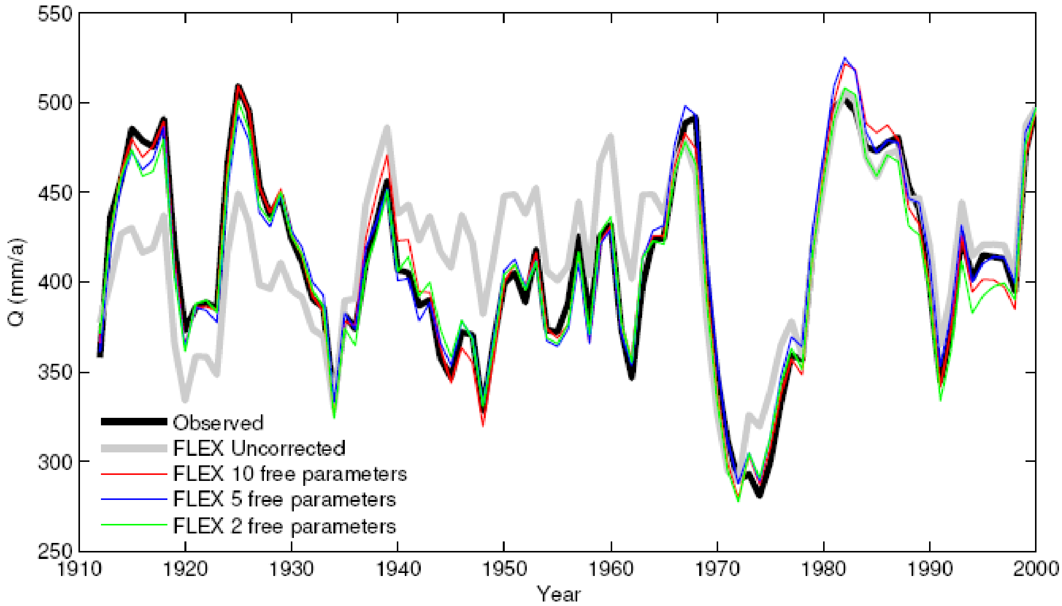

Figure 1: Observed (black line) and simulated model discharge assuming fixed (grey line) and variable (coloured lines) parameter values

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TWO STRATEGIES FOR THE QUANTIFICATION OF UNCERTAINTY IN THE EUROPEAN FLOOD ALERT SYSTEM

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1. INTRODUCTION

Flood forecasting systems form a key part of 'preparedness' strategies for disastrous floods and provide hydrological services, civil protection authorities and the public with information of upcoming events. Provided the warning lead time is sufficiently long, adequate preparatory actions can be taken to efficiently reduce the impacts of the flooding (Penning-Rowsell et al., 2000, de Roo et al., 2003). The design of the best flood forecasting system may differ due to the geographical and/or climatological conditions between catchments. Furthermore, such a system needs to balance the availability and quality of data on the one hand and the computational representation of the processes in the atmosphere, surface, soil and channels contributing to flooding on the other hand. Finally, it needs to respect the particular demands of the end user, since decision makers have different priorities. For example, urban areas require a significantly different management approach than reservoir operations.

The European Flood Alert System (EFAS) was launched in 2003 with the aim to increase flood warning time for trans-national riverine floods in Europe. It is quasi-operational since 2005 and disseminates early flood warning information to the national hydrological services in Europe (Thielen et al., 2009, Bartholmes et al., 2009, Ramos et al., 2007). Since it is set-up for entire Europe, it captures a higher number of events over a wide range of climatological regions than a local probabilistic flood forecasting system would do.

EFAS forecasts are based on two deterministic, medium-range forecasts from different weather services (and thus different models) and on two sets of EPS of which one covers the medium-range up to 10 days and the other is a limited area model EPS with a shorter range up to 5 days. The reason for the shorter term EPS is to enhance the spread of EPS within the first few days and to have a finer grid in particular for mountainous areas. This allows to better identify the location of the floods within the river basin (Thielen et al., 2009).

Despite the differences in concept and data needs between the various forecasting systems, there is one underlying issue that spans across all systems. There has been an increasing awareness and acceptance that uncertainty is a fundamental issue of flood forecasting and needs to be dealt with at the different spatial and temporal scales as well as the different stages of the flood generating processes (Cloke et al. 2009). The main sources of uncertainties arise either from input data (i.e., physical measurement errors, the difference in spatio-temporal scale between model and measurements, and meteorological forecasts) or from the model itself through the mathematical simplification and parametrisation of the different physical processes contributing to runoff.

When trying to incorporate the quantification and reduction of uncertainty in the European Flood Alert System some specific points require special attention: 1.) the methodology applied needs to perform equally well in different geographical and climatological settings as EFAS runs at the European scale; 2.) the methodology needs to be computationally very efficient in order to be used in an operational system; 3.) the methodology needs to be robust as near-real time data is received from a variety of different data providers throughout Europe making the system prone to errors in data transmission or the lack of a sufficient quality control. In this work we will present two different lines of research which are currently being conducted for the quantification and reduction of uncertainty into the European Flood Alert System. Section 2.1 outlines how sequential data assimilation using particle filtering can be used to deal with uncertainty. It furthermore presents the progress of the current research and discusses briefly its advantages and disadvantages. Section 2.2 presents how a vector autoregressive model with exogeneous input in combination with a Bayesian uncertainty post-processor can be used to efficiently deal with uncertainty at gauging stations and how this methodology is implemented into EFAS. Section 3 summarizes the findings of this work.

2. QUANTIFICATION AND REDUCTION OF UNCERTAINTY FOR THE EUROPEAN FLOOD ALERT SYSTEM

2.1 Sequential Data Assimilation using particle filtering

As already pointed out by various authors (Liu and Gupta, 2007), a first step to adequately address uncertainty in hydrologic modelling is the quantification of uncertainty. Data assimilation as a tool for the quantification of uncertainty has been extensively employed in the atmospheric and oceanic sciences (e.g. Daley, 1991), but its application to hydrological sciences is relatively new and a considerable amount of research has been published concerning this topic during the last few years (e.g., Weerts and Serafy, 2006; Clark et al., 2008). An important issue is how the data assimilation methods can be adapted and combined with hydrologic models to deal with the uncertainties in a cohesive and systematic way.

The most common methods to assimilate measured data into hydrologic models are Kalman filtering, particle filtering, and variational data assimilation. For the future assimilation scheme of EFAS we have chosen to test particle filters, because of their ability to handle non-linear, non-Gaussian state-space models (as is often the case for rainfall-runoff models) and because of their characteristics to retain spatial relations by updating particle weights rather than state variables, which renders it ideal for assimilating data in a spatially distributed model such as LISFLOOD (van der Knijf et al., 2008).

Particle filtering is a recursive Bayesian filter based on Monte Carlo simulation. The key idea is to represent posterior probability distribution functions by a set of randomly drawn samples, called particles, with associated weights (Arulampalam et al., 2002). Every time a new observation becomes available the posterior probability distributions, represented by the particles and associated weights, are then updated using Bayes theorem. A common problem in particle filtering is weight degeneracy, where after some iterations most of the particles have a zero weight. This problem can be alleviated by increasing the number of particles at the cost of an increase in computational demand and/or by resampling of the particles (e.g., Doucet et al., 2001). However, as pointed out by Gordon et al. (1993), a proper treatment of the process noise is crucial in order to avoid that the resampling procedure leads to sample impoverishment, i.e., many particles having high weights because they are selected many times.

In a first case study (Salamon and Feyen, 2009) we assessed whether the particle filter can be used in combination with the distributed model LISFLOOD and the same model setup as used in EFAS, to recursively estimate the uncertainty originating from parameters and errors in the precipitation input for the Meuse catchment. Simulations considering parameter uncertainty only, illustrated that the particle filter provided well identifiable posterior parameter distributions resulting in a reasonable agreement between the observed and the simulated discharges. However, when accounting explicitly for an additional source of uncertainty, i.e. precipitation uncertainty, posterior parameter distributions were significantly different. Predictive uncertainty was enhanced, when accounting additionally for errors in the precipitation input. However, results also illustrated that predictive uncertainty was still not fully quantified, indicating the importance of other significant sources of error (e.g., model structural error, error in evapotranspiration or temperature input), not accounted for in this case study.

In a second case study (Salamon and Feyen, under review) parameter, precipitation, evapotranspiration and model structural uncertainty were quantified simultaneously for the Rhine catchment. Precipitation, potential evapotranspiration, and structural model uncertainty were included via multiplicative error models. Using a semi-distributed calibration strategy, posterior parameter distributions clearly illustrated that the importance of model parameters controlling the fluxes from the different storages in relation to the discharge at the outlet decreases for the catchments located downstream. On the contrary, the importance of channel routing increases, as large amounts of the discharge observed at the outlet are introduced by the inflow from upstream. An analysis of the precipitation and evapotranspiration multipliers showed that uncertainty could be reduced significantly in comparison to the prior distribution for all sub-catchments and that no general bias for those errors exists. Structural model error was significantly larger for the alpine/pre-alpine sub-catchments than for the sub-catchments located further downstream indicating that the hydrological model represents less well the hydrological processes in complex terrain such as the Alps. Finally, although overall predictive uncertainty was well quantified, results also demonstrated that more sophisticated error models are required and that the error of discharge observations, which is a crucial part of the particle filtering process as all the posterior distributions are conditioned on it, needs to be properly characterized during the data collection and should be gathered alongside with the measurement itself.

2.2 Combining a vector autoregressive model with exogeneous input with the Bayesian uncertainty post-processor

Post-processing methods can greatly improve the efficiency of hydrological forecasting systems by the minimization of the error between predicted (forecasted) and observed runoff and by the estimation of the total predictive uncertainty (Krzysztofowicz, 1999). The following approach of data assimilation and error correction will be performed at points of the river network of EFAS, where observed river discharge data are available, and probabilistic forecasts can be produced through the integration of hydrological and meteorological uncertainties.

In order to minimize the errors the operational model predictions have to be put in better compliance with the current, latest available observations. Especially for the removing of the biases from ensemble forecasts various methods have been developed ranging from parametric (Wood and Schaake, 2007) to non-parametric approaches (Brown and Seo, 2010). O'Connell and Clarke (1981) and Refsgaard (1997) reported on different methodologies used for model updating. Besides Kalman Filtering (see for example Ashan and O'Connors, 1994, Szöllősi-Nagy et al., 1997) one popular and simple way of carrying out updating and error correction is by the use of AutoRegressive models with exogenous input (ARX), relating the observed river discharge value y_t at time *t* to the previous discharge y_{t-l} with time lag *l* and the simulated model output x_t at some station. Although the ARX model approach will work well for the very first time lags, model errors usually show time and scale varying properties depending on the season and local weather conditions. This kind of errors can influence the accuracy of the forecast for long lasting periods, like the runoff processes caused by snow-melting, and can be handled most efficiently by the use of wavelet transformations (Bogner and Kalas, 2008). Therefore the observed and simulated time series are transformed to the wavelet domain and then a Vector-ARX model (VARX) is fitted for the different levels of wavelet decomposition simultaneously. After predicting the next time steps ahead for each scale, a simple reconstruction formula is applied to transform the predictions in the wavelet domain back to the original time domain.

Although the updating of the model output according to the latest available observed runoff values is most crucial for the accuracy of the flood forecasting system, the end-user of the forecast system needs detailed information about the quality, reliability and sharpness of the forecast. In the previous sections the different sources of uncertainty have been discussed already. The Bayesian Uncertainty Post-Processor (BUPP) is an excellent method to estimate the full predictive uncertainty, which has been developed by Krzysztofowicz (1999) and is divided into a so called *Hydrological Uncertainty Processor* (HUP), capturing all model uncertainties, the *Input Processor* taking into account the meteorological forecast uncertainty forcing the hydrological model and finally the *Integrator*, which combines the HUP and the Input processor optimally. According to this methodology, the HUP will be applied to the normal quantile transformed (Kelly and Krzysztofowicz, 1997) and possibly error corrected discharge series at first in order to derive the predictive conditional distribution under the hypothesis that there is no input uncertainty. The uncertainty of the forecasted meteorological input is then derived from the combination of deterministic weather forecasts and ensemble predictions systems (EPS) and the Input Processor maps this input uncertainty into the output uncertainty under the hypothesis that there is no hydrological uncertainty.

Therefore the objective of the BUPP is the derivation of the conditional probability distribution of the future observed quantity (i.e. the discharge in the next days) given the available sample of model predictions, by integrating optimally the hydrological and the input uncertainty (see Fig. 1).

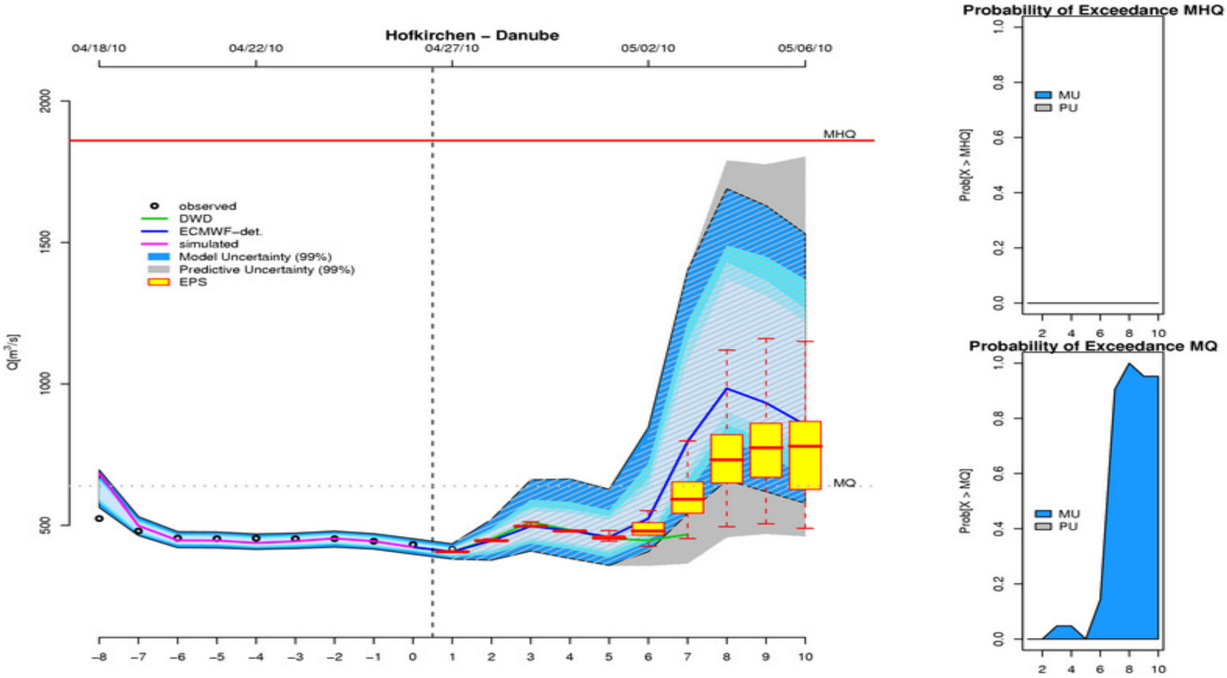

Figure 1: Example of an operational forecast for the Danube river at the gauging station Hofkirchen (Bavaria) showing the discharge forecasts for the next 10 days starting from the 26th of April at 12:00h. Forecasted discharge values are corrected by the use of the method based on wavelet transformation and VARX (Vector AutoRegressive model with exogeneous input). Hydrological uncertainty is shown in blue shades, the predictive uncertainty after integrating the hydrological uncertainty and the input uncertainty (derived from EPS) is shown in grey shades. On the right the probabilities of exceeding two thresholds are shown.

3. CONCLUSIONS AND OUTLOOK

In this paper the possible improvements of the efficiency of medium range streamflow predictions of EFAS by the estimation of the predictive uncertainty and by error analysis and correction methods are investigated. In a first step two different methods of uncertainty estimations are tested, a spatially distributed method based on particle filters and a method based on the Bayesian Uncertainty Post-Processor which is divided into Hydrological Uncertainty Processor (HUP, for model uncertainties), an Input Processor and an Integrator. The Bayesian Uncertainty Processor has been used to derive the conditional probability distribution of the future observed discharge at selected gauging stations given the available forecast sample of model predictions by integrating optimally the hydrological and the input uncertainty. Prior to the BUPP a simple vector auto-regressive model with exogenous input (VARX) and a method based on wavelet transforms is applied to correct the error.

Both methods have shown their capabilities to efficiently deal with uncertainty using the EFAS setup and that they can be useful to derive more reliable and accurate medium range forecasts. Currently, the method based on the Bayesian Uncertainty Post-Processor is being implemented at European scale in a variety of different catchments in order to be evaluated in an operational environment. The next step towards an operational implementation of the particle filter will be a feasibility study for the operational assimilation of discharge data using the posterior distributions of the parameters and error multipliers derived in the previous case studies. Here, special attention needs to be paid to the computational feasibility and to the adaptation of alert thresholds in the flood forecasting system. Furthermore, both methodologies will have to be tested on a longer data set in an operational system in order to evaluate their robustness.

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DECISION SUPPORT SYSTEMS AND DECISION MAKING UNDER KNOWN UNCERTAINTY

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1. INTRODUCTION

Flood managers need an accurate quantitative forecast of rainfall, which they can feed into hydrological and hydraulic models to simulate the resulting flood wave and the inundated areas. Unfortunately, such a forecast can not be accurate due to the highly nonlinear behaviour of the atmospheric system and the land-atmosphere interaction. The model chain adds additional sources of uncertainty, e. g. the availability and quality of input data, the initial and boundary conditions for the models, model parameters and model structure. Human interaction and technical problems may also affect the output of a flood forecast chain. Thus decision making in flood management is inherently uncertain.

Recent developments in forecasting allow for a better quantification of uncertainties. Ensemble prediction systems (EPS) provide a set of several alternative forecasts, which should frame the uncertainty range of the forecasted variables (Toth et al. 2003). Among the numerous ensemble generation methods are physics ensembles (perturbation of model parameters or use of different schemes within one model), multi-model ensembles (combination of different models) and lagged average ensembles (combination of different model runs of a single model). EPS can force hydrological models, which simulate the rainfall-runoff process, river routing and inundation. The uncertainty of these models can also be framed using different techniques. The development of hydrological applications of ensemble forecasts has been demonstrated by several studies (Cloke and Pappenberger 2009 provide a comprehensive review).

Assuming a perfect ensemble (which produces a realistic probability distribution of the variables under consideration), the former unknown (or neglected) uncertainty becomes “known uncertainty”. A probabilistic evaluation of ensemble forecasts can then be used to communicate uncertainty to decision makers. Unfortunately again, ensemble predictions are still not perfect, because there is some remaining unknown uncertainty left due to several reasons, among others:

1) not all information gaps regarding data and initial conditions of models may be expressed by the ensemble;

2) the validity of model parameters within the current situation (for which the parameters have not been calibrated) is questionable;

3) the functioning of and the interaction with the technical systems may be erroneous (and even without predictability of the resulting errors).

Thus there is no guarantee that the ensemble embraces reality. The challenge for the forecaster is to reduce the remaining uncertainty. As many sources of information as possible should be combined. One of the most reliable (but also not perfect) sources of information is observations. Because there is a delay of one to several hours in the transformation of rainfall into runoff (except in the case of flash floods), these observations can be integrated into the forecast by using data assimilation techniques. Another valuable source of information is the judgement of the experienced local forecaster (Blöschl 2008).

2. AN OPERATIONAL FLOOD MANAGEMENT SYSTEM AS A SPECIFIC TYPE OF DSS

When designing an operational flood management system (OFMS), a compromise between computational efficiency, availability of data, predictive capability of the models and the cognitive burden for the flood manager has to be found. An OFMS is typically built from components, which are among the generic components of decision support systems (DSS), namely a knowledge system, a problem processing system and a user interface (language system and presentation system, Dos Santos and Holsapple 1989). Thus the OFMS can be seen as a specific type of DSS.

An OFMS, which supports the uncertainty awareness of decision makers, needs to integrate data from different sources (e.g. EPS forecasts), simulation models (e.g. hydrological models), post-processing techniques (e.g. probabilistic assessment of ensembles), data assimilation techniques and tools for decision support (e.g. analysis of the exceedance probabilities of critical threshold values).

As mentioned in the introductory section, there is a variety of ensemble approaches. For the specific forecast situation, only a subset of the information may be accessible and useful at the same time. Furthermore, only a subset of the problem processing tools may be needed to obtain the desired outcome of the computation. An adaptive systems approach can support the efficient combination of the sources of information (e.g. forecasts and observations), which are available and useful for the current situation and the current user of the system. The OFMS concept presented here follows an adaptive approach in the wider sense. Adaptive DSS in the narrower sense as defined by Holsapple et al. (1993) include additional components for unsupervised machine learning. This means that the system is able to learn and adapt itself in order to improve the quality of the outcome by using the same input data. Extending the adaptation capabilities of OFMS is subject of further research. Nevertheless, DSS are developed to support decision but not to make them – they do not replace the human forecaster nor do they replace the human decision maker. Tackling unexpected errors as well as integrating expert knowledge still requires human interaction with the forecast system, or even the possibility to neglect the output of the system.

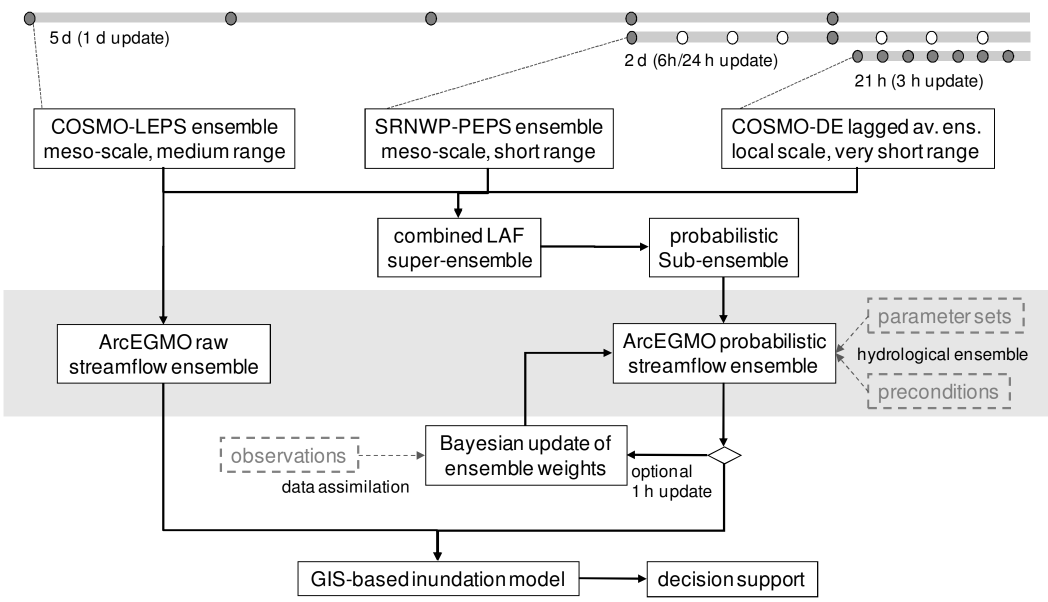

Figure 1: Flow chart of the flood forecast chain (Dietrich et al. 2009a).

The OFMS scheme presented in Fig. 1 combines medium-range forecasts (3 to 5 days lead time), short-range forecasts (1 to 2 days lead time) and very short-range forecasts (< 1 d lead time) from different operational meteorological prediction systems with hydrological models. Medium-range flood forecasts forced by COSMO-LEPS provide the basis for decisions about reservoir management and early warnings previous to a potential large or extreme flood event. Additional short range forecasts from SRNWP-PEPS can be used for issuing flood alerts and first planning of flood defence measures. For the incorporation of forecast refinements with 2.8 km horizontal resolution and 3-hourly update we use the convection resolving COSMO-DE model. The most recent model run can be combined with earlier model runs to build a lagged average ensemble.

Instead of using raw EPS output to drive other domain specific models, recent advances in the calibration/validation and in the probabilistic assessment of meteorological ensemble forecasts allow a sophisticated post-processing of ensembles. Possible tasks are the removal of a bias and the combination of several forecasts to produce a new ensemble, which reflects the probability distribution of the variables better than the original inputs. The meteorological ensembles (raw or post-processed) can be fed into hydrological models to simulate stream flow ensembles.

In the example (Fig. 1) we use the output of the members of the respective meteorological ensembles to force the hydrological models. Thus a stream flow ensemble has at least as many members as the forcing meteorological ensemble. If a hydrological ensemble approach is included (right path within the grey area in Fig. 1), the number of ensemble members increases (combinatorial). The skill of the hydrological forecast strongly depends on the skill of the precipitation and temperature forecast, because these two climate variables dominate the generation of fast runoff processes and snow melt. The OFMS prototype presented in this paper includes the distributed conceptual rainfall-runoff model ArcEGMO (Becker et al., 2002). Most of its parameters have a physical meaning and can be derived from catchment characteristics. ArcEGMO is a modular modelling system, whose modelling kernel can be controlled via an external flood management application in a computationally efficient way. This allows for the simulation of a large number of forecasts near real time within an OFMS. Thus the rainfall-runoff model can simulate ensemble forecasts of stream flow at several points of interest like gauges and vulnerable sites. Alternative approaches do not simulate the combination of all ensemble members, but they process meteorological probability forecasts within the OFMS (Krzysztofowicz 2002).

3. EXAMPLES FROM THE MULDE CASE STUDY: RELIABILITY OF FLOOD WARNINGS DRIVEN BY ENSEMBLE-FORECASTS

The upper Mulde river basin is situated in the Ore Mountains (Germany and Czech Republic). During west-cyclonic rainfall events, which caused several extreme flood events in the past, the uncertainty of precipitation forecasts in location, time and volume is crucial. Thus the reliability of flood alerts is an issue of concern. After a disastrous flood event in August 2002 local authorities reconsidered and redirected flood protection and related disaster management in Saxony (Socher and Böhme-Korn, 2008). The development of the flood forecast scheme presented here was accompanied by local flood managers. The result will be partially included into the operational flood forecast system of the State Flood Centre of Saxony. More details about the Mulde case study can be found in Dietrich et al (2008, 2009, 2009b). Here selected results related to decision making are presented.

One of the topics of the case study was to investigate the reliability of the predictions of the exceedance of flood alert levels. A reliability diagram can be used to assess the probability forecast of a binary event. This diagram plots the observed relative frequency of event occurrence. A complete overview of the reliability of a categorical forecast with a single diagram is not very convenient. Furthermore, a large sample size is needed to produce a meaningful reliability diagram. In the case of severe or extreme flood alerts, there is only a very small sample size if not only one single event. Hamill (1997) introduced multicategory reliability diagrams (MCRD) to tackle these limitations. The MCRD plots the average percentage of observations below specified quantiles. Like the conventional reliability diagram this graph provides information about the reliability or calibration of a probabilistic forecast.

The MCRD in Fig. 2 show the reliability of the probabilistic forecast of the flood alert levels. The latter build up five mutually exclusive and collectively exhaustive categories: no alert, alert 1 (observation), alert 2 (alarm), alert 3 (flood defence, inundation of settlement area), alert 4 (flood defence, risk of high damage and fatalities). We evaluated observed flood alert levels versus flood alert levels simulated by a hydrological model forced by the respective meteorological ensemble prediction systems. Note that the MCRD does not show information about the reliability of the alert level forecast for a single day. It is integrated over the complete forecast period. We assume that the flood manager is interested if the alert levels are predicted for any time step within the forecast period. That may explain, why the COSMO-LEPS forecasts with more than two days lead time do not become significantly more unreliable with increasing lead time (Fig. 2). However, the +24h COSMO-LEPS is more reliable than the other lead times, but still not as reliable as the SRNWP-PEPS, which has only a small bias.

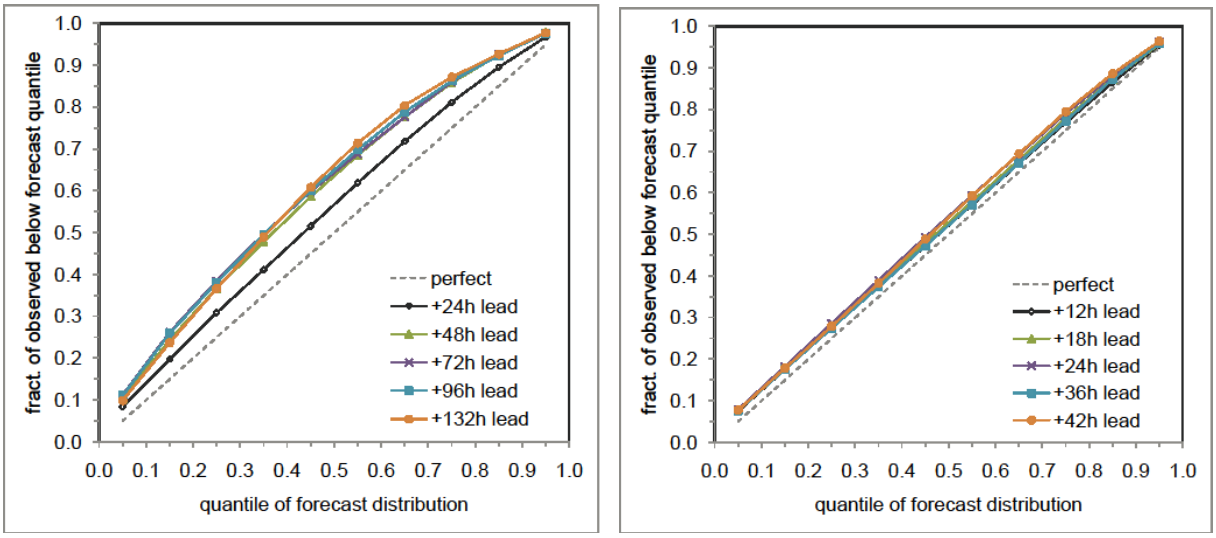

Figure 2: Multicategory reliability diagrams for the flood alert levels simulated with ArcEGMO forced by COSMO-LEPS (left) and the SRNWP-PEPS (right) with different lead times (Dietrich et al. 2009b).

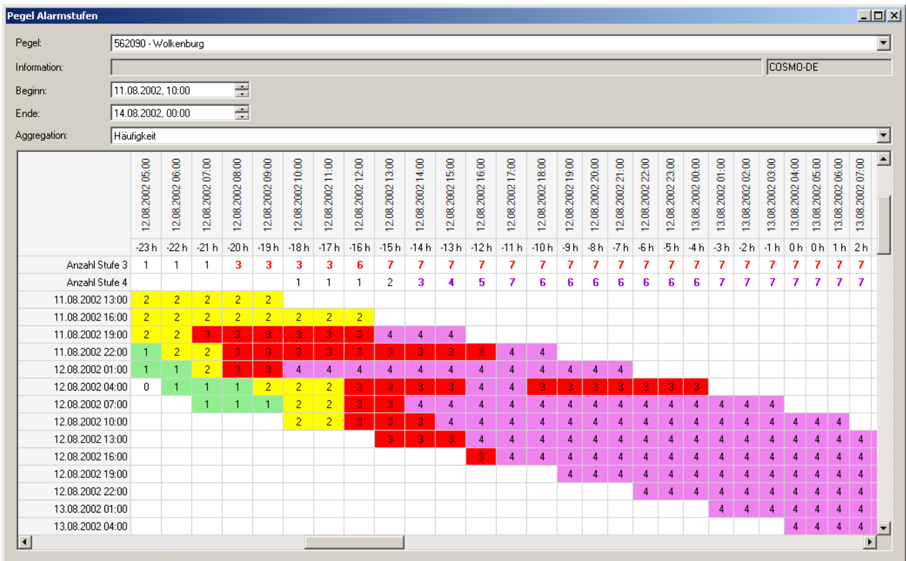

Figure 3: Persistence chart as presented by the OFMS user interface (Dietrich et al. 2009a).

The desired persistence of the decision recommendation over time adds another aspect of reliability. Persistence charts can provide a graphical representation of the predicted value and/or the exceedance probabilities for each time step and for each initialization of the forecast system as predicted by the OFMS (Thielen et al., 2008). Fig. 3 shows an example for a relatively stable hydro-meteorological situation from a hindcast of the 2002 flood event (gauge Wechselburg, COSMO-DE lagged average ensemble). The vertical axis displays the initializations (3 hourly), while the horizontal axis displays the time steps of the forecast (1 hourly). The colours show the respective alert levels. From 11/08/2002 19:00 there were evidences for the potential exceedance of alert level 4, which strengthened with the following forecasts and remained until the event occurred.

4. CONCLUSIONS AND DISCUSSION

Decision support systems can be used to support flood managers in making decisions under known uncertainty. These systems can also integrate tools to update the forecasts when new information becomes available. If practitioners demand a "simple", understandable output, one can display aggregated information like persistence charts.

The time period covered by regular operation of the ensemble forecast systems is small (COSMO-LEPS operational from 2005, SRNWP-PEPS operational from 2004, COSMO-DE operational from 2007). The limited number of available flood prone events is not sufficient to draw decision rules. There have been only two observed events with alert level 2 and above, including the disastrous 2002 flood for the case study. The latter would have been forecasted reasonably well. From this low number of forecasts, the conclusions to be drawn from the MCRD reliability analysis are still rather week for extreme rainfall events. One cannot conclude that the next extreme can be detected as well. More hindcast simulations are necessary to develop better ensemble calibration and post-processing techniques (a hindcast or reforecast is a prediction for a date in the past using the prediction system that is currently operational).

Future research should aim at finding a better compromise between the needs of meteorologists (good representation of climate) and flood managers (accurate forecast of extreme rainfall events). An ensemble with a large spread may be a better ensemble in the sense that it embraces reality more often, providing more hits/less false alarms i.e. a better relative operating characteristic. But on the other hand a larger spread produces a less sharp probability distribution, which means more uncertainty.

Despite some shortcomings, ensemble techniques are promising. Flood managers can struggle for a reduction of uncertainty by using information from different sources including observations. An adaptive DSS approach including data assimilation is recommended for the development of operational flood management systems (OFMS).

5. ACKNOWLEDGEMENTS

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DISASTER MANAGEMENT AND DEALING WITH THE RESPONSE ON FLOODING

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Key words are: evacuation modelling, crisis communication, preparedness, scenarios, measures during water crisis)

1. INTRODUCTION

In flood risk management most attention is spend into prevention and mitigation. The question: What if flooding does occur? has a complete other meaning in countries where on a yearly basis river flooding are present. (See www.FLOODsite.net for background).

The 1953 flood disaster in SW-Netherlands has changed the perceived, but also the real, threat. The decision "never again" and the subsequent governmental and engineering response were able to effectively diminish the probability of the flood risk. Since those interventions the Netherlands has not been confronted with significant and life-threatening flooding and flooding seems to even be perceived as more of a nuisance than a real threat. A flood is no longer an event that *can* happen, but an event that *may* never happen, and mitigation of the risk and disaster management is entrusted to the governmental authorities. The idea that flooding is no longer a real risk seems to have stimulated the increasing human activity throughout the most vulnerable areas of the Netherlands.

After the river flooding in the Meuse and Rhine region in 1993 and 1995 and the Katrina disaster in the US the government has spend large efforts in mitigation to the flood risk and started a Taskforce (TMO) to be better prepared.

1.1 Multiple layer Flood safety approach

Policy developments, an increasing risk awareness and a somewhat heightened sense of urgency enabled the development of a new policy framework for flood risk management, namely 'Water Safety 21st Century'.[2] (National Water Plan). While the policy on flood risk management has historically been primarily focused on prevention, over the last 5-10 years the debate has started to widen the scope of flood risk management, paying more attention to the consequences of flooding. So the policy is based on risks (probability x consequences). Over the past couple of years it has been recognized that a more balanced approach towards water safety is necessary and policy subsequently recognizes the following three pillars:

- Prevention: revision of the prevention policy, including an update of the standards for the protection against flooding for the various dike ring areas;
- Mitigation: more explicit attention to the consequences of flooding in relation to spatial planning and the robustness of infrastructure; Climate change impacts are taken into account as well
- Emergency management: strengthening of the awareness of flood risk, emergency management (capability analyses, planning, and exercises) promotion of a more water conscious behaviour of citizens, companies, policy makers and administrators.

The governance on national level dealing with the vulnerability of the highly populated delta areas try to answer the question: 'How much sea level rise / climate change and subsidence can we cope with before the consequences of global change cannot be managed anymore?' This question has to lead to a need for information services which covers all EU-delta's and coastal lowlands which can support policy development EU-Flood Directive). Next the same question is assessed for alternative adaptation strategies. The thresholds after which a policy, strategy or specific measure will no longer hold are called 'tipping points'. When these points come into view strategies will be reconsidered.

Tipping points are defined by physical (e.g. how much water can be discharged), technical (How stable can a dike be built), economical (when will a strategy be too expensive), spatial and sociological (limits of acceptance) limitations. In reaching the safety level against flooding the 3-layer approach have been adopted by the Dutch government.

1.2 Disaster management

In the chain of Safety (Disaster Management Cycle) the preparation on a flooding and the response to a flooding are well connected by planning, training and exercising in the "cold phase" and evaluation of responses in the "warm phase" (actual flooding), leading to improvements in planning and exercises.

In the figure below preparedness will build up the self reliance and the possibilities for reaction by individuals and various relevant social communities. In the presentation I will highlight the Deltares knowledge driven opportunities related to the disaster management planning and the decision making by authorities during actual flooding. Deltares is coordinating a number of projects which have to result in better prepared authorities and citizen during flooding.

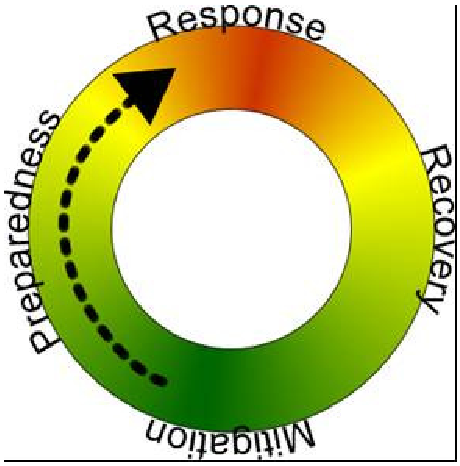

Figure 1: Relevant activities along the safety cycle to be adopted in the planning, training & exercising and preparation with respect to disaster.

1.3 Building an International research Network

Netherlands-United States Water Crisis Research Network (NUWCReN) has been formed as a reaction on Katrina. Researchers from institutions in the Netherlands (NL) and the United States (US) have conducted several joint meetings to discuss potential collaboration related to issues identified after the Hurricane Katrina disaster and to the high-risk profile of the Netherlands. Experts from these institutions participated as observers for the national flood exercise “Waterproef” in the Netherlands and have used this exercise to help identify potential research issues. These meetings have identified the need for knowledge transfer and collaborative knowledge development among US and NL research institutions. This proposal seeks funding for the creation and management of a Netherlands—United States Water Crisis Management Research Network (NUWCReN). The result of this work will be the establishment of a network of parties who will generate and share relevant knowledge to support the Dutch government in crises where flooding are causing damage and casualties.

The objectives of the project NUWCReN are getting knowledge based on lessons learned into the Dutch disaster management plans where the human factors are concerned. Getting experiences and new knowledge into the Dutch water crisis management system has large effect on the success of managing the response (Evacuation, early warning, etc.)

The identified topics for research are:

- Planning, preparing, exercising, learning

- Managing the response to disasters and catastrophic events
- Human behavioural response to disasters and catastrophic events
- Community vulnerability and resilience
- Response capacity and capability
- Public Communication/ Information

1.4 Conclusions: Water crisis management improvements

The National FLOOD exercise WATERPROEF in November 2008 all lessons learned where focusing on information sharing, organizational issues and less about uncertainties related to human behaviour during disasters (**social system**). Also the exercise on international assistance FLOODEX in September 2009 was used as an opportunity to learn about the **political system**. The expertise from the US is based on surveys held amongst persons with potential hazards of frequently appearing disasters like floods and hurricanes. This expertise has to be brought into our **control system** (planning, communication, training, exercising, and evaluation).

Finally the strong position of Deltares with the description, analysis and forecasting of the **natural/environmental system** completes the consortium with interdisciplinary science and research.

The evaluation of WATERPROEF learned that a large number of improvements should be made on technical, organizational and social aspects, like:

- Working with scenario's to be more flexible in actual large scale, unexpected disaster situations, which never are predictable in development on spatial scale and in time.

- From local to regional to national decision making must be based on SMART information sharing and stake holder involvement during preparation.

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MORE INFORMATION IS NOT ALWAYS BETTER: COPING WITH UNCERTAINTY IN ADAPTIVE WATER MANAGEMENT

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There is no doubt that uncertainty constitutes a dominant issue in present water resource management (Pahl-Wostl, 2007). Being translated into risk, coping with uncertainty has become one of the major challenges that decision makers have to face. This situation has led to a reformulation of how natural system are managed, triggering the development of new managing approaches, such as adaptive water management, which claims that to cope with uncertainty it is necessary to create solutions that are flexible and easily to adapt to emergent conditions (Gunderson et al. 1995; Lee, 1999; Pahl-Wostl, 2007; Walters, 1986). To this end, adaptive management proposes to build the capacity for collective action, promoting participation and social learning as the base of decision making processes. However, changing the way in which natural systems are managed also requires a change in the way in which uncertainty is handled (Brugnach et al. 2008). From this perspective, here I provide a set of strategies that decision makers can use in order to deal efficiently with different types of uncertainty in adaptive water management.

1. UNCERTAINTY: WHAT IT IS?

Commonly uncertainty is regarded as a deficit in information that can be eliminated, reduced or quantified by pursuing more research, collecting more data, or relying on expert opinions. Under this view uncertainty is considered as an attribute associated with the quality of scientific or technical information that is used to make a decision, and it indicates what is *not known* about a particular river basin matter (e.g., the magnitude and occurrence of flood events). However, decisions are not only based on factual information, but they are also mediated by the experiences, know-hows, values, beliefs of the decision makers. In addition, when dealing with river basin management issues, decisions are not made individually but collectively, involving the participation of multiple stakeholders. In these circumstances, there can be many different, and valid, ways of interpreting the same situation. As such, uncertainty can also indicates what is *known differently* about a particular river basin matter. For example, while for one person, building a dike is the appropriate response to cope with floods, for another one flood plains constitute a better solution.

Considering this broad perspective, *uncertainty refers to the situation in which there is not a unique and complete understanding of the system to be managed (Brugnach et al. 2008).*

2. DIFFERENT TYPES OF UNCERTAINTY

Following the above definition three types of uncertainty have been identified (Brugnach et al. 2008): unpredictability, incomplete knowledge and multiple knowledge frames (ambiguities).

Unpredictability refers to the inherently unpredictable aspects of a system, due to chaotic or complex system behaviour. With this kind of uncertainty, we accept the unpredictability of the system as something that will not change in the foreseeable future.

Incomplete knowledge refers to situations where we don't know enough about the system, or where our knowledge about it is incomplete. This can be due to a lack of information or data, to the unreliability of the data that is available, to lack of theoretical understanding, or to ignorance. This kind of uncertainty can, in some situations, be reduced when having the necessary time and means.

Multiple knowledge frames (Ambiguity) refers to different, and sometimes conflicting, interpretations that exist about river basin managing problems. This kind of uncertainty can be called ambiguity and results from the presence of multiple ways of understanding or interpreting a situation, which can originate from differences in professional backgrounds, scientific disciplines, value systems, societal positions and so forth. Under the presence of ambiguity it is not longer clear whether or not there is a problem, or if there is, what the problem or its solution are about.

To make the distinction among the different types of uncertainty is important, since it leads to different strategies to handle it. Generally speaking, it can be said that to deal with variability it is necessary to accept that there are aspects of the problem that cannot be known. To handle incomplete or lack of knowledge, more research or data collection can serve to eliminate or reduce uncertainty. To handle ambiguities it is necessary to learn how to deal with differences in interpretation and to be able to develop a common understanding about the water management problem among those that participate in the decision making process. While strategies to cope with variability and incomplete knowledge have been subject of extensive research, little has been said about how to cope with ambiguity. Below I outline some of the strategies to cope with the three types of uncertainty, making particular emphasis in those to cope with ambiguity. While the list of strategies presented is not meant to be exhaustive, neither to restrict the use of strategies to only one type of uncertainty, it provides a clear view of the diversity of strategies than can be applied under different circumstances.

3. STRATEGIES TO SUPPORT: ACCEPT NOT TO KNOW (BETTER)

To face with a (partially) unpredictable and (partially) uncontrollable phenomenon that has potential negative effects there are several relevant strategies. Strategies can be summarized as:

- To identify multiple possible future scenarios and to develop *robust solutions* which are useful under each of the different scenarios.
- To apply a *diversification* of the measures or solutions, to ensure that one or more measures will be effective under each of the possible scenarios, even when some of the measures could fail (e.g., using dikes and floodplains).
- To damage control, or to adapt to an unpredictable uncontrollable phenomenon by dealing with the consequences and not with the phenomenon itself (e.g., physical or financial damage control in the event of a flood).
- To combine multiple strategies to maximally control the negative effects in the chain of consequences (e.g., combining robust solutions with damage control).
- To apply temporary adaptation strategies: measures that are feasible within the timeframe of an unfolding event (e.g., a storm surge barrier that is closed only under extreme weather conditions).
- To improvise. This implies that the strategies are not planned beforehand but thought up and implemented in the time frame of the unfolding events. This strategy relies on good monitoring, communication and coordination capacity in crisis situations.

4. STRATEGIES TO SUPPORT: WORK ON IMPROVING KNOWLEDGE

In cases of lack of knowledge uncertainty could be reduced or even eliminated by carrying on more research, collecting more or better data, or assessing how lack of knowledge can affect the description or understanding of a situation.

Relevant strategies can be summarized as follow:

- Range estimation (confidence intervals)
- More data gathering and scientific research to complete or improve factual knowledge base
- Use simulation models to evaluate implications of imperfect knowledge
- Uncertainty propagation in models
- Use expert opinions
- Improve communication between scientist and decision makers

5. STRATEGIES TO SUPPORT: LEARNING TO DEAL WITH DIFFERENCES

Learning how to deal with difference is essential to cope with multiple, and sometimes incompatible, perspectives about a problem and its solution. While this situation, in some cases can be corrected by more information, “more is not always better”. In this case solutions are not a matter of reaching a better description of the system but of accepting and dealing with the fact that there can be many different, and valid, ways of making sense of reality.

Cognitive problem-solving: This strategy aims at finding solutions to problems by trying to eliminate differences by invoking scientific evidence. In this approach, a scientist or expert uses factual information to objectively communicate and inform others about his or her scientifically based insights into a problem.

Persuasive communication: This strategy aims at dissolving ambiguities by communicating the meaningfulness of one particular frame of reference. Even though similar to the cognitive approach, in the sense that it involves actors whose expertise ought to be communicated, it differs in its emphasis on creating a joint definition among those experts and target group representatives, whose involvement and competencies are oppositional. The expected outcome of this approach therefore is that the target group will adopt or imitate the argued expert opinion.

Dialogical learning: As the name indicates this strategy suggests handling of frame differences through dialogue and learning. The underlying rationale is that by constructive and reciprocal communication it is possible to develop a mutual understanding of how different solutions will influence different actors, and could provide more robust solutions to complex challenges. In this way actors can learn about each others perspectives and eventually change their own views during this process. So, ambiguities are handled by engaging all actors in an interactive process of communication in the search for a shared view. In this approach all actors must be considered as equally respected partners with equally valid opinions.

Negotiation approach: This strategy aims at reaching an agreement through negotiation despite the frame differences. To this end actors engage in information sharing and positioning strategy. This is different from the dialogical approach in the sense that actors take or hold strategic positions, and not necessarily communicate, their individual goals or listen to other actors point of view. Different negotiation strategies are possible, from more integrating win-win situations to more distributed ones. Many authors support the idea that this type of negotiation is more realistic than dialogical approaches.

Oppositional modes of action: This strategy is based on the idea of imposing a particular frame through power strategies or restoring the power balance between different frames. Mutual negotiation or fights are the vehicles for this type of actions. As a result, the application of this strategy could lead to freeze or dominance of certain powerful groups, which means that only certain views will be accepted as valid. This situation is encountered when parties have a history of confrontation and lack of collaboration. Conflicts can be defined as cold or hot depending on how much the interdependency among parties is recognized.

Making present / Co-presencing: This strategy attempt to initiate social innovation by changing not only the way actors approach their problems, but in addition, how they manage their roles and themselves as change agents within their roles. This strategy has similarities with dialogical learning by following systemic approaches, but in addition includes psychodynamic approaches for analyzing situations and person, group, organization interrelationships. There are two main ways in which making present / co-presencing can take place: Organisation-in-the-mind-workshops and Co-presencing.

6. CONCLUSION

Dealing with water management issues implies having to cope simultaneously with multiple sources and types of uncertainty. Here, I have enumerated a series of strategies to handle variability, lack of information and ambiguity. As such, handling uncertainties can imply engaging in very distinctive and diverse activities. It becomes the responsibility of the analysts to determine which of these strategies, or combination of them, are appropriate and applicable in each situation. While in some cases it can be argued that with more research or data collection, uncertainty can be reduced or eliminated, ambiguity requires a different approach. Under the presence of ambiguity, learning how to deal with differences constructively becomes essential for finding solutions that can adapt to changing conditions. As suggested by adaptive management, this can be achieved through reflections, dialogues and negotiations.

7. ACKNOWLEDGEMENTS

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QUANTIFICATION OF UNCERTAINTY IN FLOOD RISK ASSESSMENTS

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It is widely acknowledged that risk analyses should indicate the reliability of the risk quantification. Downton et al. (2005) have shown that information on the uncertainty is important for more informed decisions, since decision makers may have differing perspectives, different risk attitudes (risk-neutral, risk-averse) or cost-benefit ratios of precautionary measures. However, it is not standard practice to explicitly analyse the uncertainty bounds of risk estimates.

We give an overview on studies which quantify the uncertainty of flood risk analyses. Here, risk is understood in a broad sense: it results from the interaction of hazard and vulnerability and is defined as the damage within a certain time period that is exceeded by a given probability. To complement risk statements with information on their uncertainty, it has been proposed to separate two fundamentally different types of uncertainty: aleatory and epistemic uncertainty (e.g. Merz and Thieken, 2009). Aleatory uncertainty refers to quantities that are inherently variable in time, space or populations of individuals or objects, and is described by probability distributions. Epistemic uncertainty results from incomplete knowledge and is related to our inability to understand, measure and describe the system under investigation, e.g. a lack of knowledge about quantities that have fixed, but poorly known values. By separating both types of uncertainty, the flood risk analysis results in a flood risk curve, representing aleatory uncertainty, and in associated uncertainty bounds, representing epistemic uncertainty. This separation reveals the uncertainty (epistemic) that can be reduced by more knowledge and the uncertainty (aleatory) that is not reducible.

There are not many studies published which quantify the uncertainty of flood risk estimates. Typically, uncertainty bounds are large when formal and comprehensive uncertainty analyses are performed. Flood risk analyses are dealing with extreme events and failure scenarios which have hardly been (or not at all) observed before. Therefore, “observations of risk” are seldom available which impedes constraining and validating risk analyses. Data scarcity implies that uncertainty statements are associated with considerable subjectivity and that they are themselves highly uncertain. Given this subjectivity, uncertainty analyses should be accompanied by transparency and honest reporting of assumptions and methodologies (Hall et al., 2007). Attention has to be given to the widespread phenomena of overconfidence and illusion of certainty, since it has been shown that people (experts and laypeople) tend to overrate their knowledge (Hammitt and Shlyakhter, 1999).

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ON THE WAY TO ENSEMBLE HYDROLOGICAL FORECASTS: LESSONS LEARNED FROM MAP D-PHASE

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Abstract: MAP D PHASE is a Forecast Demonstration Project of the World Weather Research Programme (WWRP) that is tied to the Mesoscale Alpine Programme (MAP). D-PHASE stands for Demonstration of Probabilistic Hydrological and Atmospheric Simulation of flooding Events in the Alpine region. Its goal is to demonstrate the ability of reliably and operationally forecasting orographically influenced (determined) precipitation in the Alps and its consequences on the distribution of run-off characteristics. During the D PHASE Operations Period (DOP) from June to November 2007 an end-to-end forecasting system was operated and a vast amount of data has been analysed and evaluated. The present contribution aims at briefly summarising the approach and components of D-PHASE. A number of lessons learned will be drawn from the outcomes. These include consequences concerning the optimal use of the D-PHASE/COPS joint data set as well as open questions and further directions.

Keywords: Heavy precipitation, flash flood, forecast demonstration, WWRP, high-resolution numerical weather prediction, probabilistic forecast.

1. INTRODUCTION

A Forecast Demonstration Project (FDP) of the World Weather Research Programme, quite generally, aims at demonstrating the advances a R&D activity has brought to operational atmospheric forecasting. Thus a FDP deals with the forecast of weather with international relevance (high impact weather); demonstrates a clear advance in forecasting capability; provides clear evaluation protocols and is characterized by an expectation of success. D-PHASE is the FDP in relation to the Mesoscale Alpine Programme (MAP, Bougeault et al. 2001) and aims at demonstrating an end-to-end warning system for flood events based on high resolution deterministic/probabilistic hydrological and atmospheric modelling in the Alpine region. Some of the D-PHASE essentials are summarized in Table 1. The forecasting system's centre piece was a Visualization Platform (Figure 1), on which warnings from atmospheric and hydrological models (both deterministic and probabilistic) and corresponding model fields were displayed in uniform and comparable formats. Also, meteograms, nowcasting information and end user communication was made available to all the forecasters, users and end users. From June to August 2007 the COPS (**C**onvective and **O**rographically induced **P**recipitation **S**tudy, Wulfmeyer et al. 2008) mission planning team was among the D-PHASE users. COPS provided high-resolution observational data for a sub-area of the D-PHASE domain that can – from a D-PHASE point of view - be employed for model verification and reliability assessment.

2. RESULTS

Details on D-PHASE, including background, organisation and scientific results can be found in Arpagaus et al. (2009) and Rotach et al. (2009). The more hydrological aspects are summarized in Zappa et al. (2008). Here we only focus on the main achievements and point to directions for further analysis. Just as MAP had proved the feasibility of atmospheric/hydrological coupling, D-PHASE successfully demonstrated its operational use and extension to ensemble techniques. Judging from preliminary conclusions by atmospheric forecasters (Rotach et al. 2009) this is not only an advance in technical terms, but also helps both communities to take into account the respective other's sphere (hydrosphere vs. atmosphere) in order to improve the decisions and forecasts in one's own. This might be a 'lesson learned' that goes way beyond the present atmosphere-hydrosphere system and should be kept in mind for other applications of atmospheric modelling (such as air pollution dispersion or agro-meteorological applications).

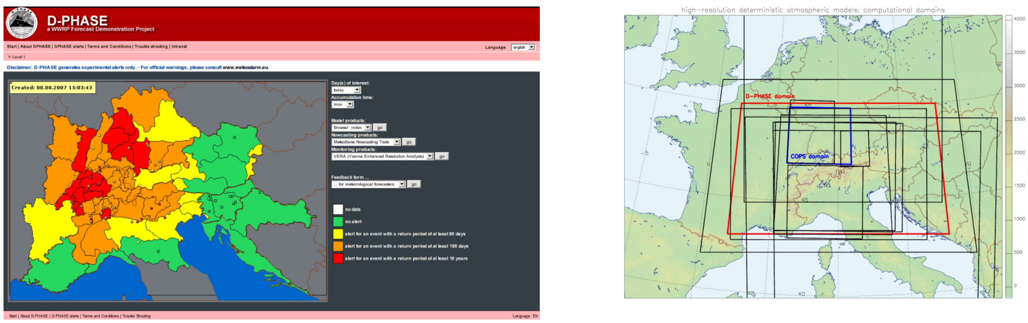

Figure 1: Left: Screenshot of the Visualization Platform (VP) for August 8 2007, level 1 (Alpine vide view); right: model domains for high-resolution atmospheric models including the D-PHASE (red) and COPS (blue) domains. Both from Rotach et al. (2009).

Clearly, the single most important factor of success for D-PHASE was the interoperability of all the models: common formats, common warning levels and common routines to actually determine the warnings from the model outputs rendered the results comparable and therefore highly valuable. The possibility of comparing objective model verification (deterministic and probabilistic) for a substantial number of models and approaches with subjective evaluation of D-PHASE results (Rotach et al. 2009, for details) makes the D-PHASE data set quite unique.

This available data set together with detailed observations due to COPS allowed to

- systematically demonstrate the additional value of very high-resolution atmospheric modelling;
- investigate the properties and performance of Ensemble Predictions Systems both for atmospheric and hydrological models. Examples can be found in Arpagaus et al (2009) or Zappa et al. (2008).
- study predictability of convection processes and convective initiation using the present model results in connection with the observational results of COPS;
- benchmark models of all types by comparing them with a range of other models of the same category, or even other model types;
- systematically evaluate nowcasting tools such as the position forecast of convective systems in the Thunderstorms Radar Tracking (TRT) tool of MeteoSwiss using the available data, and possibly extend their functionality by introducing model products;
- judge the end user feedback on its own grounds, and compare it to the 'objective' verification results - thus learning even more concerning the improvement of the overall forecasting/warning system.

The D-PHASE data set, in conjunction with the observational data set due to COPS is available as a testbed for atmospheric convection, in combination with orographic precipitation and coupled to hydrological modelling. The WWRP working group on Meso-scale Weather Forecast Research (WG-MWFR) has included the D-PHASE/COPS data set for this purpose in their strategic planning.

D-PHASE Operations Period (DOP)	June-November 2007	COPS (Jun-to Aug) MAP (Sep-Nov)
D-PHASE area	> 40 catchments across the alps	
Participants	> 30 institutions	Hydro/Met Services Universities Research institutions
Target	Forecasting system for precipitation and flooding in the Alps	End-to-end
Instrument	Visualization Platform	Uniform formats
Approach	Numerical modelling, nowcasting → 30 atmospheric models → 7 different hydrological models → Radar, Satellite and analysis tools	Probabilistic & deterministic

Table 1: Summary of some D-PHASE facts.

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MEET THE PRESS!
NOBODY CARES ABOUT FLOOD PREVENTION...

Joachim Mahrholdt

ZDF German Television, Environment Department

TV news, radio broadcasts, the national press do not talk or write (enough) about us, you might say. A common complaint. Not only hydrologists often feel neglected by the media. The same holds true for practically all who think they are doing something useful and necessary for society and are not being estimated as they expected to be.

So: who is to blame? Is this lack of interest due to the ignorance of the media, due to the famous superficiality and shallowness of journalists, who rarely seem to care about the important daily work of scientists?

Or is it the fault of those who are in charge of flood forecasting and prevention, on the scientific side, but also in administration or protecting institutions? Do they sell themselves and their concern with sufficient fantasy and commitment?

Or is it a problem of the matter itself? Is flood prevention for most people really an issue not worth caring about?

I am sure this latter possibility is certainly not the case.

In my opinion the problem should be not too difficult to solve. It is a problem of expectance and deception. What do scientists expect from the media? What is their message to the public? Do they really understand how mass media function, how journalists think and work?

Or do they perhaps expect publicity media have problems to offer – in normal times. Flood forecasting and prevention is not comparable to real flooding, of course. But even flood prevention, modelling, forecasting might hide stories that are worthwhile reporting on. You just have to find them.

Therefore I think it reasonable and instructive to make contact with journalists, to seek communication with the media. Explain your research to them, tell them what scenarios you are discussing in the scientific community, what measures should be taken to prevent flooding disasters.

Begin by inviting one journalist to your institution, without expecting an article, just for a conversation in private. Perhaps you will get some advice how to consider bringing your work into the view of the broad public. Tell them as well about the difficulties you face sometimes in making your point as a contrast to pressure groups.

Perhaps it will not be your last attempt to cope with the media before they knock at your door on the occasion of the next flooding...

So, don't hesitate: Meet the press!

WARNING COMMUNICATION, COMMUNICATION WARNING

Dominique Bérod

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1. INTRODUCTION

The modern management of flood hazards comprises three complementary elements: spatial planning, structural measures, and warning, alarm and evacuation plans. In addition to these elements, which mainly involve the authorities, individual insurance cover is also required. As natural processes producing floods are still not fully understood and as their evolution remained uncertain – in particular in a context of climate change – the organisational measures during a crisis have become ever more important. Flood warning systems have the advantages of being less expensive than flood protection structures, being reasonably fast to implement and, above all, of being flexible and easy to adapt to new experience, knowledge and observations. They are also useful in two further respects: first, they allow to reach a minimum level of safety while preparation is made for structural measures and, second, they complement these measures by enabling the management of remaining risks.

To be effective, flood warning systems must fulfil the following five general conditions:

1. Analysts and decision-makers must have access to comprehensive information about the current state of the rivers.

2. Meteorological and hydrological forecasts must be made available in due time and must be sufficiently reliable and accurate.

3. Specialists must be in a position to generate a critical synthesis based on the results provided and to propose solutions to the decision-makers.

4. The numerous actors involved in the area of natural hazards should be organised and well prepared.

5. The information available to the authorities, in particular warnings, should be forwarded to the relevant target groups in due time via dedicated communication channels. The entire warning chain should work seamlessly and without interruption.

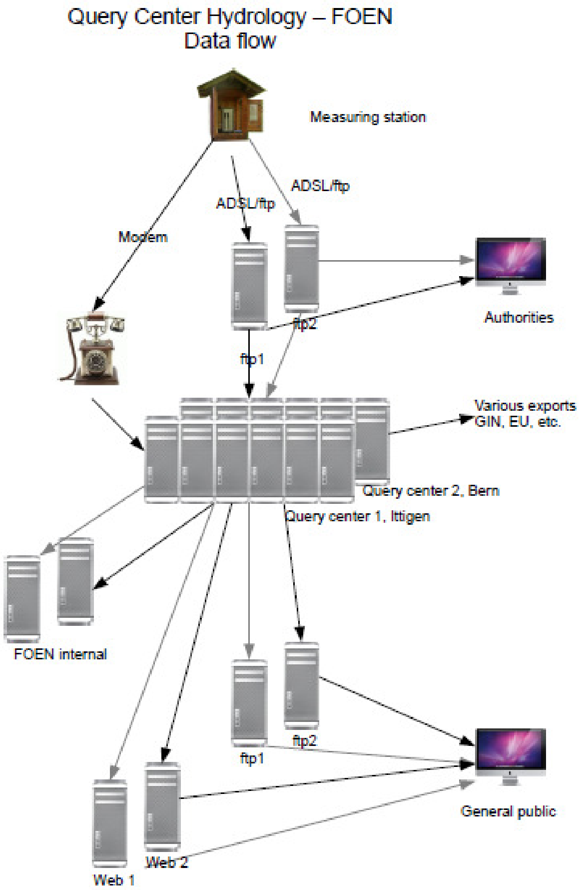
We shall now present the procedure adopted for Switzerland in the area of flood management with particular emphasis on the aspects of information and organisation.

2. WARNING COMMUNICATION

2.1 General procedure

The hydrological data from 210 national stations – out of around 300 which make up the Swiss network – are transmitted automatically and centrally as illustrated by the example shown in Figure 1.

(a) Discharge and water level network



(b) Data transfer

Figure 1: Swiss hydrometric network

The collected data are distributed in raw form on the internet and freely accessible to all. The data are processed, checked and, if necessary, corrected as quickly as possible before being considered definitive. This automatic transmission of the measurements enables the monitoring of the hydrological behaviour of the main Swiss catchment areas. Synthetic graphs presenting the state of water courses in relation to either mean flow rates or flood statistics help to provide a general picture of the situation.

The measured data generally support the flow forecasts produced – for now – at several calculation points on the Rhine (Figure 2). Initially intended for use in the navigation of this river in the 1980s, Switzerland's forecasting system is now being expanded rapidly to facilitate the response to the new challenges posed by flood protection.

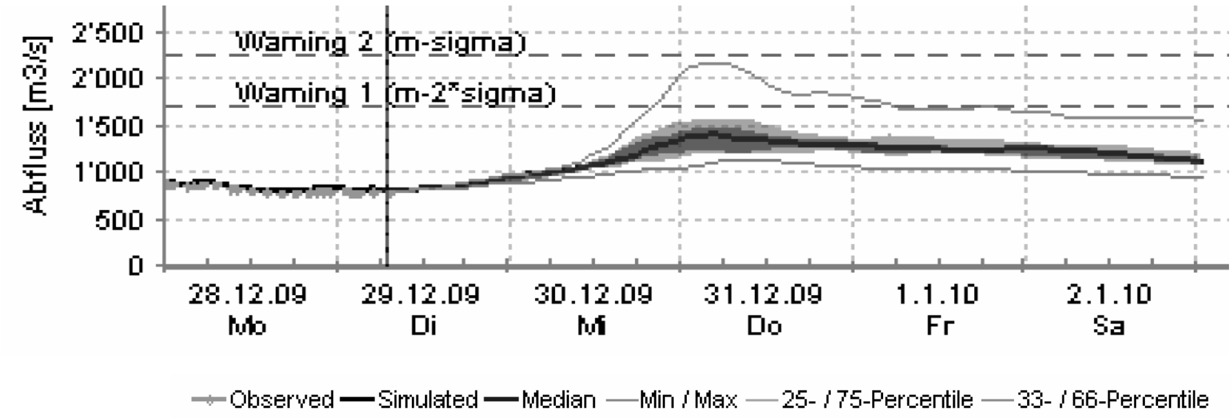


Figure 2: Example of flood forecasting on the Rhine

Developments are already under way or in planning at institutional, systemic and hydrological levels. At institutional level, the Federal Office for the Environment is preparing the extension of forecasting to the entire territory of Switzerland, but remaining on a national or regional scale in support of the cantons. These general forecasts will enable the transmission of flood warnings for the entire territory of Switzerland if required. With respect to the systemic elements: because flood forecasts must be guaranteed at all times, a stand-by service is provided and the FEWS system, which provides the forecasts, is automated to the maximum possible extent so as to win time for the interpretation of the results; this, in turn, guarantees the quality of the forecasts. Finally, in terms of the hydrological element, complementary models will enable the comparison of the results and the identification of the uncertainties inherent in the field of hydrology. A process aimed at assessing the quality of the forecasts and improving their robustness has also been initiated.

These improvements will enable the reinforcement of the role of flood forecasts in the anticipation of risk situations.

This information is used by numerous actors: i.e. crisis intervention specialists and managers at national, regional and communal levels and private individuals who can protect themselves against imminent risks on a personal level. The provision of relevant information to both the authorities and individuals guarantees the success of the strategy for protection against natural hazards.

However, information alone is not enough. Actors on all levels should be organised and trained so that they know what has to be done in the event of a crisis. Constant dialogue should also take place between the different sectors involved, i.e., natural hazard experts, authorities responsible for crisis intervention (civil protection), and the population, and between the different levels of the administration.

2.2 Warning tools

The flood forecasts constitute the basis of the flood warnings. Switzerland provides three complementary tools to enable the latter to fulfil their objectives: an information platform, specialist crisis staff and an organised structure for providing information to the population. These three tools are presented in brief below.

As shown in Figure 3, a natural hazards information platform, which is known as GIN and has been in operation since March 2010, presents all of the information and data generated in relation to meteorology, hydrology, avalanches and earthquakes.

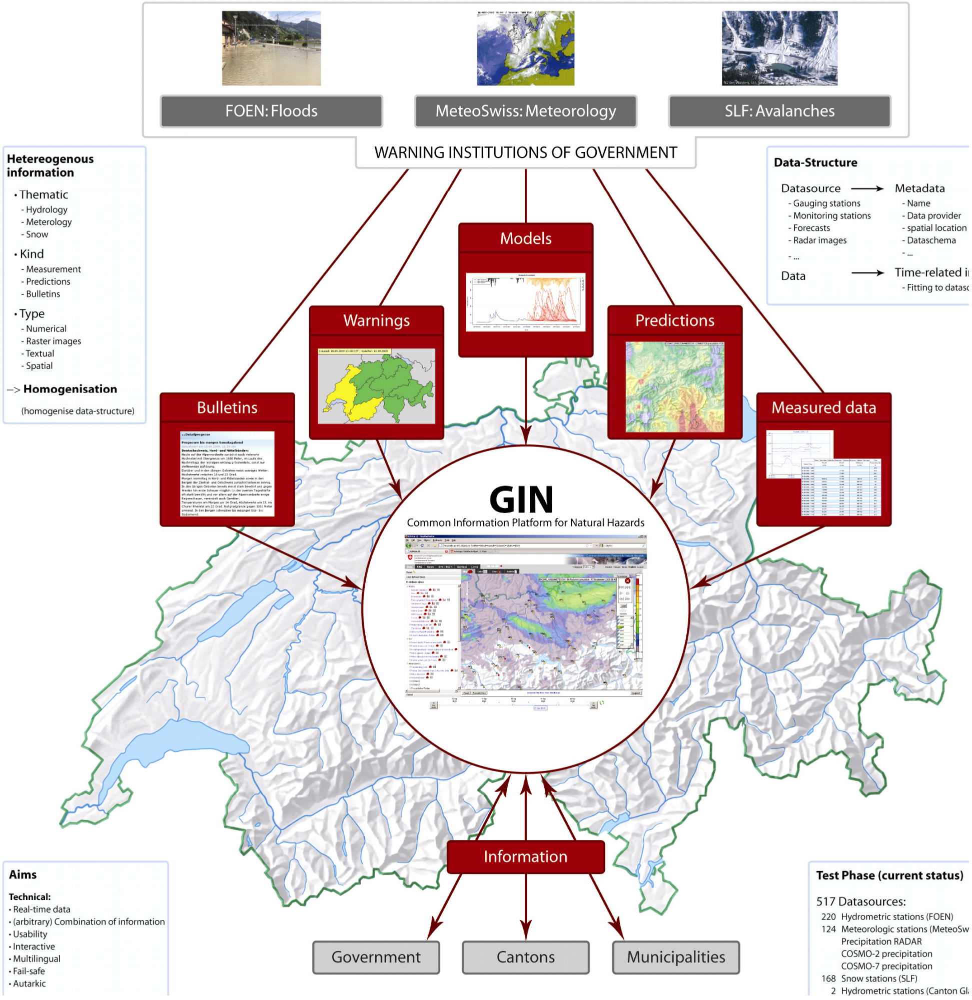


Figure 3: General organisation of GIN in Switzerland

The information presented by GIN comprises, in particular, recently recorded and current data and forecasts. This platform, which is mainly aimed at natural hazards experts working at cantonal and federal levels, complements the existing technical information provided for the operational units. It will also be possible to make the second phase of the GIN platform, which is currently still under development, to the general public.

The second tool, i.e. the specialist crisis staff, is intended for the coordination of actions in the event of a very large scale natural hazard event affecting a significant proportion of the national territory, in particular when the coincidence of a number hazardous events is feared (for example, flooding and mass movements). The specialist crisis staff, which includes experts and mangers from each of the affected areas, meets to prepare and transmit warnings to the authorities and population; the team also prepares combined information for dissemination among the cantons and general public. Figure 4 shows the organisational chart for crisis organisation within the Federal Office for the Environment.

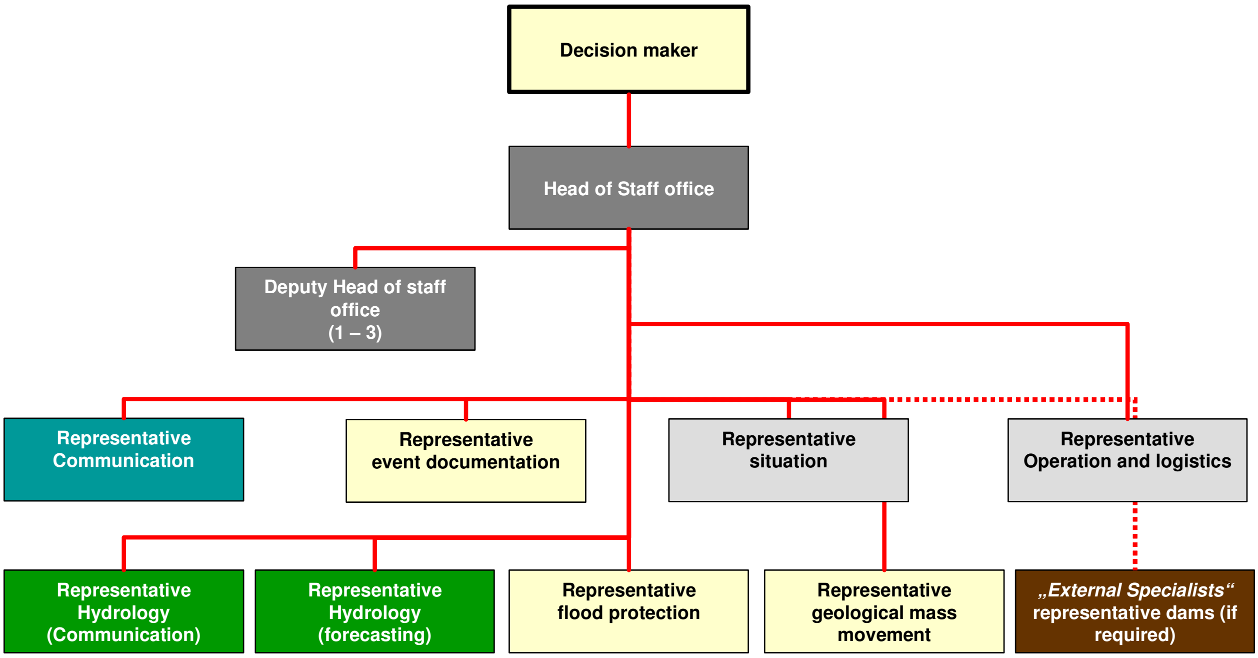


Figure 4: Crisis management organisation within the Federal Office for the Environment

Although it is essential that the organisational provisions and the assessment of the general situation be as centralised as possible, it is important not to lose sight of the fact that actual crisis management takes place at local level. For this reason it is important that the local authorities be able to add local information to the forecasts and to the general or regional warnings. This local information takes into account observations made in situ and should benefit from the experience and knowledge of local managers. The latter should, therefore, have access to ad hoc local information. In order to ensure that the warning messages and information fulfil their objectives among the population, it is important to involve representatives of the media from the outset who, in accordance with new legislative provisions, are obliged to transmit warnings to the population corresponding to the highest levels of risk.

2.3 Communication warning

Needless to say that, notwithstanding this legal obligation, the media fully retain their freedom of speech. Therefore cases may arise whereby the announcement of an imminent risk does not come from the authorities but from individuals or experts who do not belong to an administrative body. Such announcements must also be treated seriously: first, to verify their plausibility and, second, to launch an official procedure if they prove well-founded, or to issue a counter-communication if the risk is unproven. “Crying wolf” should be avoided in such situations and every attempt should be made to retain the trust of the regional and local authorities and of the population. The enormous influx of requests for information should also be kept under control and information specialists should have sufficient resources to deal with all cases.

To ensure a fast and targeted response in such cases, the two definitive requirements are good preparation and effective communication.

3. CONCLUSIONS

Natural hazard prevention requires crisis organisation and its success depends on three equally important elements:

1. The authorities responsible for natural hazards, in particular in the area of flooding, should be able to call on the support of highly experienced specialists. The latter should have the very latest technology at their disposal so as to be able to ensure the monitoring of the hydrographical system through reliable and high quality data, to produce equally reliable forecasts and to provide the necessary information for the transmission of warnings.

2. The authorities should be organised in terms of both the different hierarchical levels and the different areas of responsibility involved. The different actors should be known to each other and be accustomed to cooperating on a multidisciplinary basis so as to be able to alert the population effectively enabling it to respond in a suitable way in the event of a crisis.

3. The communication between the authorities, on the one hand, and in the management of the population, on the other, should be very well prepared so as to anticipate not only risk situations but also to defuse the inevitable false alarms, thereby also enabling the avoidance of unnecessary errors.

The aims of prevention will attained if the relationships between the partners are based on trust generated through solid scientific information, meticulous technologies and smooth organisation, and these elements are orchestrated optimally through high quality communication.

THE MEDIA DO NOT REPORT ON FORECASTS, THEY REPORT ON EVENTS

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In risk communication discourse it is commonplace to state that timely, accurate and understandable information and communication may reduce damage to property, may increase public understanding and in the end save (human) lives.

However, what is meant with information and communication is often not made explicit. Implicitly information is then top-down, one-directional, from one point to many, sometimes interactive. Information is further about leaflets and brochures distributed to households, it is about instructional videos, it is about homepages of the different authorities – but it is not specifically about mass media and journalistic reporting.

Mass media as a technical channel of information diffusion and as journalistic coverage of events are differentiations of one common feature of public communication. But this differentiation is not so well understood in risk communication. Both aspects can very well go together; but they can and will diverge.

Focusing on both aspects of mass media and journalistic reporting it can be stated that mass media may provide information to the general public in each phase of a disaster life cycle.

They may cover identified risks and raise awareness in the community. They may serve as the mouthpiece of the authorities. They may alert concerned people and provide messages what to do in unfolding events. They may transmit breaking news. They may serve as an information infrastructure when all other communication infrastructure is overloaded or even broken down. They will report in full the events taking place. They will speculate about the developing disaster and the most worst case to expect. They will count the dead and injured bodies and calculate the damages to properties. They will tell stories about villains and heroes. They will ask who is responsible and they will make the authorities accountable. Last, they will bring the disaster to an end. And they will tell “anniversary” stories a week after, a month after, a year after, five years after and so on. That is to say: Mass Media and journalistic reporting will be a relevant player in the disaster.

As far as the technical role, the channel role of mass media is concerned, the significant fact is that they can reach – think about radio broadcasts – nearly all people in time and at the same time. Mass media ascribe salience and relevance to messages. People do – in general – receive mass media messages well, they pay attention to these messages, believe the messages to be correct, accurate, appropriate. Mass media messages will be told by those who already have received the messages to those who haven’t. Mass media is the single most important source of general information for most individuals. Altogether this is what makes mass media for disaster management an essential, even inevitable tool of general information.

From this “technical” function of mass media productive effects may result. Productive, when broadcasting discharges potential overloads or even breakdowns of telephone networks and other information and communication infrastructure. Productive when people tune in to radio or television programs to get confirmation of the symbolic information they received from technical alarm systems. To receive information that is translated in native language or in languages spoken in the region; technical information that will be enriched with detail. People will receive understandable advice what to do and where to go. Information will be continuously updated. Altogether this underlines that people trust mass media and finally ascribe seriousness to the situation. And: In cases of emergency people assemble around a single and most trusted media; in Switzerland this proved and proves to be the radio programme of the Swiss Broadcasting Corporation, the public service organization.

Effects will be counterproductive when information from different sources is not consistent, contradictory even. This may be due to uncertainties within meteorological and hydrological data; this may be due to the fact that events cannot be predicted in full from the data; but it may also be due to non-coordination even non-cooperation between different authorities. Then journalistic coverage will focus on controversy and conflict. And this is to generate more stress in an already stressful situation.

Altogether this demonstrates the necessity of close coordination and cooperation between the different units of disaster management on the one hand and of close cooperation between the unit of disaster information and communication and the newsrooms on the other hand. Empirical and anecdotal evidence shows that journalists can be mobilized to play a technical role of information diffusion, and therefore be guidelined in a disaster as long as they can rely on a single source of information within disaster management and as long as they are provided in "journalistic" time, accurate, consistent, authoritative information. If not, journalists will run wild.

As far as journalistic coverage of disasters is concerned, a series of elements of coverage can be outlined. Journalistic coverage of events develops within the time frame of the medium. Journalistic coverage of events develops within the attention structures (news beats) of a medium. Journalistic coverage of events will be developed according to the rules of drama. This said, the event will be staged with a clear-cut beginning, a climax, and a clear-cut end. Elements of coverage will be: Giving updated and colourful accounts from the different scenes; experiences of people concerned; counts of injured and dead bodies; estimations of damages to properties; speculation about what will happen in the next hours; speculation about the causes of events; making authorities accountable; asking why this happened here; why this happened to us; telling stories of heroes and villains; blaming gazers for gaping; coverage of comparable events; chronology of comparable events; ranking of comparable events according to number of dead, injured, according to the damage; views from outside; consternation from outside; clean-up of the scene; first demonstrations of normality; prominent people and authorities demonstrating that the scene is safe again; that the scene is cleaned up; showing "the commander" declaring the end of the event; and - making sense of what has happened.

What is missing in the journalistic coverage are thorough descriptions of mental and psychological states of ordinary people during and in the aftermath of a disaster.

Altogether it can be stated that journalistic coverage of disasters follows known and empirical and anecdotal evident journalistic routines.

THE ROLE OF AFFECT IN COMMUNICATING FLOOD RISKS

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1. INTRODUCTION

The term “risk” has different meanings to different people. To experts, risk is defined foremost as the product of the probability and magnitude of harm, especially as the number of estimated deaths or the amount of estimated material damage. For laypeople risk assessment is more strongly connected with other characteristics, such as catastrophe potential or the degree of surprise or familiarity (Slovic, 1987). And laypeople often “underweight outcomes that are merely probable” (Kahneman & Tversky, 1979, p. 263). An important reason for that may be that rare events are less available (availability heuristic, Tversky & Kahneman, 1982) and thus often also not as connected with strong affects. The “risk as feelings” hypothesis (Slovic, Finucane, Peters, & MacGregor, 2004) postulates upon the background of the dual-process theory of thinking, knowing, and information processing (Epstein, 1994) that of the two modes experiential system and analytic system, the experiential system has the primary role. Affective responses have the function of “demarcating a positive or negative quality of a stimulus” (Slovic et al. 2004, p. 312). This process of reliance on rapidly and automatically generated anticipatory affects is called the affect heuristic. We found in a study that experience with flood damage (having been affected oneself and helping neighbours clean up after good damage) had a strong effect on risk perception (Siegrist & Gutscher, 2006). In the area of flood risks, it seems that – as in other risk areas – affects have an important influence on the perception and assessment of hazards (Keller, Siegrist, & Gutscher, 2006). Here a central role is also played by what dimensions of events that people pay attention to: These dimensions determine what emotions are triggered and not triggered, and they are also responsible for the intensity of these emotions. From reports in the media we know that floods can result in damage to buildings and that objects can be destroyed. What reports in the media do not make impressively clear are the emotions that floods evoke in the people affected. This means that people who have not been affected by floods will have a lot more trouble empathizing with the negative emotions triggered by floods. Another reason for this is connected with the fact that people find it difficult generally to imagine adequately the quality and intensity of feelings experienced in hypothetical events (Gilbert, Pinel, Wilson, Blumberg, & Wheatley, 1998; Morewedge, Gilbert, & Wilson, 2005). All in all, therefore, we should expect to find differences between persons that have actually been affected by floods and persons that are merely trying to imagine that situation. We suspect that non-affected persons can only insufficiently imagine the negative emotions that floods evoke – that is, the negative emotions triggered by floods are underestimated. The easy availability of strong emotions when people have personal flood experience is therefore likely to increase their willingness to invest in prevention; not having had the experience, and therefore falsely estimating such potential experiences, could impair people’s attitude towards precautions against damage.

The main reason for communicating risk to the public is to improve the correspondence between the assessed magnitude of a risk and people’s responses to that risk. The goal is therefore to minimize under- and overreaction to risks and to influence people’s risk assessments and their willingness to behave adequately and to invest also in prevention measures (Weinstein & Sandman, 1993). In the case of flood risks, the goal of risk communication is mostly to increase the perceived seriousness of risks, with the aim to stimulate people’s willingness for prevention measures.

2. STUDY

In this study conducted in Switzerland we compared the perceptions of persons that were affected by a flood in 2005 with the perceptions of persons that resided in comparably flood-prone regions but that did not experience flood damage in 2005 (Siegrist & Gutscher, 2008). In the regions affected by the flood we interviewed only those persons who experienced damages to home and property in excess of 1,000 Swiss francs (CHF). The regions spared the flooding in 2005 were selected based on hazard maps, and persons and addresses were selected from the telephone book. The two groups of participants were similar regarding age, sex, and number of renters. We conducted 201 personal interviews. In the first part of the interview the participant answered open format questions (no predetermined answer choices). By using open format questions, you avoid suggesting answers that the participant would not have mentioned spontaneously. In addition, with open format questions participants can name also new aspects. After the open format questions, the participants answered some standardized closed format questions that made possible to compare the two groups (affected and not affected by flood) statistically.

3. RESULTS

People without flood experience envisaged the consequences of a flood very differently than what people who were affected actually experienced. For people who had experienced the flood, the worst consequences included feelings of uncertainty, insecurity, fear, shock, powerlessness, and helplessness (see Figure 1, below). People not affected by the flood hardly mentioned negative feelings or affects. The results showed that it is in fact very difficult for us to envisage and empathize with people in hypothetical negative events. The fact that in addition to losses of property and damage to homes, also the rubble, mud, and dust can be a terrible experience was strongly underestimated by people without flood experience. But non-affected people overestimated the destruction to homes and the landscape and harm to persons.

Due to their experiences, a part of the residents affected by the flood of 2005 undertook measures to prepare for the next flood. Structural changes or renovations such as building new walls or sealing basement windows were made by 50% of persons with flood experience. Four out of 5 participants said in addition that they no longer stored valuable possession in the basement. Many of the participants also obtained further information. In contrast, people who were not affected by the flood undertook a lot less in order to protect themselves against flood, even though people in neighbouring areas had suffered great damages, as reported in the media fully and vividly. Besides that, the survey also revealed that many people falsely estimated the temporal course of the flood. Most people have a great deal of trouble with prognoses on non-linear changes. Two out of 3 participants stated that the water level suddenly rose much faster than expected.

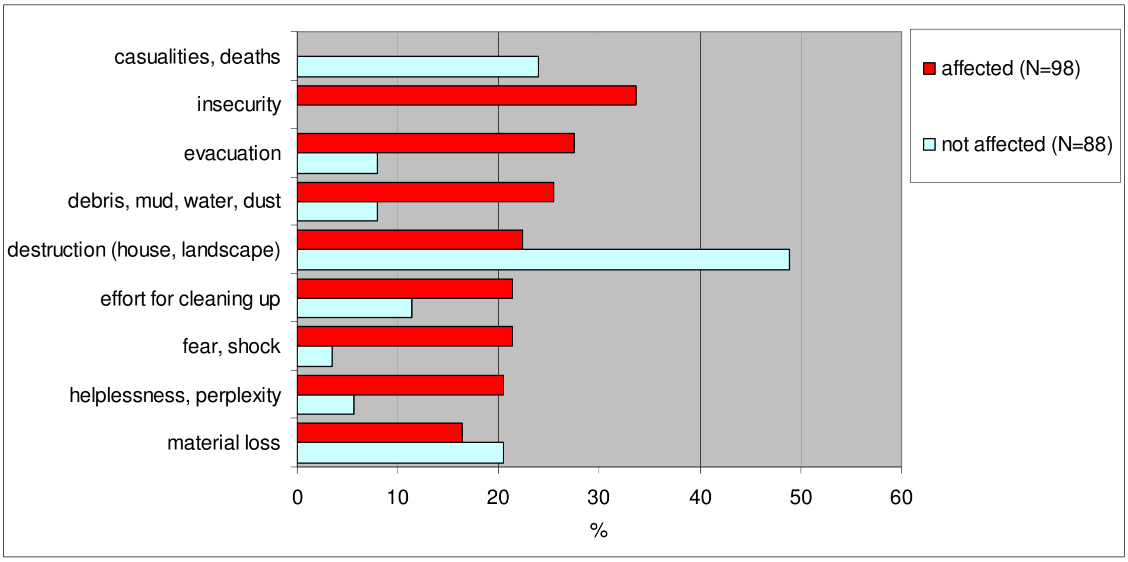

Figure 1. The open format question was, "What was the worst thing about the flood of 2005 for you?" Respondents not affected by the flood of 2005 answered the question, "When you imagine a flood, what would be the worst thing for you?"

4. DISCUSSION

The results of this study have clear implications for risk communication. Personal experience with flood and its negative consequences appear to motivate people to take prevention measures as a precaution against floods. Whereas most people can imagine that buildings and belongings can be damaged by floods, they cannot envisage the intensive negative emotions can be triggered by the consequences of floods. Most of the information brochures on floods are rather technical. They describe possible damage caused by flood events and sometimes show photographs of the damage. The negative emotions that are caused by a flood experience are not mentioned or mentioned only insufficiently. In risk communication it is important to bring up and discuss not only possible damage but also other consequences of flood, so that homeowners in flood-prone areas can become better able to put themselves in the shoes of affected persons. Through such measures, it can be achieved that more homeowners take timely prevention measures. Therefore, the challenge of risk communication lies not so much in providing rational information but in adequately addressing the experiential system (Slovic et al., 2004).

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ABSTRACTS OF POSTER PRESENTATIONS

CONTINUOUS HYDROLOGICAL MODELLING FOR FLOOD FORECASTING
DEVELOPMENT AND OPERATIONAL IMPLEMENTATION IN FRENCH FORECASTING SYSTEMS

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In 2003, flood warning services were reorganized in France to improve the alert to population. This was the consequence of a series of devastating floods that occurred in the 1990s, especially in the south part of the country and that pointed out the strong limitations of the services existing at that time. The 52 existing services were grouped into 23 entities with more staff. They are now in charge of providing flood forecasts with some expected lead times and precision. This reorganization raised the problems of modelling tools made available for these services. Indeed at that time, the services mainly relied on abacus to account for propagation in streams. Very few tools were available to account for the rainfall-runoff transformation and when existing, they were event-based with no proper procedure to determine initial conditions.

This poster aims at presenting the work done by Cemagref over the past years to develop a robust and efficient flood forecasting model based on continuous hydrological modelling and to implement it in operational conditions in French flood forecasting services. Some methodological developments will be presented. The model is currently used under various hydro-climatic conditions. Examples of results on recent flood events will be shown and perspective for future development will be detailed.

INTEGRATED FLOOD MANAGEMENT (IFM)

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World Meteorological Organization (WMO), Weather, Climate and Water

Ten years ago WMO developed the concept that is now called Integrated Flood Management (IFM). The Global Water Partnership decided to promote this concept through the Associated Programme on Flood Management (APFM). This programme started with the financial support of Japan and The Netherlands and now is continuing with the support of Japan, Switzerland and Spain. Recently (June 2009) an IFM Help desk was established to provide support to countries that decided to implement the concept in their basins.

Integrated Water Resources Management (IWRM), as defined by the Global Water Partnership, is “a process which promotes the coordinated management and development of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems”. This approach recognizes that a single intervention has implications for the system as a whole, and that the integration of development and flood management can yield multiple benefits from a single intervention.

Integrated Flood Management (IFM) integrates land and water resources development in a river basin, within the context of Integrated Water Resources Management, with a view to maximizing the efficient use of floodplains and to minimizing loss of life and to manage property losses (risk management). Integrated Flood Management, like Integrated Water Resources Management, should encourage the participation of users, planners and policymakers at all levels. The approach should be open, transparent, inclusive and communicative; should require the decentralization of decision-making; and should include public consultation and the involvement of stakeholders in planning and implementation.

The management of floods as problems in isolation almost necessarily results in a piecemeal, localized approach. Integrated Flood Management calls for a paradigm shift from the traditional fragmented approach, and encourages the efficient use of the resources of the river basin as a whole, employing strategies to maintain or augment the productivity of floodplains, while at the same time providing protective measures against the losses due to flooding. Sustainable development through Integrated Water Resources Management aims at the sustained improvement in the living conditions of all citizens in an environment characterized by equity, security and freedom of choice. Integrated Water Resources Management necessitates the integration both of natural and human systems and of land and water management.

Both population growth and economic growth exert considerable pressure on the natural resources of a system. Increased population pressure and enhanced economic activities in floodplains, such as the construction of buildings and infrastructure, further increase the risk produced by flooding. Floodplains provide excellent, technically easy livelihood opportunities in many cases. In developing countries with primarily agricultural economies, food security is synonymous with livelihood security. Floodplains typically support high population densities, such as in the Netherlands and Bangladesh, and the GDP per square kilometre is high in countries constituted mostly of floodplains: the Netherlands boasts the highest GDP per square kilometre in Europe.

The ecosystem approach is a strategy for the integrated management of land, water and living resources, a strategy that promotes conservation and sustainable use in an equitable manner. Both Integrated Water Resources Management and Integrated Flood Management encompass the main principles of the ecosystem approach by considering the entire basin ecosystem as a unit and by accounting for the effects of economic interventions in the basin as a whole. Environmental sustainability of the flood management options is one of the prerequisites in IFM.

Sustainable and effective management of water resources demands a holistic approach, linking social and economic development with the protection of natural ecosystems and providing appropriate management links between land and water uses. Therefore, water related disasters, such as extreme floods and droughts, because they play an important part in determining sustainable development; need to be integrated into water resources management.

A holistic approach to emergency planning and management is preferable to a hazard-specific approach, and IFM should be part of a wider risk management system. This approach fosters structured information exchange and the formation of effective organizational relationships. In integrated flood management planning, achieving the common goal of sustainable development requires that the decision-making processes of any number of separate development authorities be coordinated. Every decision that influences the hydrological response of the basin must take into account every other similar decision.

Adaptive management offers a robust but flexible approach to dealing with scientific uncertainties, an approach wherein decisions are made as part of an ongoing science-based process. It involves planning, acting, monitoring and evaluating applied strategies, and modifying management policies, strategies and practices as new knowledge becomes available. Adaptive management explicitly defines the expected outcomes; specifies the methods to measure performance; collects and analyses information so as to compare expectations with actual outcomes; learns from the comparisons; and changes actions and plans accordingly.

Water will be the primary medium through which the expected effects of climate change will materialize. Climate change and increased climate variability will affect flood processes in several ways simultaneously. Sea level rise will place coastal communities at higher flood risk. And changing precipitation patterns will lead to an increased occurrence of flash floods and, in some regions, riverine floods. Integrated Flood Management takes account of those expected effects, and is therefore an autonomous adaptation strategy to climate variability and change.

Conclusions. - Risk management should be the objective and not risk reduction. In some countries such as most or all countries involved in the CHR it could be that after analyzing carefully enough the situation applying the IFM concept in many cases flood risk reduction could come up as a reasonable objective. The fact that the title of the workshop includes “Risk Management” enlarges its interest worldwide. In relation to flood forecasting, which has been a WMO field of work in its 60 years of existence, it is worth to mention that a Manual on Flood Forecasting and Warnings is being prepared and that right now the draft is following the peer review process.

Geneva, 25 February 2010

ENSEMBLE FORECASTING OF PRECIPITATION AND STREAMFLOW FOR THE MEUSE BASIN

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ABSTRACT

A hydrological ensemble prediction system is running operationally at the RMI for the Meuse and Scheldt river basins in Belgium and upstream in France. It is based on the conceptual semi-distributed hydrological model SCHEME, and the ECMWF ensemble prediction system (EPS). The SCHEME model can be considered a transfer function for precipitation, with conceptual reservoirs lumped over 7 km grid cells. SCHEME makes use of nine land cover types, and was developed specifically for modelling large catchments. Forecasts of precipitation and other meteorological fields are taken from the EPS, based on a 50 member ensemble plus control run, currently at a ~30 km resolution (N320). Real time observed precipitation from weather radars and automatic rain gauges is used, and a monthly update is performed using precipitation data from the RMI climatological rain gauge network.

The system delivers daily probabilistic forecasts of areal precipitation and river discharge for the next ten days, for the important sub catchments of the Meuse and Scheldt. Probabilities of exceeding the P90 threshold and higher pre-alert thresholds (set by regional authorities) are computed.

A hindcast for the period 2006-2009 was performed using archived N200 ECMWF EPS forecasts (see Van den Bergh and Roulin, 2010). Based on these results, it was decided that there is potential value in extending the forecast range up to 14 days for the winter season. This has been done, but requires validation before communicating results to end users.

In this work, we present the current operational setup, the way of presenting the output to end users, and future plans for improving our hydrological ensemble prediction system. We also present some results on the potential advantages and disadvantages of using “lagged forecasts” in the decision making process; such as the requirement of persistence in subsequent forecasts before issuing an alert. In this way, the number of false alarms can be reduced, but at the expense of a lower hit rate. Whether the economic value can be increased in this way, depends on the cost-loss ratio of the end user.

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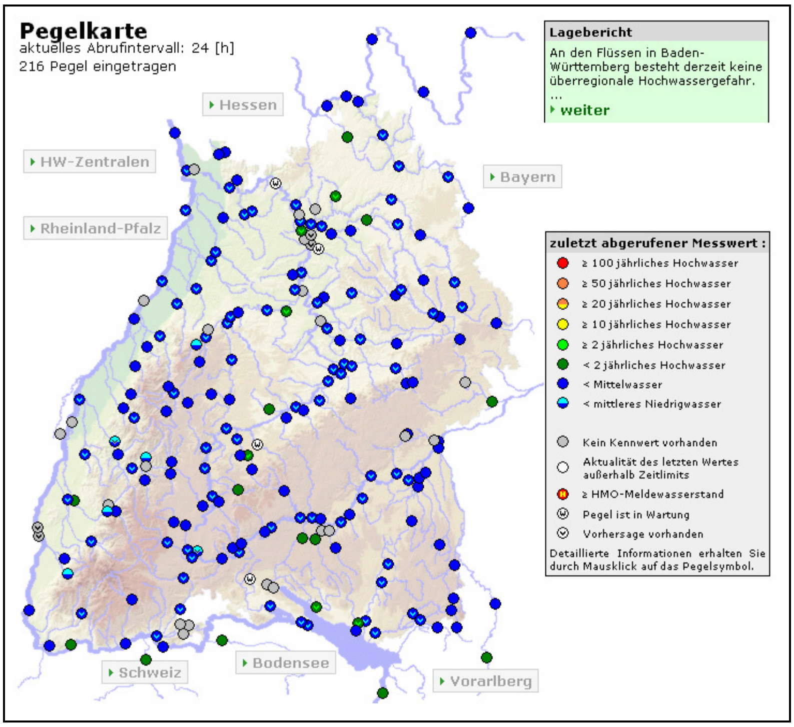
THE FLOOD FORECAST CENTRE OF THE FEDERAL STATE OF BADEN-WÜRTTEMBERG - OVERVIEW AND INFORMATION ABOUT THE FLOOD FORECAST FOR THE UPPER RHINE

Manfred Bremicker

Flood Forecast Centre (HVZ) of the State Agency for Environment, Measurement and Nature Conservation of Baden-Württemberg, Karlsruhe, Germany



The Flood Forecast Centre (HVZ) of the State Agency for Environment, Measurement and Nature Conservation of Baden-Württemberg coordinates all current information in the case of a flood. Additionally, the HVZ renders revised pieces of information to the local authorities, the affected public and the media.

The HVZ-information includes current water level and discharge data for roughly 210 gauges in Baden-Württemberg and on neighbouring rivers. This encompasses water level and discharge forecasts for approximately 90 gauges on Lake Constance, the Upper Rhine, the Danube, the Neckar and the Main Rivers as well as on their most important tributaries. Furthermore, flood status reports and information on precipitation events within Baden-Württemberg are released. The HVZ-information is being published once a day during times of routine operation and hourly during times of flood.

The transnational water level forecast for Lake Constance takes place in cooperation with the Swiss Federal Agency for the Environment and the Office of the Federal State Government of Vorarlberg (Austria). The HVZ-forecast for the Upper Rhine from Basel to Mannheim represents an integral part of the transnational collaboration of all forecast centres along the Rhine from Switzerland all the way down to the Netherlands.

In the case of operation, The HVZ hourly computes flood forecasts for the Upper Rhine gauges Breisach, Kehl-Kronenhof, Maxau, Speyer and Mannheim. If the present physical retention measures (e.g. polders) are in action, their effect is accounted for within the model computations. This is carried out in close coordination with the respective operators in Baden-Württemberg, Rhineland-Palatinate and France.

The gauge-related HVZ-information is being supplemented by an early-forecast-system for floods in small catchments. This system enables the publication of county-related information about the current flood danger within small catchments via the internet. This information is automatically being updated every 3 hours.

The information supply takes place via intranet and internet (www.hvz.baden-wuerttemberg.de, www.bodensee-hochwasser.info, www.hochwasserzentralen.de) as well as via videotext and automated phone announcement, partly in a reduced extent. An internet site for smartphones can be reached under www.hvz.baden-wuerttemberg.de/pda.html.

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TOOL FOR ANALYZING THE VULNERABILITY OF BUILDINGS TO FLOODING : CASE STUDY OF SWITZERLAND.

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1. CONTEXT

Floods have caused lots of damages to human infrastructures in Europe in recent years, particularly in Switzerland. Beyond social damages, structural damages are also very important and the financial impact is considerable. In financial terms, with states the insurance companies are one of the most important actors involved and are therefore particularly interested in reducing the financial impact of such disasters.

Property insurances have many possibilities to approach the problem. First, they could act directly on the financial statement by increasing premiums or by decreasing prestations. This solution affects the services provided to the property owners without directly decreasing the potential damages. The second possibility tries to reduce either the number of sinister or their causes. In this way, two solutions exist: (1) decrease the magnitude of the hazard with protective systems or (2) improve the strength of infrastructures or the location of vulnerable objects in the buildings. Whatever the way used to protect properties exposed to flooding, a residual risk still exists. For buildings, the second solution (2) seeks to adapt the buildings to potential flood and reduce their vulnerability. Until now, the main measures of prevention in Switzerland were limited to reduce hazards with costly protective systems, without considering the vulnerability of infrastructures such as buildings and insider equipments.

The present project is funded by the Prevention Foundation of Swiss Public Property Insurance and consists to develop an Excel-tool which allows an easiest and most adapted analyze of buildings to static flooding (See Figure 1, above).

2. METHODOLOGY

The method proposes three steps to act on the vulnerability of a building. (1) First, it is necessary to describe the building: its composition, materials of construction and their components. To perform this task, it is necessary to elaborate databases which contain all the parts and materials composing a building. These databases have been elaborated from the collection and analysis of data, information, standards and feedbacks from risk management, hydrology, architecture, construction, materials engineering, insurance or economy of construction. (2) The second step seeks to propose an adapted reduction considering the weaknesses identified in the previous step. Databases of solutions have been elaborated for all components of the buildings. The goal of this step is to propose several methods based on a cost-benefit analysis. (3) Finally, the knowledge of buildings and their vulnerability allows the elaboration of different strategies to decrease the vulnerability of a buildings or a couple of buildings.

Different levels of analysis are available. Indeed, it is possible to do a global analysis of a building, based on his typology, or a detailed analysis which includes all elements of the studied building and its organization. Thus, it is possible to provide a very detailed analysis of the real vulnerability of a building or a more global and rapid analysis related to its typology. The user cans choice between a quick and a detailed analysis. This approach may allow proposing recommendations.

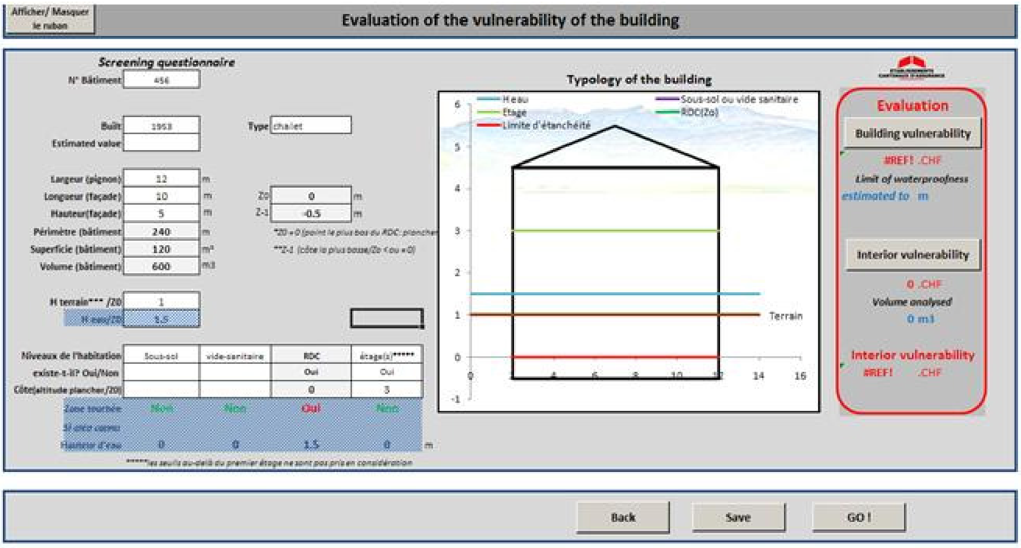

Figure 1: Overview of the Excel-tool. Several sheets are proposed according to the step of the analysis.

3. RESULTS

Analysis of data from the insurance company leads to the emergence of trends in costs of damages due to flooding. The use of the tool allows a better understanding of the damages caused to buildings. It also offers the possibility to intervene in advance of disasters, in the building permits for example. Finally, the tool allows another approach of the land use planning.

EWASE - EARLY WARNING SYSTEMS EFFICIENCY IN THE TRAISEN BASIN

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ABSTRACT

Effective flood warning requires reliable and timely flood forecasts in order to take preventive measures. The methodology of the project combines the evaluation of flood forecasting reliability and the economic viability. In this context forecast reliability is defined as a function of lead time from statistical analysis of the prediction errors available from past flood events. Uncertainties due to quantitative precipitation forecasts and hydrological modelling are considered with an ensemble approach. The risk assessment gave a resulting potential damage reduction function. This could be combined with forecast reliability and gives a warning expectation for the basin which allows economic efficient alerts.

1. INTRODUCTION

The Traisen is a tributary to the Danube and is located in the north eastern part of Austria. The basin size is approx. 900 km² and has an alpine characteristic. Annual rainfall is around 1000 mm. Since 2008 the hydrological model COSERO is integrated in the early warning system environment. It provides 48 hours forecasts for the basin. Meteorological data is available in high resolution (time and space). Hydrological simulation within this study is generated with three different hydrological models for ten historic flood events between 2002 and 2007.Three flood events were chosen for estimating hydrological and meteorological uncertainty with ensemble technique. Later these uncertainties are transformed into forecast reliability. Combined with an economic evaluation a warning expectation curve is calculated.

2. FLOOD FORECAST RELIABILITY

Uncertainties due to models, quantitative precipitation forecasts (QPF) and event specific characteristics are considered. Transformation into forecast reliability is based on the distribution function of predictive error from the ensemble of forecasted hydrographs.

Hydrologic uncertainty is estimated with a multi model ensemble of two continuous (COSERO and WBrM) and one event based (DICHITOP) model. The performance of the models is a lot dependent on the event and can be very diverse. In calibration and validation no model outperforms in all events and all performance criterions. Due to these results no clear ranking of the different models was possible. Only for snow melt events a clear winner could be defined, the model COSERO. The excellence of the model is due to well adaption to local conditions and widespread application experience in alpine regions.

When testing meteorological uncertainty with sets of precipitation ensembles a quite different reaction of the hydrological models was observed. The most significant difference was the spread of the ensemble forecast. The inter quantile range of the flood peak from precipitation ensembles varies up to 50 % between the models and increases partly enormously with lead time. This suggests a complex interaction between these two uncertainty sources (QPF input and hydrological model). It also confirms taking model uncertainty explicitly into account when evaluating forecast reliability.

Lead time dependence of forecast reliability is evaluated with a Multiple Step Ahead approach. As expected, prediction errors of all models showed increasing variation and mean values with lead time.

Additional the models showed different sensitivity to forecast changes from one time step to the next. Forecast reliability (FR) within EWASE is defined as: *FR (0.85)*= $1 - \varepsilon_\tau$ (85%) : *FR* ≥ 0, with ε_τ representing the 85 % quantile of the forecast error with lead time τ. The initial level of FR (0.85) for all events is at 66% and decreases rapidly after a lead time of four hours. After 15 hours it flattens again and later stays more or less constant at a low level of about 15 %. Event dependence shows variation of the initial level between 57 % and 72 %. Principally the shape of the FR curve is similar but start time of decrease in FR varies between three to six hours. Also relative difference of FR between the events varies with lead time and can even change sign. A systematic deviation of FR between the different hydrological models was found. It seems that models give a basic level of FR, but evolution with lead time is very similar. The reproduced hydrologic dynamic of the models appears therefore comparable. Ensemble QPF compared to deterministic QPF could not increase FR in the context of this study. This is caused by large prediction errors a wide spread of Ensemble forecasts.

Separation of hydrological and meteorological uncertainty in forecast reliability illustrates that the decrease of FR can be principally attributed to QPF. A basic level is given by the performance of hydrological models. Importance of hydrological uncertainty compared to QPF related uncertainty gets small as lead time is extended.

3. OPTIMAL ALERT

Comparative risk analysis gave a potential damage function for the basin at different flood probability levels. Risk assessment and response analysis gained damage reduction as function of lead time. Data sources are statistical records (ESA 1995, NACE, NUTS 2003), different damage functions and a questionnaire based survey in the basin. The resulting avoidable damage in combination with forecast reliability allowed the calculation of a warning expectation curve. The maximum of this curve gives the point in time for an economic optimal alert. The best lead time for releasing an alert for an event with a hundred years return period in the Traisen basin was found to be 9 hours for the industrial sector and 3-5 hours for the private sector.

4. ACKNOWLEDGMENT

EWASE (Effectiveness and Efficiency of Early Warning Systems for flash-floods) is a R&D project within the ERA-NET CRUE integrated project supported by the European Commission under FP6. The project was funded by BMBF (Germany) and MEC (Spain). The consortium consisted of IHWP (Section Engineering Hydrology and Water Resources Engineering, Darmstadt University of Technology), GRAHI-UPC (Group of Applied Research on Hydrometeorology, Universitat Politècnica de Catalunya), IWHW-BOKU (Institute of Water Management, Hydrology and Hydraulic Engineering, University of Natural Resources and Applied Life Science Vienna) and the business cooperation of Pro Aqua and Water&Finance. Thanks to our project coordinator Kai Schröter and all other project partners: Mekuria Beyene, Carlos Corral, Martin Gocht, Manfred Ostrowski, Felipe Quintero, Carlos Rubin, Daniel Sempere Torres, Carlos Velasco-Forero.

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IMPROVEMENT EFFECTIVENESS OF FORECASTING BY BETTER USE OF WARNINGS AND KNOWLEDGE OF UNCERTAINTIES

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In case of threat for flooding caused by storm surge or extreme discharges on rivers multiple stakeholders are involved. The main driver behind the recognition of a threat and possible measures is a forecast of extreme water levels that might cause flooding. Information about the threat and consequences will come available for authorities by warnings and by (situation) reports of several crisis centres. In addition each person in this centre as well as the public is also influenced by information spread by media. Recent events show the growing impact of social media. International literature describes that information will only result in adequate and realistic measures if the threat and possible measures are understood (called sense making). In case of a threat for flooding the amount of involved stakeholders increases the complexity as well as the need to deal with uncertainties (about the possible flood, the consequences of measures). Multiple interpretations can be made by crisis managers, by decision makers and by the public resulting in different perceptions and decisions.

This article (including poster) discusses possible improvements in the use of forecasts related to the decision making processes. Therefore we focus on the role of alerts or early warning and information systems that can be used as support. Also we focus on the consequences when knowledge of uncertainty is made explicit in warnings in stead of implicit.

We conclude that warnings should contain all possible events including a probability to create a dilemma for decision makers (as probability for different classes of water levels, probability of flooding or no flooding). Also we conclude that, after recognition of a possible threat, information about forecasts should be spread directly and automatically to public and all professionals as an alert. A warning (or no warning) is an extra element of information that can be added to the forecast in necessary. Finally we present a integration system developed by the program Flood Control 2015: Dashboard Water Safety. This is an umbrella system collecting information from several sources as forecasts, warning and alert but also a common picture of traffic and public perception for the actual situation and possible scenarios. The dashboard cerates for professionals and public a better understanding of the actual situation and possible consequences. The decision making process can improve (quality and less time) because of the better common picture. These conclusions are further elaborated below.

1. UNCERTAINTY AS A DILEMMA FOR DECISION MAKERS

In case of a threat for flooding uncertainty is often taken into account but implicit. For example the extreme water levels on the River Rhine in 1995 caused a threat for flooding. Finally the water boards informed decision makers that they ‘could not stand for the strength of the dikes anymore’. Decision makers decided for mass evacuation using this statement of the water boards as an argument. With hindsight the dikes did not breach and discussion rose about the consequences of the evacuation and the impact of a false alarm [1]. The lack of capacity of dealing with uncertainties is also known from other Dutch national crisis exercises. Crisis centres are less capable to define information with a strategic advise (including options and consequences) for decision makers. Decision makers therefore tend to give their own interpretation to the situation that results in less optimal decisions [3].

International literature describes the consequences of false alarms: possible delay of decision making processes [2]. On the other hand a better understanding of heuristics and biases improves the decision making process in case of uncertainty [4]. In reality water boards can declare 100% safety for the strength of their dikes. On the other hand in case of extreme forecasted water levels failure of the dike is not 100% guaranteed (as was seen in 1995). For the example of 1995 it can be questioned what decisions if uncertainty was made explicit.

The presentation of information is related to the quality of decision making. When uncertainty is made explicit in warning or alert by presenting the probability for several classes of possible events. This will result in better information for decision makers (but also more difficult). An example is to present probability for classes of 1) certain flooding, 2) certainly no flooding and 4) a possible flooding. Decision makers will have to make a risk analyses about possible measures. Decision makers and crisis managers can add advices for measures to warnings.

2. INFORMATION IS EVERYWHERE AVAILABLE: IN CASE OF A POSSIBLE THREAT FORECASTS SHOULD BE SPREAD DIRECTLY AND AUTOMATICALLY

In case of a threat each organization and person tries to gather and understand information. Measures are taken on their perception of the threat and consequences. This process is described in literature as sense making [5]. With the impact of social media and internet information is spread over the society very quickly. Information, also (very uncertain) forecasts are continuously available by public and crisis centres. Official and unofficial interpretations will be spread quickly. Information management changes from a pushing model to a pulling model that results in self synchronization of persons and crisis centres [6].

Knowing the process of sense making and accepting the impact of social media signals of a potential flood should be made available directly to public and crisis managers. A pro active role of authorities and a clear line of communication is expected to make the message more reliable [7]. This forecast should be combined by an interpretation of the forecast and consequences to support sense making. The first signals could be described as an early alert. In a later stadium, after risk analyses, warnings can be added. Authorities and public can use this alert to gather more information and prepare themselves, this could result in more available time for pre cautious measures and more effectiveness of measures.

An international comparisons shows lessons learned after Katrina in New Orleans. Improvements were made in the alarming scheme. The national level should be involved more early so national resources can be of a better use. This resulted in a better evacuation process during Gustav.

3. USE OF DIFFERENT, CONNECTED, INFORMATION SYSTEMS FOR FORECASTING, WARNINGS AND A COMMON PICTURE

The program Flood Control 2015 is developing a Dashboard Water Safety. This dashboard gives a common picture about the actual situation of the threat, the society and possible consequences for the society. This picture can be designed for each role and for the public during implementation. Two important sources of input for the dashboard are information from hydrologists (forecasts) and crisis managers (warning or alert). Different systems with equal functions are available worldwide that can be used, in the program flood control is focused in FEWS en FLIWAS. These systems are below the umbrella of the ‘Dashboard Water Safety’. By linking the processes of forecasting and warning as well as other processes (and their systems) the entire chain from measurement up to mitigation can be accessed by all users. This increases transparency and aids training roles in water- and disaster management. The decision making process will improve (in quality but also take less time) because of a more common perception of the threat and consequences and the accessibility of information.

The Delft-FEWS-system (**F**lood **E**arly **W**arning **S**ystem) is a modern data handling system that is specially developed for flood forecasting and time series management by hydrologists. The Delft-FEWS system is being used worldwide to perform flood forecasting and time series management. The British Environment Agency implemented the system in England and Wales, Scotland Environment Protection Agency (SEPA) uses it in Scotland. A nationwide roll-out is currently executed in the United States by Deltares and the US National Weather service. The Mekong River Commission uses it for their forecasts.

While managing a (provisional) flood situation, the availability of information is a key factor. FLIWAS, **FL**ood **I**nformation and **WA**rning **S**ystem, supports the spreading of information and provides authorities, water managers and other involved parties with information. FLIWAS reads (predicted) water levels and visualizes them (in time-diagrams, long- and cross profiles). When water levels exceed these reference levels, the user is automatically warned and further informed as to which actions to perform (such actions having been incorporated into the FLIWAS-based calamity plan). Furthermore, FLIWAS also monitors the progress of the execution of needed measures and informs all relevant staff members of the occurring situation using fax, e-mail or sms.

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ROBUST ESTIMATION OF HYDROLOGICAL PARAMETERS IN THE CONTEXT OF FLOOD FORECASTING

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Operational flood forecasting in small and fast responding catchments is a challenging task. Even more physically-based models consist of conceptual parts with hydrological parameters to be calibrated. A robust estimation of these parameters is neither straightforward nor unique. Normally this calibration task is understood as a mathematical optimization problem for a given objective, e.g. the Nash-Sutcliffe Efficiency criterion of the simulated and observed runoff. The hydrological parameters are adapted within their feasible range to optimize the model efficiency. The result is a single best performing single parameter set. In reality such a best performing parameter set does not exist and the calibration result depends strongly on the used data. That means for instance that possible small measurement errors are not considered and therefore parameters get overfitted. Such parameter sets are often not robust and fail in validation.

A new approach to deal with this problem is the ROPE algorithm. The idea of this approach is that a model calibration is not understood as an optimization procedure but as a search of many robust parameter sets. The assumption is that robust parameter sets can be found statistically deep within a cloud of good performing parameter sets. The result of this algorithm is a set of robust performing parameters. The good parameters are estimated by Monte-Carlo simulations and an objective function. Deep parameters are found by the halfspace-depth which can by applied to problems with arbitrary dimension. This method can be applied iteratively with different objectives to estimate a set of multi-criterial robust parameters. Furthermore advanced problems as different dominant runoff processes for different flood events can be tackled by a pre-event classification, e.g. moist/dry conditions or advective / convective precipitation) and a clustering of the good performing parameters in the case of a non-convex cloud. In operational mode the best suiting class for the current event can be selected to provide a good prognosis. All parameter sets of the according class are applied and it is possible to get a robust stochastic runoff prediction.

The developed approach was applied to the small test catchment Rietholzbach situated a the pre-alpine mountainous region in Switzerland. 24 characteristic storm events were selected, evaluated and classified. The physically bases rainfall-runoff model WaSiM-ETH with the Richards approach was calibrated for each event by state-of-the-art algorithms and ROPE. The resulting parameter sets were cross-validated for all events, regarding different possible classifications. The result is a more reasonable description of the runoff process in the context of storm events. This forms the base of a future flood forecasting framework considering parameter and model uncertainties in an appropriate way.

RIJKSWATERSTAAT NATIONAL WATER MANAGEMENT CENTRE (THE NETHERLANDS)
FOCAL POINT FOR INFORMATION AND KNOWLEDGE ABOUT OUR WATER SYSTEM

Stefan Nieuwenhuis

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The Rijkswaterstaat National Water Management Centre is one of the three network centres of Rijkswaterstaat and contributes to a uniform and optimal management of the water system in the Netherlands. For this purpose the Water Management Centre offers up-to-date information to professional users of our water system, such as information regarding the tides, water quality and the ice formation. When disasters occur due to threats of flooding, water shortages or environmental pollution of the water, the crisis advisory groups of the Water Management Centre come into action to help local and regional administrators to cope with water problems by providing timely, topical and targeted information about the expected state of the water.

Besides reporting under normal and special conditions, the Water Management Centre offers a professional helpdesk for users with questions about water policy and water management. The Water Management Centre also provides, among other things, presentations and guided tours for professional groups and the press. The Water Management Centre hopes to become a leading platform for training and innovation in the field of crisis management.

To be able to execute its duties diligently and efficiently, the Water Management Centre works closely with the regional message centres, the other two network centres, the policy executive board of Water Transport and Water Management, the KNMI, the water boards, the provinces and the safety regions.

In short, the Rijkswaterstaat National Water Management Centre is the central node for information and knowledge about our water system.

OBJECTIVES

The Rijkswaterstaat National Water Management Centre ensures that information and knowledge about our water system reach the end user quickly and efficiently. For this purpose, the Water Management Centre is:

- A service centre for rendering information regarding water under normal and special circumstances;

- A crisis centre operational 24 hours a day in special circumstances;

- A reliable and expert knowledge centre that meets the information needs of the professional user;

- An entrepreneurial innovation centre that leads the way in new developments and technologies in the field of crisis management and offers a platform for innovation and training for both governmental and private sectors;

- A visitor centre for professional groups and the press.

STATE OF AFFAIRS

The Rijkswaterstaat National Water Management Centre is developing rapidly. An important milestone is the new accommodation in the Smedinghuis in Lelystad with, among other things, facilities for training and public and press briefings in 2011.

Contact: Rijkswaterstaat, Centre for Water Management, Office of the Managing Director, Section Communication. Tel. + 31 320 298 411, E-mail: info.waterdienst@rws.nl

ECOLOGICAL AND SOCIAL-ECONOMICAL ESTIMATION OF THE FLOOD IMPACTS IN MOUNTAIN REGIONS OF TAJIKISTAN*

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Tajikistan is Mountain countries 93 % of territory which borrow mountains. Among regions of Tajikistan in Zarafshon river basin formation of floods is observed more often (nearby 7% from total across Tajikistan) and their quantity in a year reach 150 and the local population is incurred almost annually with greater economic losses. In Zarafshon river basin located the Ajni and Panjikent regional centres in which live more than 300 thousand inhabitants. The present work is devoted to monitoring of change of the precipitation quantity by climate change, formation floods and to calculation of economic damage put by floods to the population and an infrastructure of Ajni and Panjikent regional centres. For estimation of the precipitation in Zarafshon river basin had been used meteorological data from stations Madrushkat, Dekhavz, Anzob for the periods1961-2005 years. Floods forming as a result of showers in Zarafshon river basin are characterized by the greater maintenance of firm particles. Very much greater floods in Ajni and Panjikent regional centres were formed in the periods of 2002-2005 years. Economical and social consequences of the floods in Ajni and Panjikent regional centres are demonstrated accordingly fig.1 –fig.4.

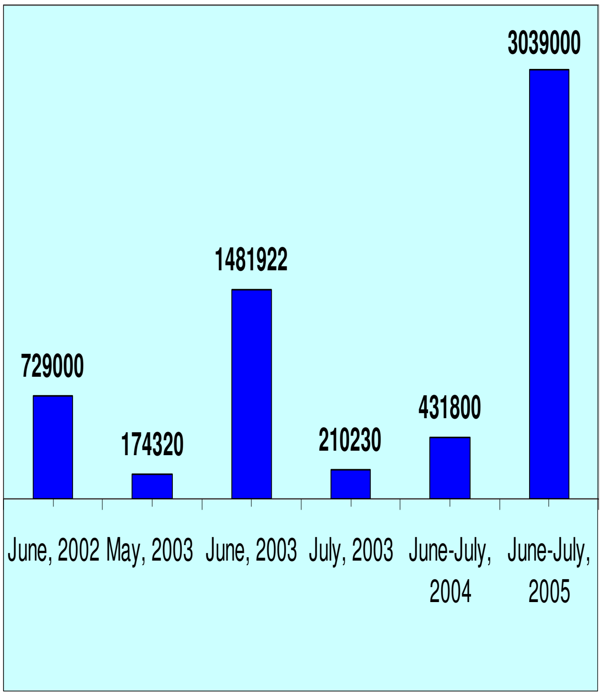

Figure 1: Economical damage of the floods in Panjikent district (US Dollars)

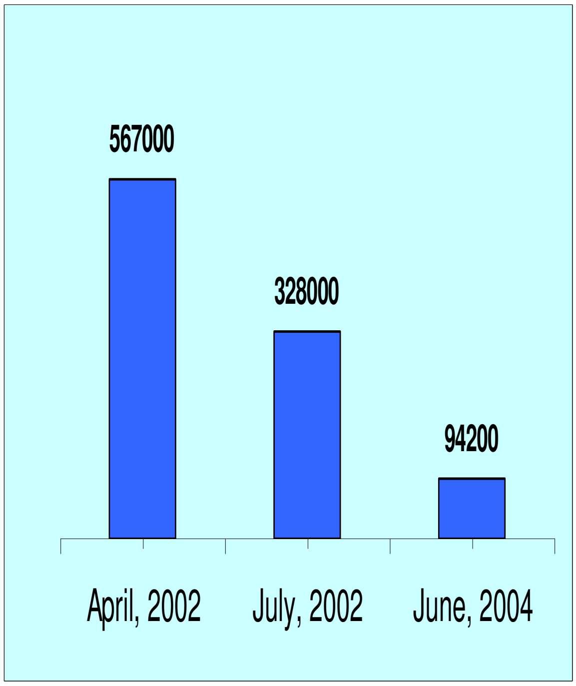

Figure 2: Economical damage of the floods in Ajni district (US Dollars)

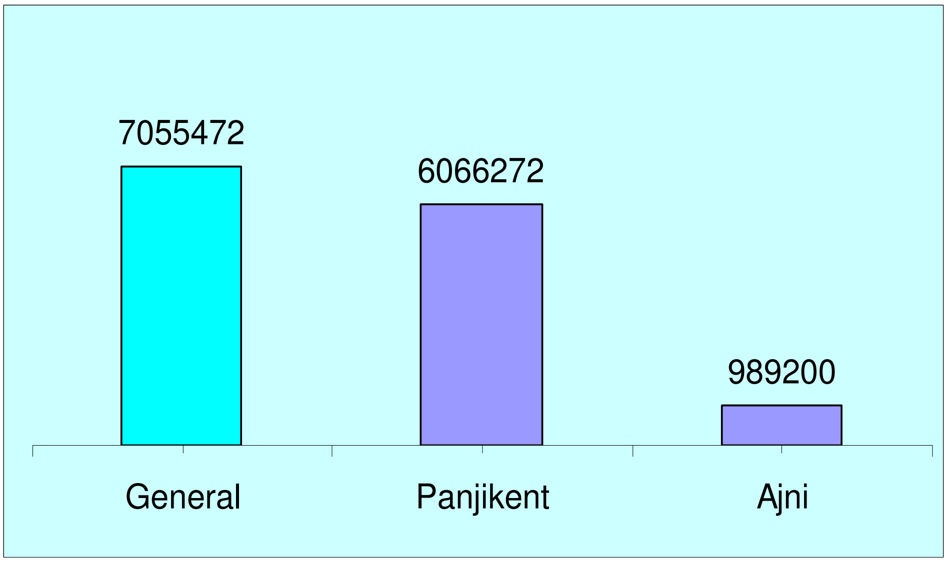

Figure 3: General economical damage (US Dollars) of Ajni and Panjikent districts in result of floods of 2002-2005 year

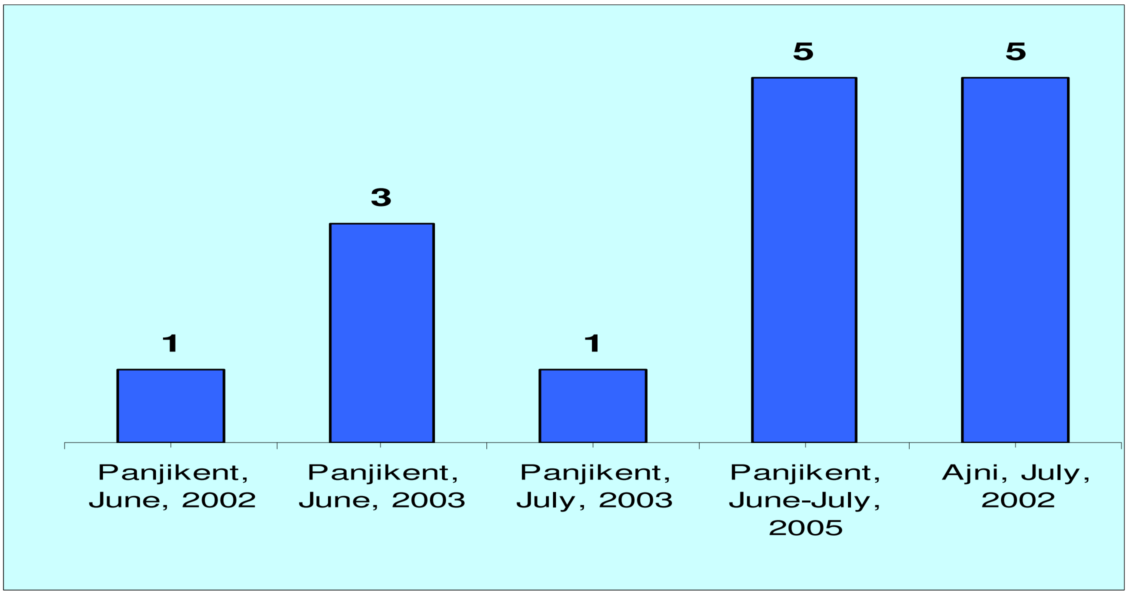

Figure 4: General Human victims at flooding in Ajni and Panjikent districts (person)

** Work was spent on the «Zarafshon" project at financial support of the Volkswagen Funds*

THE IMPACT OF WEATHER FORECAST IMPROVEMENTS ON HYDROLOGICAL ENSEMBLE PREDICTION SYSTEMS (HEPS)

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The performance of many flood forecasting systems is regularly analysed with regard to individual flood events and case studies. Although this analysis provides important insight into the strengths and weaknesses of any forecast system, it lacks statistical and independent measures of its long-term performance. In this study we assess the performance of a flood forecasting system (the European flood Alert System, EFAS) results based on ECMWF weather forecasts over a period of 10 years is presented (for all findings see Pappenberger et al., 2010). EFAS river discharge forecasts have been rerun every week for a period of 10 years using the weather forecast available at the time. These are evaluated for key river gauging stations distributed across Europe. The data are analysed with regard to skill, bias and quality of river discharge forecast.

Firstly, we focused on the impact of improvements in the meteorological forecast on HEPS. Improvements can be seen for the 10 years analysed for this paper, but surprisingly these are rather gradual and not sudden. For example, resolution upgrades and improvements in the convective scheme are not seen as a jump in improvement as one could have expected from meteorological skill score analysis. We also find that high resolution forecasts provide a better variability and thus will give better results in terms of forecasting severe events in comparison to low resolution forecast. However, ensemble forecasts are more reliable and skilful in particular at longer lead times.

The second research question focuses on the skill of the hydro-meteorological system. All scores indicate that the forecast in the medium to long range outperforms any auto regressive and climatologically driven benchmark. From this paper we can estimate that on average forecasts can be issued skilfully until day 30. The forecast improved by 2.2 days over the last decade meaning that a 7.2 day forecast today is as good as a 5 day forecast 10 years ago (see figure 1). Please note that "skilful" should here not be confused with "useful". Although the modelling system may outperform a climatological guess, it does not mean that it can be used to issue warnings which are useful.

The third research question concentrates on the dependency of predictability. In general performance increases with catchment size, but it largely depends on the type of performance measure which is used. More important is the interaction between catchment size, catchment location, flow magnitude and resolution of the meteorological forcing. It is shown that high resolution forcings produce better forecasts for smaller flashier catchments in areas of high relief and at peak flows. These findings are similar to other long term analyses and are indeed hydrologically intuitive. The overriding, but connected factor to predictability is the performance of the hydrological model in particular the modelling error and uncertainties.

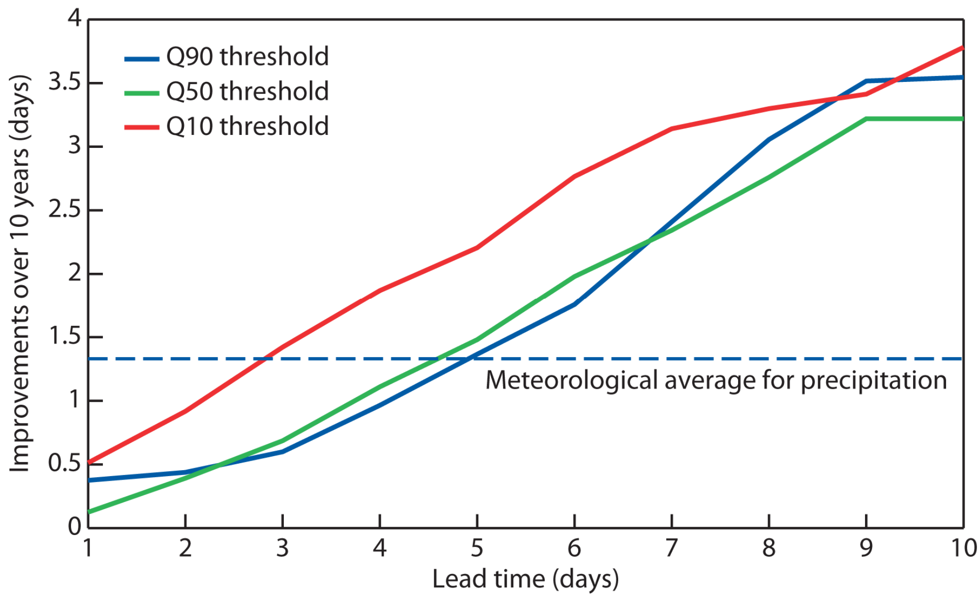

Figure 1: Gain in lead time over a decade for three thresholds (Equitable Thread Score). The dotted straight line indicates the average gain for precipitation.

The overarching goal of this study was to provide a benchmark for the European Flood Alert System and for probabilistic forecast systems in Europe in general. We can now confidently state that the EFAS system is statistically skilful over the last 10 years for the forecast horizons for which it is used and that the skill has been steadily improving over this period due to improved meteorological station network and weather forecast products. This dataset will now allow us to continue testing model improvements on a longer time scale and thus make statistically more robust decisions. It allows exploring decision making frameworks on a sufficiently large sample in future studies and implement the most optimal strategies. We also hope it to serve as a benchmark for national forecasting systems

Key recommendations from this research question include:

1. hydrological flood forecasting benefits from higher resolution and meteorological model updates; multi-model concepts (multi-model forcing as well as multi hydrological models) will yield more reliable flood forecast results.

2. a cost-loss framework has to be established with the relevant stakeholders to analyse the 'true' performance of a forecasting chain.

3. Operational research should focus on improving the hydrological core component through improved calibration, better data assimilation, adequate representation of catchment characteristics and uncertainties in the hydrological model in addition to the post- and pre processing of the HEPS system.

This research has been published (in press) in the special issue of Large Scale Hydrology of Hydrological Processes: Pappenberger, F., Thielen, J., del Medico, M, 2010, The impact of weather forecast improvements on large scale hydrology: analysing a decade of forecasts of the European Flood Alert System, in press, *Hydrological Processes.*

THE RAAB FLOOD FORECASTING SYSTEM. AN INTERNATIONAL FLOOD RISK MANAGEMENT PROJECT.

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1. THE EUROPEAN PROJECT: FLOOD FORECASTING RAAB

The Raab Flood Forecasting System generation is a project with European dimensions. The Raab watershed extends over two countries: Austria and Hungary whereas the last one is located downstream compared to Austria. Due to these geographical characteristics the probability for a flood genesis is much more significant in Austria than in Hungary but the related flooding risks are distributed over the entire watershed. The project Flood Forecasting Raab gives a concrete example of international cooperation in the field of flood management

The structure in development will be build out of one International Flood Forecasting Centre and four regional centres. It illustrates how a trans-boundary flood forecasting system can operate. The main element is the International Flood Forecasting Centre installed in Graz (Austria) where all the necessary online data and meteorological forecasts will be automatically collected and formatted for the simulations. Furthermore, each hour will start a simulation with a forecasted time of two days whereas the main results will be published on the internet. The complete model setup and the results will be transferred to the four regional centres. Therefore, on these regional centres it will be possible to analyse detailed results and to develop local scenarios using for example modified meteorological forecasts or other initial conditions.

This technical solution allows a perfect synchronisation for online data, pre and posts processing files, information and results from the simulations between all five Flood Forecasting Centres. It contributes therefore to a noticeable improvement for information organisation between Austria and Hungary and should be considered as a new method for Flood and Risk management. The new communication strategy coupled with the automatic and continuous modelling as well as the result publication on the internet delivers a concrete example for Flood prevention and resources management that can be transferred to other trans-boundary watersheds.

The Raab Forecasting system is based on the MIKE 11 modelling software and the MIKE Flood Watch real time decision support system. This combined forecasting system is a well proven approach, which has been applied successfully in many real time applications worldwide (one example is the “Trans-boundary Flood Forecasting Project in Austria, Slovenia, Hungary and Croatia” – (Ruch & Jorgensen, 2005).

The catchment area of the river Raab and its tributaries in Austria (figure 1) is located in a rural area with small villages and towns near the rivers. The lower parts outside the populated areas are mainly used for agricultural purposes. In order to safeguard the infrastructure of this living space and economic area, a variety of linear measures has been combined with the construction of flood retention basins. The protection of agricultural areas is less important. The big challenge for a forecasting model is to exactly and comprehensively simulate all the protective measures to create an unerring tool for flood management and also taking into account the relatively short times of the rising of flood waters.

The Raab Forecasting System will be developed in two phases – the upstream Austrian part and the downstream Hungarian part. This paper describes the setup for the Austrian component of the Raab catchment. The first part of the paper describes the Austrian watershed whereas the second is dedicated to the spatial and temporal data. Finally, the last part shortly introduces the modelling system used in this project.

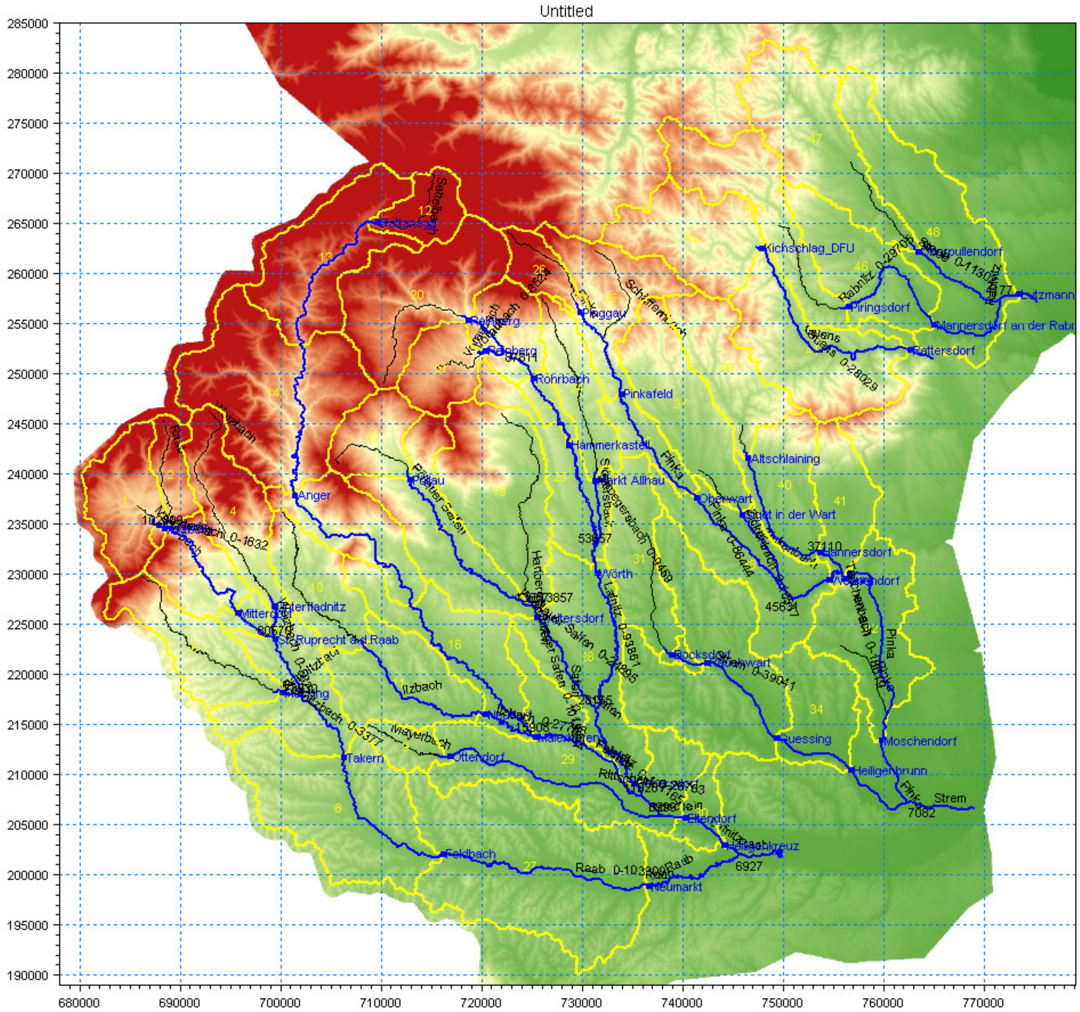

Figure 1: Austrian part of the Raab watershed with modelled sub catchments in yellow and rivers in blue

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ACKNOWLEDGMENT

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FLOOD FORECASTING SYSTEM FOR THE MARITSA AND TUNDZHA RIVERS

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1. GENERAL

Climatic and geographical characteristics of Maritsa and Tundzha River Basins lead to specific run-off conditions, which can result in extreme floods downstream, as occurred in August 2005 and March 2006. To improve the management of flood hazards, a flood forecasting system (FFS) was set up. This abstract describes a forecasting system recently developed in cooperation with the Bulgarian National Institute for Hydrology and Meteorology (NIHM) and the East Aegean River Basin Directorate in Plovdiv, Bulgaria (EARBD) for the rivers Maritsa and Tundzha.

2. THE FLOOD FORECASTING SYSTEM

The Maritsa and Tundzha Flood Forecasting System consists of calibrated hydrological models and hydraulic models that cover both river catchments. The models are set-up in such a way that a closed water balance is created.

The flood forecasting system uses the combined calibrated hydrological and hydraulic models and produces forecasted water levels and alerts at predefined control points. To assure a continuous flow of input data and a closed water balance, the system uses a data series hierarchy in which for each input data different orders are defined as stated in table 1. Data assimilation ensures that calculated input series are replaced with measured series if available. This means the system combines different sets of input, depending on their hierarchy order and availability, with which the simulations are made. More than 300 unique time series are defined. When for example a rainfall time series is not available, the system automatically takes the next order, which is the forecasted rainfall. This set up makes the system very robust and has proven itself as such. It also ensures that if available the most accurate input series are used.

Data	**Order**		
	1	2	3
Water level	Measured	Calculated[1)]	
Discharge	Measured	Calculated with NAM models based on measured meteorological data[1)]	Calculated with NAM models based on forecasted meteorological data[1)]
Meteorological			
Rainfall	Measured	Forecasted[2)]	Constant
Temperature	Measured	Forecasted[2)]	Constant
Wind	Measured	Forecasted[2)]	Constant

Table 1: Overview of input data ([1]) corrected with assimilation, [2]) using Aladin-meteorological forecast)

The difference between the calculated and measured water level series during a 5-day hindcast period is used to correct the water levels during the 5-day forecast period. This way hydrological trends can be taken into account in the forecast period as well.

Within the described study we wanted to use existing systems, infrastructure and data flows as much as possible. In order to connect all existing and new developed systems and databases the Data Exchange Tool (DET) was developed. The DET disseminates relevant information between the databases of NIHM and the EARBD, the flood forecasting system and a website that shows forecast bulletins (see figure 1).

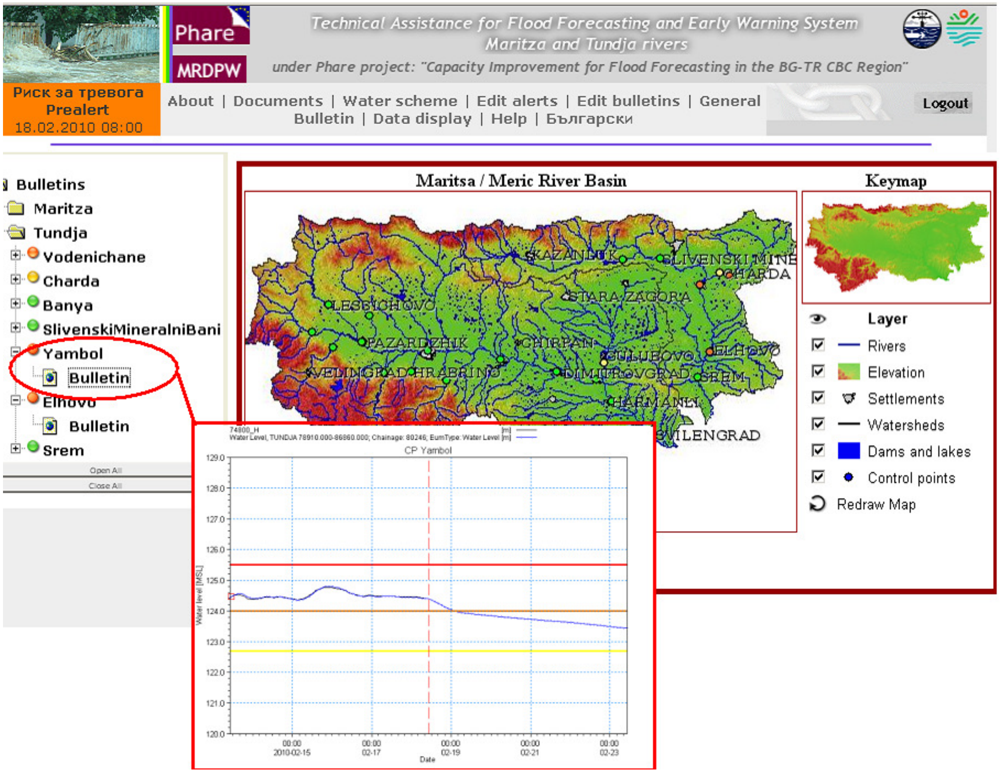

Figure 1: Screen dump of the flood forecasting dissemination website

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CRITICAL THRESHOLDS FOR ENSEMBLE FLOOD FORECASTING AND WARNING

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The use of weather ensemble predictions in ensemble flood forecasting is an acknowledged procedure to include the uncertainty of meteorological forecasts in a probabilistic streamflow prediction system. Operational flood forecasters can thus get an overview of the probability of exceeding a critical discharge or water level, and decide on whether a flood warning should be issued or not. This process offers several challenges to forecasters: 1) how to define critical thresholds along all the rivers under survey? 2) How to link locally defined thresholds to simulated discharges, which result from models with specific spatial and temporal resolutions? 3) How to define the number of ensemble forecasts predicting the exceedance of critical thresholds necessary to launch a warning?

This study focuses on the third challenge. We investigate the optimal number of ensemble members exceeding a critical discharge in order to issue a flood warning. The optimal *ensemble* threshold is the one that minimizes the number of false alarms and misses, while it optimizes the number of flood events correctly forecasted. Furthermore, in our study, an optimal *ensemble* threshold also maximizes flood preparedness: the gain in lead-time compared to a deterministic forecast. Data used to evaluate critical thresholds for ensemble flood forecasting come from a selection of 208 catchments in France, which covers a wide range of the hydroclimatic conditions (including catchment size) encountered in the country.

The GRPE hydrological forecasting model, a lumped soil-moisture-accounting type rainfall-runoff model, is used. The model is driven by the 10-day ECMWF deterministic and ensemble (51 members) precipitation forecasts for a period of 18 months. A trade-off between the number of hits, misses, false alarms (Critical Success Index) and the gain in lead time is sought to find the optimal number of ensemble members exceeding the critical discharge. In this study the focus lies on the start of a flood event, since the first day with a threshold exceedance is the most important and the most difficult to forecast.

The results show us that there is no overall ensemble threshold for the streamflow predictions based on the ECWMF forecast which results in higher CSI and a gain in lead-time for the exceedance of the Q99 streamflow threshold (99th percentile over the same period of 18 months) compared to the deterministic forecast. The optimal ensemble streamflow predictions for the lower streamflow thresholds results also in a negative preparedness score (i.e. loss in lead-time).

The same analysis is conducted for a sub selection consisting of 29 large catchments all over France. The results of this analysis show us that in this case there is an ensemble threshold for the Q99 streamflow thresholds which results in a higher CSI score and a gain in preparedness (i.e. gain in lead-time) compared to the deterministic forecast. Both scores, the CSI and preparedness, could be maximized when a catchment specific ensemble threshold is applied.

These optimal ensemble thresholds are further explored in order to search for correlations with catchment characteristics, forecast lead-time and discharge thresholds.

VERIFICATION OF RUNOFF FORECASTS BY THE FOEN AND THE WSL

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1. INTRODUCTION

This study set out to perform a systematic evaluation of the hydrologic forecasts under the MAP D-PHASE (*Zappa et al. 2008*) for the period from June 2007 to December 2008. An analysis and interpretation was carried out on the quality of runoff forecasts made by the FOEN and the WSL using different meteorological models. This was intended to quantify the advantages of the models used and the quality of the forecasts.

The hydrologic model used by the FOEN was HBV-FEWS. The WSL computed the hydrologic forecasts using PREVAH. The following meteorological models were available: COSMO-7, COSMO-2 and COSMO-LEPS. At the FOEN the forecasts were further computed using ECMWF and a corrected version of COSMO-7.

An instrument (verification script) had to be created to enable the runoff forecasts to be verified at all. All the most important quality criteria had to be combined in this verification script. Because many different approaches are possible for evaluation of runoff forecasts, suitable methods had to be defined. The verification script was written in the open source programming language *R*.

2. METHODOLOGY

The following approaches were selected for the lead-time-dependent analysis: Graphic analysis of chained plots, analysis of all hourly values, analysis of 24-hour maxima and single event analysis. A large number of scores representing different aspects of the forecast quality were calculated. A pairing of measured value and forecast value formed the basis in each case. The analyses were carried out by the FOEN and the WSL for 9 selected runoff metering stations. A comparison was also made of the simulations and forecasts using PREVAH (WSL) and HBV-FEWS (FOEN) for three joint stations.

Table 1 gives a summary of the scores used for analysis of the 24-hour maxima:

Error Statistics/ Accuracy Statistics	Mean Absolute Error (mae)
	Nash-Sutcliffe (E)
Categorical Forecasts	Frequency Bias (BIAS); Threat Score (TS)
	Miss Rate (M); False Alarme Ratio (FAR)
Forecast Skill	Heidke Skill Score (HSS)
	Ranked Probability Skill Score (RPSS)
	Ranked Probability Score (RPS)
Conditional Measures	ROC-Diagram; ROC-Fläche; Attribute-Diagramm
Distribution Properties	Rank-Histogram

Table 1: Scores used for analysis of the 24-hour maxima

The following sources give a good overview of the scores used: *Wilks (2006)*, *WWRP/WGNE (2010)*, *NOAA (2010)* and *MetEd (2010)*. The thresholds defined under the MAP D-PHASE were used as warning thresholds. For some tasks the thresholds were also based on quantiles of the runoff data during the period under review.

3. SELECTED RESULTS

Figure 1 shows two examples of graphs from the analysis:

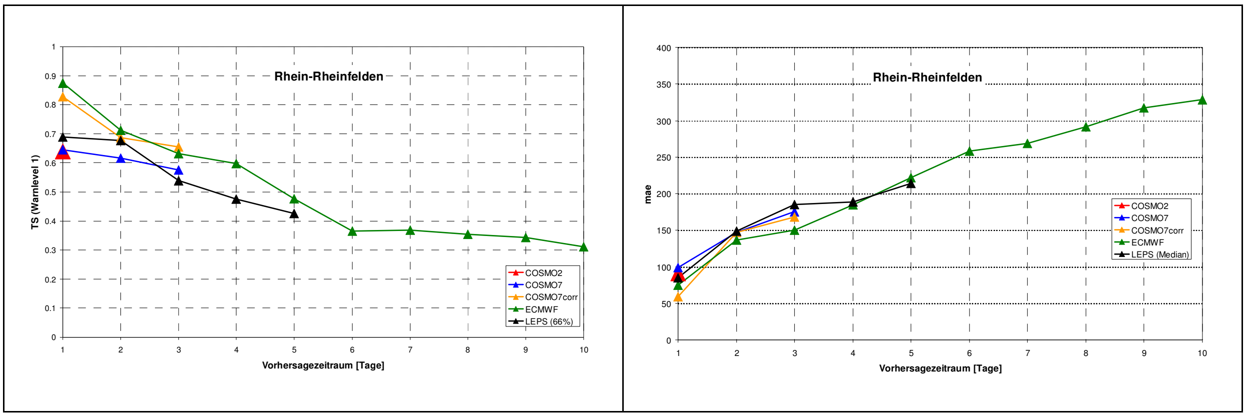

Figure 1: Examples of 24-hour maxima analysis (Threat-Score and Mean Absolute Error)

Only a few general findings can be given at this point:

It is not possible to give a general recommendation as to which model performs better at which station. The performance of the different models varied depending on the approach, methodology, forecast period and station under review. The differences between the stations reviewed are much greater than the differences between the individual forecasts for any station.

The forecasts using the high resolution COSMO-2 model are not generally better than the others. However, for some quality criteria, the COSMO-2 forecasts perform better in the analysis of the 24-hour maxima for individual stations for the first forecast period (0-24-hour) than for the forecasts with the other meteorological models (fewer false alarms, for example).

The quality of the forecasts generally falls as the forecast period increases. In particular, the quality frequently falls sharply between the 0-24-hour period and the 24-48-hour period.

4. CONCLUSION/OUTLOOK

The report provides a theoretical background for the verification of runoff forecasts and various approaches are indicated as to how forecasts can be evaluated. The quality of runoff forecasts using different meteorological models is quantified.

The aim in future should be routine, periodic evaluation of the forecasts. Any flood events and false alarms that occur should also be briefly analysed and documented.

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OPERATIONAL PROCEDURE FOR DERIVATION OF AREAL RAINFALL FOR THE RHINE BASIN

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ABSTRACT

Areal precipitation, as one of the most important hydrometeorological input parameter for rainfall-runoff modelling, is basically available in form of high resolution raster data sets for the River Rhine basin. These datasets were built up in a daily time step using station data with the highest possible spatial density. However, such a product is not available operationally and in an hourly discretisation.

During operational forecasting of water levels and discharges in the river Rhine basin, as applied by the German Federal Institute of Hydrology (BfG) and the Dutch Centre for Water Management (WMCN), the areal rainfall estimate must be derived from operationally available rainfall data at a limited amount of rainfall stations. This paper describes a procedure to emulate the high-quality areal rainfall estimates as much as possible during operational forecasting. The new approach is tested against the high-quality rainfall product and estimates derived with the current interpolation method used in the operational system. The areal rainfall estimates derived with the new interpolation procedure emulate the high-quality precipitation data better for most catchments of the Rhine basin. Especially, in those catchments where orography plays a role, like the Black Forest. In the River Moselle area, the new interpolation procedure leads to better simulations of the discharge. For those catchments, where the old method outperforms the new interpolation scheme, the difference between the two methods is always small.

1. INTRODUCTION

Precipitation maps with daily or even better resolution are necessary as input for prediction of extreme flood events (e.g. Singh and Frevert, 2002a,b). For flood prediction these maps have to be available close to real–time.

For the river Rhine, areal precipitation data are available in form of high resolution raster data sets produced by the German weather service (DWD) and is known as the REGNIE dataset. The REGNIE datasets were built up in a daily time step using station data with the highest possible spatial density. However, this product is not available operationally and in an hourly discretisation.

Therefore, during operational forecasting of water levels and discharges in the River Rhine basin, as applied by the German Federal Institute of Hydrology (BfG) and the Dutch Centre for Water Management (WMCN), the areal precipitation estimate must be derived from operationally available rain gauge data at a limited amount of gauging stations.

For flood and low flow prediction in the river Rhine basin, the hourly rainfall-runoff model HBV-96 () is used by the German Federal Institute of Hydrology (BfG) and the Dutch Centre for Water Management (WMCN). For operational forecasting, the rainfall-runoff model is forced by hourly areal precipitation and temperature estimates and long term monthly mean evaporation estimates.

For the Rhine basin as a whole, these hourly or even daily precipitation maps do not exist and certainly not near real-time. Gridded high resolution (1 km^2) daily estimate of the areal precipitation over Germany are available from the German Weather Service (DWD) and is known as the REGNIE precipitation product (Dietzer, ?). However, this product is not available operationally.

Therefore, the backbone of the areal precipitation estimates used for operational flow forecasting in the Rhine basin are still rain gauges since the reliability of remote sensing data (e.g., by weather radar or satellite) is unclear, not high enough, or still under investigation (). As a result, the areal precipitation estimates must be derived from a limited amount of operationally available rain gauges located in several countries (e.g. Switzerland, France, Germany, Belgium, Luxembourg and the Netherlands) during operational forecasting by the BfG and WMCN.

In several parts of the Rhine basin, areal precipitation is influenced by orography (e.g. Swiss Alps, Vosges mountains, Black Forest, and Sauerland) (CHR, 2001). These orographic effects should be accounted for in the operational interpolation method although no standard method is available (Sevruk, 1997; Ahrens, 2006).

This paper discusses the development and testing of an operational procedure for derivation of high resolution hourly or daily precipitation estimate for the Rhine basin which accounts for orographic effect. The operational procedure tries to emulate the high resolution daily product of the DWD as much as possible within the operational flow forecasting systems FEWS-DE & -NL of the BfG and WMCN. The procedure is tested over the period March 1996-2007 over which operationally available rain gauge data is available against estimate obtained with the current interpolation method used in the operational system and the high resolution precipitation data from the DWD which are available for the German part of the Rhine basin. For the Swiss part and the French part of the Rhine basin, no independent gridded daily precipitation estimates are available. For those areas, we compare measured and simulated discharges derived with the new interpolation procedure and the interpolation procedure currently used in the operational systems.

2. OPERATIONALLY AVAILABLE RAIN GAUGE DATA

The precipitation data that is operationally available consist of two sources: TTRR and Synop data (sy1). From September 2008 onward these two sources will be merged to one using the new Synop format (sy2-files). The TTRR data is available for the period 1990-2007. The TTRR data consists of 46 stations that provide hourly values of precipitation. The Synop files are available from March 1996 onwards. The amount of Synop stations that are operationally available increased in numbers during the 1990's and the number of precipitation stations became more or less stable after 2000. Until early 2006 when the number of Synop station suddenly increased from +/-200 to +/-650. The Synop precipitation data consists of hourly, 3-hourly, 6-hourly, 12-hourly and 24-hourly Precipitation data.

When the Synop and TTRR data are imported into the operational database several validation rules are applied to remove the most and largest errors that are present in the imported files. Table 3.1 shows the validation rules that are configured in FEWS-DE and -NL. These values are mainly based on record values measured in Germany (DWD, 2006). Data can be added manually or errors can be changed manually by a forecaster using a data editor.

Parameter	Source	Hard Min	Soft Max	Hard Max
T.m (^{o}C)	TTRR&Synop	-50	-	50
P.m (mm)	TTRR	0	50	90
P.01 (mm)	Synop	0	50	90
P.03 (mm)	Synop	0	90	120
P.06 (mm)	Synop	0	120	150
P.12 (mm)	Synop	0	150	200
P.24 (mm)	Synop	0	200	315

Table 1: Validation Rules for Precipitation and Temperature data used in FEWS-DE & -NL

After the import into the operational database, the precipitation information in the Synop files is being disaggregated into hourly values using the hydroMeteoTransformation method available in Delft-FEWS (Weerts et al., 2008). Synoptic data is available at time steps of 1h, 3h, 6h, 12h and 24h. Normally values at 06:00 and 18:00 report for the 12 hours previously, while those at 00:00 and 12:00 for the 6 hours previously. 3h and 1h values as well as 24h values can complement these readings. This means there is a lot of overlap in the data – this serves to create many fallback options, as well as when interpreted correctly to obtain a detailed precipitation profile. The 24h synop data are currently not used within FEWS-DE and -NL because these values deviate considerably from the 3, 6 and 12 hourly synop data. In the disaggregation procedure, the smaller time steps are used for disaggregation and the precipitation depth of the largest time is used to scale the precipitation amounts. The cause of the deviation of the 24 hourly synop precipitation depths is unknown (M. Werner, Personal Communication).