GERMAN RIVER FORECASTING SYSTEM
– USING MIKE 11 IN REAL TIME

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ABSTRACT
An operational real time discharge forecast system covering Germany is under development. The system encompasses hydrological models for the catchments of all rivers flowing in and into Germany. The 100 largest rivers are described by hydrodynamic models. A routine to automatically delineate the catchments and river axis was developed and applied to the NASA SRTM 90 m elevation model. The conceptual hydrological models calculate the water balance in soil, ground water, surface water and snow coverage. The meteorological input to the models is delivered by Meteomedia AG as gridded and station wise precipitation and temperature. Germany-wide 48 h-forecasts are calculated in one hour intervals. Innovatively, the results are not only disseminated as discharge but the discharge is also transferred directly into return periods calculated for every 5 km of river stretch. Furthermore, the surface run-off component is used to warn against flash floods in ungauged catchments. The system is prepared to forecast parameters like water temperature, low water, reservoir inflow, or hydropower energy yield that are important to forecast electricity production and price.

INTRODUCTION
Presently, there exists no uniform flood forecast system covering all of Germany. Therefore DHI began to develop a forecasting system for Germany based on the experience from many other flood forecast systems worldwide. Meteomedia AG delivers meteorological information and forecasts. The forecast system covers 100 major rivers in Germany (Figure 1). The main difference to other models is the architecture of the forecast system.
Figure 1: Mike 11 River network for the German Flood Forecasting System (blue).

MODEL ARCHITECTURE

The MIKE 11 model set-up is one of the largest and most complex river models developed for this purpose. The river model set-up alone covers 15,000 kilometres of rivers with 100 branches in the entire river basin areas and 585 sub-catchments (Figure 1). The catchments typically cover 500-1000 km². To our knowledge, this is the first time a complete regional model of the main German rivers including the upstream catchment areas including those outside Germany has been developed (Figure 2). Many systems are using only inflow information. The system presented here simulates also the catchments at the origin of the rivers, so there are no border conflicts like in other systems (possibility of transferring errors). Essentially, the forecast begins in the catchments and not directly in the river. The hydrological model used is MIKE 11 NAM.

Figure 2: Creation of catchments used in the system

The data needed for the forecast are metrological data in the form of precipitation and temperature. This data are provided by more than 1500 real-time observation stations (Figure 3 left) and from a 4 km grid based model (Figure 3 right) operated by Meteomedia AG.
Hydrological information as water level and discharge from publicly available sources is used as additional input to the system. The data is processed and compiled into time-series which feed the forecast model. Automatically sampling, processing and filtering of data from different sources is challenging and new routines had to be developed in close corporation with Meteomedia AG.

![Figure 3: Rain Information left: rain gauges (Meteomedia) right: weather radar (Meteomedia)](image)

**FORECASTING THE FLOOD STATUS OF THE RIVER**

It takes 20-25 minutes to gather and process the necessary data, while the actual forecast on average requires 15 minutes of computational time. A further 10 minutes is required to disseminate the forecasts. Forecasts can be disseminated via websites, with public access, subscription access or as dedicated and tailor made sites specifically developed for the end-users requirements. At present, it is not planned to create web pages with public access. The Forecasts can be presented as time-series (Figure 4 left lower corner) at selected locations on the rivers and as a coloured river status map showing the flood status of the river branches.

![Figure 4: Web based result presentation: Discharge for stations and videos for rainfall](image)
The entire data sampling and forecasting system is fully automatic and is prepared for the next forecast shortly after a forecast has been made available.

In the forecasting period, the model uses hourly input from a 4 km grid based meteorological model. Furthermore to obtain the best performance at the time of forecast, the model uses a data assimilation routine utilizing the available real time flow or discharge information used by the hydrodynamic model to ensure high accuracy.

Part of the MIKE river model is the rainfall-runoff module, which is a lumped, conceptual rainfall-runoff model, simulating the overland flow, the interflow and the base flow components based on input of rainfall, temperature and evaporation (Figure 5). The module can either be applied independently or used to represent one or more contributing catchments that generate lateral inflows to a river network. In this manner a single catchment or a large basin is schematized as an ensemble of many catchments connected with a complex network of rivers and channels.

![Figure 5: Scheme of the MIKE 11 NAM model](image)

The model describes the behaviour of each individual component in the hydrological cycle, at catchment level, by using a group of interconnected conceptual elements. In particular, it simulates the precipitation-runoff process by continuously accounting the moisture content in four storages, which represent physical elements of the catchment: snow storage, surface storage, root zone storage, and groundwater storage. Based on the meteorological input data, the model produces catchment runoff as well as other components of the hydrological cycle, such as actual evapotranspiration, soil moisture content, and groundwater level. The resulting catchment runoff is split conceptually into overland flow, interflow and base flow components.

Combining this with the forecasting module the model provides real-time data management, allowing automatic updates of the analysis and correcting for differences in observed and computed hydrographs. Therefore, the module serves two purposes, i.e. forecasting and updating. The flood forecasting component predicts the variation in discharges and water levels in a river system as a result of catchment rainfall and inflow/outflow through boundaries in the river system.
Updating consists of conditioning the model predictions to the observed data until the time of forecast. The standard updating procedure provided is an error correction routine capable of distinguishing between phase error and amplitude error (Figure 6). The procedure allows updating of both errors and makes corrections accordingly by minimizing an objective function. Typically, the corrections are carried out at several locations in the river system where real-time data are available as is the case here.

By adopting this approach accurate and reliable forecasts can be made based on the available data. This is further achieved by updating the forecasts on an hourly basis. As with any forecast the accuracy is highest the closer to the time of prediction.

TURNING REGIONAL FORECASTS INTO LOCAL FORECASTS

The present services provide regional forecasts. These can readily be turned into local forecasts by refining the local models and utilising local data, e.g. precipitation obtained from local rain radars which are becoming more and more common. The regional model feeds the local model with the boundary data, e.g. water level and discharge upstream. This is used in the local model to obtain the more detailed local forecasts.

UTILIZATION OF THE FORECASTS

The forecasts may serve many purposes many of which are related to the energy sector:

- Inflow forecasting to reservoirs and hydro power stations including production

Forecasts of reservoir inflow can be used to optimise the operation of reservoirs along river branches or to forecast the hydropower energy yield (Figure 7).

- Forecast of hydropower production

On a regional scale, the system can be used to forecast the energy production through hydropower. This information may be used to plan operation of the reservoirs themselves or of other power plants.

- Temperature forecasts
River temperature forecasts can be an important tool on a local, regional or even Europe-wide scale. On a local scale, a detailed temperature forecast may optimise the operation of thermal power plants. On a regional or larger scale, temperature forecasts may be essential as high temperatures may affect the energy production by thermal power plants.

- Low water forecasts

Low water forecasts may be an important tool as low water impedes not only shipping but may also impede energy production as some power plants require minimum discharges for operation.

Figure 7: Hydropower energy yield as possible model output

Another logical application is for example a regional warning of sub-catchments status or flood mapping at selected locations (Figure 8).

Figure 8: Flood mapping as product
Other applications which could be provided are:

- Detailed radar based forecasting in local and urban areas
- Water quality forecasting (e.g. oxygen concentrations, transport and dispersal of pollutants)

The forecasting service presented here cannot only be used to forecast hydrological data but also enables a number of important parameters to be forecasted, e.g. parameters used for decision support systems. The system is modular and can be adjusted to include more detailed information where needed and available depending on the requirements of potential users. The system design is such that a large degree of customization is possible and forecasts can be tailor-made for a large variety of applications and users at various scales.

REFERENCES

Gregers Jørgensen: Senior Hydrologist DHI-DK, has more than 20 years experience with development of forecasting systems worldwide.

Ole Larsen: Head of DHI-NTU Research Centre in Singapore. Ole Larsen started DHI’s office in Germany 5 year ago and has now moved to DHI Singapore.

The development of the forecasting system has only been possible with a mayor effort from Silvia Matz and Christian Pohl DHI-WASY.

Silvia Matz: Project Manager Forecasting Systems with 5 years experience in NAM and hydrodynamic modelling.

Christian Pohl: Customer Care Manager and Project Manager for Flood Modelling has up to 8 years experience in Flood Modelling