Flood early warning and forecasting across Europe:

Germany

While the warning about extreme weather events is done nationwide by the German Meteorological Service, the Deutscher Wetterdienst (www.dwd.de), flood forecasting and warning is decentralised in Germany. Within the federalistic structure the 16 constituent states are legally responsible for flood forecasting and warning on their territory. Almost every state runs its own flood forecasting or warning centre, often supported by several regional centers and along the navigable rivers in cooperation with federal agencies (www.hochwasserzentralen.de).

This form of organisation reflects the administrative structure but at the same time it also tends to exploit the local hydrological knowledge within the regional centers as well as the available forecast models, which have been set up for the individual catchments. This aspect is quite relevant as the hydrological behavior of the different landscapes in Germany - ranging from alpine basins in the south to rainfall-dominated low mountain ranges up to low land dominated by groundwater-interaction and tidal influences areas in the north - significantly varies.

However, such a decentralised organisational structure together with the fact that many of the German river basins are transnational offers several challenges, too. One main challenge is the handling of measured data coming from various providers and monitoring networks in individual formats, based on different spatial and temporal reference systems, in varying supply intervals etc. Beside the more technical aspect mentioned before, a close cooperation between the different forecasting centers is vital for successful flood forecasting in transboundary catchments. Another aspect which needs good coordination is the publication of forecasts and warnings, which should follow the single-voice principle in order to avoid competing forecast information which will probably confuse / alienate the public.

While flood forecasting and the underlying procedures and models have been improved over and over again within the last decades and centuries (e.g. the beginning of flood forecasting for the River Elbe is dated to the late 19th century), especially the remarkable floods in the Rhine basin happening within 13 months in 1993 and 1995 as well as the devastating floods in the subsequent years - 1997 on the Odra, 2002 along the Danube and Elbe rivers and in 2005 in the alpine area - significantly stimulated the development of forecasting techniques and improved the cooperation between the forecasting centers sustainably, not only in Germany. Also the joint development of forecasting systems across administrative borders was strengthened in this context. Nowadays forecasting and warning for larger rivers crossing administrative borders, like Rhine, Elbe or Danube, are organised in the form of a ‘chain’ coupling data, information and warning pathways between forecasting centers, typically in downstream direction. That means the downstream centers base their forecasts on monitoring values and forecasts provided by those upstream. For further information you could take a look at ‘Flood Forecasting, A Global Perspective’, edited by Thomas Adams and Tom Pagano (see: https://hepex.irstea.fr/flood-forecasting-systems-around-the-world-interview-with-thomas-adams-and-tom-pagano/). Chapter 5 (‘Flood Forecasting in Germany - Challenges of a Federal Structure and Transboundary Cooperation’) provides a detailed description of technical and organisational networking between flood forecasting centers in transboundary river using the example of the Rhine basin.
Although the German hydrological services use a range of forecasting models / systems, as described in the aforementioned book chapter, there are common features of these systems. Usually they consist at least of the following four components:

- **hydrological (water balance) models** translating measured and forecasted hydro-meteorological drivers (especially precipitation, temperature) into discharge;
- **hydrodynamic models**, usually one-dimensional primarily due to their computational speed, which calculate the behavior of the flood wave in the main rivers and the interaction with waves entering via the tributaries;
- **various pre-and postprocessing modules** preparing the data to be used in the forecasting models, executing the assimilation of real-time data into the models, correcting the model output based on statistical techniques etc.; and
- **dissemination module** (generating the final products for the users / the public and distributing the products and associated warnings).

The most current large-scale flood event affecting Germany happened in May / June 2013, which caused enormous damages and let to new highest water levels at several gauges, mainly in the Danube and Elbe basins. Amongst several countries and regions, the southern and eastern part of Germany was heavily affected by the 2013 flood. The following aerial photo shows the inundated interchange of the federal motorways A3 and A 92 at the Danube in June 2013 (Source: [http://doi.bafg.de/BfG/2014/BfG_Mitteilungen_31.2014.pdf](http://doi.bafg.de/BfG/2014/BfG_Mitteilungen_31.2014.pdf)).
A more detailed description of the flood 2013, its impacts (with a focus on traffic infrastructure as this is one of BfG's focal points in IMPREX) and BfG's involvement / experiences in the forecasting process might be reported in a later post. At this point we just state that this extreme flood event was the decisive factor in Germany for the development of a national flood protection programme. It is the first time that a nationwide position is adopted with a set of crucial measures taking effect across all regions in Germany for flood protection. In this context, a working group of the federal and state water authorities also developed recommendations for further improvements in flood forecasting for Germany. These recommendations cover a wide range of different aspects. Besides forecasting model / system oriented issues (e.g. improving / adding model features for extreme events, e.g. dike breaches, or the increase of forecast frequencies) the importance of technical requirements (e.g. reliability and stability of gauges and all kind of data transfer) and human resources (sufficient manpower, highly skilled, within the forecasting centers) is emphasised in this paper. One important aspect pointed out is keeping flood memory alive and to reveal that improving flood forecasting and warning facilities is not a singular issue but that it requires permanent effort.