Flood risk reduction using flood forecasting systems. An example from the region Styria in Austria

Christophe Ruch & Till Harum

Abstract

The present paper deals with flood risk and its reduction using flood forecasting systems. Two recent systems setup in Styria (Austria) for the Mur and Enns Rivers are briefly described. The main characteristics of both systems are presented focussing on the modern possibilities of data acquisition and transfer as well as automatic simulation correction. The last chapter provides recommendations to further enhance forecasts and warnings.

Keywords: flood forecasting, flood risk, flood warning, rainfall-runoff modelling

1 Introduction

Floods can be considered as the most devastating natural hazard over the world with a trend to increasing losses of life and economic values. Flood risk originates from the exposure of vulnerable elements to a flood hazard. The management of this risk deals with the analysis and governance of the flood hazards and the flood vulnerability whereas flood risk reduction should be central from a societal point of view. Plenty of measures can help to minimise flood risks but striving for "zero risk" is clearly unrealistic. Action plans dedicated to the reduction of flood effects include measures broadly classified into four types (European Commission 2005):
1) Information (flood risk mapping and communication, flood forecasting-warning systems, public awareness on best practices, establishment of an emergency plan);
2) Prevention (limit the use of floodplains, increasing retention capability of soils, increasing retention capability of floodplains and wetlands);
3) Protection (measures to reduce peak runoff, reduce level of flooding for given runoff, measures reducing impact of flooding); and
4) Emergency (implementation of emergency plans).

Although all these measures shall be considered as equally important for flood risk reduction, it appears that new communication and information technologies have led to substantial developments in the field of flood forecasting. The next two paragraphs briefly introduce the concept of flood risk and the modern structure of flood forecasting systems. Application of such systems is illustrated for the region Styria, Austria, in the fourth chapter followed by conclusions and recommendations for further improvement.

2 Flood risk

The term "risk" is understood and defined differently depending primarily on the scientific field wherein it is used, e.g. social and physical scientists employ risk in their own way. Whereas for social scientists risk depends on and is affected by the risk observer, for the natural scientist risk can be made precise and accurate. But even within the realm of natural hazards, plenty of risk definitions exist, the simplest being: Risk = Probability * Consequences (Helm 1996 in Kelman 2003, FLOODsite 2005). This definition is equivalent to Risk = Hazard * Vulnerability but the term vulnerability is subject to considerably differing definitions implying therefore possible confusions.

Applied for floods, risk (the flood risk) is then to be seen as the probability of social, economic and ecological damages due to a particular flood event. The concept of return period is generally used to determine the flood event in the risk analysis: an event with a return period of T years is likely to be exceeded, on average, once in T year (a hundred year event has a probability of 0.01 to occur during a year, or expressed in percentage 1%). Consequences are generally expressed in monetary units but consequences like losses of life can clearly not be evaluated in terms of costs.

To assess flood risk the concept of source-pathway-receptor is used, where the source (or cause) can be understood as the event generator like a storm, the pathway (or response) connects the source with the receptor being a kind of "water transporter", and the receptor (or consequence) as the flood-affected material and immaterial goods. This concept has the great advantage to be easily integrated in spatial planning considerations at various scales. The source becomes the runoff generating area; the pathway is then the physical property of this area that permits the flood wave to propagate, and the receptor encompass all human activities susceptible to be harmed from this event (figure 1).

Defining flood risk in space is then a logical succession. This is done using the so-called "flood risk zoning" that is based on flood hazard mapping. Whereas determining flood hazard spatial characteristics is quite straightforward using hydraulic models, flooding consequences in space are much more difficult to precisely tackle with. Therefore, flood risk definition in space should be primarily understood as a

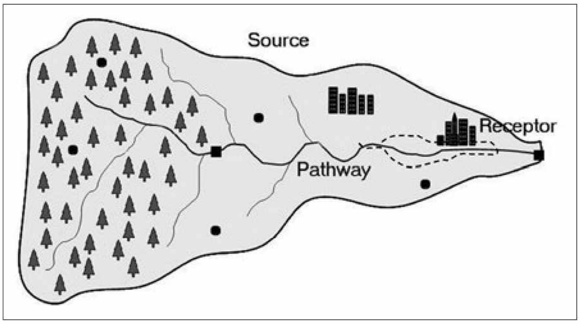

Figure 1: The source-pathway-receptor concept used at the catchment scale. Dashed lines define the spatial flood extent, dots are rainfall stations and squares are gauging stations.

reinterpretation of the flood hazard modelling using mainly water depth and velocity as key factors. Flood risk exists in areas where the modelling results overlap with human activities. The final result is then a flood risk zoning with usually high, medium and low flood risk zones for a given event of a given return period.

The flood risk concept replaces more and more the flood protection or flood defence approach because it was recognised that total flood protection is unwise and unrealistic. Increasing losses of life and economic values together with rising costs for dam and dike construction is a paradox illustrating that flood protection is not the correct way to go. Flood risk is now at the core of a new European Parliament directive that foresees the implementation of flood risk management plans by the end of 2015 (European Parliament 2007). Within the context of flood risk management a preparedness strategy aims at ensuring effective responses to the impact of an event. Accordingly, flood forecasting systems belong to the most efficient tools for consequently reducing flood impacts and flood risks.

3 Flood forecasting

The purpose of a flood forecasting system is to estimate the future states, especially runoff amounts and water levels, of hydrologic systems. The mathematical formulation of the forecasting problem for a hydrologic variable Q can be stated simply as (Butts et al. 2002): Given a set of observations up to the time of forecast t_N, (Qt_1), (Qt_2), (Qt_3), …(Qt_N), find (Qt_{N+1}), (Qt_{N+2})… Figure 2 shows a simple graphic of this formulation. But, it must be pointed out that a flood forecasting system is seldom a stand alone construction. In fact, the overall objective for each flood forecasting system is to deliver warnings to the population at risk to reduce human and economic losses. It should therefore be integrated in a structure dedicated to flood warnings as illustrated on figure 3.

The flood forecasting system is an important element of this structure but flood danger can also be detected using online real time data and/or meteorological fore-

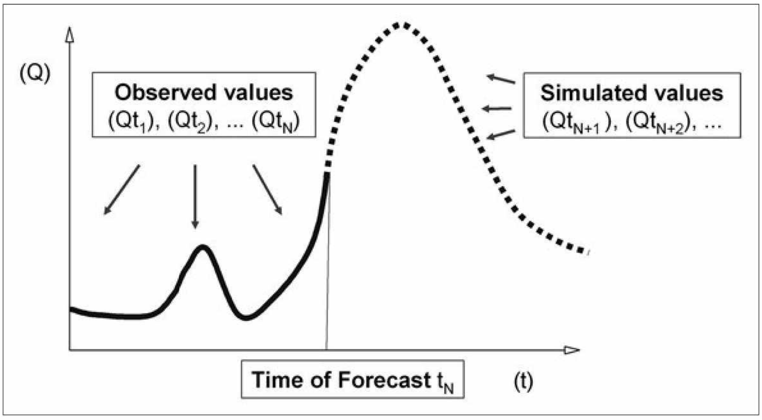

Figure 2: Schematic representation of a forecasted hydrograph (cf. text for explanation), where Q is discharge and t is time.

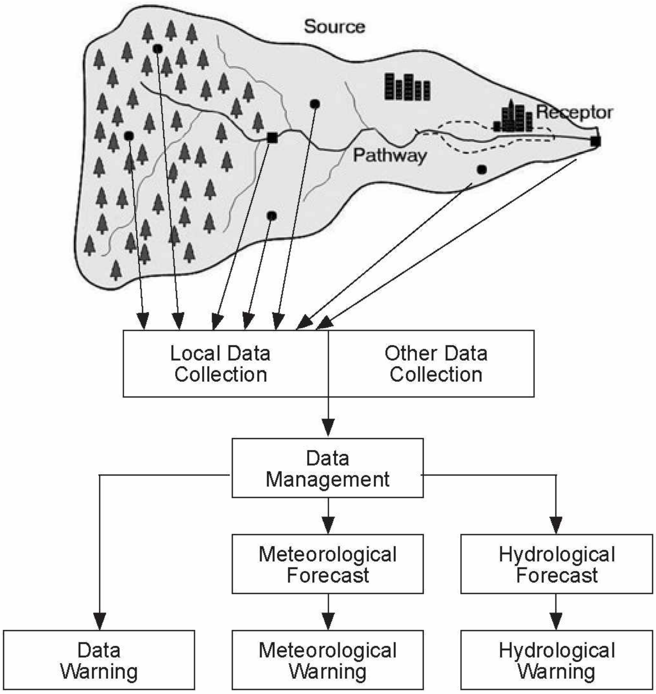

Figure 3: The three sources of flood warning.

casts. Of course, the flood forecasting system has its justification through the detailed modelling of the flood event. Information like for example the timing of the flood peak and the maximum water level or water amount are then available at specific locations generally called the forecasting points. This is certainly the reason why flood forecasting systems are often referred to as flood forecasting warning systems in literature (e.g. Schmitz et al. 2007).

A practical way to classify different existing flood forecasting systems is to examine the basin concentration time (basin time of response to rainfall) primarily depending on 1) the drained area and its form, and on 2) the length of the river network. The concentration time is positively correlated to these control parameters meaning that the flood wave travel time to the watershed outlet will increase and the hydrograph shape will modify. Thus, when the concentration time is long, forecasting the hydrograph at the basin outlet is possible, provided that upstream information is available in real time. Consequently, meteorological forecasts are not compulsory for delivering flood forecasts in such environment but they are required if the concentration time is short as is typically the case for urban areas.

Clearly, the ability to deliver warnings to the population at risk will largely depend on the position of the flood-risk area relative to the head water. This is one reason for using meteorological forecasts in modern flood forecasting systems: they allow the increase of the period over which flood forecasts can be simulated (lead time). Meteorological forecasts used in flood forecasting systems range typically from few hours (INCA in Haiden et al. 2006) to few days (model ECMWF). Nowadays, communication technologies enable to easily and automatically retrieve data as soon as the meteorological institutions make them available.

Such meteorological forecasts including rainfall and air temperature further allow forecasting discharge using Rainfall-Runoff models. Although these parameters are delivered on a grid basis, it seems that distributed hydrological models do not outperform lumped conceptual ones in the frame of flood forecasting modelling (Reed et al. 2004, Butts et al. 2004). Rezler et al. (2007) used a modified version of the HBV model on a 1 km x 1 km grid for the Kamp River (Austria) whereas an example of a lumped model application for the Mur River (Austria) can be found in Ruch et al. (2006) and Schatzl & Ruch (2006).

Developments regarding online hydro-meteorological data availability in real or quasi real time also gave a supplementary boost to flood forecasting technology. First, forecasts can now be made in a quasi real time manner. Second, rainfall-runoff modeling can be made in a continuous mode compared to event-based simulations currently used in former system generations. The ambiguous choice of initial conditions that led to a large uncertainty range for the forecasted hydrographs is therewith not necessary anymore. Finally, automatic forecast updating procedures using retrieved real time hydro-meteorological data enable to 1) adjust the model to the observations, and to 2) modify the forecasted values taking into account the errors made before the forecast (Drabek 2006, Komma et al. 2006).

4 Flood forecasting in Styria, Austria

The flooding event from August 2002 has severely affected Austria and especially the regions Upper Austria, Lower Austria, Styria, Salzburg and Tirol (StartClim9 2003). In Styria, damages were relatively limited compared to the four other regions. However, large flooding occurred in the Enns River catchment. One consequence was that flood risk management in Styria had to be reorganised and large efforts were undertaken to enhance flood damage mitigation measures.

In this respect, it was decided that the possibility to deliver hydrological forecasts should become an active part of the overall flood risk reduction strategy. In the following, the flood forecasting systems for the Mur and Enns Rivers in Styria are briefly presented. These systems were setup in an operational modus in 2006 and 2007 and are still under "observation" explaining why warnings are not automatically made public but only after analyses from the "Amt der Steiermärkischen Landesregierung – FA19A".

The Mur River watershed covers approximately 10,000 km² at the downstream border of the region, and the Enns River watershed around 4,000 km². The head of both basins is located in the region Salzburg. The main characteristics of these systems are:

1. automatic hourly forecasts;
2. automatic exploitation of online quasi real time hydro-meteorological data via intranet;

3. automatic import of meteorological forecasts via ftp connections; and
4. automatic publication of the main results on the internet. All these steps are implemented in the central software Mike Flood Watch (DHI 2005a).

Simulations are done using the model NAM (DHI 2005b) for rainfall runoff modelling at the sub-catchment scale. Runoff dynamic is simulated for 56 hydrological units whereas the NAM model has been calibrated on 19 sub-catchments. The simulated discharge is transferred to the hydrodynamic model MIKE11 (DHI 2005a) for the 1D simulation of the flood wave propagation in the simplified river network illustrated in figure 4. This allows modelling the water level where cross sections are available. 1D simulation of the floodplains with automatic mapping of the flood extent is further implemented in the Enns system only (Ruch & Jørgensen 2007).

The forecasts are delivered over a 48 hours' lead-time using the meteorological forecasts worked out from the Central Institute for Meteorology and Geodynamics, Vienna. Rainfall and air temperature data are available on a 1 km x 1 km grid with a one hour time resolution. These values are obtained using the INCA (Haiden et al. 2006) methods for the first 6 hours and the 9.8 km x 9.8 km grid downscaled ALADIN results. Data from the meteorological measurement network TAWES are retrieved in 15 minutes time steps so that extrapolation made in the frame of the nowcasting system INCA can follow precisely the meteorological dynamics. These data are made available each hour on the ftp server.

Finally, data assimilation procedures ensure that the hydrological simulations fit the observed discharge data at the time of forecast. Analysing the difference between simulated and observed values at different gauging stations, water is then added or subtracted from the river network. Furthermore, error correction is distributed over the first forecast hours using an exponential decay, i.e. it is assumed that the largest error is made at the time of forecast and that the error value decreases with time.

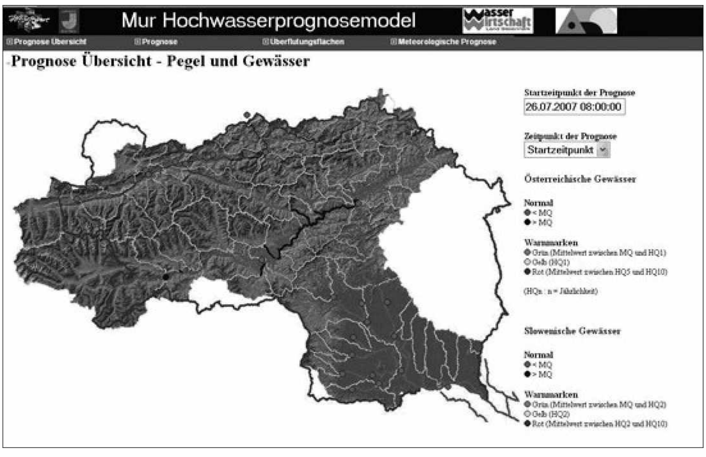

Figure 4: Front page from the Mur and Enns flood forecasting results publication on the Internet. White lines represent sub-catchments boundaries, dots are the online gauging stations, and the bold line is Styria's border.

5 Conclusion and outlook

Today, both structural and non-structural measures, adequately related in time and space, represent the cornerstones of a unified contemporary flood risk management concept. Structural measures are related to the physical control of the basin drainage by means of constructions or devices such as dams, dikes, channels, and canalisation. Non-structural measures are those in which floods damages are mitigated by procedures such as insurances, flood zoning and flood forecasting.

A timely and reliable flood forecasting system depending on "actual" hydro-meteorological conditions should be considered as a precondition for the improvement of the flood protection. An effective system as presented shortly for the Mur and Enns Rivers should be supported by meteorological forecasts increasing the forecast lead time so to deliver the earliest possible warning. It should also be embedded in a larger flood warning structure as presented in figure 4.

The two systems setup for the Styria region effectively combine new technological possibilities. The automatic and hourly simulation together with error correction procedures and the implementation of "actual" meteorological forecasts should deliver hydrological forecasts with high quality. Floodplain modelling like in the Enns system should enhance warning efficiency. Forecast quality analysis could not be done as both systems are too recent.

Nevertheless, first results clearly show a severe quality degradation from the main Rivers to the tributaries indicating the need to enhance the hydrological forecast performances at the sub-catchment scale. Furthermore, information and results from the many ongoing 2D floodplain modelling in Styria should be used to increase the hydrological forecast quality and warning accuracy. Finally, an extension of the online real time hydro-meteorological Tawes network would be suitable to decrease uncertainty of the nowcasting data and could also be used in the hydrological forecast systems. These evolutions would further enhance the flood risk management level in the region and contribute significantly to flood risk reduction.

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