Predictability of Flood Events in View of Current Meteorology and Hydrology in the Conditions of the Czech Republic

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Abstract: In central Europe, floods are natural disasters causing the greatest economic losses. One way to reduce partly the flood-related damage, especially the loss of lives, is a functional objective forecasting and warning system that incorporates both meteorological and hydrological models. Numerical weather prediction models operate with horizontal spatial resolution of several dozens of kilometres up to several kilometres, nevertheless, the common error in the localisation of the heavy rainfall characteristic maxima is mostly several times as large as the grid size. The distributive hydrological models for the middle sized basins (hundreds to thousands of km^2) operate with the resolution of hundreds of meters. Therefore, the (in) accuracy of the meteorological forecast can heavily influence the following hydrological forecast. In general, we can say that the shorter is the duration of the given phenomenon and the smaller area it hits, the more difficult is its prediction. The time and spatial distribution of the predicted precipitation is still one of the most difficult tasks of meteorology. Hydrological forecasts are created under the conditions of great uncertainty. This paper deals with the possibilities of the current hydrology and meteorology with regard to the predictability of the flood events. The Czech Hydrometeorological Institute is responsible by law for the forecasting flood service in the Czech Republic. For the precipitation and temperature forecasts, the outputs of the numerical model of atmosphere ALADIN are used. Moreover, the meteorological community has available operational outputs of many weather prediction models, being run in several meteorological centres around the world. For the hydrological forecast, the HYDROG and AQUALOG models are utilised. The paper shows examples of the hydrological flood forecasts from the years 2002–2006 in the Dyje catchment, attention being paid to floods caused by heavy rainfalls in the summer season. The results show that it is necessary to take into account the predictability of the particular phenomenon, which can be used in the decision making process during an emergency.

Keywords: meteorological forecast; hydrological forecast; model ALADIN; model HYDROG; summer floods; flash floods; case study; predictability

During the last decades, a great progress has been achieved in the area of the development of the systems simulating meteorological and hydrological processes in the Earth environment. With the available computer technology, the development of complicated mathematical operations is less time-consuming, numerical models are able to operate with more detailed data and/or with smaller spatial and time steps.

Hydrometeorological forecasting systems, i.e. numerical weather prediction (NWP) models cou-

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pled with hydrological forecasting models, are an important category. The outputs of the atmosphere models provide hydrological simulations with the time series of the forecast precipitation and temperature, the outputs of the hydrological models are subsequently a continuous course of the probable flows in the given catchment.

The so-called limited area models (LAM) of atmosphere operate with horizontal spatial resolution of several kilometres. However, the space error of the forecasting element is within the range of several dozens of kilometres and the time error of the 24-hour-forecast of the precipitation is typically within the range of several hours. The distributive hydrological models operationally utilised for the middle-sized basins (hundreds to thousands of km^2) operate in much more detailed resolution.

Since they are connected with the atmosphere models, it is obvious that, besides the precipitation measured and other quantities observed, good results of the hydrological forecast significantly depend on the quality of the meteorological forecast.

The temporal and spatial distribution of the rainfall and the flows in the stream network should be treated as stochastic processes. However, the operational approach to the flow forecasting is rather deterministic, i.e. the random process is forecast by the deterministic models. It is necessary to realise that hydrological forecasts are made under the conditions of great uncertainty which stems from the basin schematisation, the spatial and temporal precipitation approximation in the respective catchment, the inaccurate description of the complex rainfall-runoff process by simplifying models, the rating curves errors in the tested profiles on the flows, the problem of the scaling factor caused by various spatial scales of the metorological and hydrological models, etc.

The accuracy of the meteorological and hydrological forecast generally decreases with the forecast lead time. Convective heavy rainfalls occurring over an area of several km^2 and with their lifecycle of several dozens to hundreds of minutes are from the spatial viewpoint almost unpredictable or can be forecast only with the lead time of several dozens of minutes (Šálek *et al.* 2006).

The users always need the most accurate forecast with the longest lead time. These two conditions contradict each other. The catastrophic flood events from the last years, however, show that, in spite of the given dilemma, it is necessary to proceed further with the improvement of the flood forecast and also to let the users know of the possibility and limitation of the predictability of the flood events.

In the following text, flow forecasts are given of various flood events in the Dyje catchment. One of the goals is also to demonstrate the cooperation of two sciences applied – meteorology and operational hydrology. For the hydrological forecast calculation the rainfall-runoff model HYDROG was used while the precipitation forecasts were taken according to the numerical weather prediction model ALADIN. However, the particular type of the forecasting system utilised is not crucial; the above mentioned models can serve only for the demonstration of the approach.

The hydrological forecasting and warning system utilises a very sophisticated system in real-time operations. Nevertheless, the users often misunderstand the results which originate from the simplified perception of the hydrological forecast. The most significant point is the different predictability of the phenomena, some of which are virtually unpredictable, taking into account the exact time and location of their occurrence. The paper aims to describe the issue, to demonstrate the present limits of the predictability of the precipitation type, and to recommend possible approaches and solutions. Even though the hydrological forecast is burdened with great uncertainty, it can be – in the case of expert interpretation – a valuable means in the decision process within the scope of the flood protection.

MATERIAL AND METHODS

Precipitation types

Precipitations can be classified by the prevailing mechanism leading to the condensation of water vapour. Leaving aside the direct condensation on the surface, which is usually of negligible significance (especially for the flood forecasting), the dominant portion of a precipitation occurs as a consequence of the air cooling. The main cause of the air cooling is the upward vertical motion of air leading to the expansion of the air volume and to the decrease of temperature to the dew point, i.e. the state when the water vapour in the given air volume condensates. After a cloud is formed, another cooling is caused by radiation of the upper part of the given cloud, but these effects are of minor importance.

The classification of the precipitations can be based on the forcing leading to the upward motion.

The large-scale (also synoptic-scale) precipitation occurs when the air rises over a relatively large area of tens to hundreds thousands square kilometres. Although within this rising volume the particular vertical velocity is also variable, this precipitation causes rather a steady long-lasting rain or snowfall, usually with a low-to-middle intensity from 0.1 to 20 mm/h. The upward motion at the velocity of about centimetres per second (up to meters per second) is caused by large-scale dynamic and thermodynamic processes, i.e. processes leading to the development of atmospheric phenomena like baric lows, atmospheric fronts etc. These processes are also accompanied by and connected with advection, i.e. the horizontal transport of air. This means that the moisture evaporated at some places (e. g. oceans) is advected to another locations where, given the favourable conditions, it can precipitate. The typical duration of the large-scale precipitation is tens of hours (from the point of view of Lagrangian reference frame, i.e. moving with the velocity vector of the given air volume). An example of this type of precipitation is the intensive rainfall occurring on 4–8 July 1997, inducing a widespread extreme flooding in the eastern part of the Czech Republic (e.g., Šálek 1998). A large-scale precipitation accompanied by a strong wind also results in a considerable orographic enhancement in the mountains. The seasonal variation of this type of precipitation is not very significant; it can take place over the whole year but is a little more typical for the cold season when convection is suppressed (see below). A typical cloud producing a large-scale precipitation is Nimbostratus, i.e. stratiform cloud (see, e.g. Houze 1993).

The convective precipitation results from the vertical movement of the given air particles caused by buoyancy, which is called convection. A sufficiently intensive convection leads to the development of convective storms, i.e. strong or violent convective processes possibly accompanied by lightning, thunder, hail, strong wind gusts, and/or heavy precipitation. According to Doswell (2001), the convection producing the phenomena mentioned can be named as deep, moist convection. The vertical velocities in convective storms range from meters per second to tens of meters per second. The precipitation intensity is usually highly variable and can reach hundreds millimeters per hour, but the duration of the convective rainfall is usually about tens of minutes, occasionally extending to several hours. The typical horizontal scale is about several to tens of square kilometers in the case of single isolated storms. Sometimes the convective cells organise in mesoscale convective systems (MCSs, e. g., Frotsch & Forbes 2001) or develop a supercell (Davies-Jones *et al.* 2001). Unlike with the short-lived isolated convective storms, the lifecycle of the MCSs and/or the supercells is of the order of hours or tens of hours. The convective precipitation is significant especially in the warm season of the year when the surface is heated by more intense solar radiation. The cloud type induced by the moderate (non-precipitating) convection is Cumulus, while the deep, moist convection is connected with the cloud type of Cumulonimbus. It must be noted that the cumuliform precipitating clouds are sometimes accompanied also by stratiform clouds developing usually at the dissipating stage of the storm when the vertical velocities decrease (Houze 1993).

A heavy convective rainfall caused, e. g., the flash flood at the stream Hodonínka on 15 July 2002 (Šálek *et al.* 2006).

The processes inducing the upward vertical motion of air can also combine, especially in summers, when the convection plays a more important role. The large-scale precipitation can contain embedded convective cells producing heavy rain, which occurred during floods in the Central Europe in August 2002 (e. g., Šálek *et al.* 2002), while the original convective development sometimes transforms into a typical stratiform large-scale precipitation. This can make the categorisation of the precipitation into the above mentioned classes difficult (Šálek *et al.* 2004) .

The predictability of a flood is dependent on the lifecycle, size, and predictability of the phenomenon causing the flooding, usually the rainfall; the convective storms are very difficult to forecast before their initiation, but large-scale precipitations can be relatively well predicted with the lead time of tens of hours (1–3 days), although the quantitative values of the precipitation are not often of the quality desired for hydrological modelling. The typical space shift of the 24-hour forecasts of precipitation "cores" is about tens of kilometres and the error of the timing is approximately of the order of hours.

Some convective precipitations can occur as a consequence of a large-scale forcing which can trigger also the convective process; due to higher predictability of the large-scale forcing, the convective storms can be better predicted. This was the case of the heavy rains occurring on 29 June 2006 when the model ALADIN predicted both the high instability and the considerable large-to-meso-scale upward motion over the affected areas (Figure 2).

As mentioned above, the key tool for the precipitation forecasting is the numerical weather prediction models. However, a possibility also exists to extrapolate the imminent movement of precipitation by some methods of very short-range forecasting of the lead time in the order of several hours, often called nowcasting. It takes the advantage of the remote sensing methods, especially weather radar and satellite, and predicts cloud and/or precipitation patterns for several hours, utilising the movement vectors calculated from the most recent measurements or retrieved from a NWP model. However, the predictability decreases rapidly with time and these predictions are useful for only up to several hours, in the convective cases usually for up to several tens of minutes (up to half an hour, e. g. Novák 2004; Šálek *et al.* 2006). It must be also noted that there is a considerable progress in the data assimilation scheme of the mesoscale remote sensing data in the NWP models, promising a better prediction for several upcoming hours from the given time.

Prediction models used in CHMI

Meteorology – NWP model ALADIN

The numerical weather prediction models play nowadays the key role in meteorological forecasting. They are based on a set of partial differential equations describing the behaviour of the dynamic system (known as Navier-Stokes equation of fluid dynamics), combined with the mass and energy conservation laws (thermodynamical law, continuity equation etc). The NWP equations also encompass the influence of friction, turbulence, radiation, sub-scale convection, and other processes in the form of the so-called source terms. The only possible integration of the equations can be made only by numerical methods and therefore the quality and operational feasibility (timeliness) of their forecast is dependent on the computing capacity.

A NWP model has some number of directly forecast fields/variables. All the other fields are diagnosed from the set of prognostic fields (e.g., ECMWF 2006). E.g., the directly forecast variables of the NWP model ALADIN/CE (version of 2006) are the surface pressure, temperature, wind vector, and specific humidity, from which many additional parameters can be derived, like vertical velocity, geopotential, etc. (see, e.g. Yessad 2006). In the context of flood forecasting, of particular interest are the precipitation quantities and the parameters indicating atmospheric (in) stability, which show the probability of the convective processes.

The Czech Hydrometeorological Institute utilises the local (regional) NWP model ALADIN that has been developed as an international project under the auspices of the Météo France. Some basic information about the model ALADIN is mentioned in Table 1 (Janoušek 2006).

The NWP variables that are mostly utilised for hydrological predictions are the quantitative precipitation forecast (QPF), near-surface (2 m) temperature, and the phase of precipitation. However, it must be noted that the NWP predictability of precipitation varies; the timing of a precipitation differs typically in the order of hours and the location of the precipitation maxima is usually shifted by at least tens of kilometres.

Hydrology – model HYDROG

HYDROG (Starý 1991–2005) is a distributive event rainfall-runoff model which has been in use routinely in the Czech Hydrometeorological Institute (regional office Brno and Ostrava) since

Table 1. Basic information on numerical weather prediction model ALADIN

Area	Majority of Europe, centred around Slovenia/Austria
Horizontal grid length	9 km
Number of vertical levels	43
Time of the initial analyses of the operational forecasts	00, 06, 12, 18 UTC
Forecast range	54 h (run of 00 and 12 UTC) 24 h (run of 06 and 18 UTC)

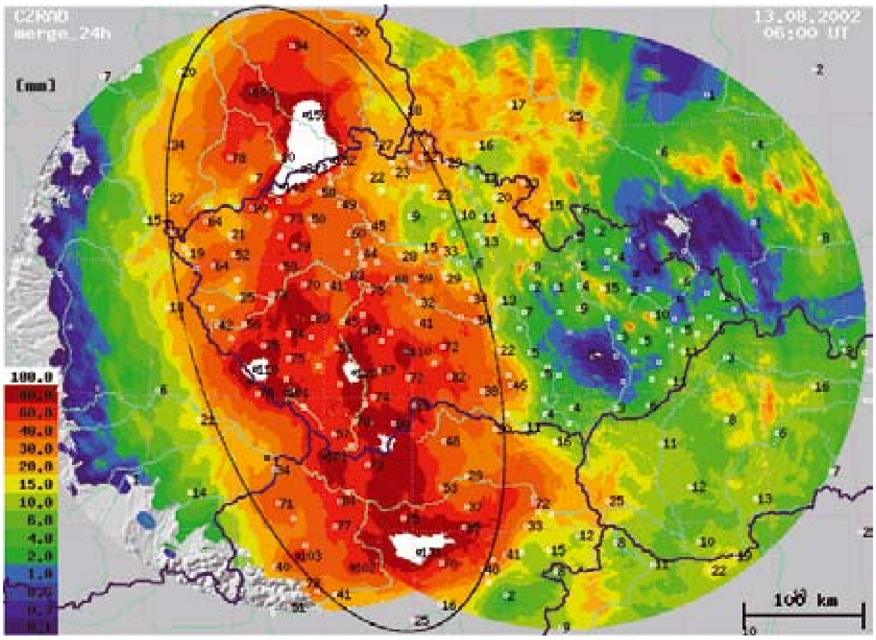

Figure 1. Daily sum of precipitation calculated as a multisensor (combined) radar and raingauge estimate from 13 August 2002, measurement taken at 06 UTC; the rainfall caused widespread record-breaking floods in the Vltava and Labe basins it is a large-scale heavy precipitation with remarkable orographic enhancement in the mountains located in the North-west Bohemia (300 mm on the ridge, 40–50 mm at the foothill on the lee side); in Southern Bohemia the convection development was observed, but played a minor role

2000 for the operative discharge prediction in the Dyje catchment (see Soukalová 2002; Březková & Soukalová 2006; Šálek *et al.* 2006).

If we perform a schematisation of a catchment by subdividing it into subcatchments with constant properties (slope, roughness, hydraulic

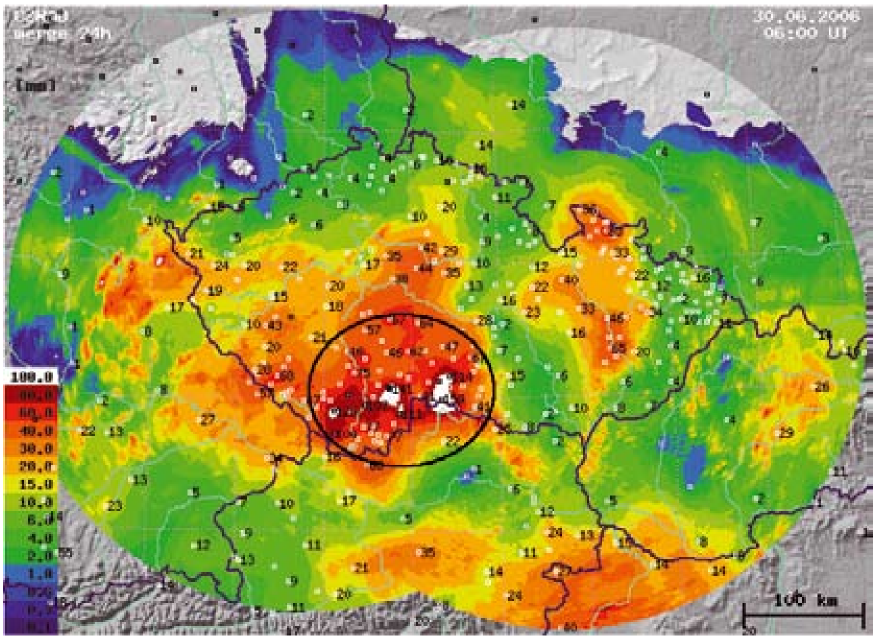

Figure 2. The same analysis as in Figure 1; daily rainfall accumulation from 30 June 2006, the measurement taken at 06 UTC; the precipitation resulted from an intense and widespread convective activity, accompanied by large scale precipitation which was more pronounced only at the end of the episode; the rainfall resulted in a flood which could be characterised as a large-scale flash flood

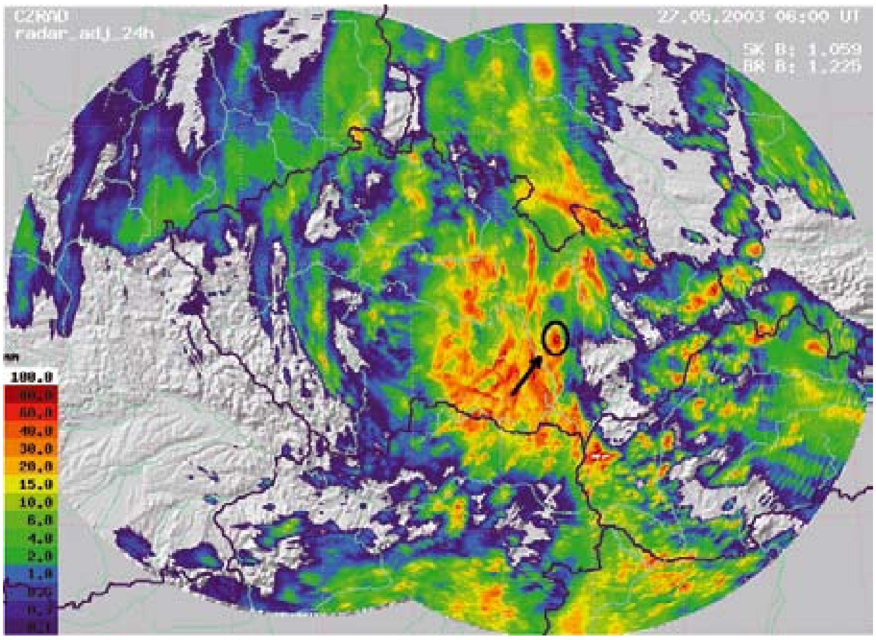

Figure 3. Routinely adjusted radar precipitation estimate of daily rainfall accumulation from 27 May 2003, 06 UTC; example of pronounced convective development which produced a localised flash flood in the depicted region

conductivity in the saturated environment), the rainfall-runoff process can be solved in a simplified way, i.e. as a one-dimensional problem. When simulating the flow of water through a subdivided catchment (spatial-surface runoff and concentrated runoff), the Saint-Venant Equations (continuity equation and an equation based on the law of motion preservation) simplified by a

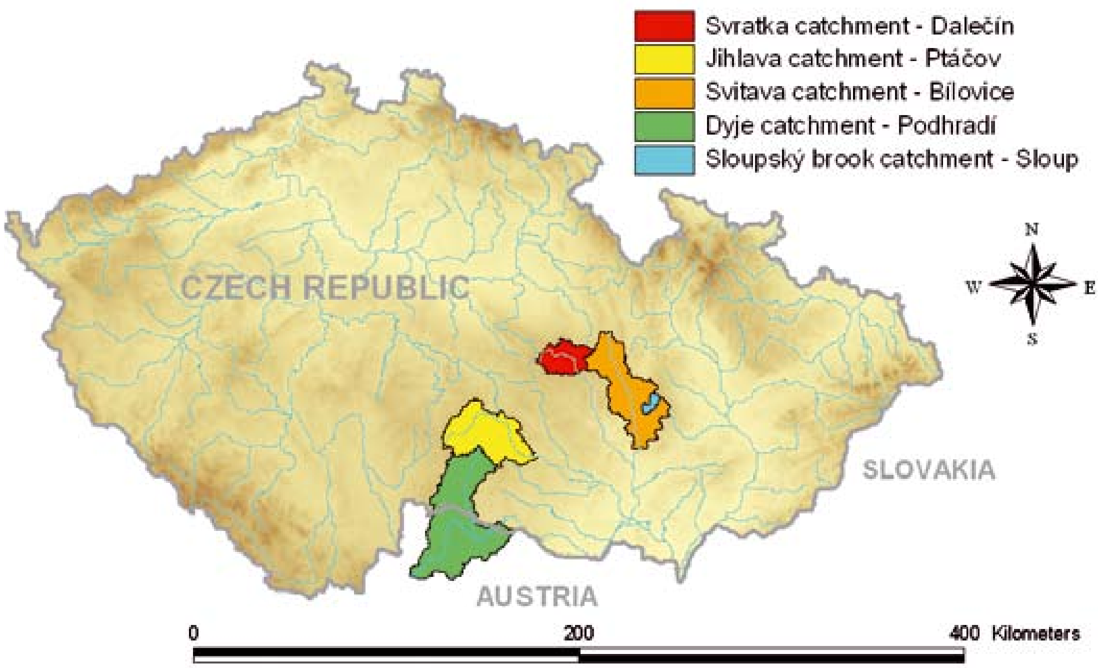

Figure 4. Tested parts of the Dyje catchment – Svitava catchment (closing profile Bílovice), Svratka catchment (Dalečín), Jihlava catchment (Ptáčov), upper part of the Dyje catchment (Podhradí) and Sloupský brook chatchment (a part of the Svitava catchment with closing profile Sloup

kinematic wave approximation (Stephenson & Meadows 1986) are used for the description of the dynamic performance of the system. For the computation of the dynamic change of the groundwater runoff, a conceptual regression model (McCuen & Snyder 1986), which uses only groundwater storage, is used. Of the hydrological losses, an important one is the infiltration loss – for its calculation the model uses the modified Horton method (Jacobsen 1980), which estimates the amount of initial infiltration from the rainfall sum that occurred in the preceding period (week). Other losses are included in the initial threshold value, when the aerial surface runoff is triggered off only after this value is exceeded. The process of creation of flow forecasts sequence comes out from the adaptivity principle. For more detail about HYDROG model see (Starý 2005; Šálek *et al.* 2006).

Floods caused by different types of precipitation

The following events represent different types of flood according to the causal precipitation.

August 2002 – flood caused by the large-scale stratiform precipitation, Dyje catchment (Figure 1).

June 2006 – flood caused by large-scale precipitation accompanied by severe convective deevelopment, Dyje catchment (Figure 2).

26. 5. 2003 – flash flood, purely convective precipitation, the Sloupský brook (Figure 3).

In the case of floods caused by large-scale precipitations, the discharge forecasts in following river profiles are depicted (Figure 4):

Bílovice, the Svitava River, catchment area 1120 km^2,
Dalečín, the Svratka River, 367 km^2,
Ptáčov, the Jihlava River, 964 km^2,
Podhradí, the Dyje River, 1756 km^2.

The calibration of the hydrological model was done for each flood event separately to obtain the best fit of the simulated and measured discharge time series. Thus, the simulated discharge forecast (based on ALADIN precipitation forecast) represents mostly the influence of the precipitation forecast (the inaccuracy caused by hydrological model is minimised). The input precipitation data were of the same type as those used in the standard operation practice of CHMI Brno (Březková & Soukalová 2006; Šálek *et al.* 2006), e.g. hourly quantitative precipitation estimates calculated for the areas of average size of about 150 km^2. The precipitation forecast of ALADIN model is provided for 6-hour time intervals for the areas of average size of about 2300 km^2. For the purpose of hydrological modelling, the relief is simplified to the surface elements of the size of 600–14 000 km^2, the river network to the segments of the size of 500–10 000 m (the same simplification is used in the operation practice of CHMI Brno).

In the case of flash flood, the discharge forecast was calculated for the Sloup river profile (the Sloupský brook belongs to the Svitava catchment, the catchment area is 50 km^2 – Figure 4). The measured and forecast precipitation data of a very detailed time and spatial resolution were used (10 min time step for the areas of average size about 7 km^2). For the precipitation forecast, the nowcasting methods (PERSISTANCE, COTREC – see Novák 2004) were used. The relief was simplified to the surface elements of the size of 0.1–2.3 km^2, the river network to the segments of the size of 400–3000 m.

Table 2. Precipitation forecast (by ALADIN) compared with the measurement – average rainfall for catchments with given closing profiles (August 2002)

	Average rainfall sum (mm) for a catchment with the given closing profiles					
Period	11. 8. 07 CET–13. 8. 02 CET		11. 8. 19 CET–13. 8. 14 CET		12. 8. 07 CET–14. 8. 02 CET	
Closing profile	forecast	measurement	forecast	measurement	forecast	measurement
Podhradí	55	69	73	81	46	65
Bílovice	28	27	80	48	19	28
Dalečín	36	28	98	67	39	68
Ptáčov	53	57	79	72	50	58

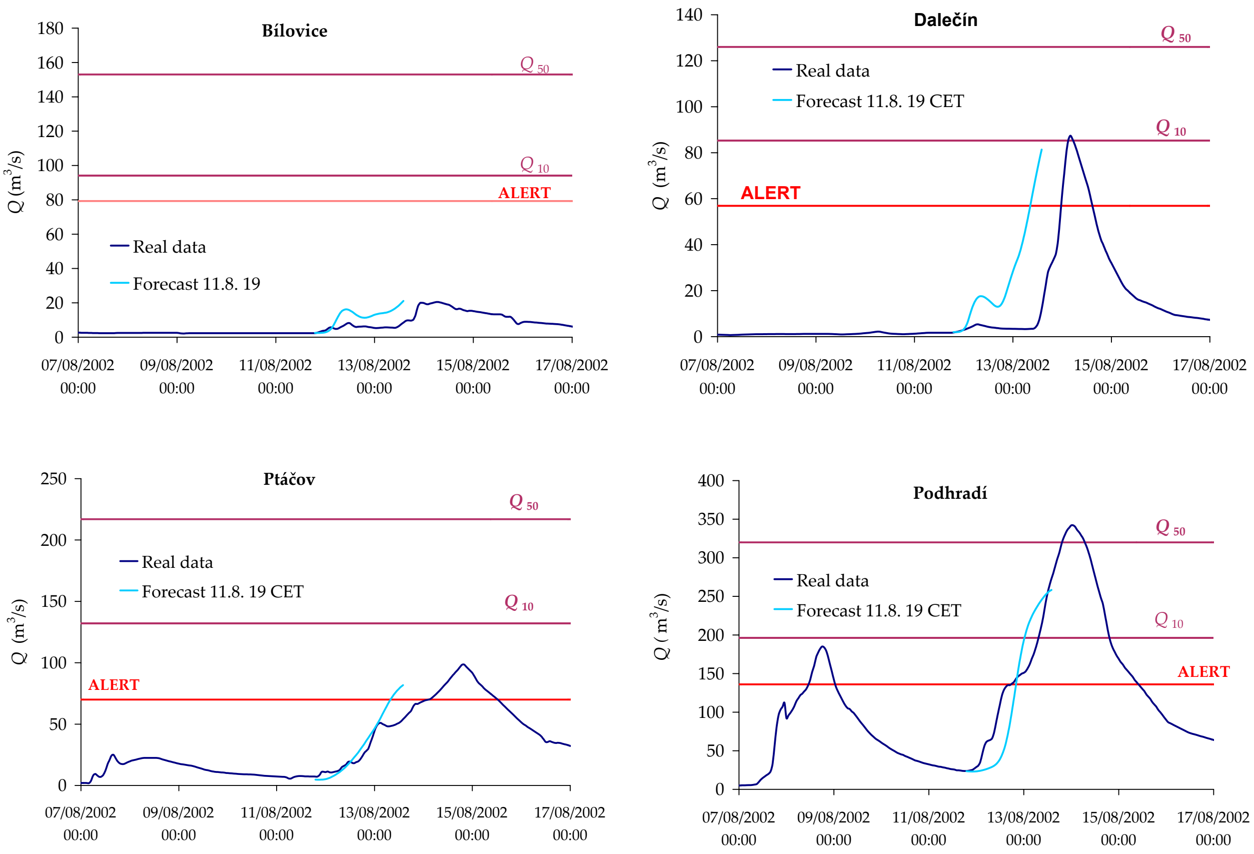

Figure 5. Simulation of discharge forecast in the selected profiles of the Dyje catchment in August 2002; alert, Q_{10} and Q_{50} discharge levels are marked; in all tested profiles a good correspondence of the measured and the forecast discharges is achieved

It is very difficult to find a proper form and quantity for the evaluation of the accuracy of meteorological and hydrological forecasts. It is necessary to evaluate the phenomena as a complex, not only to compare the sums of the measured and the predicted precipitation. The predictability of meteorological phenomena can differ very much according to the type of precipitation – this difference should be involved in the evaluation of the accuracy of the forecast.

For this reason, the accuracy of both meteorological and hydrological forecast was classified subjectively according to the scale failure – unsuccessful – successful – very successful. The evaluation comes from the experience with the hydrometeorological operation routine and tries to take into account both

Table 3. Precipitation forecast (by ALADIN) compared with the measurement – average rainfall for catchments with given closing profiles (June–July 2006)

	Average rainfall sum (mm) for a catchment with the given closing profiles			
Period	29. 6. 07 CET–01. 07. 06 CET		29. 6. 19 CET–01. 07. 18 CET	
Closing profile	forecast	measurement	forecast	measurement
Podhradí	92	82	54	73
Bílovice	113	24	123	24
Dalečín	135	20	93	20
Ptáčov	107	34	41	31

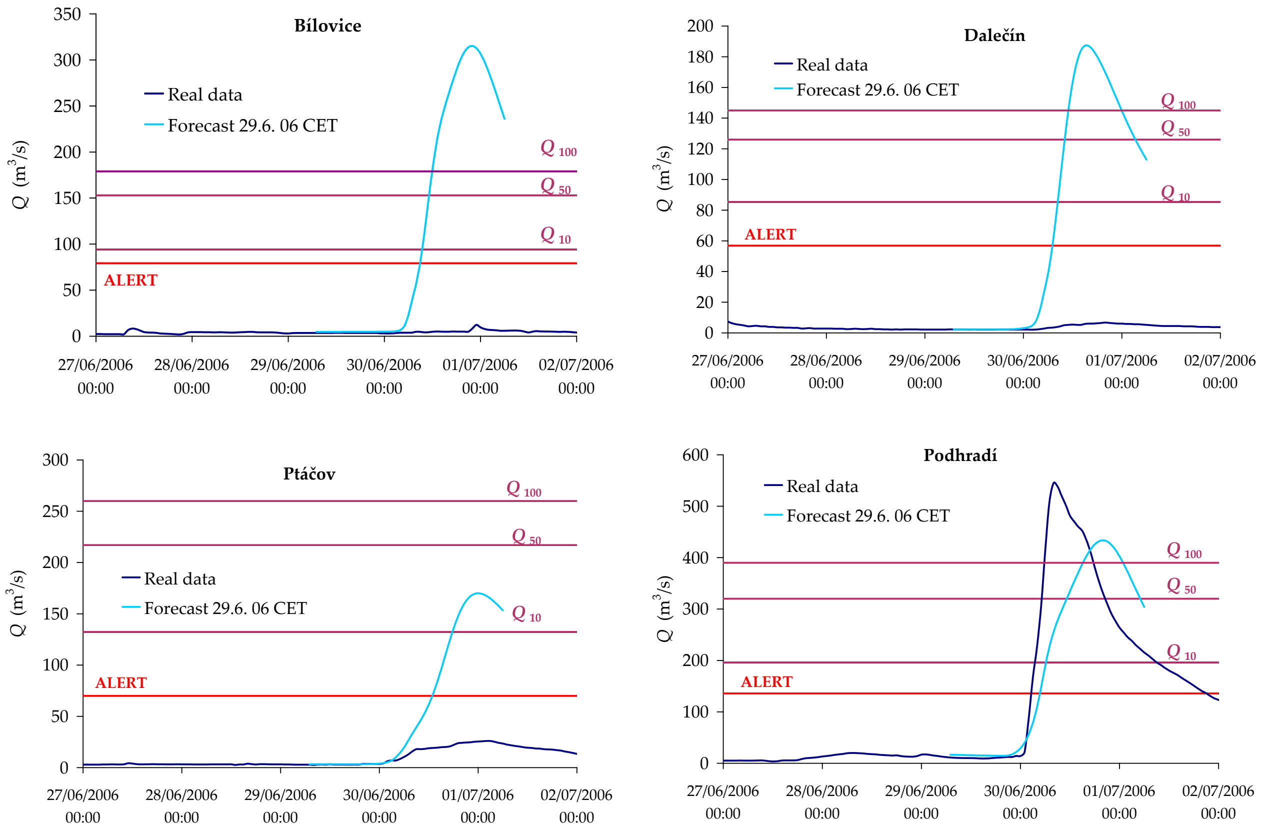

Figure 6. Simulation of discharge forecast in selected profiles of the Dyje catchment in June 2006; alert, Q_{10}, Q_{50} and Q_{100} discharge levels are marked; it is obvious that, in spite of the successful meteorological forecast, only in the profile Podhradí was achieved a successful hydrological forecast

the accuracy of the predicted precipitation and the predictability of the particular precipitation type.

RESULTS AND DISCUSSION

The predictability of different precipitation types (and subsequently flood types) is demonstrated by the following examples.

Floods caused by large-scale precipitation of the stratiform character

This precipitation type causes floods which usually hit large catchments. Typical examples are the floods which affected central Europe in July 1997 and August 2002. From the hydrological point of view, they represent a relatively well predictable event type. The flood that occurred in August 2002 is classified thereafter.

Meteorological forecast

The precipitation forecast is classified as successful. The forecast precipitation sums (48 h) were nearly identical with the data measured with all catchments tested (Table 2), although the time distribution of the precipitation forecast was different from the development observed.

Table 4. Classification of the meteorological and hydrological forecasts of floods in August 2002 and June 2006

Profile	Forecast August 2002		Forecast June 2006	
	meteorological	hydrological	meteorological	hydrological
Bílovice		successful		failure
Dalečín	successful	successful	successful	failure
Ptáčov		very successful		unsuccessful
Podhradí		very successful		very successful

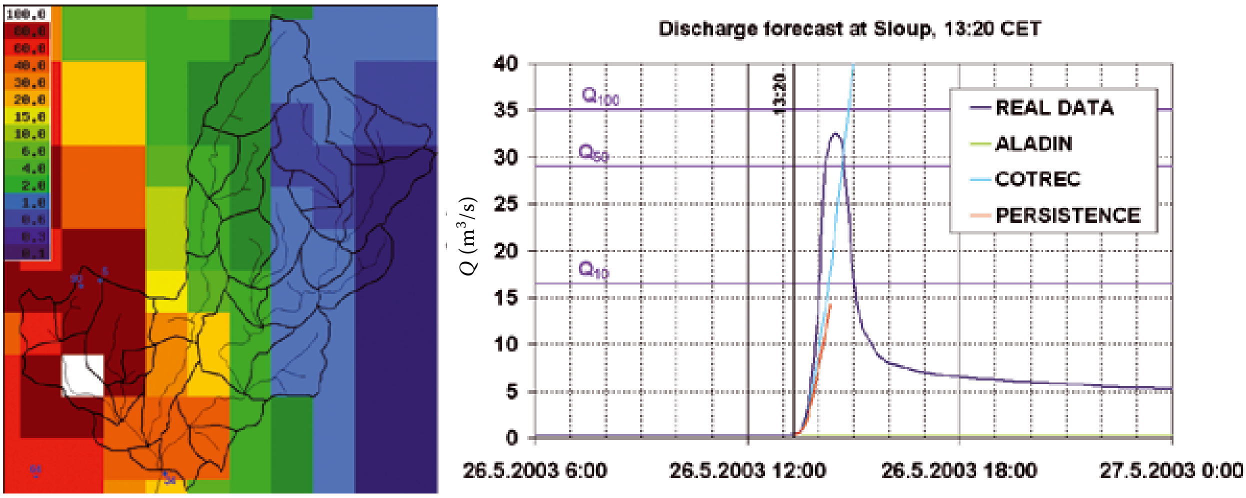

Figure 7. Simulation of the discharge forecast from 26. 5. 2003 in the Sloup profile (the Sloupský brook catchment); NWP models (ALADIN) are not able to predict this type of event, however, with the help of nowcasting methods (COTREC, PERSISTANCE) we can predict the rapid discharge rise about 1 hour in advance

Hydrological forecasts

Figure 5 depicts the simulations of the discharge forecast (based on 48 h precipitation ALADIN forecast) calculated for the date 11.8.2002 19 CET as compared with the observed flood waves in all river profiles tested. The hydrological forecast is classified subsequently.

Bílovice – forecast flows do not fit very much with the real data. However, the peak discharge did not reach a significant value, the forecast is classified as successful.

Dalečín – the forecast flow rise began 6–10 h sooner then the real time. From the point of view of an early warning, this is not an essential error, the forecast is classified as successful.

Ptáčov – a very good correspondence of the real and forecast flows, the forecast is classified as very successful.

Podhradí – a very good correspondence of the real and forecast flows, the significant value of peak discharge was reached (Q_{10}), the forecast is classified as very successful.

Floods caused by mesoscale convective system

This type of flood occured on 29. 6.–1. 7. 2006 and affected the Dyje and Lužnice catchments. The record peak discharge within the whole monitoring period in Podhradí station was reached.

Table 5. Predicted and measured rainfall sums in mm for flash flood in the Sloupský brook catchment

Type of rainfall sum	Whole catchment (50 km^2)	Hit area (10 km^2)
1h COTREC forecast	8	45
1h PERSISTANCE forecast	8	40
1h RADAR QPE*	11	47
2h COTREC forecast	17	89
2h RADAR QPE*	11	47
6h ALADIN forecast	2	2

*The radar rainfall estimates were adjusted according to the measurements obtained from the raingauges stations and field survey

Meteorological forecast

The precipitation forecast indicated very high values of the precipitations sums, but the predicted rainfall centre affected a larger territory than that observed. The extreme rainfall finally hit mostly the upper part of the Dyje catchment (Podhradí closing profile) – Table 3. In other parts of the Dyje catchment, only relatively small rainfall sums occurred. Given the presence of severe convection, we can assess the forecast as successful.

Hydrological forecasts

Figure 6 depicts the simulations of the discharge forecast in the tested river profiles from 29. 6. 2006 06 CET. The lead time is again 48 h. The hydrological forecast classification follows:

Bílovice – the predicted flood highly exceeded that designed Q_{100}, while only an insignificant flow rise occurred. The prediction is evaluated as a failure.

Dalečín – the predicted peak discharge highly exceeded the level of Q_{100}, the real flows rose only insignificantly. The prediction is evaluated as a failure.

Ptáčov – the flow prediction highly exceeded the designed flood Q_{10}, the real flows rose only slightly. The prediction is evaluated as unsuccessful.

Podhradí – a good correspondence of the predicted and the real data, which exceeded the level of $Q_{100.}$ Although in reality the flood wave had a steeper rise, the prediction could be evaluated as very successful.

The listed forecasts are collectively classified in Table 4. The classification is accomplished on the basis of the hydrologists experience and takes into account the precipitation forecast error and the difficulty of the flood event predictability. It is obvious that, in some cases, the meteorological forecasts classified as successful may not lead to a successful hydrological forecast. However, a successful hydrological forecast is always contingent on an accurate meteorological forecast.

Flash floods

The event from 26. 5. 2003 in the Sloupský brook catchment is an example of a strictly localised flash flood. Table 5 shows the precipitation forecast variations based on different types of nowcasting (PERSISTANCE and CORTREC, see Novák 2004) and NWP precipitation prediction (ALADIN) in comparison with the observed precipitation sum estimates (Quantitative Precipitation Estimates, hereinafter QPE, see Šálek *et al.* 2006) and the *in situ* survey in side the affected area. The precipitation forecast made on the basis of the radar data extrapolation (COTREC) shows a very good correspondence with the real precipitation sums which is documented by the hydrograph presented in Figure 7. Both the meteorological and hydrological forecasts could be evaluated in this case as very successful. Since the ALADIN model predicts the mean precipitation sum for the areas of the size of several hundreds km^2, this flood type is presently unpredictable by NWP local models.

It is necessary to stress that this is an example of an extremely successful flash flood forecast which probably happens only rarely. Nevertheless, if nowcasting methods are implemented, the prediction of the flash flood can be possible in some cases.

CONCLUSION

The above given examples of hydrological forecasts showed the predictability of various types of floods caused by heavy precipitations.

The best predictable floods are those induced by a large-scale precipitation of stratiform type. The NWP models can predict this precipitation relatively well, although such forecasts are not free of failures.

Much more difficult is the forecast of the large flash floods that are caused by the precipitations of prevailing convective type. If the convective processes are formed or accompanied by large-scale forcing, then the NWP models are capable to predict the real development and the rainfall intensity, but the timing and localisation of the precipitation is rather uncertain.

The localised flash floods on small catchments (approx. 10–500 km^2) were regarded until recently as absolutely unpredictable events. NWP models are not able to predict heavy rainfalls on such a small scale successfully, but a system utilising weather radar measurements can identify heavy rainfalls and, with the help of a nowcasting extrapolation system, it is possible to assess the real development with a lead time of tens of minutes. However, much more tests are needed because of the risk of a considerable amount of false alarms if the system is run operationally. The operative flow forecasts of the flash floods of local character are currently under investigation. The Technical University in Brno – The Institute of Water Landscape Management in cooperation with the regional office of the CHMI in Brno is engaged in this problem as part of a research project.

The predictability of a particular flood type can provide crucial information for the decision makers which include the water management and flood emergency commissions responsible for the measures possibly mitigating the flood damage, such as the discharge control of the reservoirs, the construction of the flood walls or deploying sand bags, etc. According to the experience of the authors, the users tend to either doubt the forecast or to trust the forecast output uncritically. Therefore, it is recommended to supplement the hydrological forecast with a qualitative explanation which outlines the limitations of the particular forecast that should be also considered as "what-if" scenario.

Through the use of the distributive hydrological models, it is possible to simulate the approximate flood run caused by large-scale precipitations of both stratiform and convective type. Only roughly is it possible to simulate the local flood run of the flash flood type – in this case it is very difficult to estimate the temporal and spatial distribution of the precipitation over the catchment.

The adaptivity principle enables a successful operation of the hydrological model in the conditions of uncertainty. During a flood event, the situation development in a catchment is continually monitored, the hydrological model outputs are continually compared with the real development, and the model closer approaches the reality. Therefore, it is recommended to update the forecasts according to the data measured as often as possible, taking into account the predictability weakening with the lead time increasing.

The flow forecast is therefore a very difficult task which is given largely by the uncertainty of the forecasting input data. That is why the probabilistic solution of the flow forecasts (which takes account of various scenarios of the precipitation forecasts) is preferred but not applied operationally in the Czech Republic. Still, the deterministic hydrological forecast could be a very valuable basis for further decision-making processes, but it must be well understood and interpreted.

Finally, we have to highlight the necessity of a good communication between the meteorologists and hydrologists which leads to a better understanding of the possibilities and limitations of the current forecasting systems and to the development of a new and better tool that will incorporate the uncertainties associated with the data used for the flood forecasting.

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