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AUGUST 2002 FLOOD IN THE CZECH REPUBLIC: METEOROLOGICAL CAUSES AND HYDROLOGICAL RESPONSE

J. Daňhelka: *August 2002 Flood in the Czech Republic: Meteorological Causes and Hydrological Response.* – Geografie – Sborník ČGS, 109, 2, pp. 84–92 (2004). – The paper describes synoptic situations that resulted in heavy precipitation over the SW Bohemia in August 2002. Spatial and temporal distribution of precipitation and its effect on the flood development is explained. Flood peak flows return period reached very high values in the Vltava River catchment and couldn't be largely affected by reservoirs within the catchment. Nevertheless the role of Vltava River Dam Cascade is mentioned as well as the flood forecasting during the flood. We show also some similarities and differences between 2002 and some historical flood.
KEY WORDS: Flood – Vltava River – August 2002 – Czech Republic.

Introduction

Flood in the Czech Republic in August 2002 was extreme event from many points of view. First of all it was the hydrological and meteorological extreme, but flood affected also daily life of many people in Bohemia and central Europe.

If we lived in medieval times the chronicle writers would probably started their describing of that flood with sentence: "There was no such flood since the times of Noah". This sentence is the evidence of lost of the historical memory. Because of rare occurrence of great floods people usually couldn't keep it in memory for period longer than is the life of one generation. Unfortunately the longer period between floods leads to change in human behavior in the floodplain and on the riverbanks. It's closely connected to increasing vulnerability of human society and activities to catastrophic floods such as the one in 2002.

The previous catastrophic flood in the Czech Republic occurred in the Odra River and Morava River catchments in July 1997. The experience in flood forecasting and management from that event was extremely valuable and saved many human lives and property during 2002 flood.

The evaluation of the flood causes, development and consequences is crucial for possible next improvement in hydrometeorological service as well as in the other phases of the flood management.

Meteorological causes of August 2002 flood

Flood was caused by two periods of heavy precipitation following in very short interval of time.

The first precipitation period occurred in south Bohemia from 6th to 8th of August. A casual pressure low absorbed wet air mass from the Mediterranean and moved very slowly from the northern Italy in northeast direction in those days. Because of windward effect and orographic increase of precipitation there were observed daily rainfall amounts 80–150 mm in two consecutive days in Novohradské hory Mts. That represents highest daily precipitation ever observed in that area. The spatial extend of the maximum precipitation field was relatively limited to the highest parts of the Novohradské hory Mts. and could not caused major flood in the larger scale. The most important thing for the next development of the flood was the saturation of nearly the whole Vltava River catchment where fell mostly from 40 to 100 mm during that period.

More than 280 mm of water fell in Pohorská Ves and Staré Hutě during approximately 60 hours from 6th to 8th of August. That was 1.5–2 times higher than the value of two days precipitation with 100-year return period in that area and led to extreme flood in Malše River catchment. Similar rainfall amounts observed in Austrian part of the mountains caused extreme flood on smaller stream and rivers in the Dyje River catchments in the same time.

Another pressure low reached the central Europe after only about two and a half day without precipitation. The low was formed over the Atlantic Ocean and moved to the Mediterranean where it deepened and absorbed wet air. It continued then in northern direction to the central Europe where the pressure low center stop its movement. In comparison to the previous cyclone this ones trajectory was situated more to the north and therefore not only south part of Bohemia but nearly the whole area of the Czech Republic was affected by heavy precipitation.

It rained over the Vltava River catchment from Sunday August 11th to Tuesday August 13th. Main precipitation field was formed into the shape of wide strip trough the Bohemia in north-south direction and did not move its position significantly during the whole period. Because of anticlockwise rotation of the wind in the cyclone the wet air flowed to Bohemia from the north. That caused strong windward effect on northern slopes of Czech mountains. It was very strong mainly in the Krušné hory Mts. (Ore Mts.) – German meteorological station (about 2 km from the Czech border) recorded 312 mm of rainfall in 24 ours on 12th of August what is the highest daily precipitation amount ever recorded in Germany. Similarly in the highest parts of Jizerské hory Mts. automatic raingauge in Knajpa recorded daily amount of 278 mm on August 13th. So extreme rainfalls even they were spatially very limited caused "flashflood-like" response of the smaller stream in those areas.

Strong windward effect caused increase of precipitation also on the north slopes of Krkonoše Mts., Šumava Mts., Novohradské hory Mts., Brdy Hills and Českomoravská vrchovina Hills.

Mostly from 80 to 200 mm of rainfall fell in the Vltava River catchment during the second precipitation period. It accorded to 200–300 % of the value of 100-year precipitation for three days period in the south part of the Vltava River catchment.

The MAP (mean areal precipitation) for the whole Vltava River catchment (27 039 km^2) during the first precipitation period was 69.0 mm while during the second period it was 110.7 mm. All together from 6th to 13th of August 2002 the MAP value was 184.1 mm. That represents the volume of water of 4.98 km^3 (1.87 km^3 during the first precipitation period and 2.99 km^3 during the second one; Fig. 1).

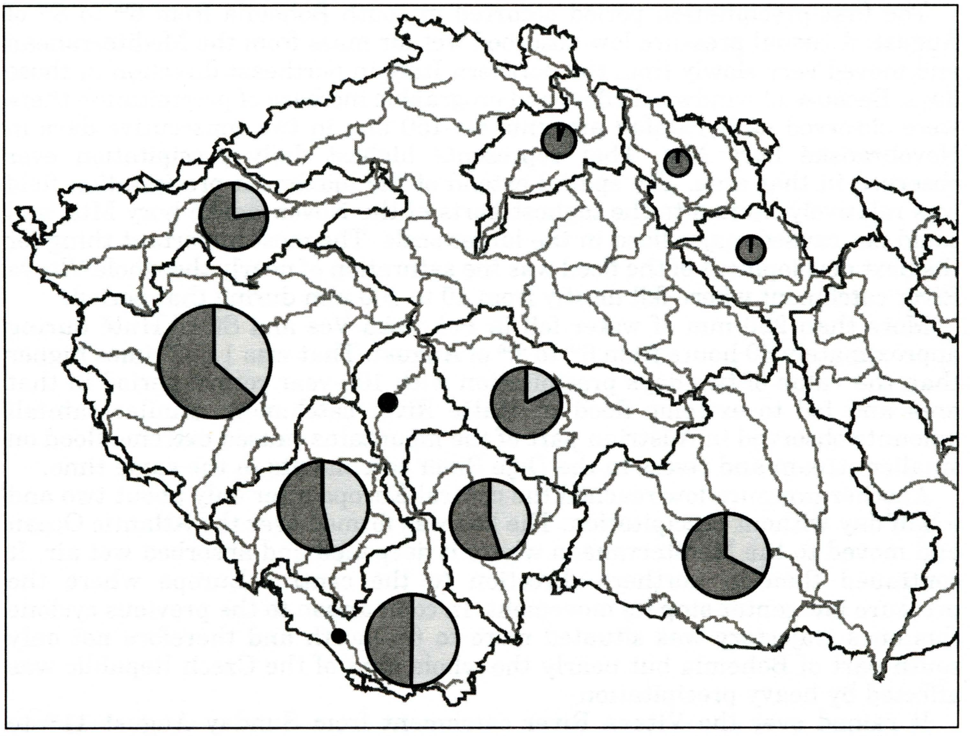

Fig. 1 – Precipitation volumes for selected catchments. Explanations: circle area corresponds to the volume of felled precipitation; light gray – 1st precipitation period; dark gray – 2nd precipitation period.

From the historical records we know about at least similar if not higher rainfall amounts in particular precipitation events in Bohemia. The crucial for the response of the rivers was the repeating of extreme precipitation in very short period of one week. The first precipitation fully saturated the most of the catchment the second one led to fast and high runoff.

Hydrological characterization of flood

In the response to two precipitation periods there were observed two peaks in hydrographs of the most of the rivers in the Vltava River catchment.

The first precipitation event in August 2002 caused extreme flood in the catchment of Malše River and in the Austrian part of the Dyje River catchment. Some minor flood occurred in the Lužnice, Otava, upper Vltava and Berounka River catchments where in some particular profiles discharges reached levels of 1–20 years floods (on tributaries of the Otava River up to 50 years flood).

Malše River and Vltava River downstream Malše River inflow were the most affected. The peak flow return period was estimated to more than 500 years there. Smaller mountainous streams in Malše River catchment (as Černá Brook) were the only streams where the peak flows of the first flood event were higher than the peaks of the second one. The flood wave was transformed downstream in Orlík reservoir on the Vltava River; therefore

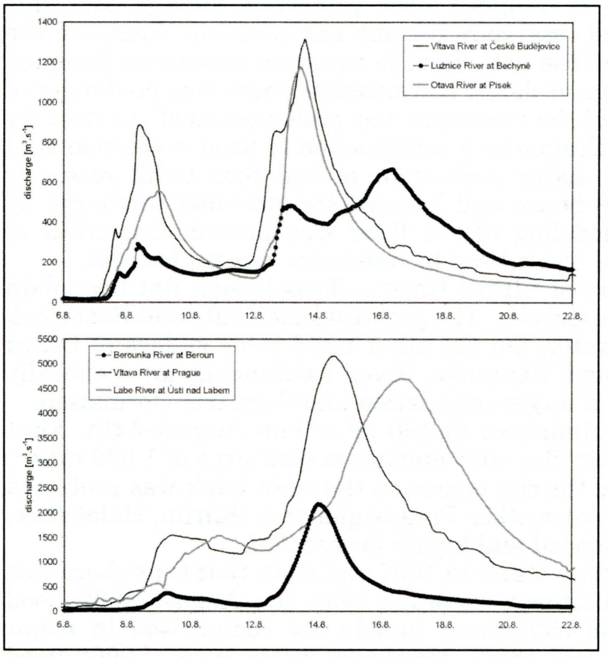

Fig. 2 – Discharge hydrographs of selected rivers and profiles; time on axis x, discharge ($m^3.s^{-1}$) on axis y.

there was no significant damage in Prague and central Bohemia. But the floodwater fulfilled the reservoirs before the second flood peak.

Very steep and high rising limbs of hydrographs were typical for the second flood episode. The reason was already mentioned; it was the high saturation of the soil and catchment.

Peak flows of south Bohemian rivers occurred mainly on August 13th. The return period of flood was generally bigger than 100 years but in some cases it reached statistical values of more than 1 000 years. Table 1 lists values for main selected profiles while figure 2 shows the discharge hydrographs in main water gauges in Czech Republic.

Table 1 – Peak flow characteristics for selected profiles.

Profile	River	Date	Water level [cm]	Discharge [$m^3.s^{-1}$]	Return period [years]
Roudné	Malše	8. 8.	446	562	200-500
České Budějovice	Vltava	8. 8.	548	888	500-1000
Heřmaň	Blanice	8. 8.	272	191	50-100
Roudné	Malše	13. 8.	465	695	>1000
České Budějovice	Vltava	13. 8.	652	1310	>1000
Bechyně	Lužnice	16. 8.	640	666	500-1000
Heřmaň	Blanice	13. 8.	427	443	>1000
Písek	Otava	13. 8.	880	1180	500-1000
Lhota	Radbuza	13. 8.	432	360	200-500
Štěnovice	Úhlava	13. 8.	513	398	1000
Plzeň	Berounka	13. 8.	799	858	100-200
Koterov	Úslava	13. 8.	371	459	>1000
Beroun	Berounka	13. 8.	796	2170	500-1000
Prague	Vltava	14. 8.	782	5160	500
Mělník	Labe	15. 8.	1066	5050	200-500
Ústí nad Labem	Labe	16. 8.	1196	4700	100-200
Podhradí	Dyje	14. 8.	476	343	200
Vranov	Dyje	14. 8.	378	364	100

Very important for flood protection activities in Prague was the development on the Vltava River dam cascade. The flood protection storage of the reservoirs there is sufficient for transforming the minor floods. Accordingly operation of the reservoirs fully transformed the first flood episode. Next extensive emptying of reservoirs provided approximately 118 mil. m^3 of free space what was the double of designed flood protection storage. But this storage was quickly filled and reservoirs became uncontrolled. Therefore the water level in all reservoirs of the dam cascade exceeded maximum designed levels and caused big damages at dams. Nevertheless there was no danger of dam collapse. The main role of the reservoirs was prolongation of the time for flood protection activities in Prague as a construction of flood protection wall and inhabitants evacuation. Later evaluation proved that Orlík reservoir delayed the peak flow by 18 hours and lowered the maximal discharge by 800 $m^3.s^{-1}$ (about 20 %). Modeling of the flood also proved that effect of different operation and initial water level in reservoirs was neglectable.

Lužnice River – a tributary of Vltava River – flows trough flat floodplain with lot of ponds and small reservoirs. The greatest medieval pond Rožmberk stored about 60 mil. m^3 of water. On the other hand river valleys of Otava River upper Vltava River and Berounka River catchments are generally narrow with no possibilities of larger inundation and flood transformation.

Vltava River in Prague culminated (5 160 $m^3.s^{-1}$) on August 14th. First flood wave of the flood was very flat with maximum discharge of 1 500 $m^3.s^{-1}$. During the second flood wave the city center on the right bank was protected by flood protection wall. But some other Prague quarters (Karlín, Holešovice, Kampa, Radotín etc.) were flooded and highly devastated.

Prague water level time series starts in 1827 and since that time there was no higher water stage or discharge recorded than the August 2002 flood (Fig. 3). Flood marks in the city center enable the comparison to major historical floods (1784, 1845 and 1890). Maximum water level of 2002 flood was 55 cm higher than 1784 level, 75 cm higher than 1845 level and 120–140 cm higher than 1890 level. Because of hydraulic condition of the valley and may be some change in that the level difference between 1890 and 2002 levels reached up to 300 cm in Karlín.

There was no comparable flood in last two centuries. From historical chronicles we know that the last comparable or possibly greater flood flooded Prague in summer 1432. Another fact visible from figure 3 is that there was nearly no significant flood in twentieth century and especially since forties. That affected the historical memory of Prague's inhabitants as well as the lack of experience of hydrologists and the lack of suitable flood data available for calibration of the hydrological forecasting system.

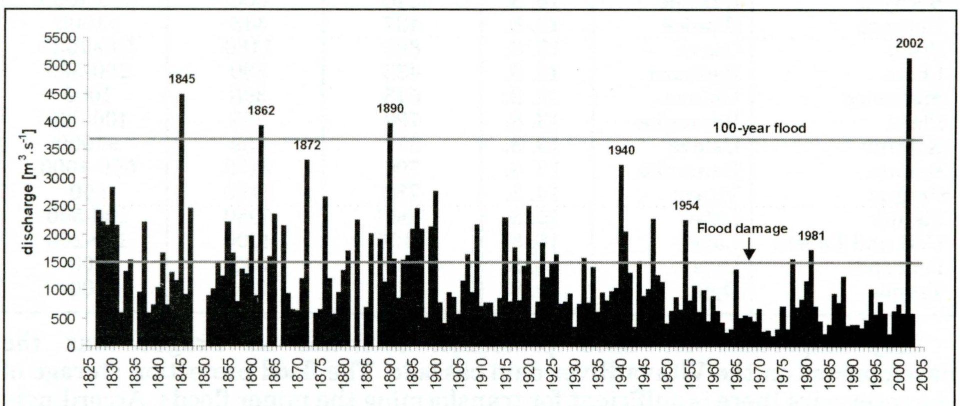

Fig. 3 – Time series of floods of Vltava River at Prague; time on axis x, discharge ($m^3.s^{-1}$) on axis y.

Vltava River inflows the Labe (Elbe) River about 50 km downstream from Prague. Area of the confluence and Labe River flood plain in the central Bohemia is very flat and provides great inundation storage. Therefore, in spite of another tributaries, the peak flow discharge decreased from Prague to Ústí nad Labem where Labe (Elbe) River culminated with discharge of 4 700 $m^3.s^{-1}$ on 16th of August.

Hydrological and meteorological forecasts

Meteorological and hydrological forecast is under the responsibility of the Czech Hydrometeorological Institute (CHMI) in the Czech Republic. For this purpose there is Central Forecasting Office (CFO) in Prague and six Regional Forecasting Offices (RFOs). Every forecasting office has meteorological and hydrological part.

For meteorological forecasting the actual data (from satellites, radars, ground meteorological stations, vertical profiles) and meteorological model outputs are used. The main sources for quantitative precipitation forecast (QPF) are local models of German weather service (DWD) and model ALADIN computed in the CHMI.

QPF forecast for the first precipitation period wasn't successful because of underestimation of expected precipitation by meteorological model. Therefore the forecast was about 30 mm in the mountainous areas in the south Bohemia for 6th and 7th of August while measured precipitation exceeded 100 mm on some stations in both days. On the other hand the QPF forecast for the second precipitation period was quite accurate as shown in figure 4. Meteorologist

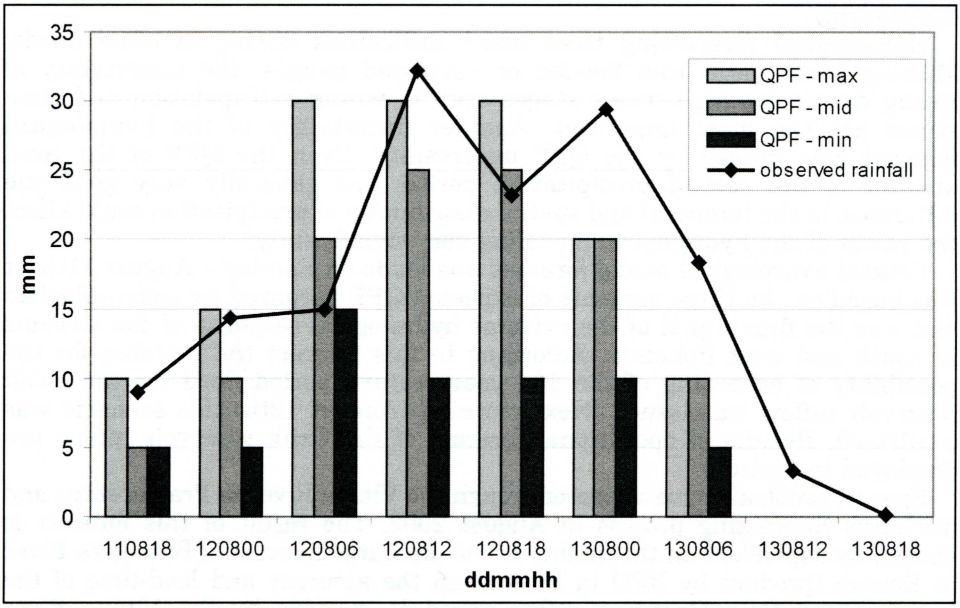

Fig. 4 – Three variants of quantitative precipitation forecast (QPF) of 6 hours amounts for S and SW Bohemia compare to observed precipitation. QPFmax (light gray) – maximal variant, QPFmid (middle gray) – middle variant, QPFmin (dark gray)– minimal variant. Time in 6 hours time step (ddmmhh) on axis x, precipitation (mm) on axis y.

prepared three possible variants of QPF that was used accordingly to count three variants of hydrological forecast.

CFO is responsible for the issuing of warnings and alerts for the dangerous hydrometeorological situations. All together 7 warnings and 14 alerts (most of them for heavy precipitation and floods) were issued during August 2002. Hydrological forecasting office of CFO issued 70 information reports on the flood recent and expected development during both flood episodes. All the reports were distributed using the standard risk management lines and directly send to some another institutions (f.e. Czech Government, Crisis Managements of Czech Republic and some districts, Ministry of Agriculture, Ministry of Environment, Czech TV, Czech Radio Broadcasting, Czech Press Agency, River Authorities etc.). All the reports were published on CHMI web for public.

Hydrological forecast is made using two methods in the Labe (Elbe) River catchment. The first one is daily (morning) manual method of according discharges and travel times. The method uses measured discharge data in the upstream profiles and rating curves. Hydrologist based on the precipitation and his experience estimates the inflow from the area between gauging profiles. The disadvantage of this method is the relatively short lead-time of the forecast – only from 6 to 24 hours in the condition of Czech part of the Labe (Elbe) River catchment – and it could be used only for few forecasting profiles.

To provide longer lead-time of the hydrological forecast is necessary to use rainfall-runoff modeling. Therefore the hydrological forecasting system AquaLog for Labe (Elbe) River catchment with Sacramento rainfall-runoff model is used to produce continuous forecast with lead-time of 48 hours. The advantage of the model is also the possibility of forecasting smaller catchments and streams and the possibility of multiple runs using different variants of QPF. Every CHMI regional office operates its competent part of the system.

Hydrological forecasting faces many difficulties during extreme floods. Missing input data from flooded or destroyed gauges, the uncertainty of rating curves for high water stages and its wrong extrapolation and time stress are the most important. Another uncertainty of the hydrological forecast was caused by the QPF uncertainty. Even the QPF of the total amount of the second precipitation period was generally very good the difference in the temporal and spatial distribution of precipitation could affect the result of the hydrological modeling very significantly.

Crucial hydrological model forecast was made on Sunday – August 11th. It was based on the three variants of expected QPF prepared by meteorologists and was the first signal of the extreme hydrological response of the streams in south and west Bohemia. According to this forecast the warning for the possibility of exceeding of the 100 years return period flood for the Orlík reservoir inflow was issued. Next morning (August 12th) this scenario was confirmed. Results of operational forecast of the Orlík reservoir inflow are displayed in figure 5.

Specific problems have appeared trough the Vltava River in Prague stage and discharge forecasting process in August 2002. The result of this forecast is absolutely dependent on the quality of the discharge forecast of Berounka River in Beroun (produce by RFO in Plzeň) and the accuracy and lead-time of the Vltava River Dam Cascade outflow schedule (provide by the Vltava River Authority). Both of these inputs were highly uncertain. Therefore only a short lead-time estimation of water stages of Vltava River in Prague should be made. The estimation of the peak flow stage was underestimated at the beginning but

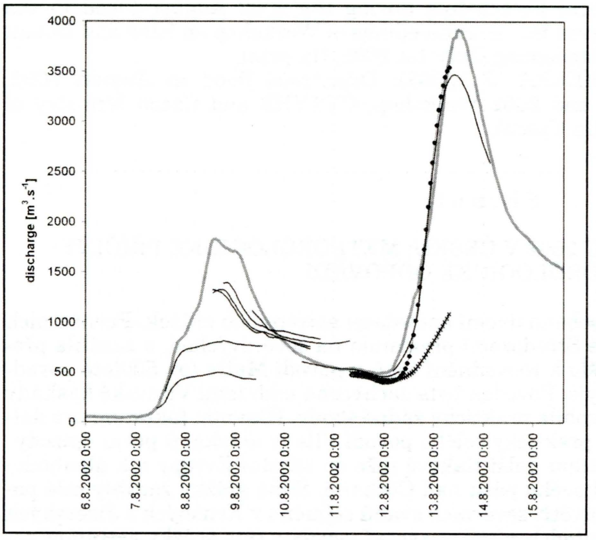

Fig. 5 – Hydrological forecasts (black) based on QPF for Orlík Reservoir inflow compared to later evaluated inflow (gray). Not correct QPF affect the hydrological forecast of the first flood episode. Uncertainty of hydrological forecast according to QPF scenarios (see fig. 4) during the second flood episode is documented by two variants QPFmax (circle line) and QPFmin (crossed line). Time on axis x, discharge ($m^3.s^{-1}$) on axis y.

was elaborated later on. Water stages and discharges of Labe (Elbe) River in Mělník and Ústí nad Labem were forecasted very accurately with the lead time of first forecast of the peak flow more than 2,5 day before it occurred.

Conclusion

Results of the after flood evaluation proved that flood in August 2002 was an extreme event in the meaning of precipitation amounts as well as in the meaning of peak flow discharges in the rivers. Most important was occurrence of two consecutive cyclones bringing extreme precipitation to the same area – the Vltava River catchment – within one week. Highest rainfall amounts were recorded in Novohradské hory Mts. and Šumava Mts. Totally about 5 km^3 of water fell on the Vltava River catchment in both precipitation episodes.

Flood in the streams had two flood peaks according to precipitation episodes from which mostly the second one was higher. First flood episode affected mainly Malše River, where return period of the peak flow reached values of 500 years. Second flood episode affected the most of the Vltava River catchment with peak flows return periods of 100 to 1 000 year.

In comparison to historical floods in Prague the 2002 flood was the biggest flood from those reliable documented and its return period was estimated as 500 years. But the extremity of flood decreased downstream from Prague and on the Labe (Elbe) River.

Hydrological forecasting is very difficult during extreme floods because of input data missing and its uncertainty. Nevertheless the issued forecasts had mostly good quality and were useful in flood protection management.

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Shrnutí

SRPNOVÉ POVODNĚ ROKU 2002 V ČESKU: METEOROLOGICKÉ PŘÍČINY A HYDROLOGICKÉ ODPOVĚDI

Povodeň v srpnu 2002 byla způsobena dvěmi epizodami extrémních srážek. První z nich spojená s tlakovou níží, která se ze Středozemí přesunula na severovýchod, a zasáhla především Novohradské hory. Zde došlo k rozvodnění toků v povodí Malše (až 500leté povodně), následně Vltavy a rakouské Dyje. Povodeň byla zachycena nádržemi Vltavské kaskády a na dolním toku Vltavy tak nezpůsobila prakticky žádné škody. Hlavním faktorem pro další vývoj povodně ale bylo nasycení prakticky celého povodí Vltavy srážkami první epizody.

V krátkém odstupu došlo k postupu další tlakové níže do střední Evropy a k dlouhodobému setrvání s ní spojeného srážkového pásu nad Čechami. Silné srážky zasáhly celé povodí Labe s nejvyššímu úhrny na návětří severních svahů zejména v Krušných a Jizerských horách a na Šumavě. Vzhledem k předchozímu nasycení vyvolaly tyto srážky extrémní povodně na naprosté většině toků v povodí Vltavy.

V jižních Čechách vypadlé srážkové úhrny dosáhly celkově za obě epizody v extrémech až 400–450 mm. Přitom na povodí Vltavy celkově vypadlo okolo 5 km^3 vody, které způsobily povodně s dobou opakování 100 až 1 000 let. Vltavská kaskáda povodeň mohla transformovat pouze částečně a v Praze tak byla povodeň hodnocená jako 500letá. Přitom překonala všechny historicky dochované povodňové značky. Následné mohutné rozlivy ve středních Čechách pak měly za následek zploštění povodňové vlny, tak že v Ústí byla povodeň hodnocena již jen jako 100letá.

Předpovědi srážek v průběhu první vlny nebyly úspěšné, naopak druhá srážková epizoda byla předpověděna velmi přesně. Hydrologické předpovědi narážely na komplikace způsobené výpadky vstupních dat a jejich nejistotou, přesto většinou měly dobrou kvalitu a byly užitečnou informací pro protipovodňová opatření.

Obr. 1 – Srážkové objemy vypadlé na vybraná povodí. Plocha kruhu odpovídá celkově vypadlému objemu srážek; světle šedě srážky první epizody, tmavě šedě srážky druhé epizody.

Obr. 2 – Hydrogramy průtoků ve vybraných tocích a profilech; na ose x zobrazen čas, na ose y průtok v m^3.s^{-1}.

Obr. 3 – Historický řada povodní na Vltavě v Praze; na ose x zobrazen čas, na ose y průtok v m^3.s^{-1}.

Obr. 4 – Tři varianty předpovědi srážek (QPF) pro jižní a jihozápadní Čechy v šestihodinovém intervalu a porovnání s pozorovanými srážkami. QPFmax (světle šedá) – maximální varianta předpovědi, QPFmid (středně šedá) – střední varianta, QPFmin (tmavě šedá) – minimální varianta. Osa x – čas v šestihodinovém kroku (ddmmhh), osa y – srážky (mm).

Obr. 5 – Operativní hydrologické předpovědi (černě) přítoku do nádrže Orlík na základě předpovědi srážek a porovnání s vyhodnoceným přítokem (šedě). Nepřesná předpověď srážek pro první povodňovou epizodu ovlivnila úspěšnost hydrologické předpovědi. Závislost nejistoty hydrologické předpovědi na variantních předpovědích srážek (viz obr. 4) druhé povodňové epizody je dokumentována dvěmi předpověďmi QPFmax (kroužkovaná čára) a QPFmin (křížkovaná čára). Na ose x je zobrazen čas a na ose y průtok v m^3.s^{-1}.

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