ACTA UNIVERSITATIS CAROLINAE
2003 GEOGRAPHICA, No. 2, PAG. 49–64

Overview and Classification of Historical Floods in the Otava River Basin

TOMÁŠ VLASÁK

Czech Hydrometeorological Institute (CHMI), Prague

Abstract

The paper collects all fundamental data on hydrometeorological causes and development of twelve major floods on the Otava river in 1888–2002. All events were selected according to peak flow values exceeding the ten-year-flood discharge as recorded in the Písek water gauge station. For each flood, the paper specifies the route of the driving air pressure formation, rainfall spatial distribution and volume, river basin saturation prior to the flood, and the Otava flow hydrograph recorded in the Písek station. The overall analysis of all features describes the most distinctive characteristics of the Otava major floods triggering mechanism.

Key words: floods, hydrometeorological causes, the Otava river

1. Introduction

Devastating floods occurring in August 2002 arouse interest in historical floods in the Czech Republic. Results of studies on meteorological causes and hydrological development of historical floods can be used for flood control, development of technical defence features (e.g. to dimension flood control dykes) and adoption of other measures, e.g. forecast model calibration. Data on historical floods are also used as supporting material for studies on regionalization of flood risks burden.

In the past, historical floods in the CR were studied by numerous authors. Meteorological causes of the Odra river floods were analysed for the first time by Brádka [1967]. Pursuant to historical floods data on the Odra river, Kakos [1974] designed a simple forecast analogical system based on monitoring of variations of air pressure formation centres at the 500hPa level. Buchtele [1972] categorised flood regimes in three river basins of the Vltava upstream area (Vltava down to Hluboká, Otava to Písek, and Lužnice to Bechyně) and described their main characteristics. Vavruška [1989] compared flood drivers in Otava and Lužnice river basins and identified the most frequent synoptic types preceding the floods. The Otava river basin was specifically studied by Hladný, Černý, Řičica [1993, 1995] who defined guidelines for completing a databank of flood causes and development. Vlasák [2000] specified causes and categorised winter floods occurring in 1960–1998.

The main objective of this paper is to collect available data on causes and development of Otava major historical floods, including floods from the end of the 19th century. Drawing on such data, we describe the most distinctive characteristics of the local flood-triggering mechanism.

2. Material and Methods

Historical data selection is mostly significantly limited by their availability and reliability. Particularly historical flow values may be marked by errors, which should be taken into account when interpreting results of any quantitative analysis based on such data. Conclusions of this paper are therefore limited to general and structural evaluation of major historical floods on the Otava river. Input data were collected in the archives of the CHMI and in old annual bulletins published by various hydrographic institutions operating under the Austro-Hungarian Empire.

Floods were selected by the criterion of peak flow, recorded in the Písek station, exceeding the ten-year-flood discharge, i.e. $Q = 420\ m^3 \cdot s^{-1}$. Since 1888, there have been 12 cases, which in terms of frequency roughly corresponds to the statistic principle of a 10-year flood level. Moreover, flooding from 1784 is mentioned only for informative purposes due to its extraordinary peak level edging nearer to the August 2002 floods, and its seasonal occurrence in winter hydrological period (see hereunder). Besides Písek records, we also gathered available data from other Otava profiles in Sušice and Katovice, and in Heřmaň on the Blanice river. Data from the stations mentioned above were used as the only factor for runoff response classification of individual Otava river basin areas. For each flood, we calculated indicators of previous rainfall volumes (UPS, or API) [Hladný, 1978] and average rainfall total volumes on critical days prior to culmination employing information on rainfall volumes and climate taken from old yearbooks. Results were transformed into a map by applying the method of orographically conditioned interpolation in the GIS environment.

3. Results

3.1. Flood Occurrence and Types

Occurance of major floods in time has not uniform distribution (see Figure 1). At the end of the 19th century, a number of flood events occurred consecutively one after another, while the second half of the 20th century (1954–1981) was relatively low in major floods. In terms of occurrence annual seasonality, most floods are detected in the summer hydrological six-month period (LHP) – 11 cases against 1 case, or 2 respectively, identified in the winter hydrological six-month period (ZHP), see Table 1.

Tab. 1 Otava floods marked by $Q_{max} > Q10$

Culmination Date	Písek		Culmination Date	Prague		Flood type (Kakos, 1983)*
	Peak Flow [m³ · s⁻¹]	N-year flood		Peak Flow [m³ · s⁻¹]	N-year flood	
*28. 2. 1784***	950	>100	*28. 2. 1784*	4580	>100	Z (?)
4. 9. 1888	440	10	*4. 9. 1888*	1918	10	L
4. 9. 1890	750	50–100	*4. 9. 1890*	3975	100	L
5. 10. 1894	600	20–50	*6. 10. 1894*	1627	5	L
5. 5. 1896	560	20	*6. 5. 1896*	2470	20	L
14. 9. 1899	560	20	*14. 9. 1899*	2130	10	L
8. 10. 1915	500	20	*8. 10. 1915*	2100	10	L
31. 5. 1932	460	10–20	*31. 5. 1932*	1588	5	L
31. 5. 1940	440	10	*?*	?		L
9. 7. 1954	800	100	*10. 7. 1954*	2920***	20–50	L
21. 7. 1981	500	20	*21. 7. 1981*	2400***	20	L
22. 12. 1993	520	20	*23. 12. 1993*	1020	2	Z
13. 8. 2002	1175	>100	*13. 8. 2002*	5160	>100	L

* Until 1981, peak flow values in Prague and flood types were borrowed from Kakos [1983] where L stands for summer floods and Z = for winter floods.
** 1784 flood isn't included in the folowing analysis
*** After disregarding the impact of the Orlík dam.

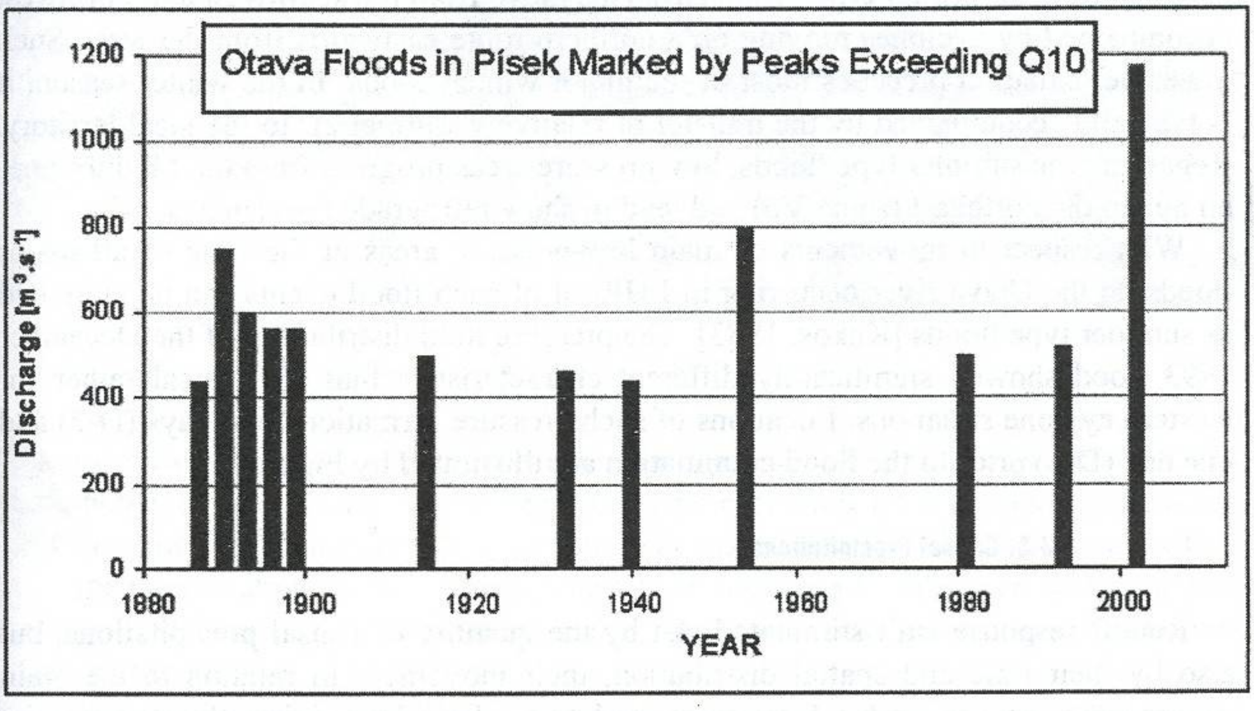

Fig. 1 Distribution and culmination of Otava floods in Písek marked by peaks exceeding $Q10$ in 1888–2000

Absence of floods in the months of local snow melting indicates that snowmelt mostly isn't the main cause of major floods on the Otava river. Exceptional winter floods are mostly driven by a variety of factors, e.g. rainfall or ice movements in watercourses as proved by Vlasák [2000]. The only mixed flood with $Q_{max} > Q10$, defined as such by supporting evidence, occurred in December 1993 when snow volume in the highest Šumava areas equalled 100 mm of water prior to the flood. However, even in this case rainfall played the major role in the total flood wave volume.

In all analysed events, flood-triggering rainfall affected the whole river basin area and wasn't locally limited as in cases of a storm-driven water surge. Undoubtedly, storm water may cause floods exceeding $Q10$ in individual areas of the Otava river basin, but their limited spatial impact results in lower final flow values, recorded in Písek, in comparison with less strong but widespread frontal rainfall.

3.2. Weather Causes

Many studies on historical floods analyse weather causes and conditions preceding floods. Identified links between circulation conditions and generated runoff response can be applied under so called hydrosynoptic approaches that make it possible to issue warnings much in advance.

Kakos [1983] analysed 36 major historical floods occurring in Prague in 1876–1982 and defined two fundamental weather cause groups of floods in the Czech Republic pursuant to temperature variations and movements of driving air pressure formations:

1) progress of frontal systems from the Atlantic Ocean towards Central Europe (winter type),
2) cyclogenesis in South and Central Europe (summer type).

Regarding the winter type, frontal systems move from the southwest and northwest accompanied by cyclones moving on a northern route eastwards from the west. Such a weather situation precedes most of the major winter floods. In the winter season, it is typically accompanied by the transfer of relatively warmer air to the local territory. Regarding the summer type floods, low-pressure areas progress from the Mediterranean Sea to the northeast (route Vb) and tend to show retrograde movements.

With respect to movements of main low-pressure areas at the time of all major floods on the Otava river occurring in LHP, all of such flood events can be classified as summer type floods [Kakos, 1983]. The pressure field distribution of the December 1993 flood showed significantly different characteristics that are typical rather for western cyclone situations. Locations of such pressure formations two days (D-2) and one day (D-1) prior to the flood culmination are illustrated by Figure 2.

3.3. Causal Precipitations

Runoff response isn't stimulated just by the quantity of causal precipitations, but also by their time and spatial distribution, their movement in relation to the main watercourse and orographic formations, and particularly by precipitation types (rain, snow, or mixed). Historical evaluation of precipitation fields in relation to individual

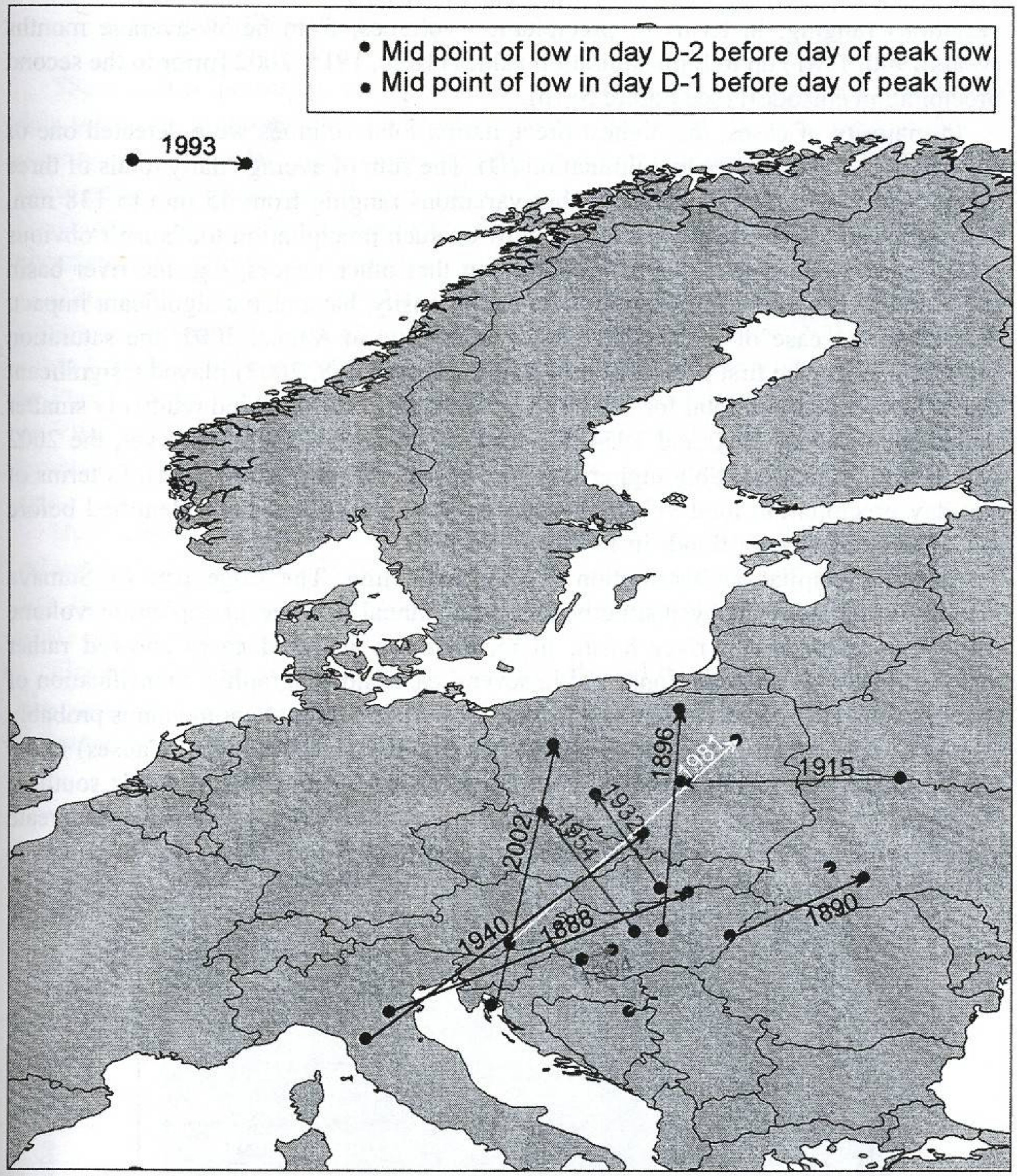

Fig. 2 Progress of cyclone centres on D-2 and D-1 prior to flood culmination

flood events was based on daily precipitation totals indicated by old yearbooks. Such data however don't allow for description of precipitation field movement dynamics and therefore we analysed only precipitations spatial distribution, and calculated the average precipitations volume in the Otava river basin applicable to critical days prior to the flood. Resulting precipitations fields were then recorded in a map in the GIS environment.

In the whole set of analysed floods, the indicator of antecendent precipitation index (API), calculated as of the last day prior to casual precipitations, shows significant variations ranging, in terms of precipitation volumes, from below-average months (years 1940, 1981) up to high-saturation values (1890, 1915, 2002 [prior to the second precipitation episode]) (see Figure 5–16).

In majority of cases, the highest precipitation total volumes were detected one or two days (D-1, D-2) prior to culmination (D). The sum of average daily totals of three days (from D-3 to D-1) also shows big variations ranging from 45 mm to 138 mm, and regression dependency of the peak flow on such precipitation totals isn't obvious (see Figure 3). This leads us to a conclusion that other factors, e.g. the river basin saturation and precipitations distribution and intensity, have also a significant impact. Particularly in case of the second bigger flow wave in August 2002, the saturation level defined by the first precipitation episode (August 6–8, 2002) played a significant role. The precipitation total for D-3 – D-1 in 2002 ranks third behind relatively smaller floods occurring in 1890 and 1954. In terms of seven-day totals, however, the 2002 precipitation total is notably higher than any of the analysed flood events. In terms of one-day precipitation total values, the highest average volume was identified before one of relatively minor floods in 1940.

Spatial precipitation distribution is also interesting. The ridge part of Šumava that is mostly affected by distinctively higher annual average precipitation volume than other parts of the river basin, in most of the analysed cases showed rather average precipitation conditions, and in several cases no orographic intensification of precipitations was detected (floods in 1888, 1894, 1981). This phenomenon is probably related to the summer type of causal weather conditions (see Weather Causes) under which precipitations move mostly from the southeast or northeast towards southern Bohemia, which jointly with a higher temperature stratification lability doesn't create such favourable conditions for intensified precipitations in the highest Šumava areas as in winter months under western cyclones (see the 1993 floods).

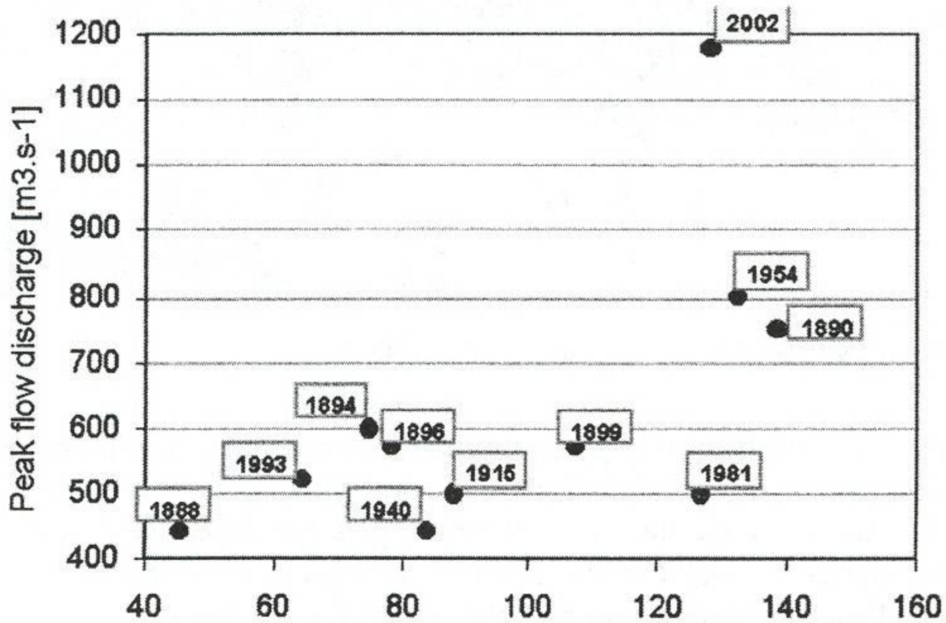

Fig. 3 Links between three-day precipitation volumes in the Otava river basin and peak flow values in Písek. (1932 flood is not included due to lag of data)

3.4. Runoff Response

The runoff response analysis, performed within this project, was based on limited data series due to absence of water-stage records in the Otava river basin in the 19th century – available data on old floods mostly represent morning water levels read from water gauge. Comparing peak flow values, it is necessary to bear on mind that water levels were transformed into flow values on the basis of rating curves implying higher uncertainty affecting particularly high water level areas.

During most of the major Otava floods, also Prague stations detected high flow values exceeding 1500 $m^3 \cdot s^{-1}$, which is a 3 or 4-year discharge [Kakos, 1983], see Table 1. Although the Otava river basin covers only 11% of the Vltava basin delimited by Prague, it participated by approximately 20–30% in the peak flow values measured on Vltava in Prague. Such results indicate that major floods on the Otava river have never been only of a local importance. To the contrary, high runoff affects quite a large area.

Hydrographs enclosed in the annex show evident and fast rise of dangerous flow values in all studied cases. With respect to the seven days prior to and after culmination, only the August 2002 flood generated a significant compound wave with several peaks while other waves had rather simple forms.

Flood flow on the Otava river is typically affected by delayed culmination of the Blanice river lagging behind the main watercourse culmination. This important aspect reducing potential peak flow in Písek is caused by the Husinec dam located in the

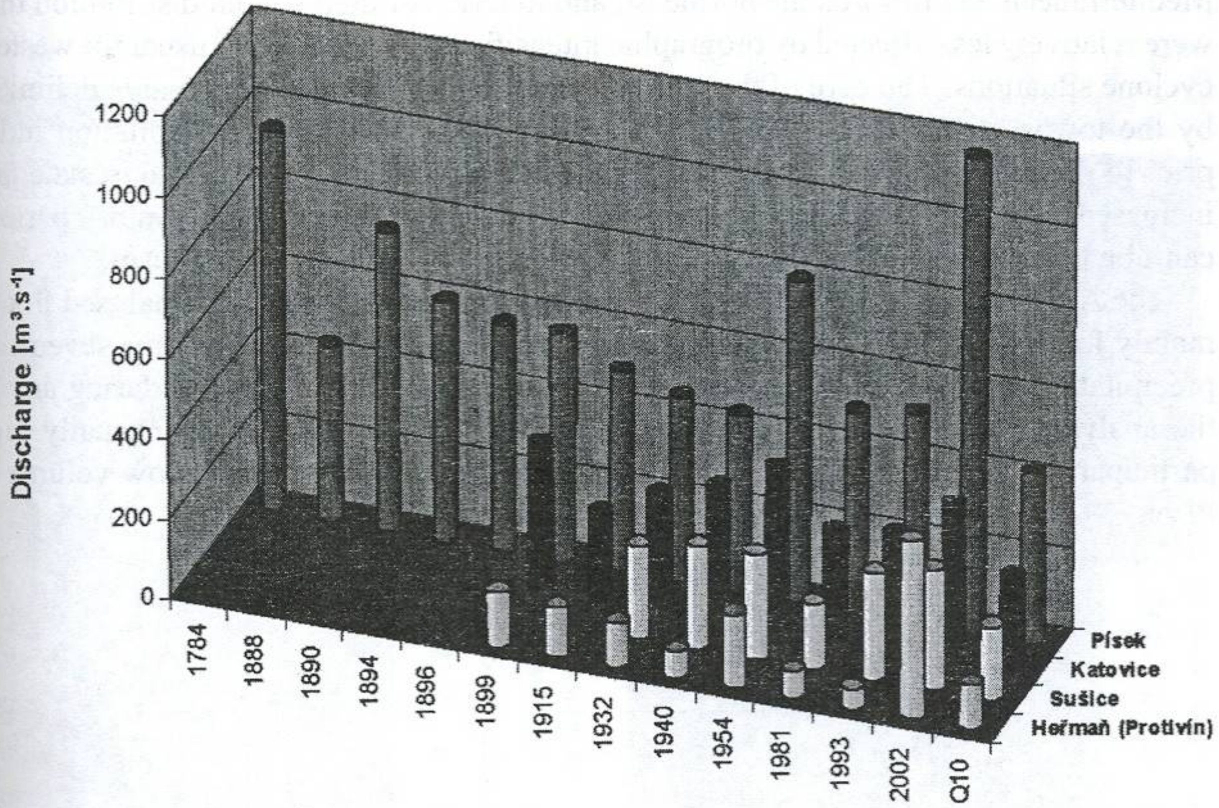

Fig. 4 Maximum specific runoff in selected catchment areas in Otava river basin (*Q*10 = 10-year flood in specific runoff)

upstream area of the river basin and by natural conditions prevailing in the downstream Blanice river basin that prolong the progress time of the flood wave and transform the wave significantly. During floods conditional on western cyclone situations, lower flow values on the Blanice river are also caused by the Šumava rainfall shadow affecting the river basin (see also the 1993 flood). However, the second August 2002 flood wave was to a great extent caused by the Blanice river, which was absolutely extraordinary in comparison with other analysed floods for which Blanice data were available (see Figure 4). The main causes of such an extreme situation are as follows:

- the Blanice river basin showed the highest precipitation total values during the second wave,
- physical and geographical conditions in the Blanice downstream area (hill slopes, subsoil) result in slower drainage and higher sensitivity to rainfall events repeated subsequently one after another,
- the Husinec dam was mostly full and its protective effect during the second wave was negligible.

4. Conclusion

In the past, major floods on the Otava river were more likely to occur in the period from May to October rather than in other periods of the year. They were caused by intensive frontal precipitations hitting mostly large areas of the Czech basin. In case of all summer floods, precipitations were associated with cyclones progressing from the Mediterranean Sea towards the northeast, and in terms of their spatial distribution they were relatively less affected by orographic intensification than what is usual for western cyclone situations. The core of the causal wave was often located in the area delimited by the towns of Kašperské Hory and Vimperk. The antecendent precipitation index prior to floods showed variations in individual cases, even if it is possible to state that increased saturation significantly affects the flood wave culmination, even dry periods can't be taken as a guarantee of no major flood risks in the Otava river basin.

The August 2002 flood was quite unique in comparison with other analysed floods mainly for its significantly higher peak flow. It was also marked by extreme seven-day precipitation total volumes that strongly exceed such volumes recorded during any of the analysed floods. Repetitive subsequent rainfall events resulted in unusually high participation of the Blanice river, the main tributary, in the flood peak flow volume in Písek.

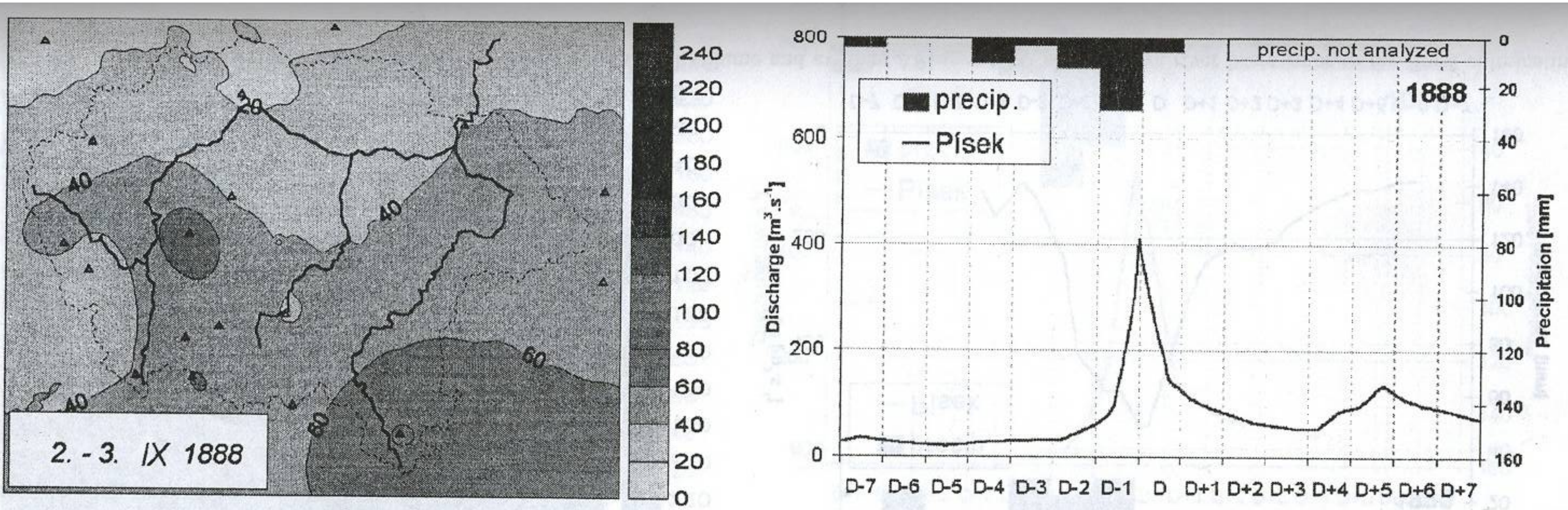

Fig. 5 Causal precipitations, hydrograph, average precipitation total volume and average API (see text) in the Otava river basin prior to the flood culminating in Písek on September 4, 1888

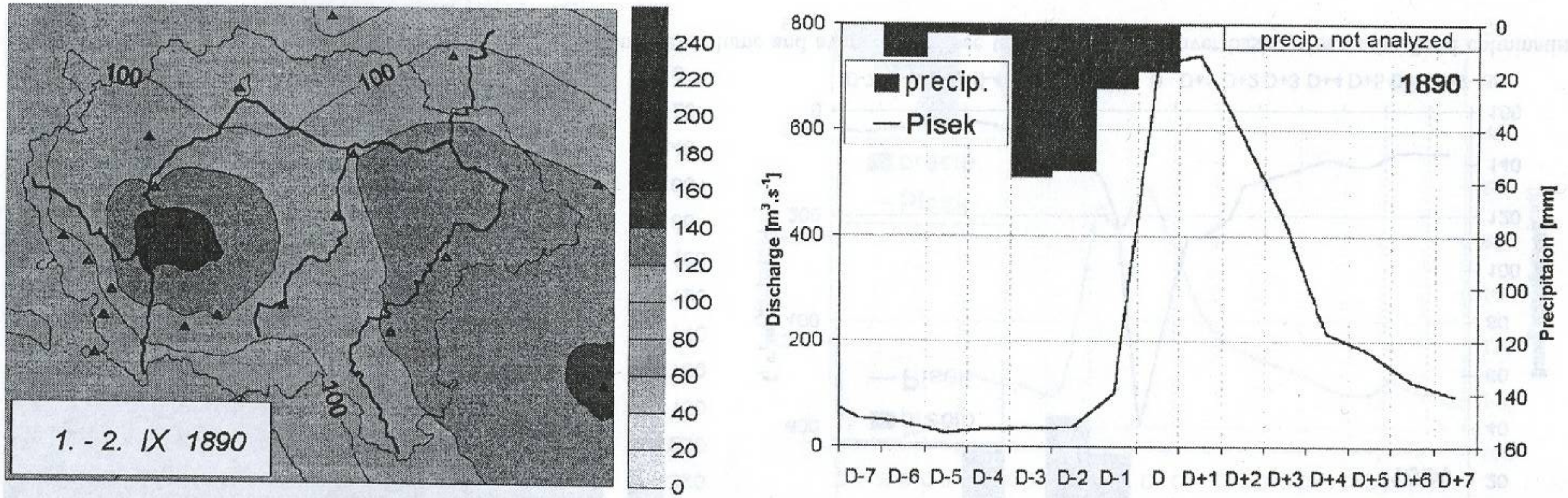

Fig. 6 Causal precipitations, hydrograph, average precipitation total volume and average API (see text) in the Otava river basin prior to the flood culminating in Písek on September 4, 1890

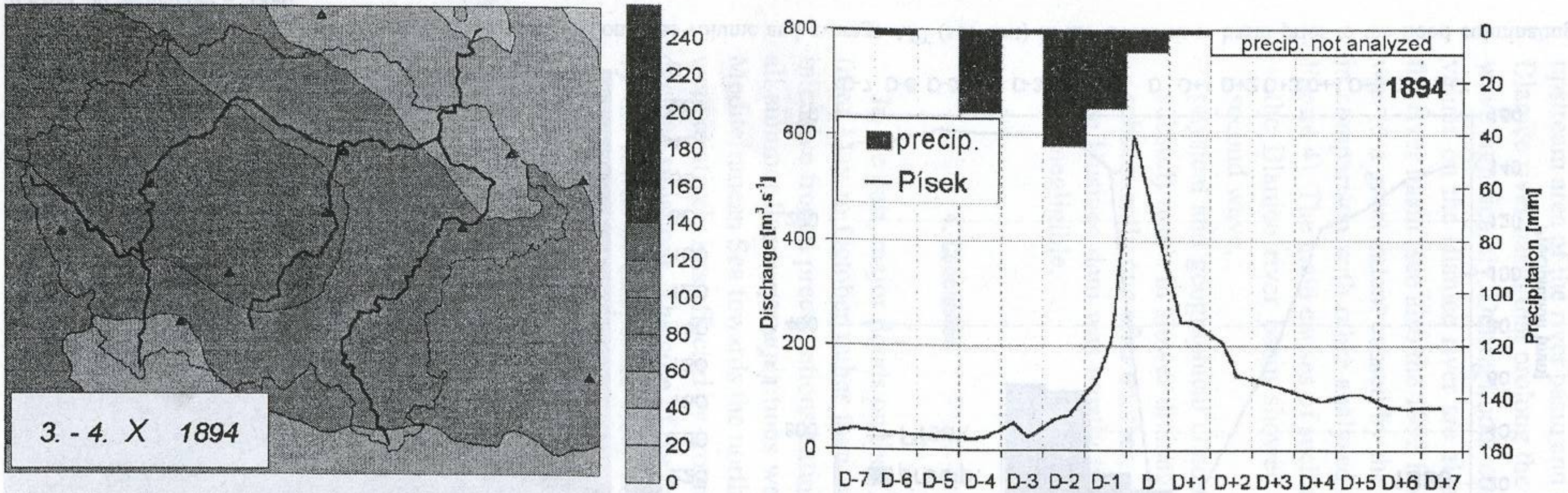

Fig. 7 Causal precipitations, hydrograph, average precipitation total volume and average API (see text) in the Otava river basin prior to the flood culminating in Písek on October 5, 1894

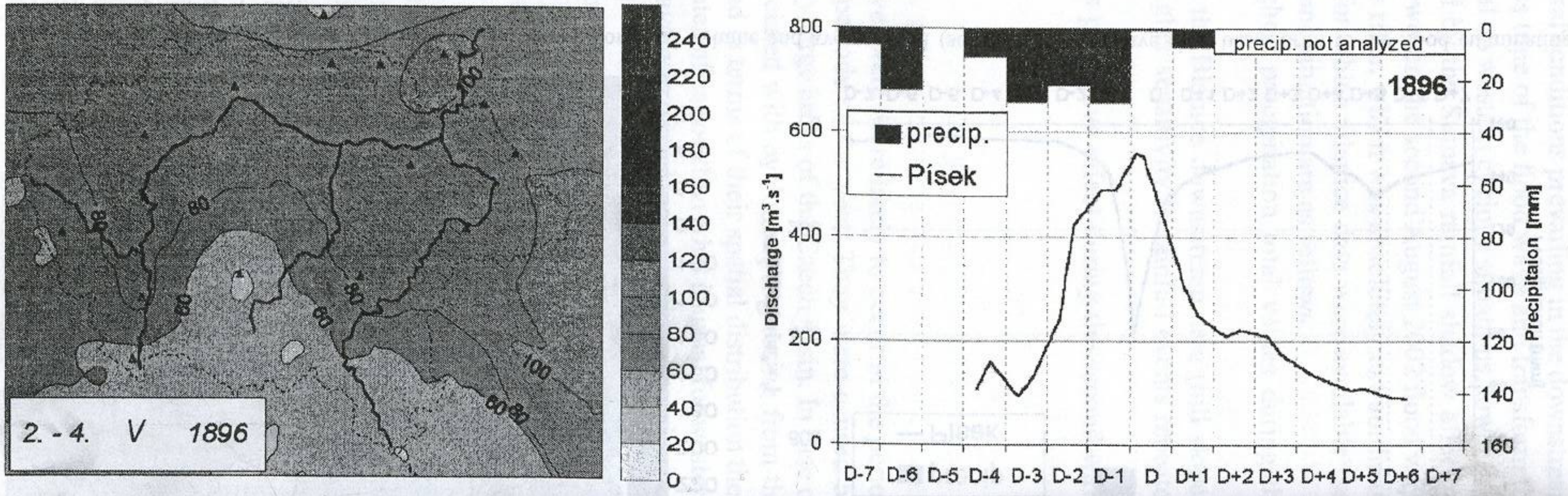

Fig. 8 Causal precipitations, hydrograph, average precipitation total volume and average API (see text) in the Otava river basin prior to the flood culminating in Písek on May 5, 1896

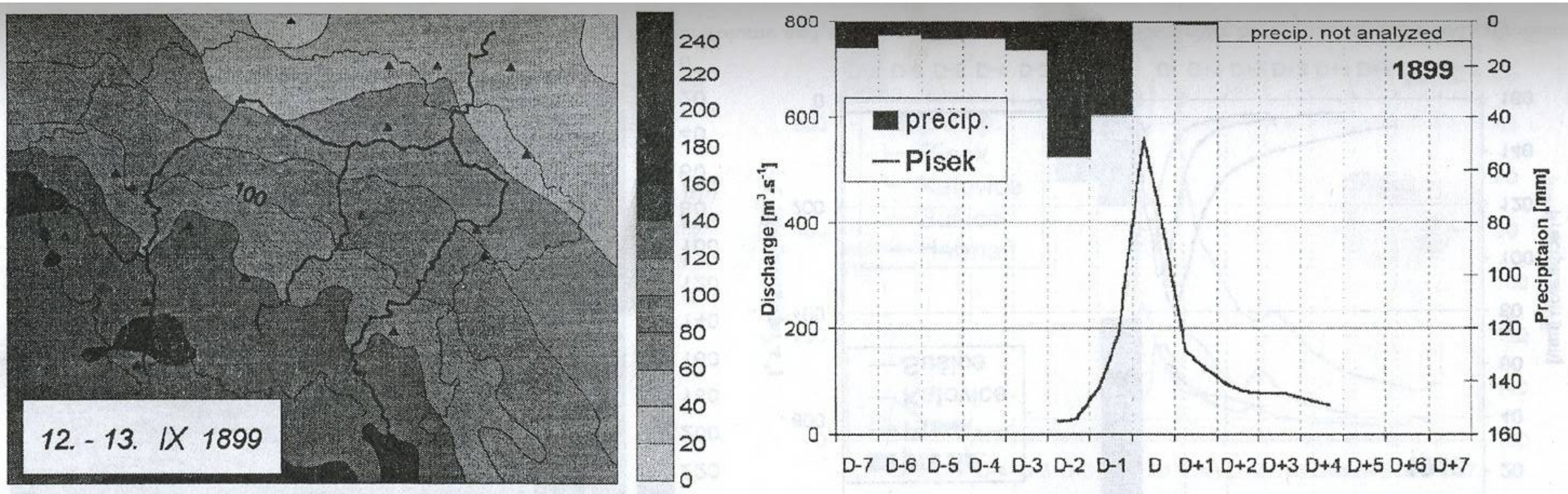

Fig. 9 Causal precipitations, hydrograph, average precipitation total volume and average API (see text) in the Otava river basin prior to the flood culminating in Písek on September 14, 1899

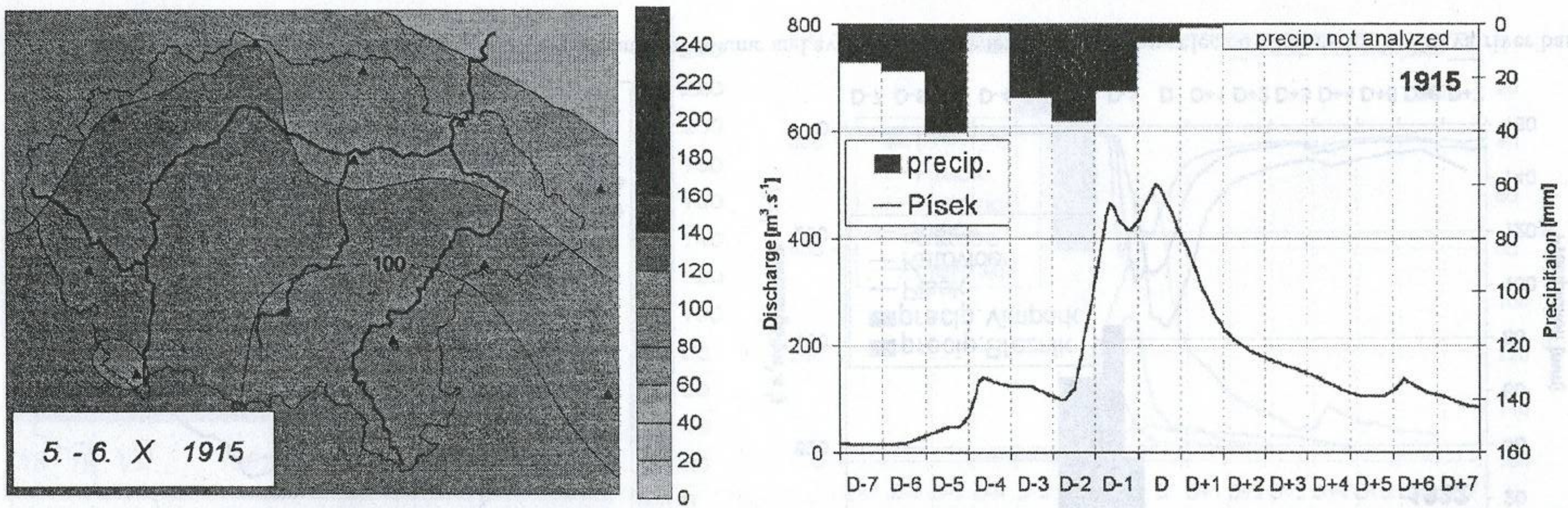

Fig. 10 Causal precipitations, hydrograph, average precipitation total volume and average API (see text) in the Otava river basin prior to the flood culminating in Písek on October 8, 1915

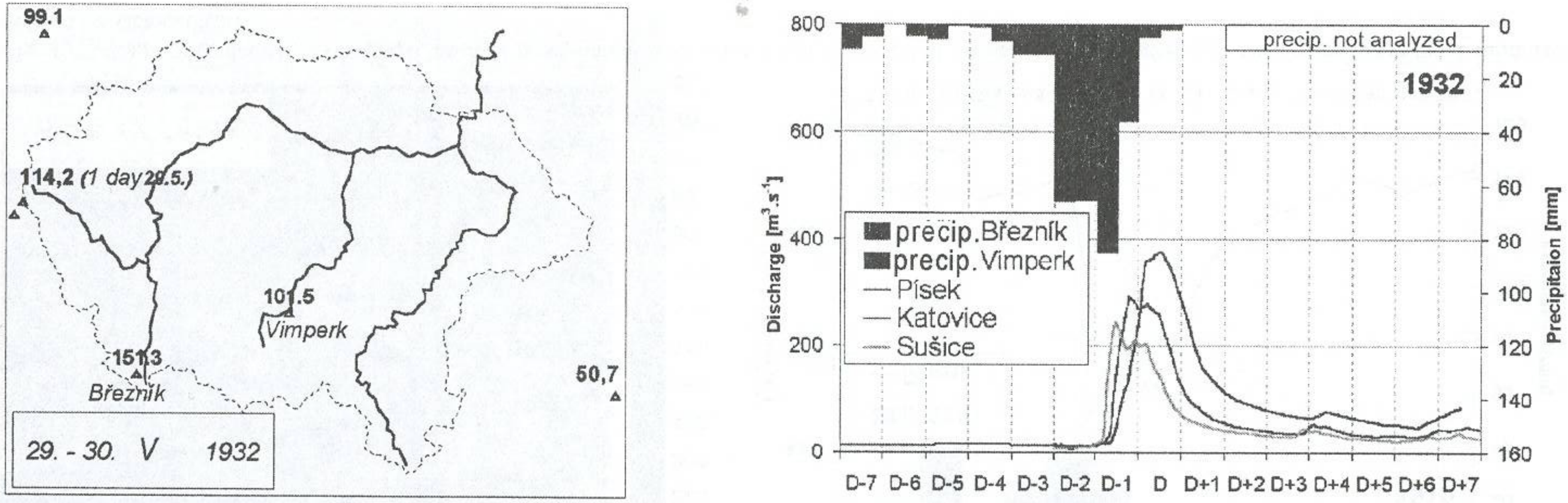

Fig. 11 Causal precipitations, hydrograph, average precipitation total volume and average API (see text) recorded by selected stations in the Otava river basin prior to the flood culminating in Písek on May 31, 1932

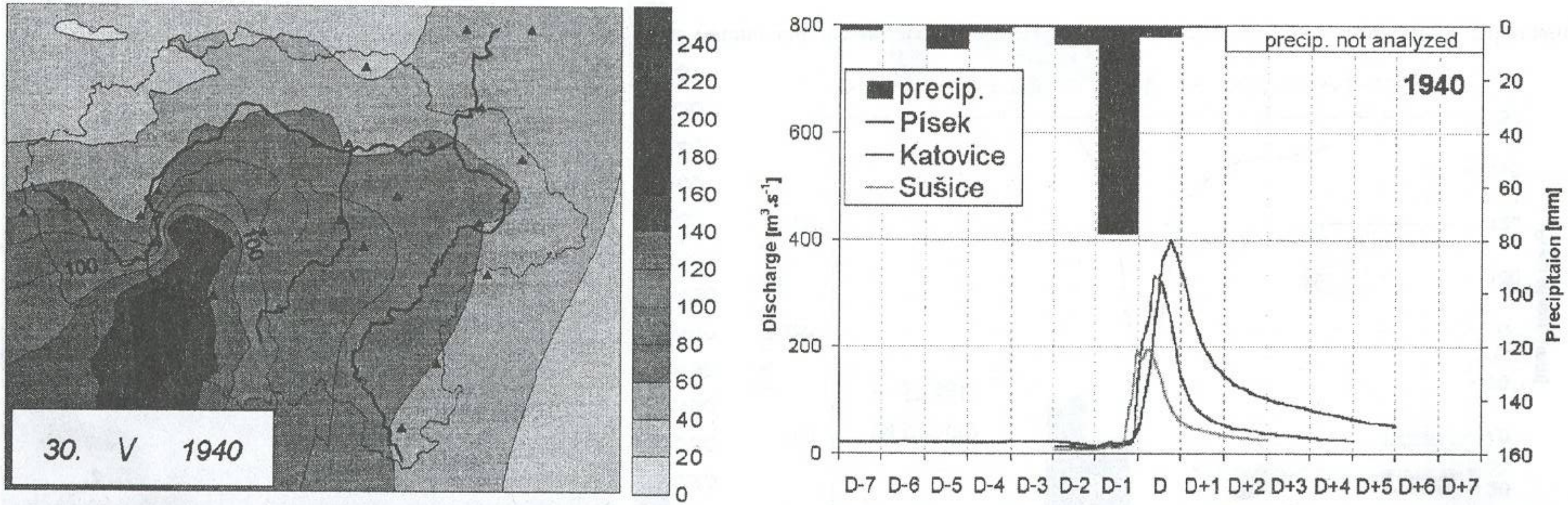

Fig. 12 Causal precipitations, hydrograph, average precipitation total volume and average API (see text) in the Otava river basin prior to the flood culminating in Písek on May 31, 1940

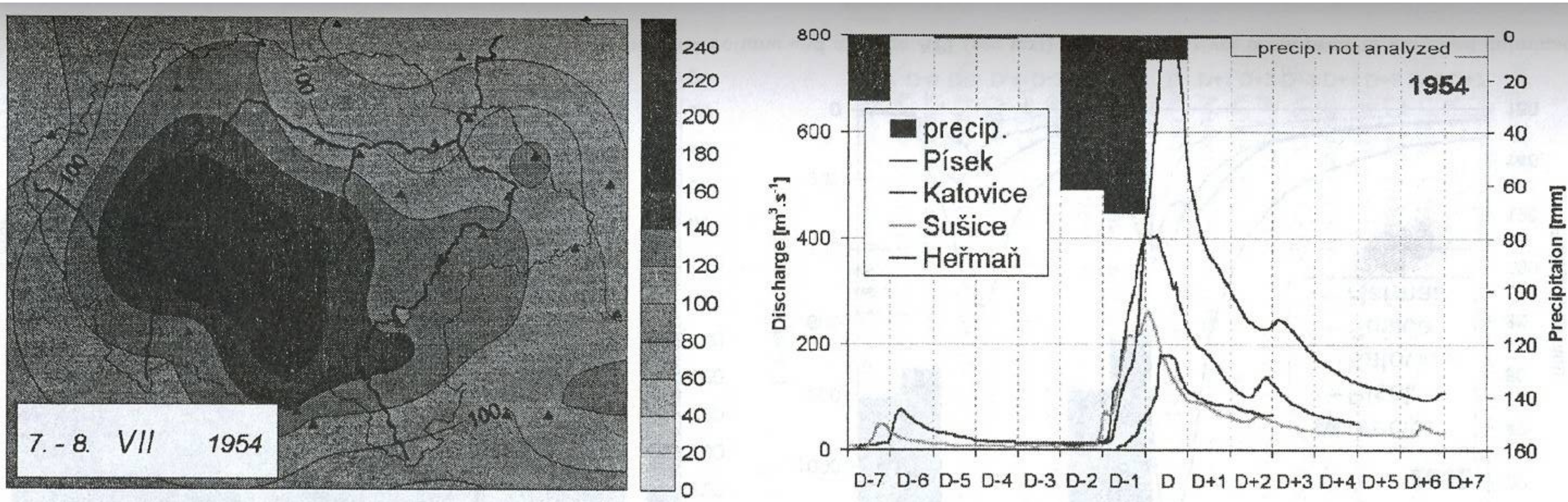

Fig. 13 Causal precipitations, hydrograph, average precipitation total volume and average API (see text) in the Otava river basin prior to the flood culminating in Písek on July 9, 1954

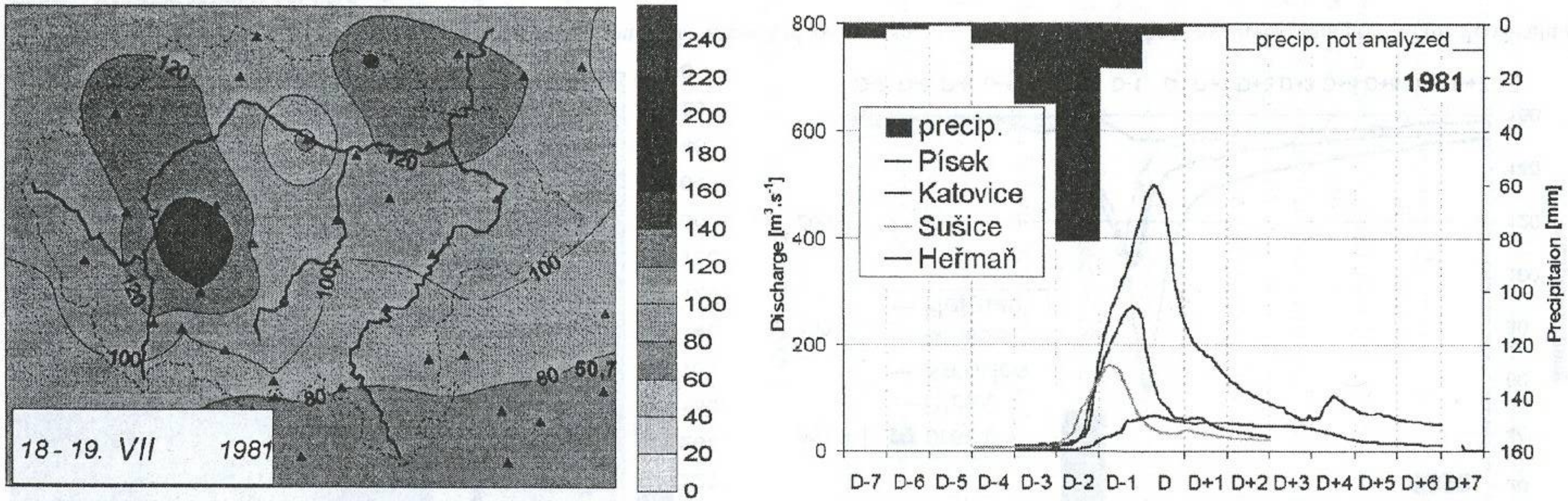

Fig. 14 Causal precipitations, hydrograph, average precipitation total volume and average API (see text) in the Otava river basin prior to the flood culminating in Písek on July 21, 1981

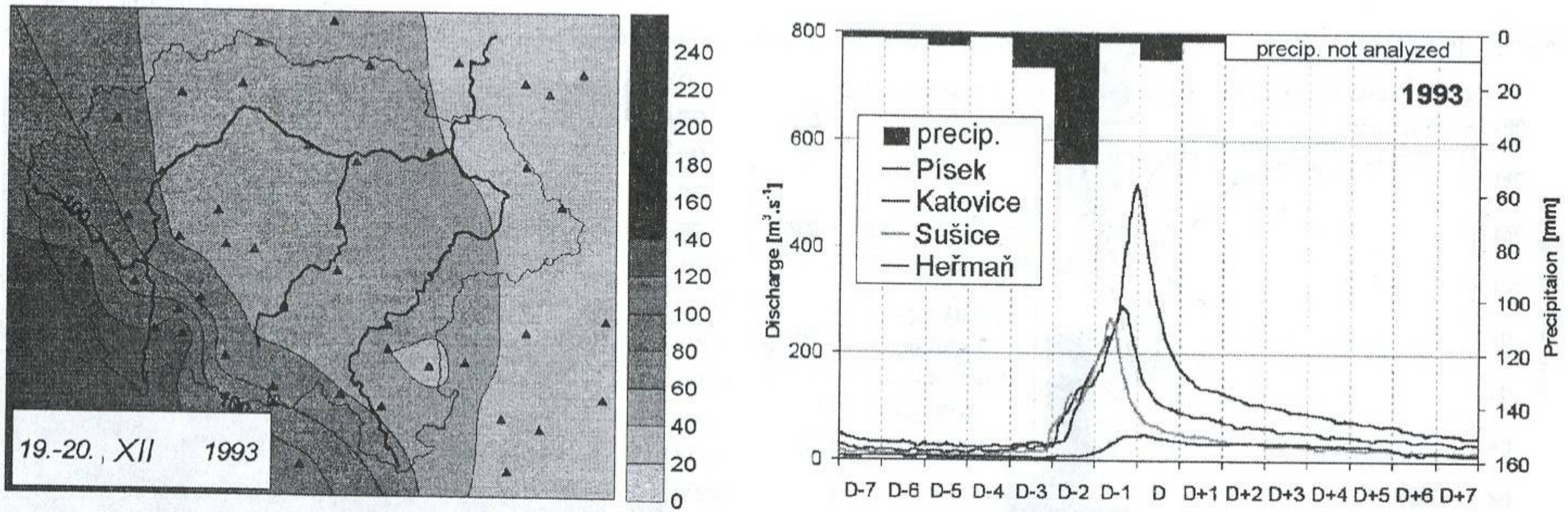

Fig. 15 Causal precipitations, hydrograph, average precipitation total volume and average snow water equivalent in the Otava river basin prior to the flood culminating in Písek on December 22, 1993

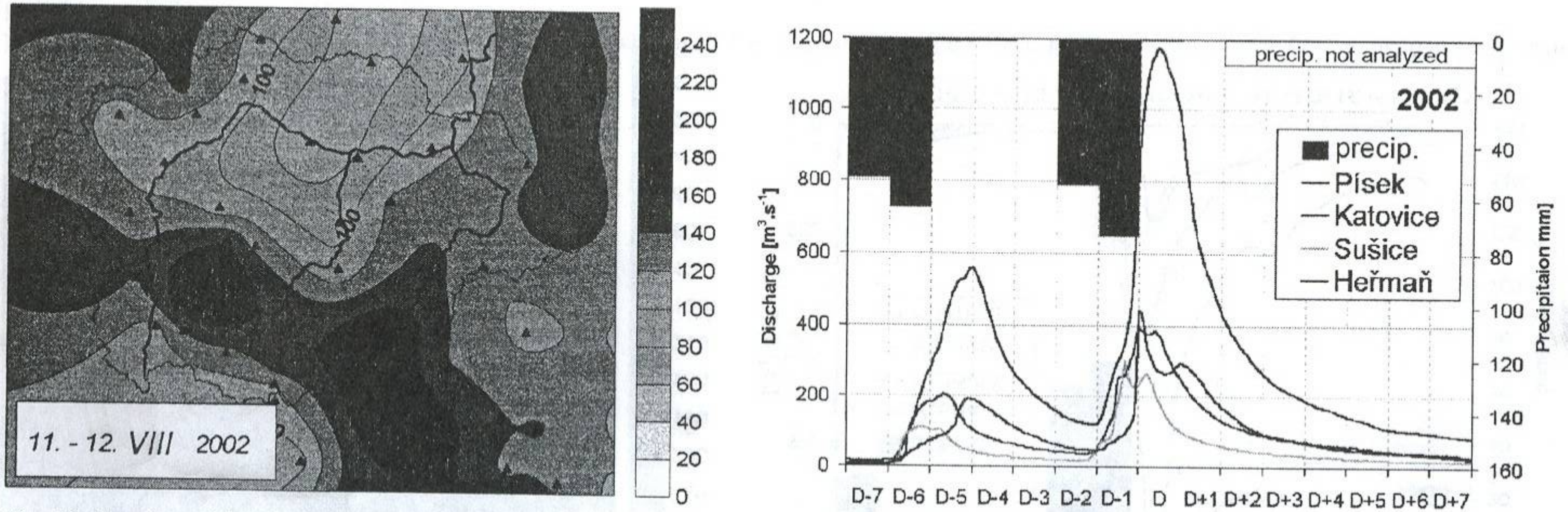

Fig. 16 Causal precipitations, hydrograph, average precipitation total volume and average API (see text) in the Otava river basin prior to the flood culminating in Písek on August 13, 2002

References

BĚHALOVÁ, K. (1995): Možnosti odhadu vývoje povodňových situací na základě analýzy historických případů. Diplomová práce, Katedra fyzické geografie a geoekologie, Přírodovědecká fakulta UK, Praha, s. 52.

BRÁDKA, J. (1967): Meteorologické příčiny povodní ve Slezsku. Meteorologické zprávy č. 20 (1), 1967, ČHMÚ Praha, s. 3–9.

BUCHTELE, J. (1972): Kategorizace povodňového režimu na tocích Vltavské kaskády. Sborník prací Hydrometeorologického ústavu v Praze, svazek 18, HMÚ v Praze, s. 64–139.

HLADNÝ, J., ČERNÝ, H., ŘIČICA, J. (1993): Odhad vývoje povodňových situací analýzou historických případů – 1. část Databanka povodňových vln průtoků. Praha, SPIS s.r.o., s. 1–45.

HLADNÝ, J. A KOL. (1995): Odhad vývoje povodňových situací analýzou historických případů – 3. Část Meteorologické symptomy. Praha, SPIS s.r.o., s. 1–37.

HLADNÝ, J. (1978): Hydrologická prognóza, HMÚ, Praha 1978, s. 105.

KAKOS, V. (1974): Možnosti hydrometeorologických předpovědí havarijních odtokových situací. Sborník prací Hydrometeorologického ústavu, 21, Praha, s. 55–85.

KAKOS, V. (1983): Hydrometeorologický rozbor povodní na Vltavě v Praze za období 1873 až 1982. Meteorologické zprávy 36, ČHMÚ, Praha, s. 171–181.

VAVRUŠKA, F. (1989): Meteorologické příčiny povodní na Otavě a Lužnici. Meteorologické zprávy, 42, ČHMÚ, Praha, s. 111–115.

VILÍMEK, V., LANGHAMMER, J., ŠEFRNA, L. et al. (2004): Posouzení efektivnosti změn ve využívání krajiny pro retenci a retardaci vody jako preventivní opatření před povodněmi, PřF UK, Praha, 78 pp.

VLASÁK, T. (2000): Analýza zimních povodňových situací v povodí Otavy. Diplomová práce. Přírodovědecká fakulta Univerzity Karlovy, Praha.

PŘEHLED A KLASIFIKACE HISTORICKÝCH POVODNÍ V POVODÍ OTAVY

Résumé

Tím jak fyzicko-geografické charakteristiky povodí a jeho okolí ovlivňují vznik a průběh extrémních odtoků, určují charakter povodní nejen z hlediska odtokové odezvy, ale i z hlediska jejich nejčastějších příčin. Za tohoto předpokladu by mělo být možné identifikovat v mechanismu vzniku povodní symptomy, které jsou pro sledované povodí charakteristické a které se budou alespoň u části povodní opakovat. Je zřejmé, že znalost těchto symptomů může být nápomocná například při regionalizaci povodňového rizika nebo v hydrologické prognóze.

Cílem této práce bylo shromáždit podklady k vybraným historickým povodním, zpracovat je do jednotné formy a na základě jejich analýzy popsat nejzřetelnější rysy povodňového mechanismu povodí Otavy. V příspěvku jsou shromážděny základní informace k dvanácti největším povodním na Otavě z let 1888–2002. Tyto případy byly vybrány na základě kulminačních průtoků ve stanici Písek, který ve všech případech překročil hodnotu desetileté vody. U každé povodně je v práci popsána dráha řídícího tlakového útvaru z příčinné povětrnostní situace, průtokový hydrogram Otavy z vodoměrné stanice Písek a pomocí orograficky podmíněné interpolace byly v prostředí GIS pro jednotlivé případy zobrazeny mapy prostorového rozložení příčinných srážek. Denní úhrny srážek stejně jako ukazatele nasycenosti povodí byly přepočteny na průměrné hodnoty na povodí Otavy a jsou vyneseny ve výsledných grafech.

Výsledky analýzy potvrzují především vysokou citlivost povodí Otavy na letní přívalové lijáky spojené s postupem tlakové níže z oblasti Středozemního moře přes naše území směrem k severo-východu. Nejintenzivnější srážky při těchto situacích se vyskytly mnohem častěji v podhůří Šumavy v oblasti středního toku Otavy a Volyňky než v jiných částech povodí a způsobovaly extrémní odtokovou odezvu i v případech, kdy nasycenost povodí byla vzhledem k sezóně spíše podprůměrná. Extremita povodně ze srpna 2002, která svým kulminačním průtokem vybočuje z řady ostatních povodňových případů, byla v porovnání s ostatními

případy způsobena především opakování dvou srážkově bohatých epizod. Tyto epizody – analyzované samostatně nebyly z hlediska úhrnů srážek největší ze zpracovávaných povodní, ale krátká prodleva mezi nimi (3 dny) zapříčinila, že povodí před druhou srážkovou vlnou bylo velmi nasycené a odtoková odezva byla výrazně větší.

Author's full address:
TOMÁŠ VLASÁK
Czech Hydrometeorological Institute (CHMI)
Antala Staška 32, 370 07 České Budějovice
tomas.vlasak@chmi.cz