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CZECH
HYDROMETEOROLOGICAL
INSTITUTE

FLOODS
IN THE CZECH REPUBLIC
IN JUNE
2013

CZECH HYDROMETEOROLOGICAL INSTITUTE

FLOODS IN THE CZECH REPUBLIC IN JUNE 2013

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This publication presents key outputs of the project „*Evaluation of Floods in the Czech Republic in June 2013*“ guaranteed by the Ministry of Enviroment of the Czech Republic.

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INTRODUCTION

Not so long ago, we commemorated the 10th anniversary of the catastrophic flood in August 2002 by organizing a professional conference with the topic of floods. It was an useful event, which not only revived memories of that exceptional flood, but also revealed a number of measures and activities that have been taken since then to increase the protection against floods. Older generations may remember the round anniversaries of major historical floods being previously commemorated by similar events, (e.g. the conference held to commemorate the 100th anniversary of the 1890 flood in Prague, or the conference held to commemorate the 150th anniversary of the 1845 flood in Ústí nad Labem).

In fact, unlike the second half of the 20th century, which was rather poor in floods, when similar events were mainly organized to arouse the public and responsible authorities to a greater interest in flood issues, today it is not necessary to remind anybody of the seriousness of this topic. It seems that since 1997 we have been living in a period rich in the occurrence of floods, which is similar in this sense to the end of the 19th century. We can just mention the floods in Moravia in July 1997, in Bohemia in August 2002, spring floods in March 2006, in Moravia in the period from May to June 2010, in North Bohemia in August 2010 and again mostly in Bohemia in June 2013. And in addition, it is also possible to point out the local flash floods in July 1998, June 2009 and at other times.

In this context, we will not address the question of whether the number and intensity of floods increases or whether this means an irregular occurrence of floods within the natural variation. It is important that the current generation has already become accustomed to the increased incidence of floods and is able to prepare for them. Whether this is the implementation of structural measures supported by the Government funding programmes or preventive measures consisting in the preparation of flood plans, forecasting and warning services, flood authorities and components of the Integrated Rescue System. What still sometimes does not work is the regulation of the construction and land-use of floodplains according to the degree of flood risk. The very process of assessment and management of the flood risk, based on the implementation of the European Directive 2007/60/EC, is now in its third phase – development of the Flood Risk Management Plans. Land use planning process should also bring improvements in this area.

The floods in June 2013 were somewhat similar to those in August 2002 and are often compared with them. They were also caused by two large-scale precipitation events and they affected roughly the same area, while reaching the maximum flow on the lower Elbe and Vltava Rivers. Even though the 2013 floods were smaller than the 2002 floods as to the extremity of flow and negative impacts on the lives and property, in terms of observed discharge of the Vltava and Elbe rivers, they were the third largest summer floods in instrumental history (after the floods that occurred in 2002 and 1890).

Like the previous large floods since 1997, the floods in June 2013 were evaluated through a comprehensive project developed on the basis of the Czech Government Resolution No. 533/2013 and supported by the state budget. The Ministry of the Environment of the Czech Republic charged the Czech Hydrometeorological Institute with the coordination of the project documentation and evaluation. The project was divided into thirteen individual tasks grouped into the following four thematic areas:

1. Causes and hydrological progression of the floods.
2. Flood Protection System operation.
3. Evaluating the function of reservoirs and flood control measures.
4. Flood Impact Documentation.

The project tasks were solved from September 2013 to June 2014, and in addition to the Czech Hydrometeorological Institute, the following entities participated in the individual tasks: T. G. Masaryk Water Research Institute, v. v. i., Bison & Rose s. r. o., Povodí Vltavy, s. p., Povodí Labe, s. p., Povodí Ohře, s. p., Povodí Moravy, s. p., Vodní díla TBD, a. s., Vodohospodářský rozvoj a výstavba, a. s., Czech Geological Survey, Czech Environmental Inspectorate, and their subcontractors.

The project results are very comprehensive. All the individual reports with attachments have a total of 2,200 pages. The full reports are deposited in the Library of the Czech Hydrometeorological Institute and published on its website. Their results are provided in the Final Summary Report, which was submitted to the Czech Government.

This publication, which aims at popularizing the project results to the wider professional community, understandably makes no ambitions for their completeness. In detail, we therefore refer the readers to the Czech Hydrometeorological Institute website, containing all the individual reports, Final Summary Report and Government Resolution No. 570/2014, which was adopted to ensure the implementation of the proposed measures. Unless stated otherwise, all the time data referred to in this publication are related to the Central European Summer Time (CEST).

1. METEOROLOGICAL CAUSES AND HYDROLOGICAL DEVELOPMENT OF FLOODS

The weather in the first half of 2013 in Central Europe was characterized by frequent significant changes in air temperature and variable precipitation regime.

From January to early April, an unusual high number of pressure lows reached or directly formed in the Western Mediterranean, and over the Mediterranean Sea, they gathered humidity and usually progressed eastward to north-eastward. When located east of the Czech Republic, they entrained cold air from Scandinavia and Russia to Central Europe, while also bringing precipitation, which was most pronounced east and south-east of our territory, where it caused heavy snowfalls. In January and February, this situation occurred six times and in March, ten times.

The deviation from the normal in the sea-level pressure field over the Northern Hemisphere for the period between January and March 2013 is illustrated in Fig 1.1.

These circulation anomalies were caused by an exceptionally strong jet stream over the North Atlantic, which was shifted further south. This led to an atypical distribution of pressure over the Atlantic, when over the Azores, where there is usually an area of high-pressure air, there was a large low-pressure area. This phenomenon is known as the negative phase of the North Atlantic Oscillation (NAO), see Fig. 1.2. Such distribution of air pressure supported the formation of depressions and their progression along the above-mentioned path across the Mediterranean towards Eastern Europe.

Subsequently during May, a low-pressure trough remained over the area of the British Isles and Western or Southwestern Europe for a long time.

In the first half of May, the fronts progressed over Central Europe mostly from the west, and when proceeding to the east, they slowed and usually undulated.

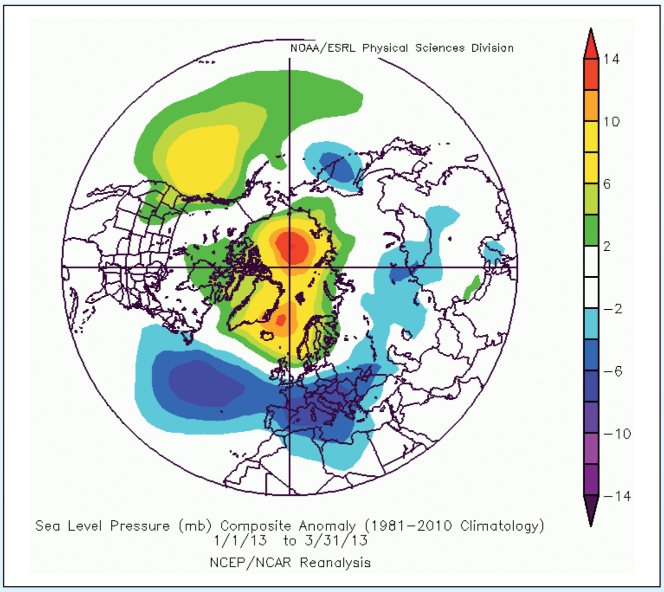

Fig. 1.1 Deviation of Sea-Level Pressure Field from Normal (1981-2010) in mb (mb = hPa) over the Northern Hemisphere for the Period between January and March 2013 (source: NOAA/ESRL).

In the second half of the month, a meridional (north-south) flow gradually originated over Western Europe, which caused ground-level cold air to frequently flow to the areas above the Mediterranean and North Africa.

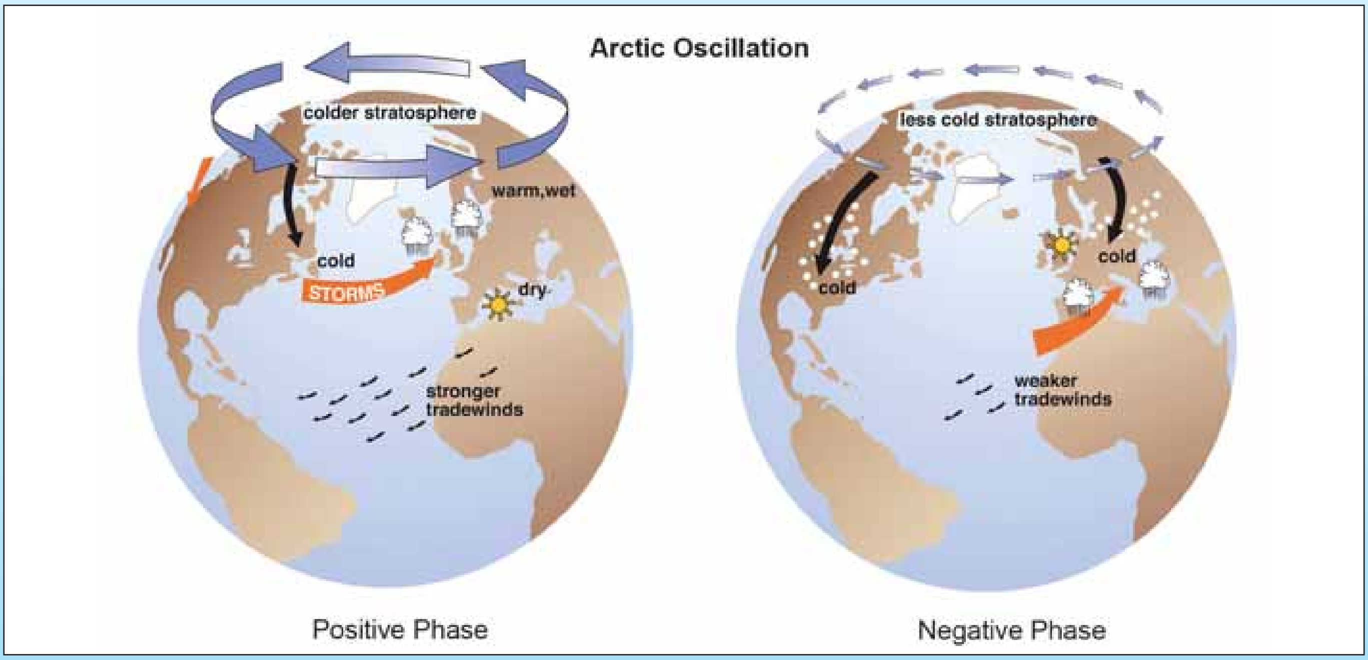

Fig. 1.2 Arctic Oscillation Diagram (Source: University of Washington, taken from the Gnosis9.net Internet Magazine).

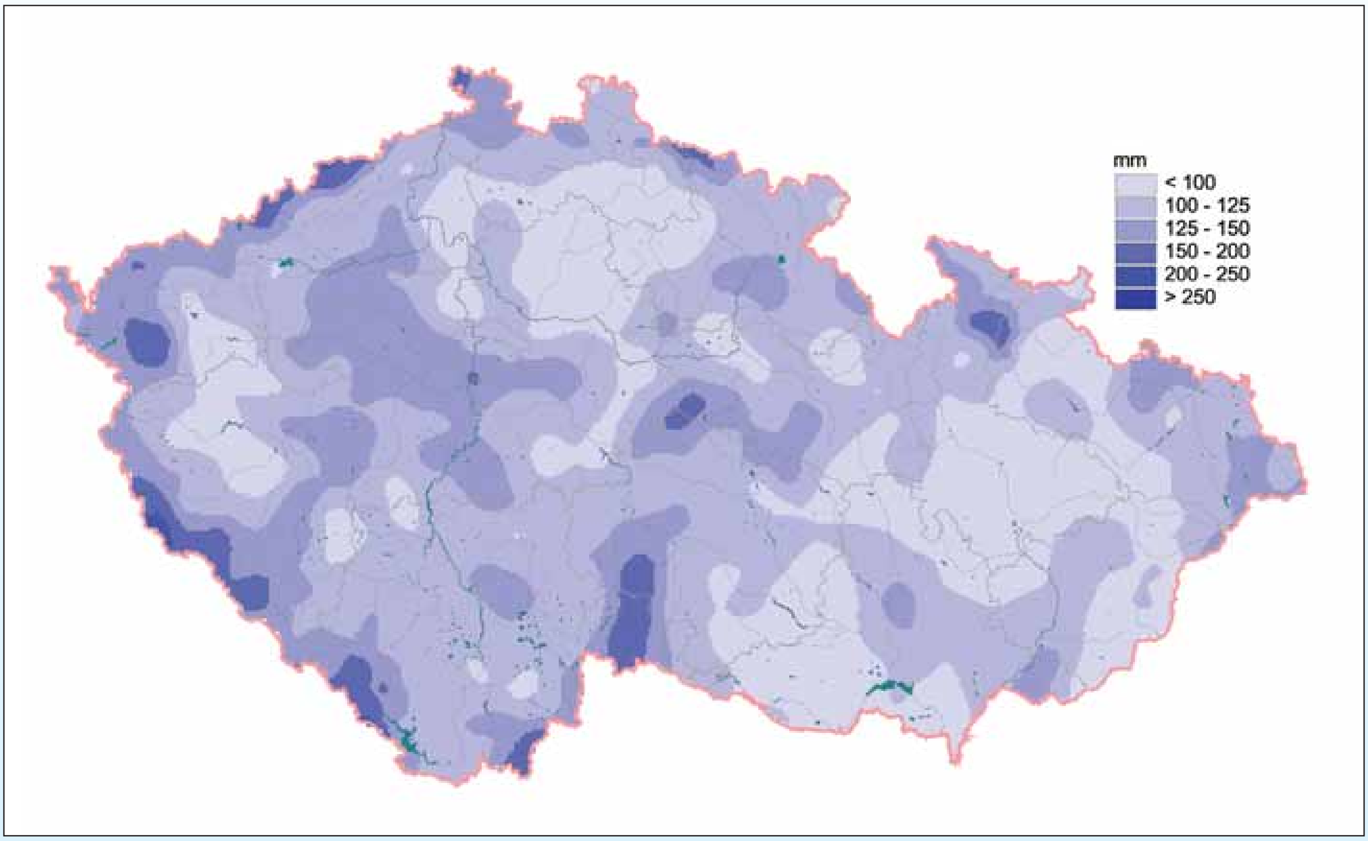

Fig. 1.3 Monthly Precipitation Total in the Czech Republic in May 2013.

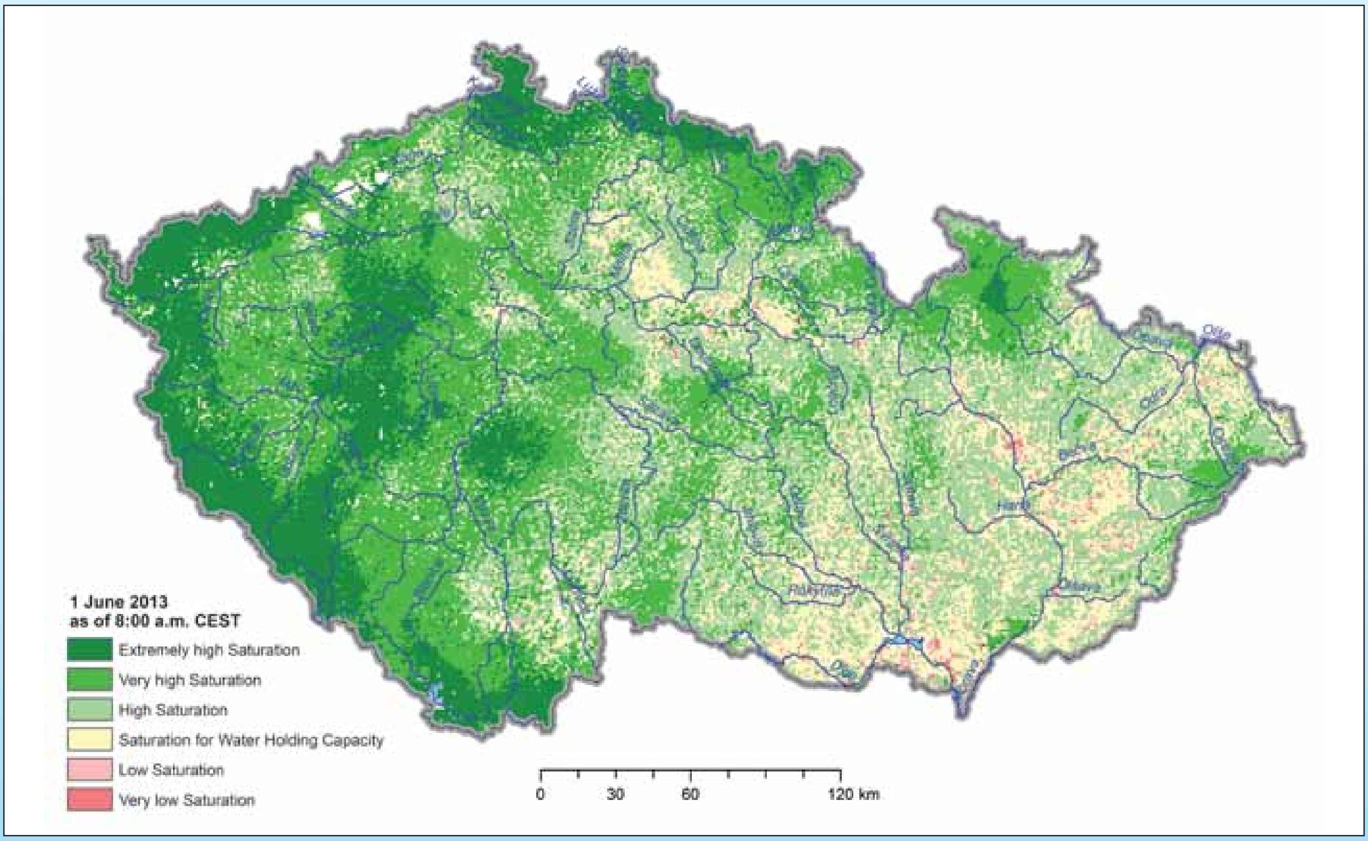

Fig. 1.4 Territory Saturation Index as of 1 June 2013 8:00 a.m., Central European Summer Time (CEST).

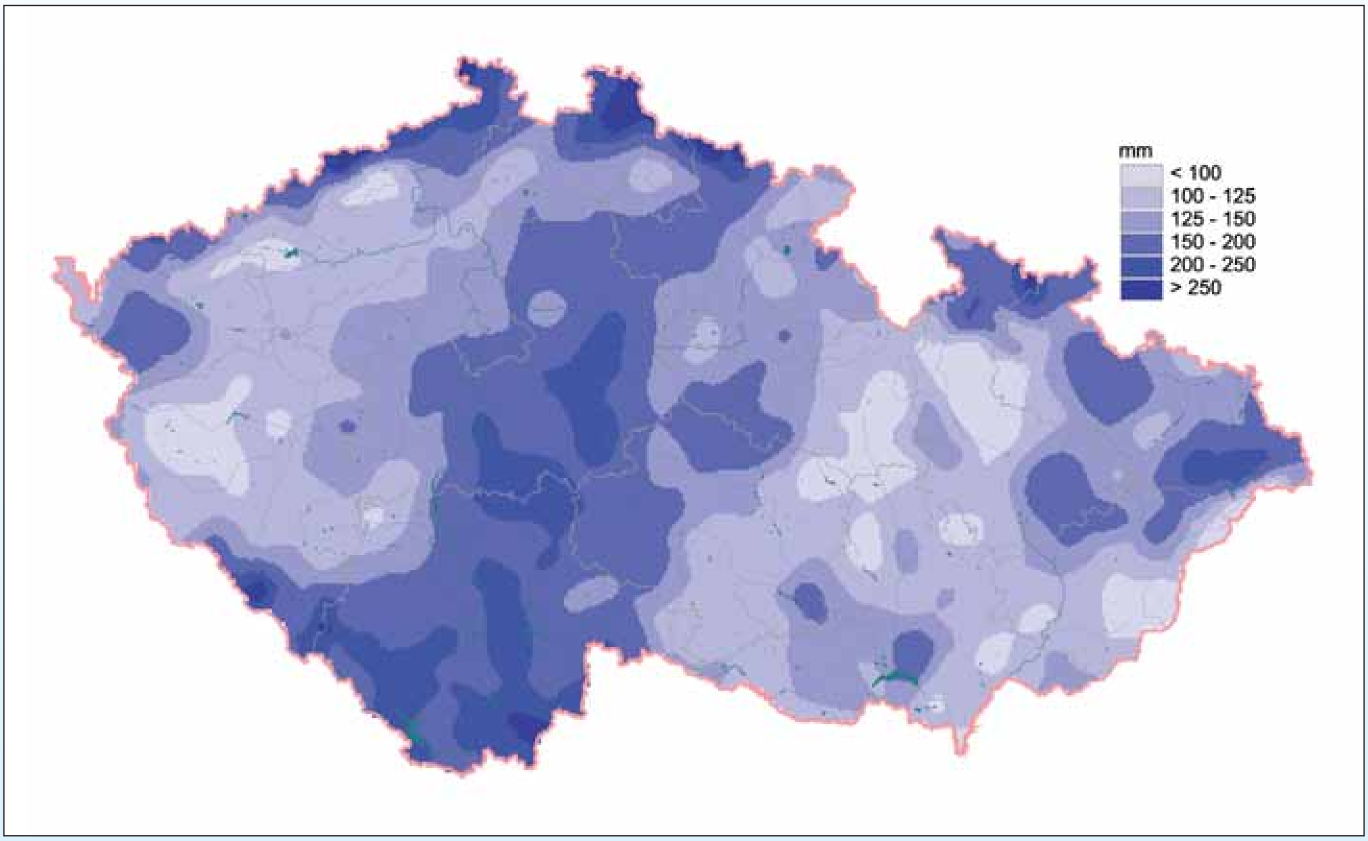

Fig. 1.5 Monthly Precipitation Total in the Czech Republic in June 2013.

There, in the interaction between the polar and subtropical jet streams, depressions were formed that gathered huge masses of moist air from the Mediterranean and progressed into the interior of the continent of Europe. The air temperature in the territory of the Czech Republic was significantly below the average for that period and there were numerous, locally even heavy rainfalls, occasionally accompanied also by thunderstorms, with daily totals of up to 40 mm.

In total, May was the month with subnormal temperatures and strongly above-normal precipitation. In the whole territory of the Czech Republic, an average precipitation total of 113 mm was measured, which represents 152 % of the long-term average for the period between 1961 and 1990. May was rich in precipitation, especially in Western Bohemia, where the total precipitation in the Karlovy Vary (Carlsbad) Region reached 125 mm, which is 205 % of the long-term average; in the Pilsen Region, it was 122 mm, i.e. 175 % of the long-term average. The spatial distribution of monthly precipitation totals in the Czech Republic in May 2013 is shown in Fig 1.3.

In most of the territory of the Czech Republic, the extreme rainfall in May caused an extreme saturation of soil, which is shown by the saturation index in Fig. 1.4. The increasing value of the saturation index results in the reduced soil ability to absorb precipitation as well as in an increased share of water that runoff from the subsequent precipitation. Its value is derived using balance calculations from the daily rainfall data, actual evapotranspiration and an estimated runoff depth.

From Fig 1.4 it is clear that in early June, the soil was most saturated in the western part of Bohemia, especially in the border areas and Krkonoše and Jeseníky mountains. This factor greatly influenced the runoff response during the heavy rainfall episodes on 1 and 2 June and 8 to 10 June.

In the Czech Republic, June 2013 was the month with strongly above-normal precipitation, and the mean areal precipitation reached 146 mm, which represents 174 % of the long-term average for the period between 1961 and 1990. It has been the highest total for June since 1961. Higher monthly precipitation totals were only recorded in July 1997 (204 mm) and August 2002 (177 mm). It is necessary to add that just in those months, there were extreme floods in the Czech Republic.

The highest areal precipitation totals, as compared with the long-term mean, were reached in June 2013 in the Central Bohemian Region (163 mm, which is 217 % of the long-term mean), Liberec Region (175 mm, 211% of the long-term mean) and Ústí nad Labem Region (141 mm, 207 % of the long-term mean). The spatialdistribution of the monthly precipitation totals in June 2013 in the Czech Republic is presented in Fig. 1.5.

In June, significant rainfalls were grouped into three major precipitation episodes that caused three episodes of floods. The first episode in the period from 29 May to 3 June hit almost solely Bohemia. In the following episode from 9 to 11 June, there were mostly local convective rainfalls with varying intensity. In the second half of June, there were a few days when the air temperature reached the summer or even tropical values. Afterwards

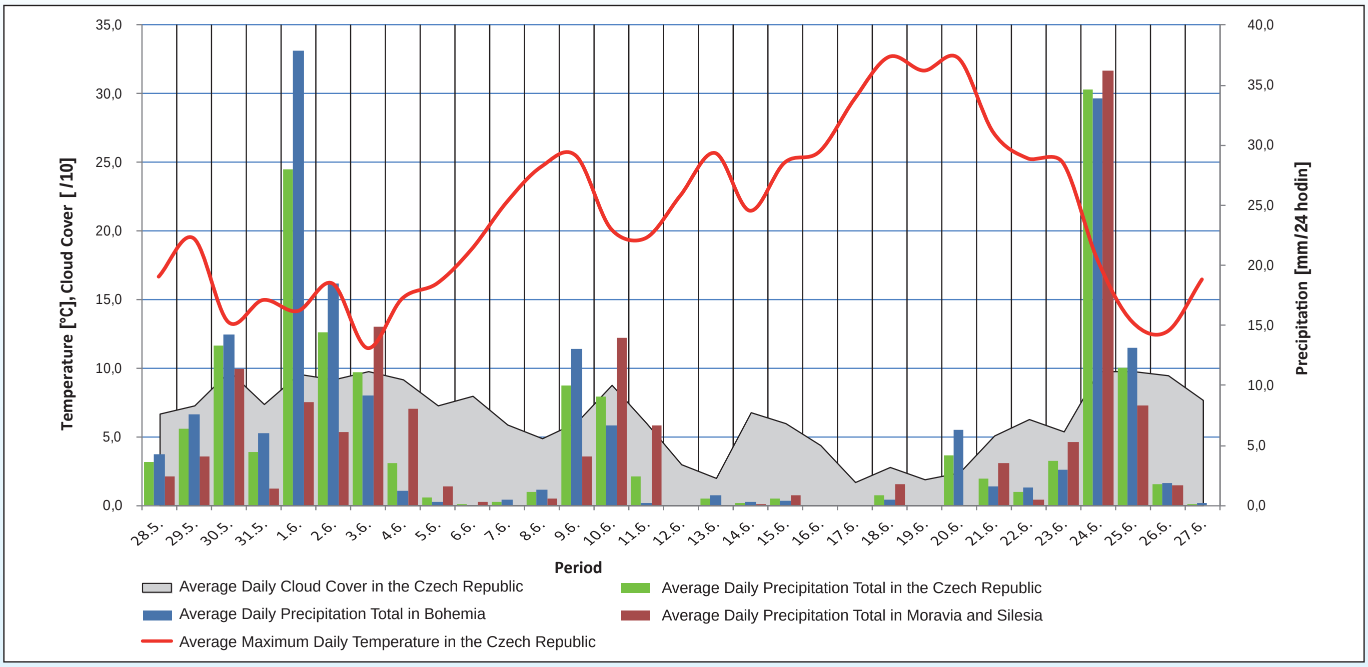

Fig. 1.6 Course of Selected Meteorological Elements for the Period from 28 May to 27 June 2013.

on 24 and 25 June, the third major precipitation episode occurred with the highest totals especially in the eastern part of Bohemia and in Moravia.

FIRST FLOOD EPISODE from 29 May to 7 June 2013

At the very end of May and at the beginning of June, a large low pressure area occurred over a large part of the continent of Europe with the centre progressing from Southwestern Europe north-westward. The significant rainfall episode on 1 and 2 June was caused by the depression formed on 30 May on the frontal wave east of the Czech Republic and slowly progressed over our territory. At that time, an anticyclone (area of high pressure) remained over Northern Europe, and at the same time, the Azores anticyclone wedge spreaded over Western Europe. Both the anticyclones gradually blocked the progression of the depression northward and westward, which caused the area of depression to remain over the centre of the continent of Europe. Over our territory, there was a wavy frontal boundary, which lasted almost twenty hours without any significant movement.

Uplift movements resulted in a significant convergent air stream at the ground level, and at the same time, there was a considerable wind shear (above 15 m.s^{-1}) between the ground layer and a height of 3 km. The wind shear means a situation where wind flows in different directions at different heights in the atmosphere. This phenomenon supports a rising air flow and thus also the formation of intense precipitation when air cools down during upward movement. The so-called convergence line remained at the same location for a few hours, and on 2 June, it was located in the line from Northern over Central Bohemia, reaching into Southern Bohemia.

Another element that contributed to significant precipitation was an unstable stratification of the atmosphere, especially in Northern Bohemia, where thunderstorms occurred in addition to permanent rain. The thunderstorms mainly arose on the northern windward slopes of the Krkonoše Mountains (Giant Mountains), hit by moist air, which had to rise, and convective precipitation cells were repeatedly formed there. The cells progressed south-westward, while reaching the same areas all the time (i.e. so-called train effect).

In the next days, the depression over Eastern Europe began to slowly fill, but its influence continued until 5 June, when it influenced the eastern areas of the Czech Republic. Afterwards, a ridge of higher air pressure spread over our territory, and in the next days, an indifferent pressure field maintained itself over Central Europe.

A five-day precipitation period, which lasted from 29 May to 3 June, hit almost solely Bohemia (Fig. 1.7). On 29 May, the precipitation totals exceeded 30 mm, while reaching 40 mm at some stations on 30 May. On 31 May, the rainfall was significantly lower, and the daily precipitation total at most stations amounted up to 15 mm, except for several stations in the west of Bohemia.

The precipitation totals for 1 June (i.e. rainfall from 1 June 2013, 8:00 a.m. CEST until 2 June 2013, 8:00 a.m. CEST) reached more than 80 mm, sporadically even more than 100 mm, at some locations in the Šumava and Krkonoše Mountains (Giant Mountains) and Central Bohemia. At the Horní Maršov station in the Krkonoše Mountains, the rainfall amounted up to 130 mm, and during thunderstorms, the hourly rainfall intensity of 46 mm was measured there. The above-mentioned daily precipitation total recorded at the Horní Maršov rain-gauge station exceeded 100-year precipitation for this location. On 1 June, 100-year precipitation totals were also exceeded at the Hlasivo station in the Tábor Region and Střezimíř station in the Benešov Region.

The highest daily precipitation total for 2 June (from 2 June 2013, 8:00 a.m. CEST until 3 June 2013, 8:00 a.m., CEST) was recorded in the town of Poděbrady (88 mm), which represents 100-year precipitation for that station. On that day, the totals exceeded 70 mm in mountain areas: in the Jizera Mountains at the Bedřichov station – 76 mm and in the Šumava Mountains at the Železná Ruda – Špičák station – 73 mm.

The daily precipitation totals measured at selected stations for 1 and 2 June 2013 are presented in Table 1.1. As a standard, the daily precipitation totals are measured at 7:00 a.m. CET (8:00 a.m. CEST) of the following day.

During the six-day precipitation period from 29 May to 3 June, the highest rainfall amount was measured on 1 and 2 June, and the heaviest rainfall was recorded during 24 hours from 1 June, 3:00 p.m. until 2 June, 3:00 p.m. CEST, as shown in Fig. 1.9. The highest 24-hour precipitation totals exceeded 100 mm in the eastern area of the Krkonoše Mountains (Giant Mountains), in the Kolín Region, in a relatively large area south of Prague and in some areas of the South Bohemian Region. It was just on smaller watercourses in those most affected areas where the extremity of peak flows exceeded the return period of 100 years. Using the colour symbols for the water gauges, the map indicates the return periods of peak flow.

A significant water level rise started to occur first on the tributaries of the Berounka River (i.e. Klabava and Úslava Rivers), already during 31 May as a result of the rainfalls of 30 and 31 May (approximately 20–45 mm), which hit the already very saturated area.

Causal precipitation of the first flood event started over the territory of Bohemia on 1 June and hit the watercourses in the Berounka River basin downstream of Pilsen and gradually also in the Otava and Lužnice River basins downstream of the Rožmberk pond, as well as in the catchment areas of smaller tributaries of the Vltava River flowing directly to the reservoirs of Vltava River Cascade. The water level also rose on the Lužnice, Otava, Berounka and Vltava Rivers. In the afternoon and evening, there were also heavy rainfalls on the ridges of the Krkonoše Mountains (Giant Mountains), which resulted in the water level rising on the Elbe River upstream of the Labská reservoir and on the Úpa River.

After the midnight of 1 June, there were intensive convective rainfalls in the Krkonoše Mountains, which mainly hit the tributaries of the Úpa River between Horní Maršov and Trutnov and tributaries of the Elbe River upstream of the Les Království reservoir. The runoff response was, also due to the strong previous saturation of soil, very quick. The basin of the Čistá Brook, flowing into the Elbe River in the town of Hostinné, was the most affected. Flash floods and local flooding were accompanied by very strong erosion phenomena of an areal and local nature, as well as by numerous small scale landslides and erosion. The levels of watercourses culminated in the morning on 2 June. The course of flood hydrograph at the selected profiles in the Elbe River basin upstream of the Les Království reservoir is shown in the graph in Fig. 1.11.

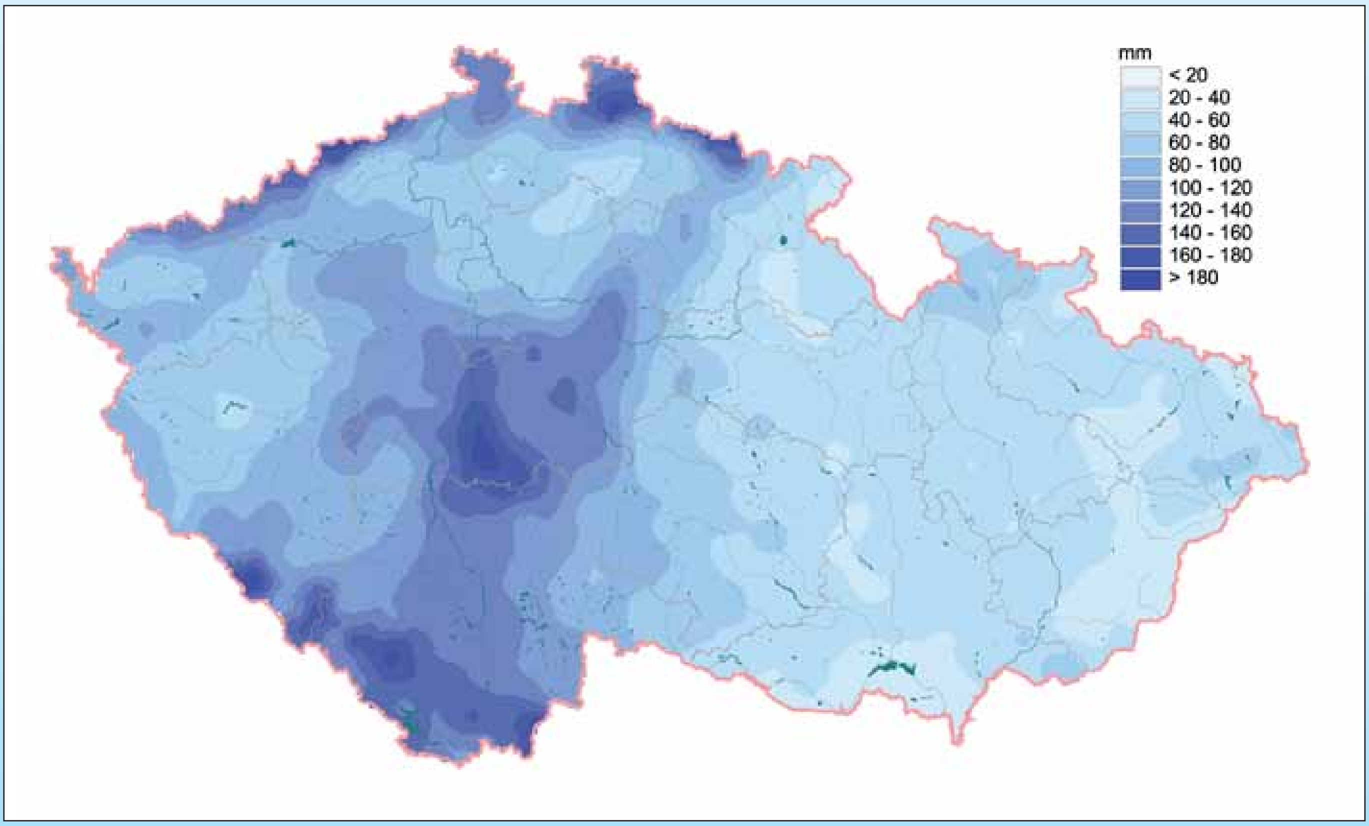

Fig. 1.7 Precipitation Total from 29 May, 08:00 a.m. CEST to 3 June 2013, 08:00 a.m. CEST in the Territory of the Czech Republic.

Tab. 1.1 Precipitation Total of >100 mm and Its Extremity from 1 June, 08:00 a.m. CEST until 3 June 2013 CEST at Selected Climatological Stations of the Czech Hydrometeorological Institute.

Station	Altitude [m above sea level]	District	Catchment Area	1 June [mm]	2 June [mm]	Sum [mm]	Return Period [years]
Chelčice	466	Strakonice	Blanice	72.5	28.5	101.0	20–50
Frantoly	726	Prachatice	Blanice	101.0	25.0	126.0	20–50
Železná Ruda	763	Klatovy	Danube	79.0	33.0	112.0	10
Labská bouda	1,315	Trutnov	Elbe	74.4	32.2	106.6	< 5
Poděbrady	189	Nymburk	Elbe	41.6	87.9	129.5	> 100
Dolní Chvatliny	290	Kolín	Elbe	57.5	52.4	109.9	50–100
Český Jiřetín	740	Most	Elbe	83.8	44.0	127.8	20
Nová Ves v Horách	725	Most	Elbe	73.6	28.0	101.6	20
Bedřichov	777	Jablonec nad Nisou	Lužická Nisa	62.7	76.0	138.7	10
Bechyně	409	Tábor	Lužnice	83.5	22.4	105.9	50–100
Hlasivo	547	Tábor	Lužnice	99.8	14.9	114.7	100
Jistebnice	581	Tábor	Lužnice	95.6	32.5	128.1	> 100
Milevsko	442	Písek	Lužnice	73.9	32.5	106.4	50
Nadějkov, Větrov	616	Tábor	Lužnice	81.0	31.7	112.7	50
Benešov nad Černou	665	Český Krumlov	Malše	70.1	31.6	101.7	10
Pohorská Ves	807	Český Krumlov	Malše	65.6	41.8	107.4	10
Branná, Františkov	586	Šumperk	Morava	62.7	58.6	121.3	20–20
Bavorov	442	Strakonice	Otava	77.4	29.5	106.9	20–50
Churáňov	1,118	Prachatice	Otava	86.7	36.3	123.0	20
Kašperské Hory	741	Klatovy	Otava	50.7	57.5	108.2	10–20
Paseky	482	Písek	Otava	72.3	33.0	105.3	50
Prachatice	607	Prachatice	Otava	77.7	31.8	109.5	10
Zbytiny	790	Prachatice	Otava	108.3	34.5	142.8	50–100
Sázava	302	Kutná Hora	Sázava	41.2	64.3	105.5	50
Votice	500	Benešov	Sázava	73.5	33.1	106.6	20–50
Hejnice	396	Liberec	Smědá	45.3	60.6	105.9	5
Železná Ruda, Hojsova Stráž	867	Klatovy	Úhlava	71.0	46.1	117.1	10
Železná Ruda, Špičák	947	Klatovy	Úhlava	84.6	72.8	157.4	20
Horní Maršov	565	Trutnov	Úpa	130.3	17.7	148.0	50–100
Pec pod Sněžkou	816	Trutnov	Úpa	89.4	22.0	111.4	5
Červený Dvůr, Chvalšiny	588	Český Krumlov	Vltava	75.0	34.8	109.8	20
Filipova Huť	1,110	Klatovy	Vltava	80.3	47.3	127.6	20
Kvilda	1,059	Prachatice	Vltava	82.0	26.8	108.8	10
Brloh	559	Český Krumlov	Vltava	75.8	25.9	101.7	20–50
Frymburk, Svatý Tomáš	972	Český Krumlov	Vltava	70.2	37.5	107.7	20
Kovářov	529	Písek	Vltava	85.1	26.3	111.4	50
Křemže, Mříč	524	Český Krumlov	Vltava	84.3	21.1	105.4	20
Střezimíř	588	Benešov	Vltava	107.0	29.3	136.3	> 100

What weather conditions can cause floods in the Czech Republic?

Comparison of the synoptic situations before and during the 2013 floods and other flood situations in our country, including the years 1997 and 2002, showed similarities of the mechanism of the synoptic formation of the flood situation (Fig. 1.8). Frontal disorders, which usually arise on the eastern coast of North America and move over the North Atlantic to the west coast of Europe, are entrained southward in the area of the British Isles [1]. The strong flow between the British Isles and the Iberian Peninsula then directs these disorders either as closed depressions or troughs above the warm waters of the Western Mediterranean, where depressions are deepened or newly formed in the interaction between polar and subtropical jet streams [2]. If there is no blocking anticyclone above Central Europe, the depression movement from the Western Mediterranean is routed to the northeast [3] along the track called Vb (according to van Bebber). On their front side, the depressions usually gather huge masses of warm and humid sea air during their progression. Although most of such cyclone movements have a northeasterly direction, the trajectories may significantly differ. Some depressions progress northward over the Alpine area to Western Bohemia, other depressions progress from the Alpine area via Austria and Slovakia (Moravia and Silesia) further to the northeast, or from the Western Mediterranean to Central and Eastern Europe along the eastern route via the Balkans. During their movement, there is sometimes a retrograde progression towards the northwest to west [4a], or depression centres often maintain themselves at one location for a longer period of time. The location of other pressure systems over Europe and the Eastern Atlantic is an important factor in the depression movement. In almost all cases of floods, there was a ridge of high pressure or anticyclone at the ground level in the areas north or northeast of Central Europe [5]. The progression of depressions further northward was therefore blocked and slowed down. When the depression centre reaches approximately the boundary of Central and Eastern Europe (usually over southern Poland or western Ukraine), an Azores anticyclone begins spreading to Southwestern and Western Europe [6], which finally closes the space for further movement of depressions westward. In this grip, cut off from the influx of warm and moist air from the Mediterranean Sea and Black Sea, the depressions begin weakening, gradually fill up and usually slowly progress eastward.

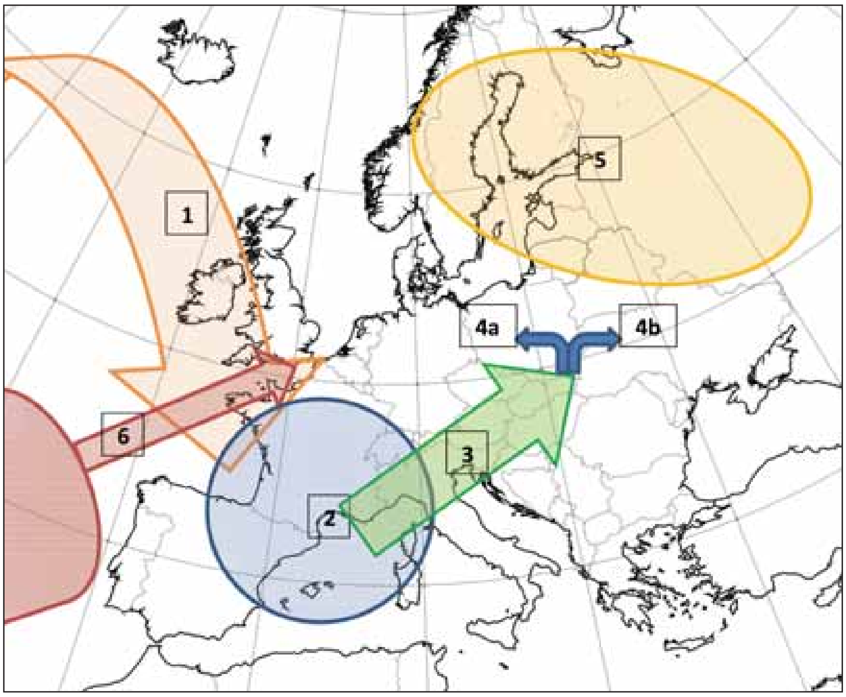

Fig. 1.8 Mechanism of Circulation over Europe in Case of Heavy Rainfalls and Floods in Central Europe.

The heavy rainfall also resulted in the water level rising on the left-bank tributaries of the Cidlina River (i.e. Javorka and Bystřice streams), which also reached their peak flows in the morning on 2 June.

With some delay, no sooner than around the noon on 2 June, precipitation also culminated in Central Bohemia, more specifically, over the catchment areas of the Mrlina, Vrchlice Rivers and especially Výrovka River, where it caused extensive flooding. A dramatic situation occurred in the Mrlina River basin, where the Komárovský pond dam on the Štítarský stream breached upstream of the water gauge of Svídnice.

A sharp rise in water levels also occurred on the right-bank tributaries of the Vltava River into the Vltava Cascade reservoirs, on the tributaries of the Lower Sázava, Lužnice and Otava Rivers and on the tributaries of the Vltava River downstream of the Lipno reservoir. This resulted in a very rapid filling of the Vltava River Cascade reservoirs, and due to the uncontrolled flow from the Sázava and Berounka Rivers, also in the Vltava River water level rising in Prague.

The flow rates of the observed tributaries of the Vltava River downstream of the Orlík reservoir, i.e. on the Brzina, Mastník and Kocába Rivers, culminated dur-

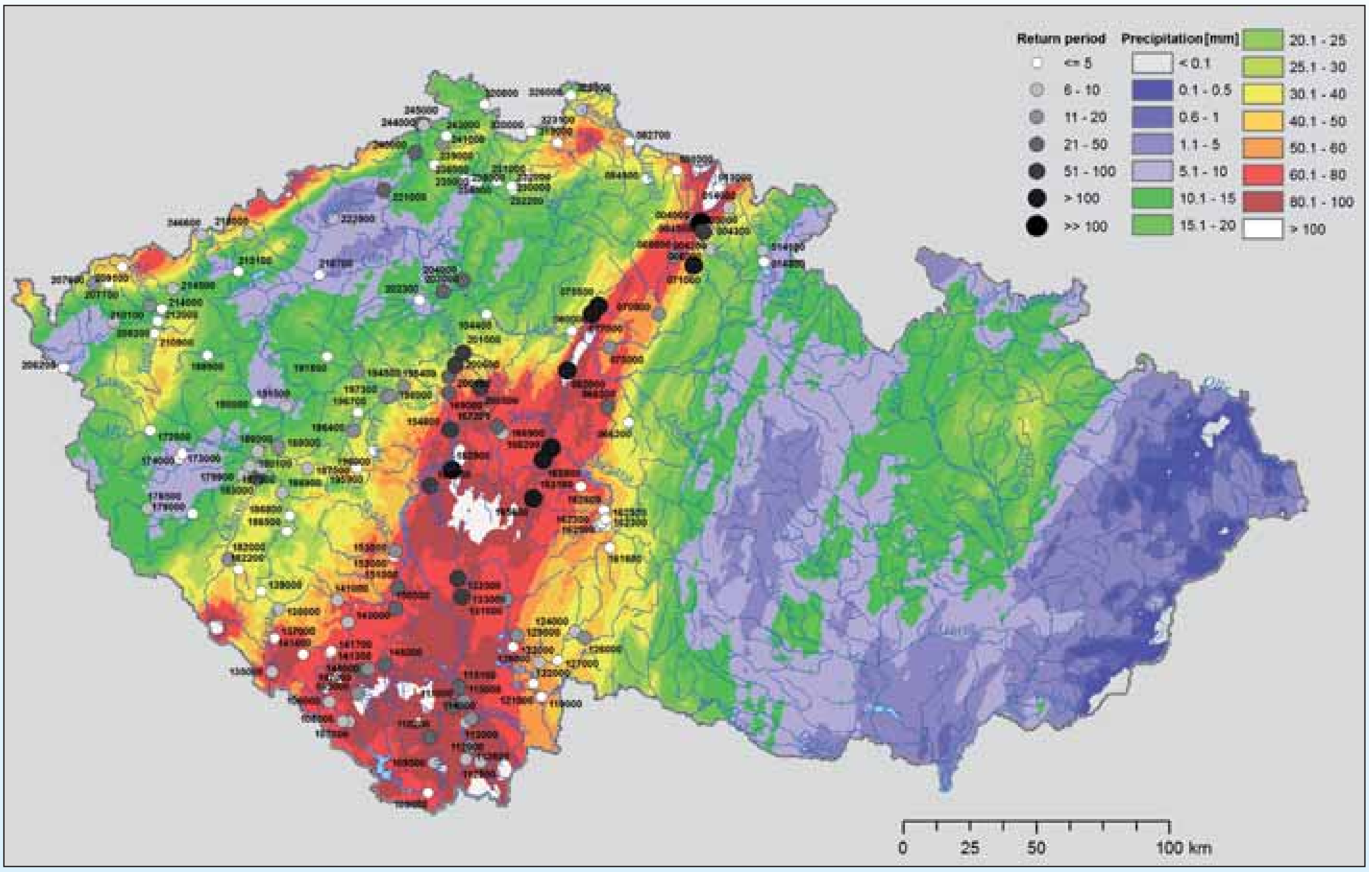

Fig. 1.9 Rainfall Distribution from 1 June, 03:00 p.m. until 2 June, 03:00 p. m. CEST and Return Period of Peak Flows at Selected Hydrometric Stations.

Fig. 1.10 Čistá Brook in Arnultovice – One Day after Peak flow (Source: Povodí Labe, s. p.).

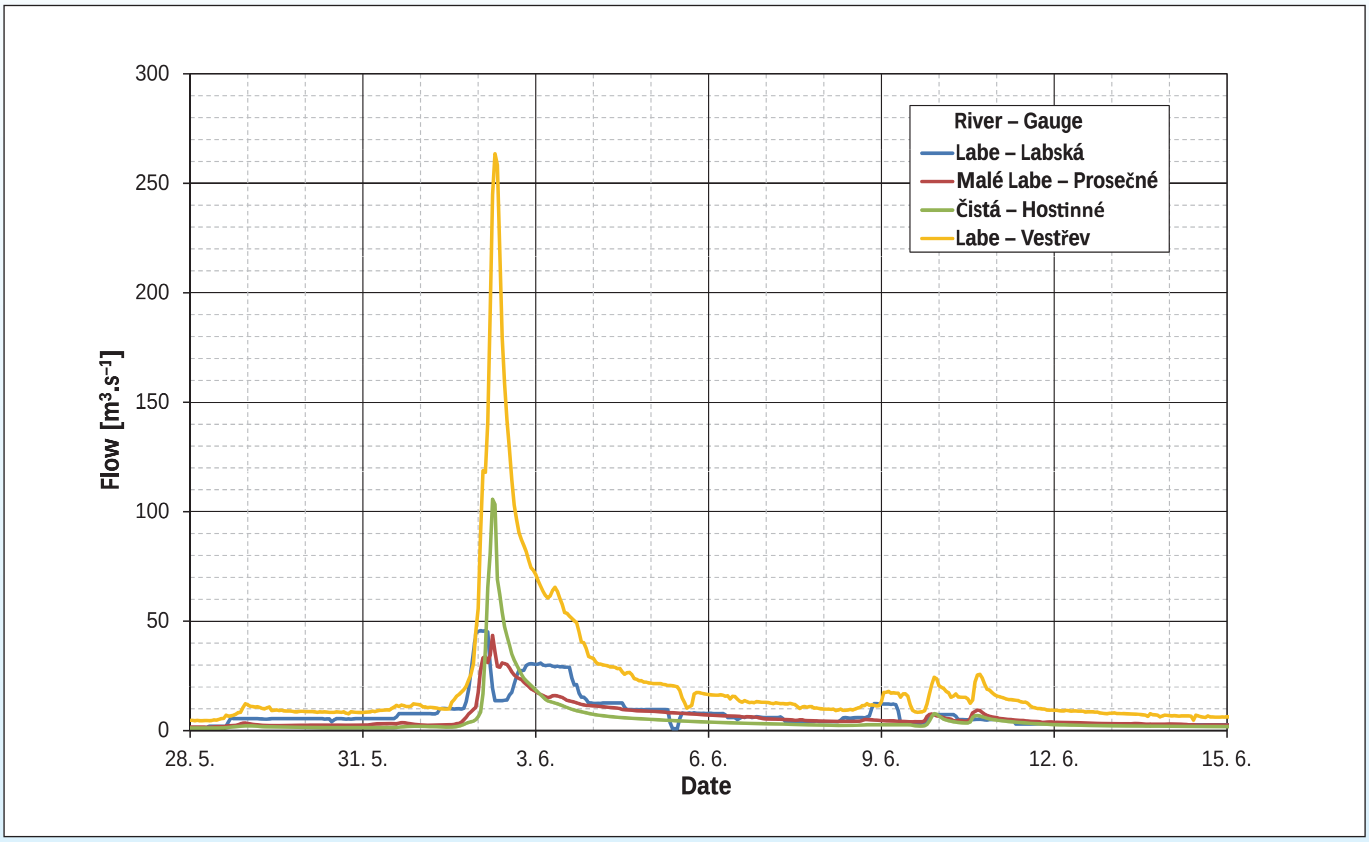

Fig. 1.11 Flood Hydrographs at Selected Gauges in the Upper Elbe River Basin.

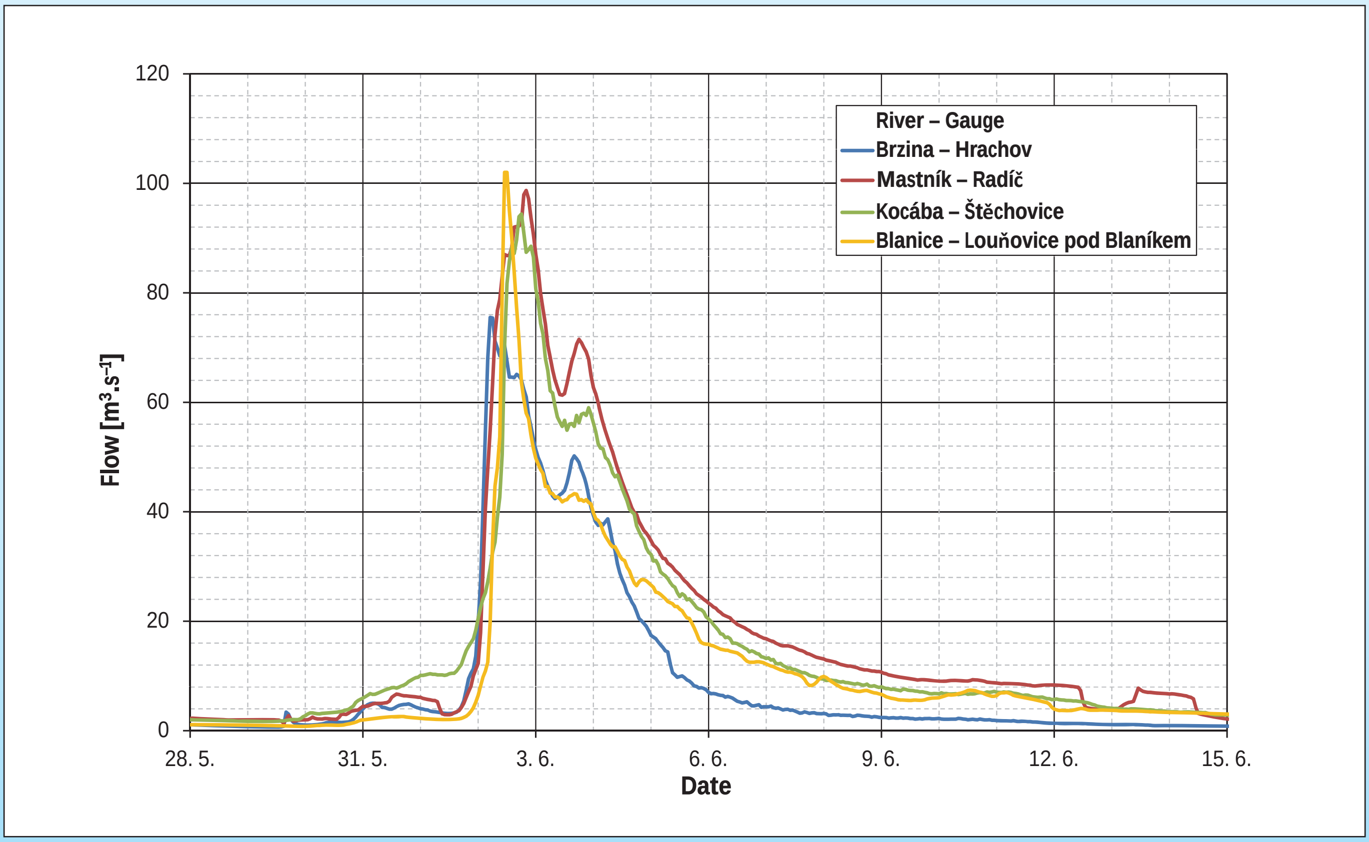

Fig. 1.12 Flood Hydrographs at Gauges on Tributaries of the Vltava and Sázava Rivers.

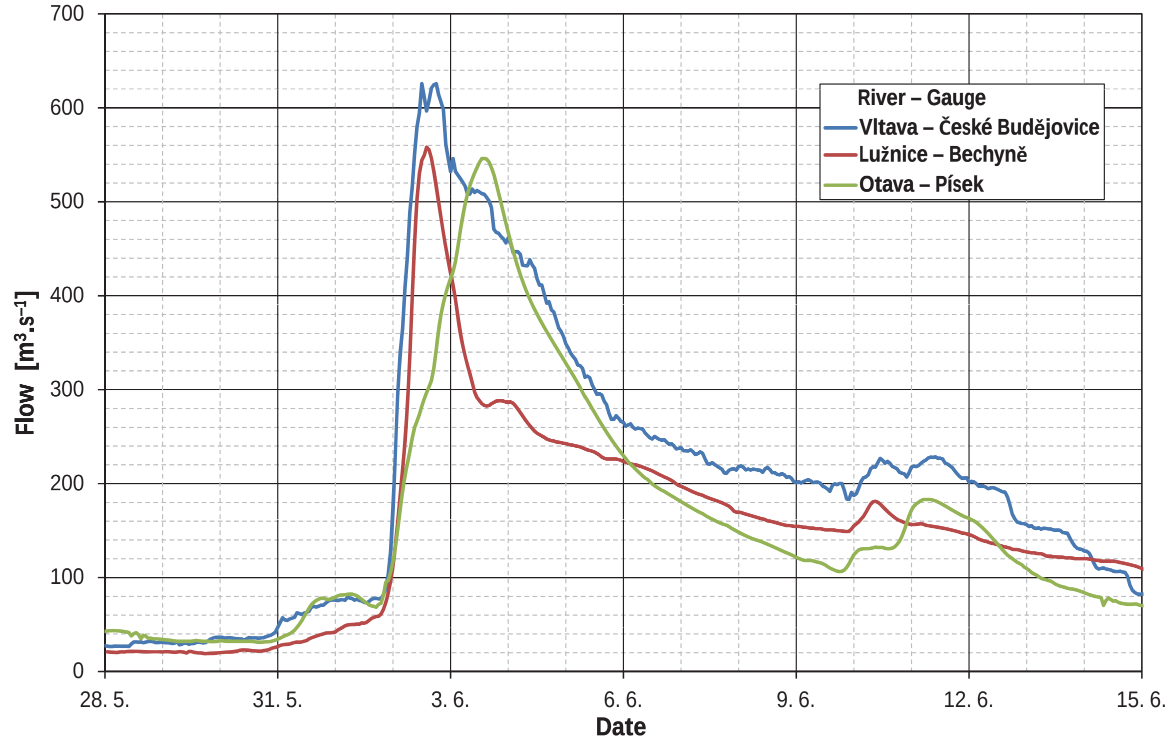

Fig. 1.13 Flood Hydrographs of Main Rivers Upstream of Orlík Reservoir.

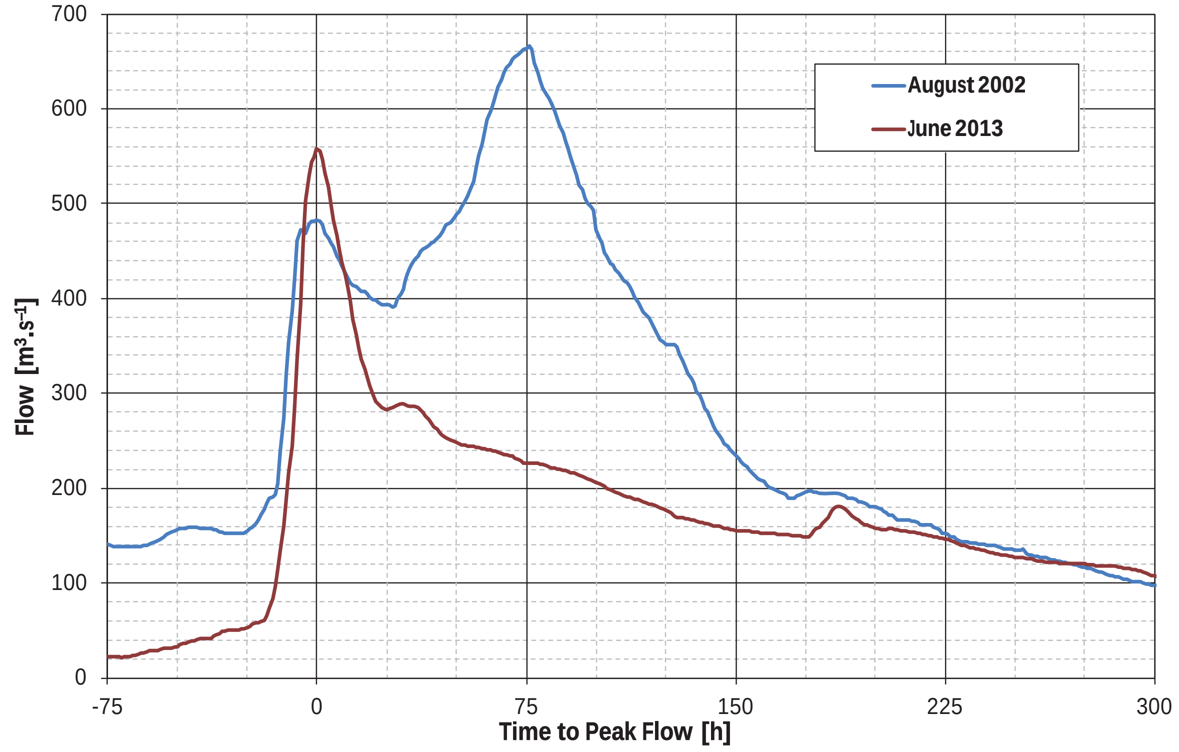

Fig. 1.14 Comparison of Flood Hydrographs on the Lužnice River in Bechyně in August 2002 and June 2013.

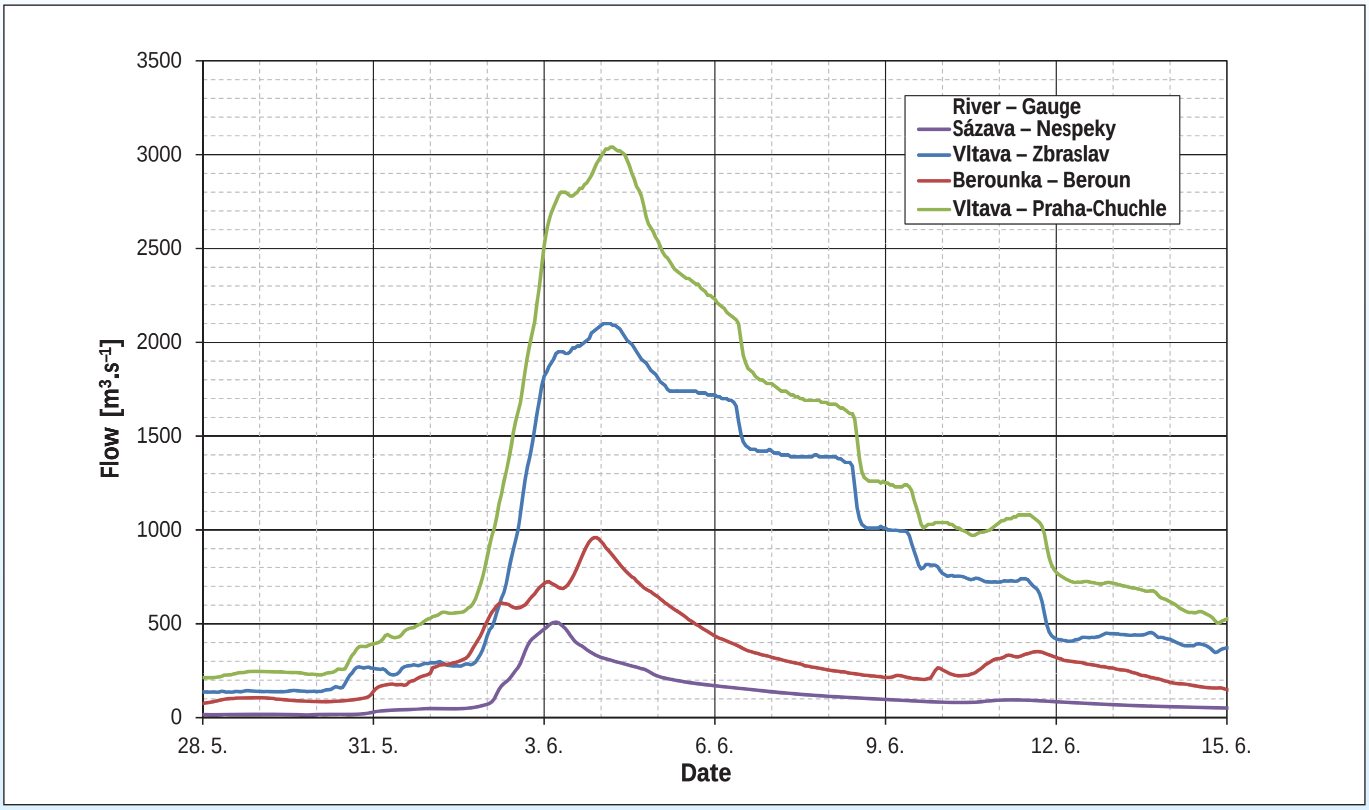

Fig. 1.15 Flood Hydrographs of the Vltava, Berounka and Sázava Rivers.

ing the afternoon, while reaching the highest peak flows in the history of observations. A similar situation also occurred on the tributaries in the Lower Sázava River basin, where especially the Vlašimská Blanice River overflowed its banks (Fig. 1.12).

Precipitation strongly affected the area around the reservoirs of the Vltava River cascade, which was filled by the inflow from small water streams, as well as from the major watercourses flowing into the Orlík reservoir, i.e. from the Vltava, Lužnice and Otava Rivers. The flood rise on the Vltava River in České Budějovice, as well as on the Lužnice River in Bechyně was very sharp, whereas at that time the flood of Otava River in Písek somewhat lagged behind the typical historical floods (Fig. 1.13).

The most dramatic development of the flood occurred on the Lužnice River, where its peak flow in Bechyně in June 2013 (561 m^3.s^{-1}) approached the flood in August 2002 (666 m^3.s^{-1}), but had a completely different character. Two-peaks shape is typical for flood hydrograph on the Lower Lužnice River, where the first, mostly smaller peak comes from the runoff arising in the Central Bohemian Highlands, through which the Lower Lužnice River flows. The second, usually larger peak lags behind, coming from the headwaters after transformation in the innundation and large pond system in the Třeboň Region. Since the precipitation of the 2013 flood strongly hit only the lower reach of the Lužnice River, the second peak of the flood did not occur there. Therefore, the culmination of the Lužnice River did not have its typical lag and occurred approximately simultaneously with the culmination of the Vltava River in České Budějovice, but sooner than the culmination of the Otava River in Písek. The comparison of hydrographs of the floods in August 2002 and June 2013 on the Lužnice River in Bechyně is shown in the graph of Fig. 1.14.

Even though the Berounka River basin was hit first after the water level rose up to the 3rd Flood level on the Klabava River, it was not affected by the most intensive rainfall of 1 and 2 June. As such, the flood progression was more gradual there. However, due to the extreme saturation of the river basin, there was still an intense runoff there also in the case of less intense precipitation, especially in the catchment area downstream of Pilsen.

On the Vltava River in Prague-Zbraslav and Prague-Chuchle, the flow rate was increasing more strongly in the night from Saturday, 1 June to Sunday, 2 June. Even though the outflow from the Vltava River Cascade was temporarily reduced and delayed by measures taken on the Orlík reservoir, the Vltava River flow rapidly increased in Prague. When the Berounka River flow reached its peak in the evening of 3 June, the retention capacity of the Orlík reservoir was completely exhausted, and the outflow from the Vltava River Cascade had to be increased. The Vltava River in Prague-Chuchle culminated on 4 June with a flow of 3,040 m^3.s^{-1} – approximately three hours after the flood peak was recorded in Prague-Zbraslav and six hours after the Berounka River reached its peak in Beroun (960 m^3.s^{-1}), see Fig. 1.15. Therefore, it is obvious that at the confluence of the Vltava and Berounka Rivers, their flood waves concurred.

In the area of inundation at the confluence of the Berounka and Vltava Rivers, both rivers always influence each other in a complicated way during floods. The

Fig. 1.16 Confluence of the Vltava and Berounka Rivers in Prague (Photo by Libor Sváček).

Fig. 1.17 Vltava River in Prague, Šítkovský Weir and Malostranská Water Tower (currently VRV a. s.) on 3 June 2013 (Photo by Jan Kubát).

flow and reached water level at the confluence are also influenced by human activities, such as land use in the peak growing season, (e.g. oilseed rape planting), terrain changes (e.g. intersection of the Prague circle highway, landfill near Lahovičky, embankment around the golf course in Zbraslav) and other interventions in the area (steel fence of the racecourse in Prague-Chuchle, etc.). It is most likely that the transformation in the Radotín innundation area was relatively small and reduced the peak flow just by a few dozen of m^3.s^{-1} at the Berounka River inflow, which is considerably separated by the Strakonická Street embankment from the Vltava River. Nevertheless, the total volume of water retained in that innundation area is estimated to be 12.3 mil. m^3.

Big problems were caused by the flood of right-bank tributaries of the Vltava River in the Capital City of Prague, more specifically, the Botič and Rokytka streams, where especially the onset of the flood on the Botič stream, in the stretch downstream of the Hostivař reservoir, was very quick and unexpected (Fig. 1.18). The Rokytka River, near its confluence with the Vltava River in Prague-Libeň, overflowed its channel banks as a result of backwater after the flood gate was closed and the pumps were not able to drain water flowing from the Rokytka River to the Vltava River.

In a way similar to the flood in August 2002, an overflow and backwater of the Elbe River occurred at the confluence of the Vltava and Elbe Rivers due to the swollen Vltava River. It is obvious that the flood peak at the confluence of the Vltava and Elbe Rivers was decreased and lagged behind. The total inundation volume during the 2013 flood was estimated at 114.5 mil. m^3 of retained water. The innundation effect resulting in the reduced peak flow rate can be approximately estimated at the range of 150 to 200 m^3.s^{-1}. The travel time of the maximum flow between the Vltava River in Prague and the Elbe River in Mělník reached approximately 22 hours, and the flow travel time between the Vraňany station at the beginning of the Mělník inundation and the Mělník gauge was 14 hours. The above-mentioned travel times are comparable with the flood in August 2002 when the peak flow travel time reached 25 hours between Prague and Mělník and 17 hours between Vraňany and Mělník.

However, the evaluation of the flood development in the Mělník inundation area pointed out a significant discrepancy between the 2013 flood levels recorded at the individual locations and similar data for the historical floods. In Mělník, the Elbe River reached its peak flow at 03:00 a.m. on 5 June with a flow rate of 3,640 m^3.s^{-1}. Even though the maximum water level in June 2013 was lower than in August 2002, at several locations it was higher than the surveyed flood marks of historical floods with higher flow, e.g. 1845 or 1890. The Mělník water gauge measured the water level that corresponded to a flow of approximately 4,300 m^3.s^{-1} according to then applicable rating curve. The cause of this phenomenon can be attributed to a combination of natural and anthropogenic influences. The natural factors include the process of long-term material aggradation and ground elevation, influence of flood hydrographs interference from the Elbe and Vltava Rivers, change in the vegetation cover and thus

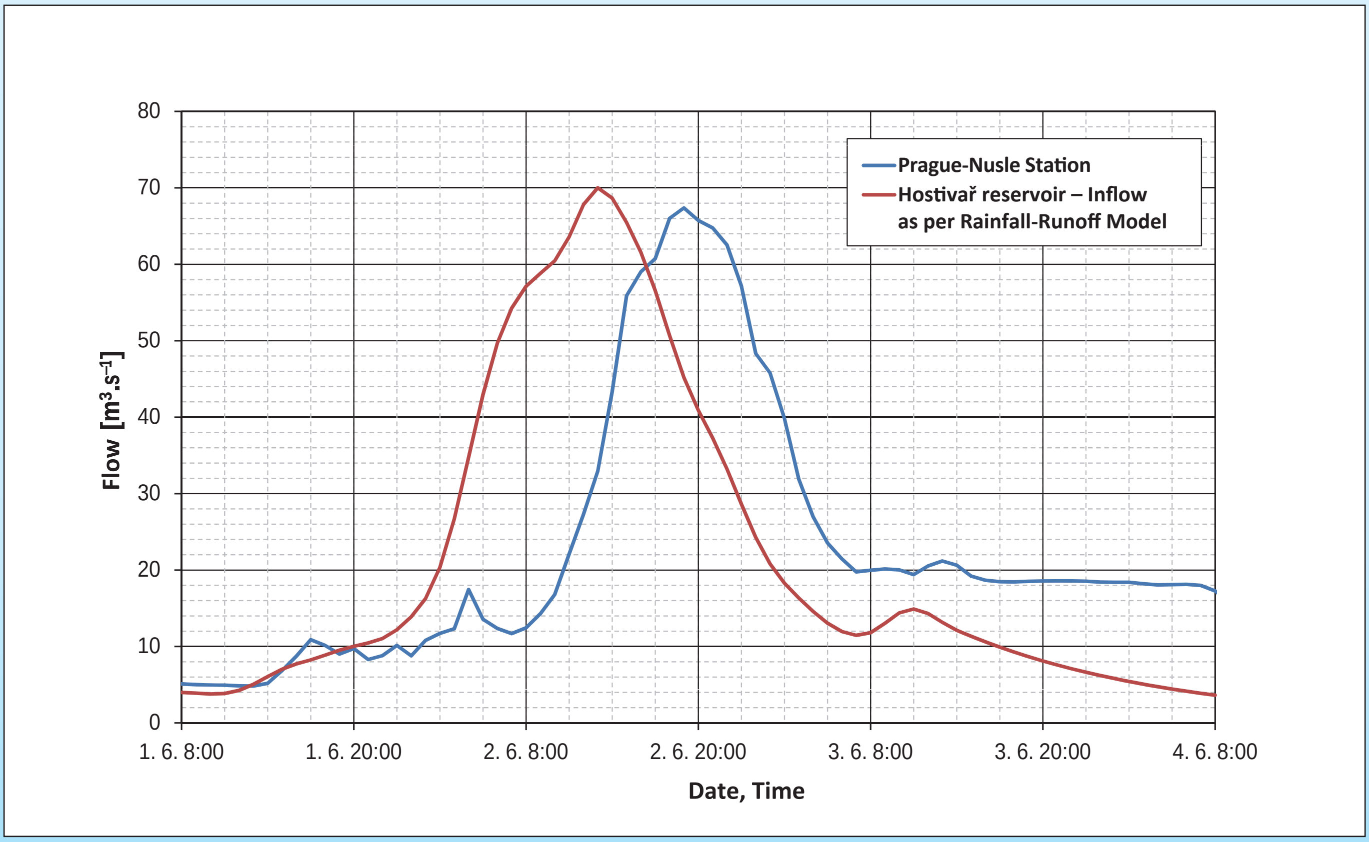

Fig. 1.18 Flood Hydrograph of the Botič Stream at Prague-Nusle Station, together with the Inflow to Hostivař Reservoir Derived Using the Rainfall-Runoff Model.

Fig. 1.19 Botič Stream Estuary into Vltava River (Photo by Radovan Tyl).

Fig. 1.20 Elbe River – Počáply, 5 June 2013 (Source: Povodí Labe, s. p.).

Fig. 1.21 Confluence of Elbe and Ohře Rivers on 5 June 2013 (Source: Povodí Ohře, s. p.).

Fig. 1.22 Elbe River in Ústí nad Labem on 5 June 2013 (Source: FOTO STUDIO H, s. r. o.).

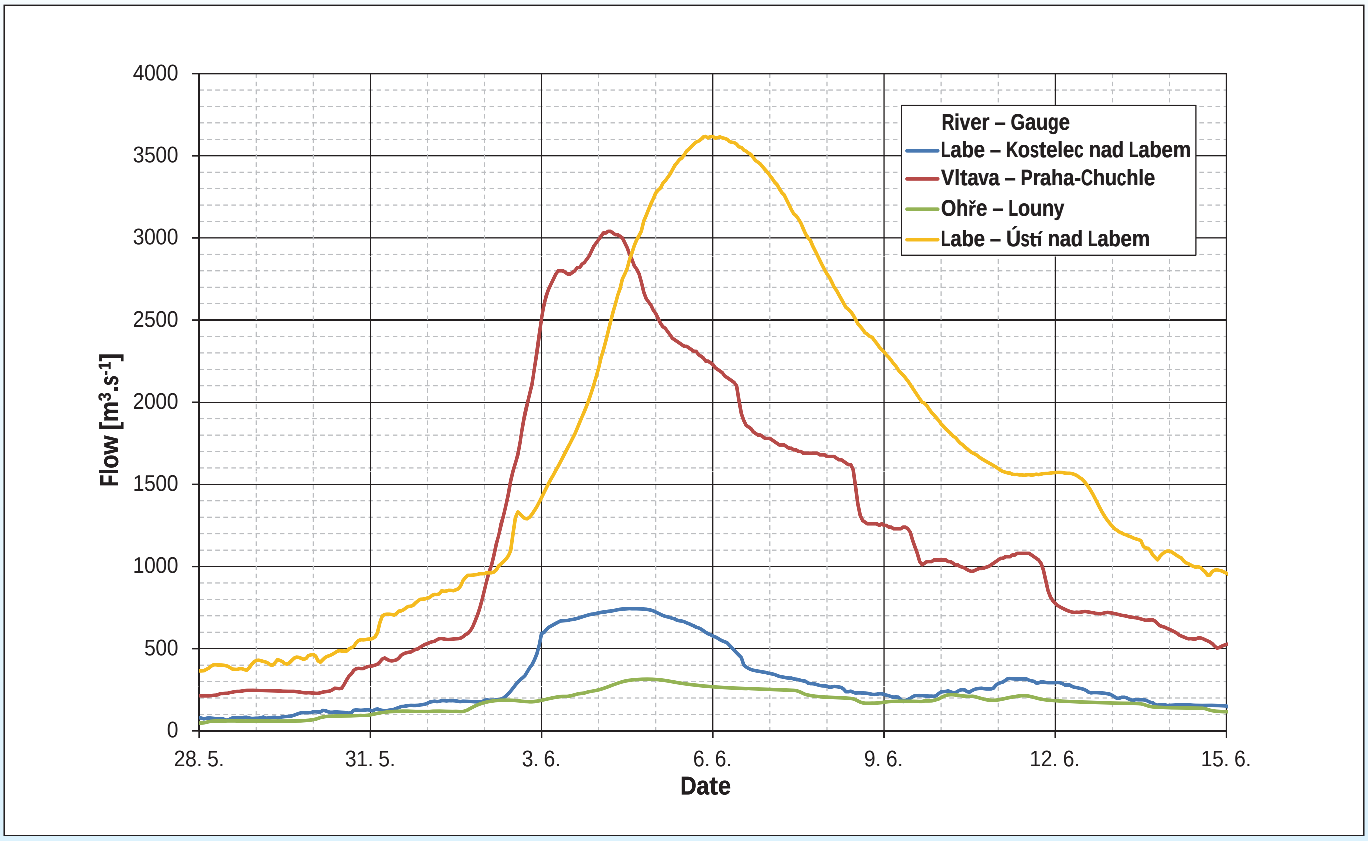

Fig. 1.23 Flood Hydrographs of the Vltava River in Prague, Ohře River in Louny and Elbe River in Kostelec nad Labem and Ústí nad Labem.

also in the permeability of inundation for flow etc. On the other hand, there are unambiguous anthropogenic influences which most likely contributed to the water level rise. They include the construction of water structures, such as the construction of Mělník – Vraňany navigation channel, terrain changes, construction of dikes, and their potential breach during individual floods, etc. The degree of influence of the individual factors is not known, but may be essential for the flood risk assessment and subsequently, for the flood protection in that area and downstream areas of the Elbe River.

Another transformation of the flood occurred in the innundation area at the confluences of the Elbe and Ohře Rivers, where the total volume of retained water was estimated in the range of 62.7 to 64.9 mil. m^3 and the reduction of the peak flow due to the transformation effect can be estimated at the range of 150 to 250 m^3.s^{-1}.

The lag time between the peak flows in Mělník and Ústí nad Labem reached approximately 17 hours in June 2013, while amounting to approximately 27 hours in 2002. The overall peak flow travel time from Prague to Ústí nad Labem thus reached 39 hours (contrary to 52 hours in 2002). In Ústí nad Labem, the Elbe River reached its peak flow in the evening of 5 June with a flow rate of 3,630 m^3.s^{-1}. In Děčín and Hřensko, the Elbe River reached its peak flow early in the morning of 6 June. The peak flow corresponded to the return period of 20 to 50 years there.

Along the German stretch of the Elbe River due to the significant contribution of the subbasins, especially those of the Mulde and Saale Rivers, the peak flow was increasing along the river, and in Magdeburg, the peak flow exceeded 5,000 m^3.s^{-1}. The water level rose up to 747 cm there, i.e. 67 cm higher than in 2002. In the stretch between Dessau and Wittenberge, this was the highest flood historically recorded for the Elbe River.

The flood extremity in the hydrometric profiles is assessed on the basis of the peak flow return period. The probability of flood occurrence is statistically evaluated on the basis of long-term observation. For small ungauged streams, the return period is determined by expertise according to regional regression relationships using physical and geographical characteristics of river basins, analogons, etc.

The following floods occurring at the foothills of Krkonoše Mountains were assessed as extreme floods with a return period of more than 100 years: floods on the Čistá Brook, in the Cidlina basin on Bystřice stream, in the Mrlina basin, at Plaňany on the Výrovka stream, at Radíč on the Mastník stream and at all hydrometric profiles of the Vlašimská Blanice River basin. The flow rates with this extremity most likely also occurred on many ungauged streams in the most affected areas.

The Lužnice River was the most swollen river of the main tributaries of the Vltava River, where the return period reached 100 years in Bechyně. A 20–50-year flow was recorded on the Otava River in Písek and on the Sázava River in Nespeky. A 20-year flow was reached on the Berounka River in Beroun. Along the stretch of the Vltava River from České Budějovice as far as the confluence with the Elbe River, the peak flow extremity at the water gauges corresponded to the recurrence

Runoff Coefficient

One of the hydrological indicators evaluated during floods is an assessment of a balance between rainfall and flow volume, using the so-called runoff coefficient indicating the proportion of how much water from rainfall ran off through rivers and streams. The evaluation of runoff coefficients for the first flood wave was carried out for the basins with an area of up to 500 km^2. In most cases, the runoff coefficients ranged from 0.5 to 0.7 at the three-day areal precitation of 70 to 140 mm over the basin.

The balance between the rainfall and runoff volume for the selected hydrometric profiles on the Vltava River and its main tributaries is presented in Tab. 1.2. The runoff volume and rainfall amount were taken into account from the midnight of 28 May 2013 until the midnight of 15 June 2013. The runoff coefficients in these large catchment areas are already lower with the exception of the České Budějovice profile, where the higher value of the runoff coefficient is partially influenced by water release from the Lipno reservoir.

Tab. 1.2 Rainfall and Runoff Balance at Selected Water gauges.

Identifier	*River*	*Profile*	*Catchment Area [km^2]*	*Precipitation [mm]*	*Runoff [mm]*	*Runoff Coefficient [–]*
115100	*Vltava*	*České Budějovice*	*2,847.42*	*179.6*	*83.3*	*0.46*
133000	*Lužnice*	*Bechyně*	*4,057.06*	*136.6*	*34.4*	*0.25*
151000	*Otava*	*Písek*	*2,913.70*	*159.8*	*56.5*	*0.35*
167200	*Sázava*	*Nespeky*	*4,038.65*	*120.4*	*33.2*	*0.28*
198000	*Berounka*	*Beroun*	*8,286.26*	*116.0*	*40.6*	*0.35*
200100	*Vltava*	*Praha-Chuchle*	*2,6729.97*	*137.3*	*48.7*	*0.35*

Tab. 1.3 Peak Flows and Return Periods at Selected Water Gauges during First Flood episode.

Ident.	River	Gauge	Catchment Area	Peak Flow Data				
				Date	Time	Water Stage	Flow	Return Period
			[km^2]		CEST	[cm]	[m^3.s^{-1}]	[years]
003000	Little Elbe	Prosečné	72.75	2/6	6:00	175	47.6	10–20
004000	Čistá	Hostinné	77.42	2/6	6:20	345	120	>> 100*
004200	Elbe	Vestřev	299.99	2/6	7:50	354	272	50–100
004300	Pilníkovský Stream	Chotěvice	103.50	2/6	6:30	223	30.5	5–10
004500	Kalenský Stream	Dolní Olešnice	62.00	2/6	11:20	262	44.7	20–50
006000	Elbe	Království	531.96	2/6	14:20	240	156	5–10
014000	Úpa	Horní Staré Město	144.75	2/6	9:10	183	98.1	10
014100	Úpa	Slatina nad Úpou	401.36	2/6	12:40	272	133	5–10
014800	Úpa	Zlíč	456.58	2/6	5:30	230	81	2–5
016000	Elbe	Jaroměř	1,224.10	3/6	2:50	–	243	10
066500	Vrchlice	Vrchlice	97.43	2/6	17:30	187	37.1	50
069000	Javorka	Lázně Bělohrad	38.35	2/6	7:10	166	18.4	10–20
070000	Cidlina	Nový Bydžov	455.92	3/6	13:00	285	89.8	10–20
071000	Bystřice	Rohoznice	43.47	2/6	6:00	157	30.1	> 100
075000	Cidlina	Sány	1,151.01	5/6	0:10	323	134	10–20
075500	Štítarský Stream	Svídnice	209.79	3/6	4:40	338	60.2	> 100
077000	Mrlina	Vestec	458.98	3/6	22:50	314	111	> 100
080000	Elbe	Nymburk	9,722.48	4/6	9:30	372	562	2–5

Tab. 1.3 Peak Flows and Return Periods at Selected Water Gauges during First Flood episode – continued.

Ident.	River	Gauge	Catchment Area	Peak Flow Data				
				Date	Time	Water Stage	Flow	Return Period
			[km^2]		CEST	[cm]	[m^3.s^{-1}]	[years]
082000	Výrovka	Plaňany	263.78	2/6	19:50	454	110	> 100
104400	Elbe	Kostelec nad Labem	13,183.73	4/6	13:00	712	744	5
106000	Teplá Vltava	Lenora	176.09	2/6	8:30	177	63.2	10
107000	Teplá Vltava	Chlum	347.63	2/6	12:50	267	90	5–10
108000	Studená Vltava	Černý Kříž	102.44	2/6	12:00	184	34.7	5–10
109000	Vltava	Vyšší Brod	997.13	7/6	10:10	262	131	5
110200	Polečnice	Český Krumlov	197.65	2/6	11:20	299	107	20–50
111000	Vltava	Březí	1,825.48	2/6	15:10	326	420	20–50
112000	Malše	Kaplice	257.75	2/6	17:00	239	87.7	10
112500	Černá	Ličov	126.45	2/6	12:30	255	82.2	10
112600	Malše	Pořešín	436.55	2/6	17:20	300	177	10–20
113000	Malše	Římov	493.68	2/6	22:30	267	152	10
114000	Stropnice	Pašínovice	399.87	2/6	14:10	342	105	10–20
115000	Malše	Roudné	962.17	3/6	3:20	380	236	10–20
115100	Vltava	České Budějovice	2,847.72	2/6	18:00	486	628	20–50
119000	Lužnice	Pilař	935.23	4/6	0:00	419	120	10
123000	Lužnice	Frahelž	1,534.38	2/6	22:50	184	33.4	5
124000	Nežárka	Rodvínov	297.20	3/6	5:20	160	43.7	5–10
126000	Hamerský Stream	Oldříš	208.74	4/6	17:20	123	19.4	20
128000	Nová řeka	Mláka	64.70	5/6	1:30	327	75.5	10
129000	Nežárka	Hamr	981.02	5/6	6:00	426	136	10–20
131000	Lužnice	Klenovice	3,153.67	5/6	9:20	330	204	10–20
132500	Smutná	Rataje	218.33	2/6	12:00	349	136	100
133000	Lužnice	Bechyně	4,057.06	2/6	14:40	594	561	100
135000	Vydra	Modrava	89.80	2/6	18:00	160	54.6	5–10
138000	Otava	Sušice	533.67	2/6	20:30	220	205	5–10
141000	Otava	Katovice	1,133.77	3/6	4:10	270	240	5–10
143000	Volyňka	Němětice	383.36	2/6	14:20	266	95.8	5–10
145000	Blanice	Blanický Mlýn	85.47	2/6	8:30	249	60	10–20
147000	Blanice	Podedvory	202.72	2/6	9:50	273	120	20–50
148000	Blanice	Husinec	212.28	2/6	14:30	251	94.8	10–20
148500	Zlatý Stream	Hracholusky	74.97	2/6	9:10	190	41.5	50
150000	Blanice	Heřmaň	841.33	3/6	6:50	279	199	20–50
151000	Otava	Písek	2,913.70	3/6	14:40	522	548	20–50
152000	Lomnice	Dolní Ostrovec	391.35	3/6	19:10	216	58	5
153000	Skalice	Varvažov	367.86	2/6	16:00	258	75	10–20
153800	Brzina	Hrachov	133.24	2/6	6:00	259	79.6	100
153900	Mastník	Radíč	268.62	2/6	20:50	282	103	> 100
154600	Kocába	Štěchovice	308.59	2/6	16:50	248	101	100
165600	Blanice (Vlašim)	Louňovice	211.33	2/6	11:30	410	107	> 100
165800	Chotýšanka	Slověnice	117.11	2/6	13:30	270	76.4	> 100
166200	Blanice (Vlašim)	Radonice-Zdebuzeves	541.86	2/6	19:30	504	189	> 100
166900	Konopišťský Stream	Poříčí nad Sázavou	89.33	3/6	10:50	155	16.4	10

Tab. 1.3 Peak Flows and Return Periods at Selected Water Gauges during First Flood episode – continued.

Ident.	River	Gauge	Catchment Area	Peak Flow Data				
				Date	Time	Water Stage	Flow	Return Period
			[km^2]		CEST	[cm]	[m^3.s^{-1}]	[years]
167200	Sázava	Nespeky nad Sázavou	4,038.65	3/6	5:10	544	509	20–50
169000	Vltava	Zbraslav	17,826.39	4/6	1:00	1,605	2,100	20–50
178500	Radbuza	Tasnovice	172.02	3/6	3:40	232	41.6	5–10
179900	Radbuza	Lhota	1,181.85	3/6	12:50	335	112	10
180100	Radbuza	České Údolí	1,264.36	3/6	13:00	344	129	10
182000	Úhlava	Klatovy	338.74	3/6	8:10	313	68.5	10–20
183000	Úhlava	Štěnovice	892.84	3/6	3:30	357	189	20–50
186000	Berounka	Bílá Hora	4,017.50	3/6	6:40	524	387	10
186900	Bradava	Žákava	102.55	1/6	22:40	177	27.4	10
187000	Úslava	Koterov	733.26	3/6	3:10	275	133	5–10
187500	Klabava	Hrádek	158.12	2/6	23:10	230	57.7	5–10
188000	Klabava	Nová Huť	359.48	3/6	6:30	251	115	10–20
191000	Berounka	Liblín	6,455.83	3/6	12:40	443	651	5–10
191800	Rakovnický Stream	Rakovník	302.25	2/6	9:30	268	30.9	5
194500	Berounka	Zbečno	7,520.32	3/6	21:00	607	804	10–20
196000	Litavka	Čenkov	158.19	2/6	6:30	94	31.9	5
196400	Červený Stream	Hořovice	71.06	2/6	21:50	120	36	20
197300	Litavka	Beroun	625.49	2/6	3:50	261	159	10–20
198000	Berounka	Beroun	8,286.26	3/6	22:30	578	960	20
198400	Loděnice	Loděnice	253.75	2/6	7:20	262	38.5	20
200100	Vltava	Praha-Chuchle	26,729.97	4/6	4:50	546	3040	20–50
200500	Dobřejovice Stream	Průhonice	13.00	2/6	9:30	131	16.6	100
200600	Botič	Praha-Nusle	134.89	2/6	19:00	319	68.5	50–100
201000	Rokytka	Praha-Libeň	137.32	2/6	18:40	191	46	50–100
201000	Rokytka	Praha-Libeň	137.32	3/6	23:00	388	swollen	
203000	Vltava	Vraňany	28,062.12	4/6	13:10	785	3,080	20–50
204000	Elbe	Mělník	41,831.53	5/6	3:00	936	3,640	50
207600	Svatava	Kraslice	115.12	2/6	8:40	139	55.8	10–20
208200	Svatava	Svatava	291.64	2/6	12:10	204	76.5	10
210100	Stará Role	Rolava	126.35	2/6	4:50	184	55.8	10–20
214000	Ohře	Karlovy Vary	2,857.03	3/6	2:30	274	277	2–5
214500	Bystřice	Ostrov	127.57	2/6	4:30	159	38.6	5–10
215100	Ohře	Kadaň	3,508.24	3/6	15:00	226	363	5
219000	Ohře	Louny	4,979.76	4/6	18:20	543	314	< 2
221000	Elbe	Ústí nad Labem	48,560.58	5/6	19:50	1,072	3,630	20–50
222900	Bílina	Bílina	557.26	4/6	6:30	201	32.7	5–10
226000	Bílina	Trmice	918.60	5/6	9:30	275	swollen	
239000	Ploučnice	Benešov nad Ploučnicí	1,156.74	1/6	17:00	165	102	5
240000	Elbe	Děčín	51,120.39	6/6	1:20	1,074	3,740	20–50
241000	Kamenice	Srbská Kamenice	97.29	1/6	15:20	162	38.2	10–20
243000	Chřibská Kamenice	Všemily	61.79	1/6	16:10	147	18.5	5
244000	Kamenice	Hřensko	214.90	1/6	17:30	178	56.0	5–10
244000	Kamenice	Hřensko	214.90	6/6	3:20	385	swollen	
245000	Elbe	Hřensko	51,408.49	6/6	2:50	1,108	3,750	20–50

* – The symbol ‚>>‘ corresponds to the return period of 500 years and more

interval of 20–50 years; however, the inflow into the Orlík reservoir was assessed as a 100-year flow. On the Elbe River in the Mělník watergauges, downstream of the confluence with the Vltava River, a 50-year flow rate was reached, and in Ústí nad Labem, Děčín and Hřensko, a 20–50-year flow rate was evaluated on the Elbe River.

SECOND FLOOD EPISODE – Flash Floods from 8 June to 15 June 2013

On 8 June, a pressure low associated with a frontal system was progressing from the southwest to Central Europe. At the same time, another pressure lows associated with an occluded front maintained themselves over Scandinavia. On 9 June, these two systems interconnected over Central Europe, and on the next days, the newly formed wavy frontal boundary was only slowly progressing northeastward.

The warm and moist air influx from the southwest created conditions for the formation and development of storm activity in the unstable stratification of the atmosphere. Convective precipitation at some locations caused local flooding of the area and flash floods. The decisive factor was the extreme saturation of soil with water from the previous flood episode, and therefore, a larger surface runoff was also caused by torrential rainfall of smaller intensity, which the land would have been able to more significantly transform under other circumstances.

On 8 June, intense rainfall occurred only very locally, mainly in the northwestern part of Bohemia. Due to the fact that there was an insignificant pressure field, and therefore only a weak flow over Central Europe, the thunderstorm cells over our territory were almost motionless. Even though the daily totals did not usually exceed 40 mm, there were several situations when an extreme surface runoff occurred. Flash floods were recorded in the Krkonoše Mountains foothills, Pilsen and Kladno Regions, where the flood of the Dolanský stream in the villages of Dolany and Běloky in the Zákolanský stream basin became the most famous case.

On 9 June, local storm rainfalls were more intense than on 8 June and occurred in most of the regions of Bohemia and in the area of the Jeseníky Mountains. On the wavy frontal boundary, thunderstorm cells were organized into bands progressing slowly from the southwest to the northeast. At many locations, there were also hails recorded during thunderstorms. The heaviest rainfall occurred in the regions of Mladá Boleslav, Mělník, Děčín (in the Šluknov region), Broumov, in the vicinity of Netolice in the České Budějovice Region, near Soběslav in the Tábor Region, in the vicinity of Podbořany and Lubenec in the Louny Region, near Jirkov in the Chomutov Region and in the vicinity of Horšovský Týn in the Domažlice Region and in the area of Jeseníky Mountains in Moravia. Absolutely the highest precipitation total was measured at the Mladá Boleslav station (78.4 mm), which corresponds to the 50-year rainfall there. Hydro-

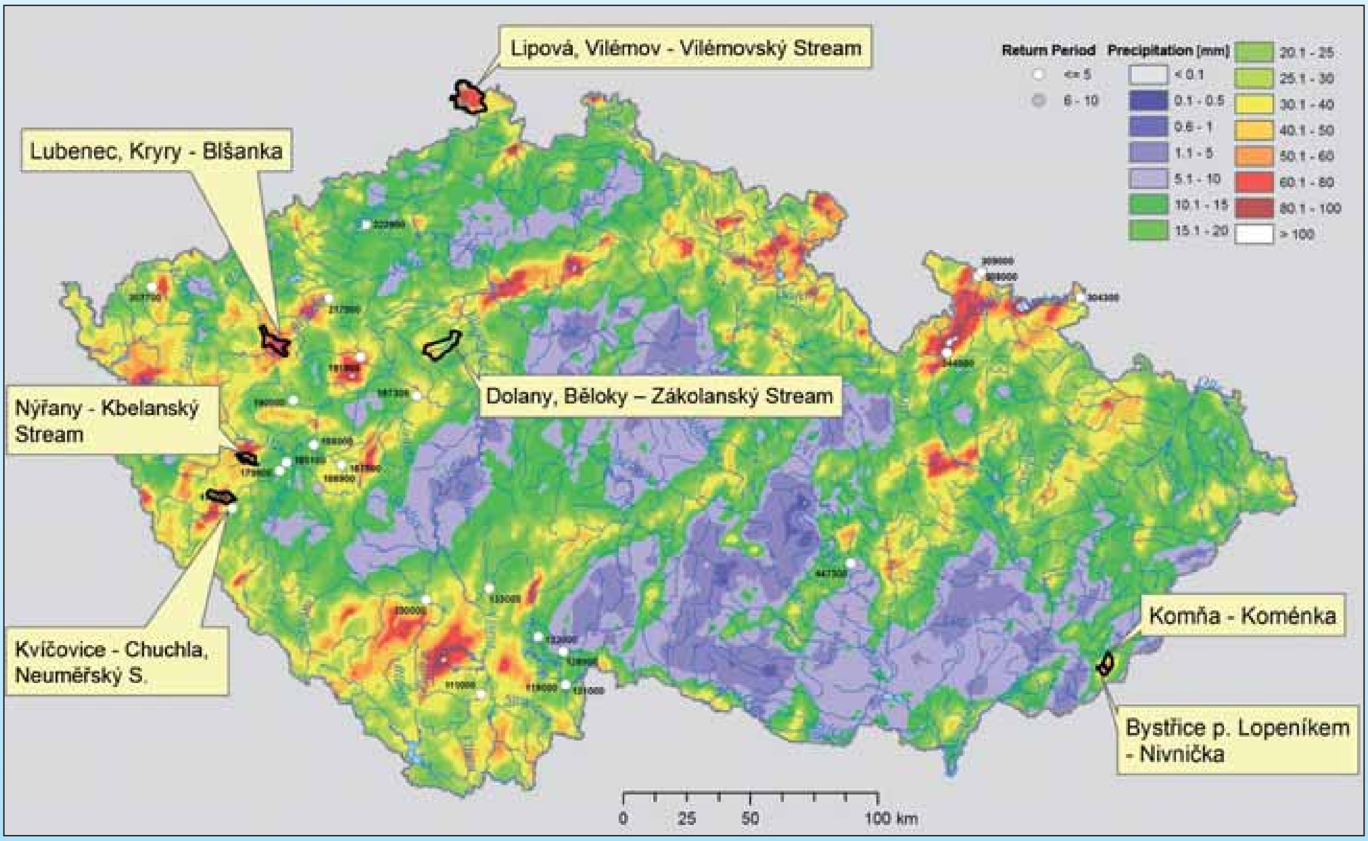

Fig. 1.24 Distribution of Rainfall from 8 June, 08:00 a.m. until 11 June, 08:00 a.m. CEST, together with Indication of Peak Flow Return Period in Water Gauges and Divides of Catchment Areas where the Flood Progression was Evaluated.

logical response in the form of flash floods was recorded in the Šluknov Region (Lipová, Vilémov), Krkonoše Mountains, Mladá Boleslav, Chomutov and Louny Regions (Lubenec, Kryry), Domažlice Region and area of the Jeseníky Mountains.

Similarly, convective rainfall associated with the storm activity occurred in most of our territory on 10 June. However at that time, the local storm rainfall hit, apart from Bohemia, also Moravia and Silesia. The maximum daily total was reached in the Jesenníky Mountains at the Branná station (58.6 mm). Apart from the area of the Jeseníky Mountains, the Opava, Šumperk and Blansko Regions and other, rather smaller areas (Bystřice pod Lopeníkem) were affected. In Bohemia, more significant rainfall occurred in the vicinity of Mariánské Lázně, and in the regions of Rokycany, Pilsen and Prachatice. Flash floods and local overflows were reported for example from the area of Bystřice pod Lopeníkem, as well as from the Šumperk and Pilsen Regions.

As a result of the storm rainfalls over the territory of the Czech Republic in the period from 8 to 10 June, the water levels of some major rivers, such as the Lužnice, Radbuza, Klabava, Berounka Rivers and streams in the Jeseníky Mountains, also rose. However, the peak flows only sporadically exceeded the return period of five years there. On the contrary, the recorded local flash floods were evaluated as more than 100-year floods.

Tab. 1.4 Peak Flows Episode and Return Periods at Selected Water Gauges during Second Flood Episode.

Identifier	River	Water Gauge	Watershed Area	Peak Flow Data				
				Date	Time	Water Stage	Flow	Return Period
			[km^2]		CEST	[cm]	[m^3.s^{-1}]	[years]
123000	Lužnice	Frahelž	1,534.38	11/6	6:00	191	35.8	5
150000	Blanice	Heřmaň	841.33	11/6	22:30	193	85.3	5
186900	Bradava	Žákava	102.55	10/6	16:30	165	22.7	5–10
197300	Litavka	Beroun	625.49	10/6	21:40	182	82.6	2–5
222900	Bílina	Bílina	557.26	14/6	6:30	125	10.1	2–5
304300	Osoblaha	Osoblaha	200.97	11/6	11:10	192	25.3	2–5

Tab. 1.5 Estimated Peak Flows and Return Periods during Second Flood Episode at Selected Ungauged Basins.

Stream Order No.	Stream	Location	Watershed Area	Peak Flow Data		
				Date	Flow	Return Period
			[km^2]		[m^3.s^{-1}]	[years]
1-12-02-0260-0-00	Dolanský Stream	Běloky	26.31	8/6	23.0**	100
1-10-01-1940-0-00	Kbelanský Stream	Nýřany	22.37	9/6	9.50	5–10
1-10-02-0710-0-00	Chuchla	Kvíčovice	28.27*	9/6	13.5	5–10
1-15-01-0230-0-00	Liščí Stream	Lipová	10.82*	9/6	13.9	100
1-15-01-0260-0-00	Vilémovský Stream	Vilémov	53.97*	9/6	65.0	100
1-13-03-0490-0-00	Blšanka	above Ležecký Stream	46.39	9/6	36.2	100
4-13-01-0890-0-00	Koménka	Komňa	6.16*	10/6	21.3	50–100
4-13-01-1170-1-00	Nivnička	Bystřice pod Lopeníkem	7.12*	10/6	21.4	50

* Watershed area determined from the HEC-HMS Model, ** Flow rate derived using the Hydraulic Model

THIRD FLOOD EPISODE
from 23 June to 26 June 2013

At the beginning of the second half of June, very warm air flowed from the south to the Czech Republic. From 18 to 20 June, the maximum daily temperature rose above 35 °C. Afterwards, precipitation began to occur in the form of showers and thunderstorms on a cold wavy front, which affected our area from 21 June. In the evening and night hours of 24 June, a separate depression formed southeast of our territory on a slowly progressing wavy cold front, and in its back, the cold air influx to our territory from the northwest to north became stronger. Subsequently on 25 June, the whole Western and Central Europe was influenced by a trough of low pressure in upper layers of the atmosphere, and when progressing, the trough of low pressure was blocked by a high-pressure ridge over Northeastern Europe and a low-pressure trough over Eastern Europe. The mentioned situation resulted in the occurrence of a closed upper-level low northeast of our territory. Around that low, moist and initially also relatively warm air was drawn from the Mediterranean and Black Sea and interfered with cold air at lower levels, which contributed to the formation of intense rainfall. On the next day (26 June), the pressure low progressed to the south of Scandinavia and precipitation gradually declined.

The most intense rainfall over the territory of the Czech Republic occurred on 24 June 2013, and gradually affected the Bohemian-Moravian Highlands, Southern Moravia, Central and Eastern Bohemia. The strong rainfall zone remained almost motionless and slowly progressed back to the west in the night of 24 June. In the morning of 25 June, the precipitation intensity gradually faded, and by the evening, the rainfall mostly ceased.

In terms of the mean areal precipitation, 24 June was the rainiest day of the whole June 2013. The highest precipitation totals for 24 hours were recorded at the meteorological stations of Džbánice (103 mm), which recorded rainfall exceeding the return period of 100 years, and Moravský Krumlov (85 mm). On 25 June, most precipitation was measured in the Jizera Mountains, where the Bílý Potok station recorded a daily total of 93 mm.

The runoff response was the most pronounced in the Chrudimka and Doubrava Rivers basins. The peak flow with the highest extremity (of up to 50 years) was recorded on the Novohradka River in Luže and Úhřetice, and the Žejbro (a tributary of the Novohradka River) was also significantly swollen in Vrbatův Kostelec (20–50-year flow).

The flood on the Chrudimka River upstream of the confluence with the Novohradka River was transformed by effects of the reservoir system, in particular, by effects of the Seč reservoir, and the peak flow return period did not exceed five years. On the Doubrava River, whose basin was the second most affected, the 10-year flow was exceeded in Spačice. The 5-year flow was exceptionally exceeded on the Sázava River and its tributaries.

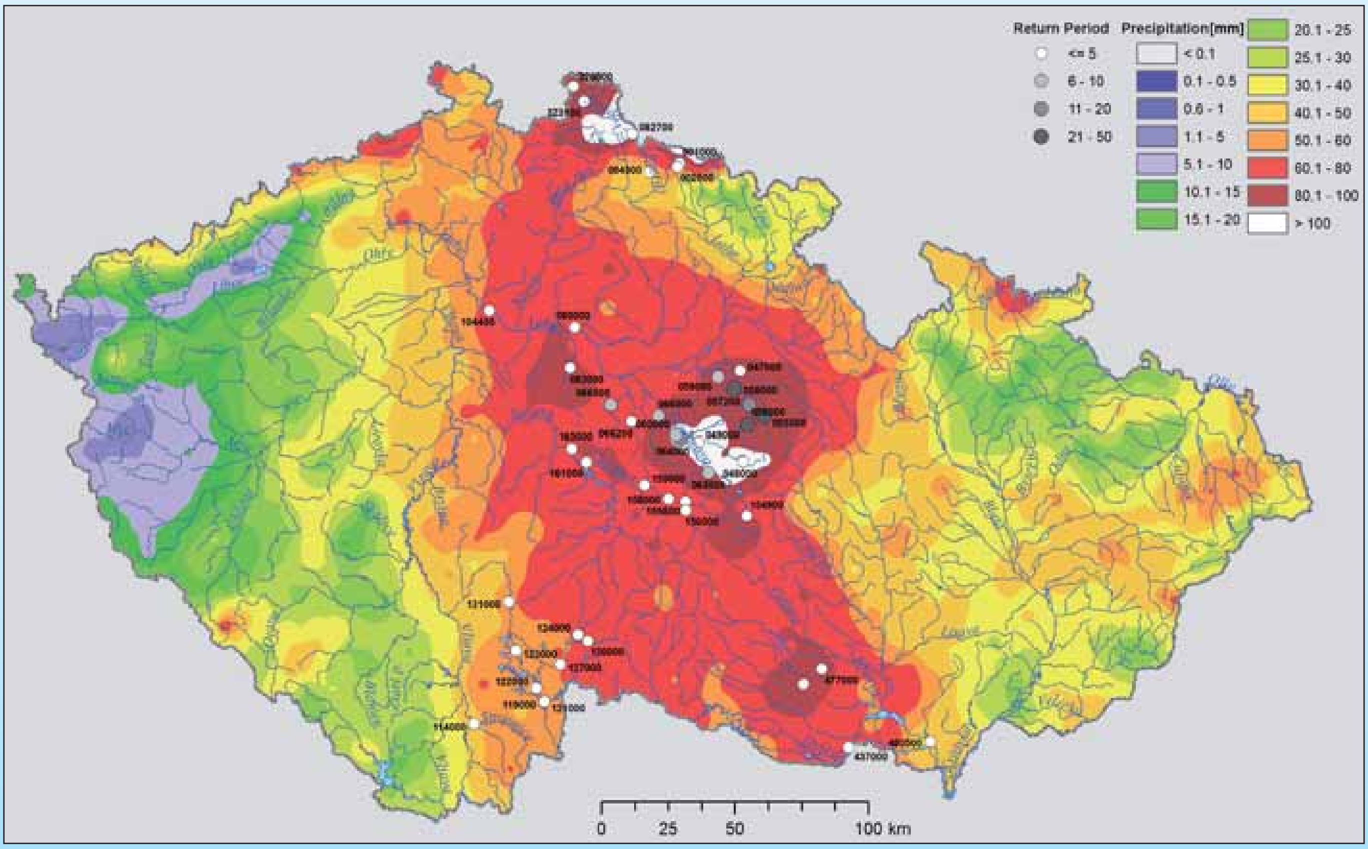

Fig. 1.25 Distribution of Rainfall from 24 June, 8:00 a.m. until 26 June, 8:00 a.m. CEST, together with Indication of Return Periods at Affected Water Gauges.

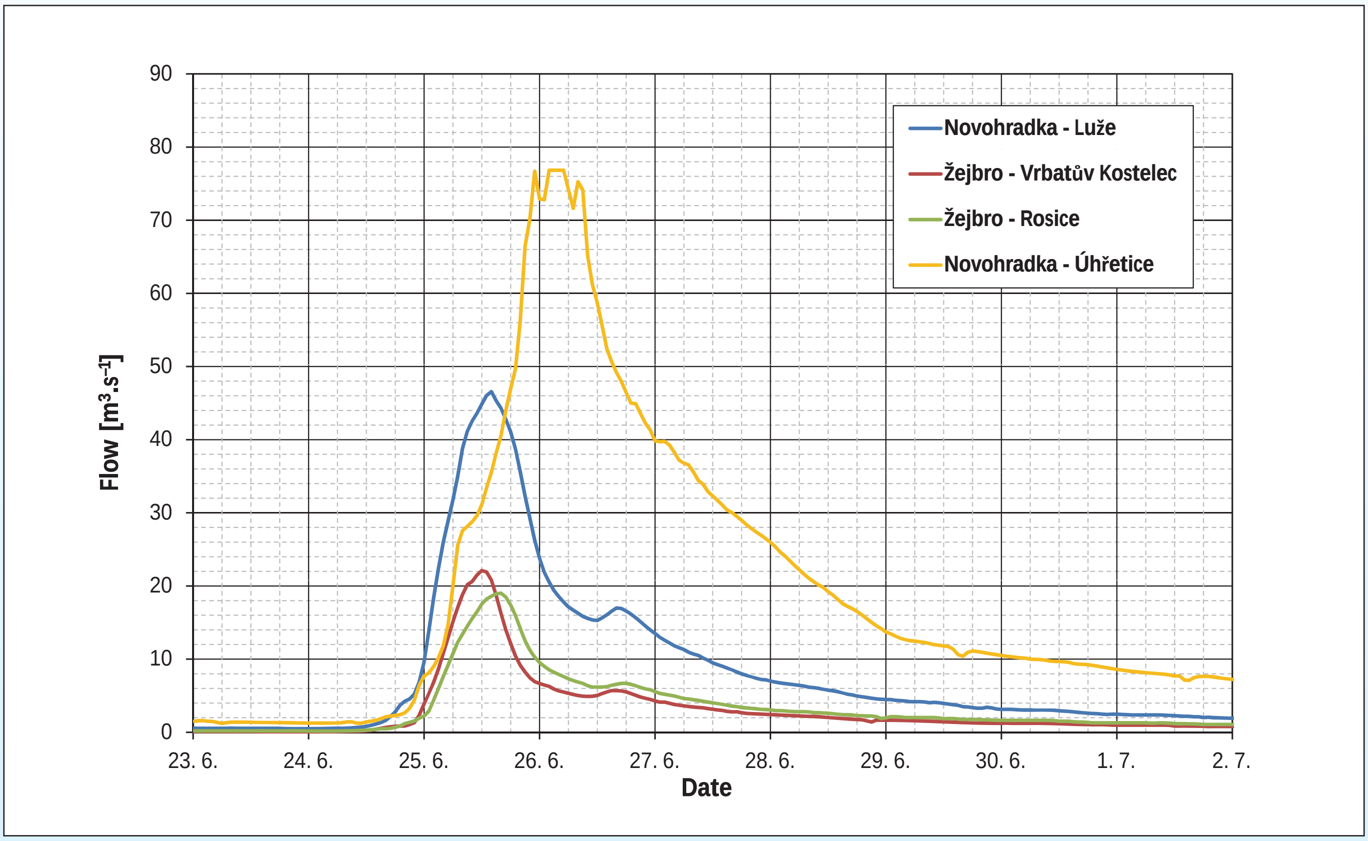

Fig. 1.26 Flood Hydrographs at Selected Gauges in Novohradka River Basin.

Tab. 1.6 Peak Flows and Return periods at Selected Water Gauges during Third Flood Episode.

Identifier	Watercourse	Water Gauge	Watershed Area	Peak Flow Data				
				Date	Hour	Water Stage	Flow	Return Period
			[km^2]		CEST	[cm]	[m^3.s^{-1}]	[years]
055500	Novohradka	Luže	152.45	25/6	15:20	255	47.2	20–50
056000	Žejbro	Vrbatův Kostelec	48.49	25/6	13:50	197	22.6	20–50
057200	Žejbro	Rosice	81.68	25/6	16:40	116	19.1	10–20
058000	Novohradka	Úhřetice	458.91	26/6	10:00	332	80.7	20–50
059000	Chrudimka	Nemošice	856.50	26/6	13:40	314	121	10
063000	Doubrava	Bílek	64.17	25/6	19:10	217	24.0	10
064000	Doubrava	Spačice	197.30	25/6	14:20	228	65.5	10–20
065000	Doubrava	Pařížov	201.18	25/6	20:20	149	49.7	10
066000	Doubrava	Žleby	381.86	26/6	0:20	234	82.1	5–10
066500	Vrchlice	Vrchlice	97.43	25/6	20:40	138	18.2	5–10
080000	Labe	Nymburk	9,722.48	26/6	16:10	369	554	2–5
082000	Výrovka	Plaňany	263.78	26/6	1:40	263	31.2	5
104400	Labe	Kostelec nad Labem	13,183.73	26/6	13:30	667	657	2–5
156000	Šlapanka	Mírovka	252.91	25/6	23:50	217	27.6	5
158000	Sázava	Chlístov	794.87	26/6	1:10	214	101	5

Evaluation of Floods in Ungauged Basins

Since torrential rainfall and thunderstorms often hit small areas, the relevant events are not mostly recorded by measuring equipment of the Czech Hydrometeorological Institute station network (precipitation gauges, water gauges). It is then necessary to estimate the flood development and peak using other available sources and tools, such as weather radar precipitation estimates to determine a detailed time-course of precipitation and rainfall-runoff models in order to derive the hydrograph.

In our case, the HEC-HMS deterministic event-based rainfall-runoff model of the Hydrologic Engineering Center of USACE (US Army Corps of Engineers) was used to simulate the direct runoff in the catchment area based on an input time series of precipitation and initial soil saturation. To determine the volume of direct runoff, the Curve Number Method was used, and to transform the runoff, the method of Clark Unit Hydrograph was used, where its parameters were estimated from the physical-geographic characteristics of the catchment area.

Precipitation data entered into the model in 15-minutes time steps as a combination of radar precipitation estimates and precipitation from ground observations in two variants:

Variant 1 – combination of data from all available ground rain gauge stations and precipitation estimates from weather radar measurement, including data from weather radars of the surrounding countries.

Variant 2 – combination of data from selected approx. 160 rain gauge stations and precipitation estimates from the Skalky and Praha (Brdy) radars, using the so-called MERGE method, whose outputs are operationally available at the Czech Hydrometeorological Institute Flood Forecasting Service website: <http://hydro.chmi.cz/hpps/main_rain.php?t=r&mt=&id=24>.

By rainfall-runoff modelling, we evaluated seven areas that were significantly affected by torrential rains and where flash floods were reported and documented. It is not possible to exclude that peak flows and floods of the same or even greater importance could occur at some other locations but remained unreported.

The flow rates were derived using both variants of input precipitation. It is understandable that more accurate estimates of the rainfall distribution and thus probably also a more accurate estimate of the runoff response should be provided by Variant 1 outputs, where all the rain gauge observations and radar data from the neighbouring countries were used.

Zákolanský Stream Catchment – Dolany, Běloky

Local torrential rains began to fall mainly in the headwater area of the Dolanský stream basin on Saturday, 8 June after 7:00 p.m., and the heaviest rainfall occurred from 7:30 p.m. to 8:45 p.m. CEST. At about 9:15 p.m. precipitation ceased, and later, more specifically from 10:30 p.m. to 11:45 p.m., there were just weaker showers and intermittent, very weak rain. In the most affected catchment area, the rainfall intensity ranged from 15 to 20 mm in 15 minutes, and within one hour, the rainfall amounted to more than 50 mm according to radar estimates.

The significant soil saturation by previous rainfall caused a very rapid surface runoff from the entire upper basin of the Dolanský and Sulovický streams. At first, the villages of Velké Přítočno and Malé Přítočno were hit,

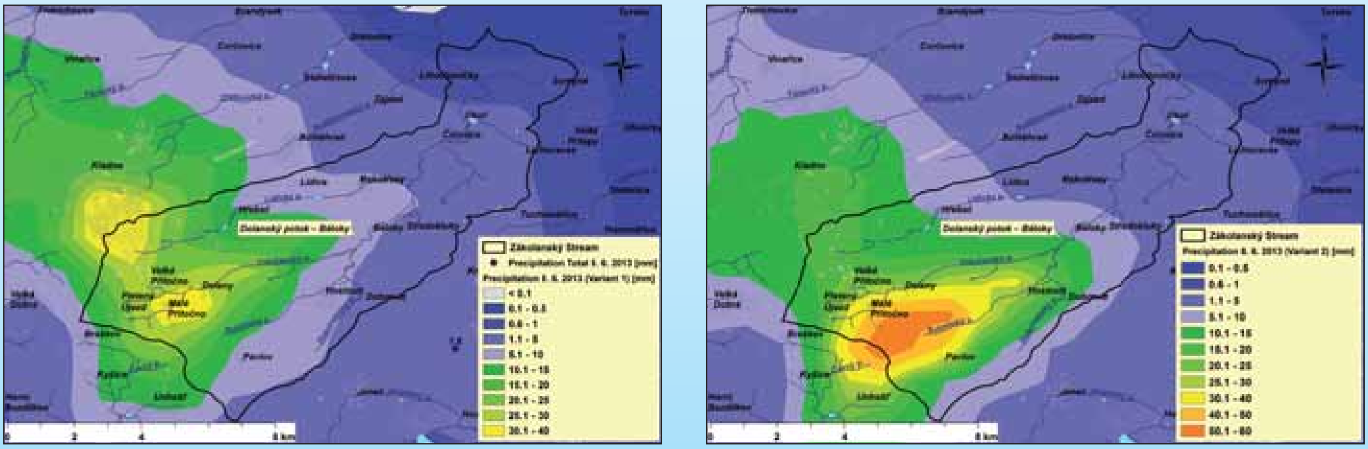

Fig. 2.1 Distribution of Precipitation (Variant 1 on the left, Variant 2 on the right) with Indication of Affected Catchment Area.

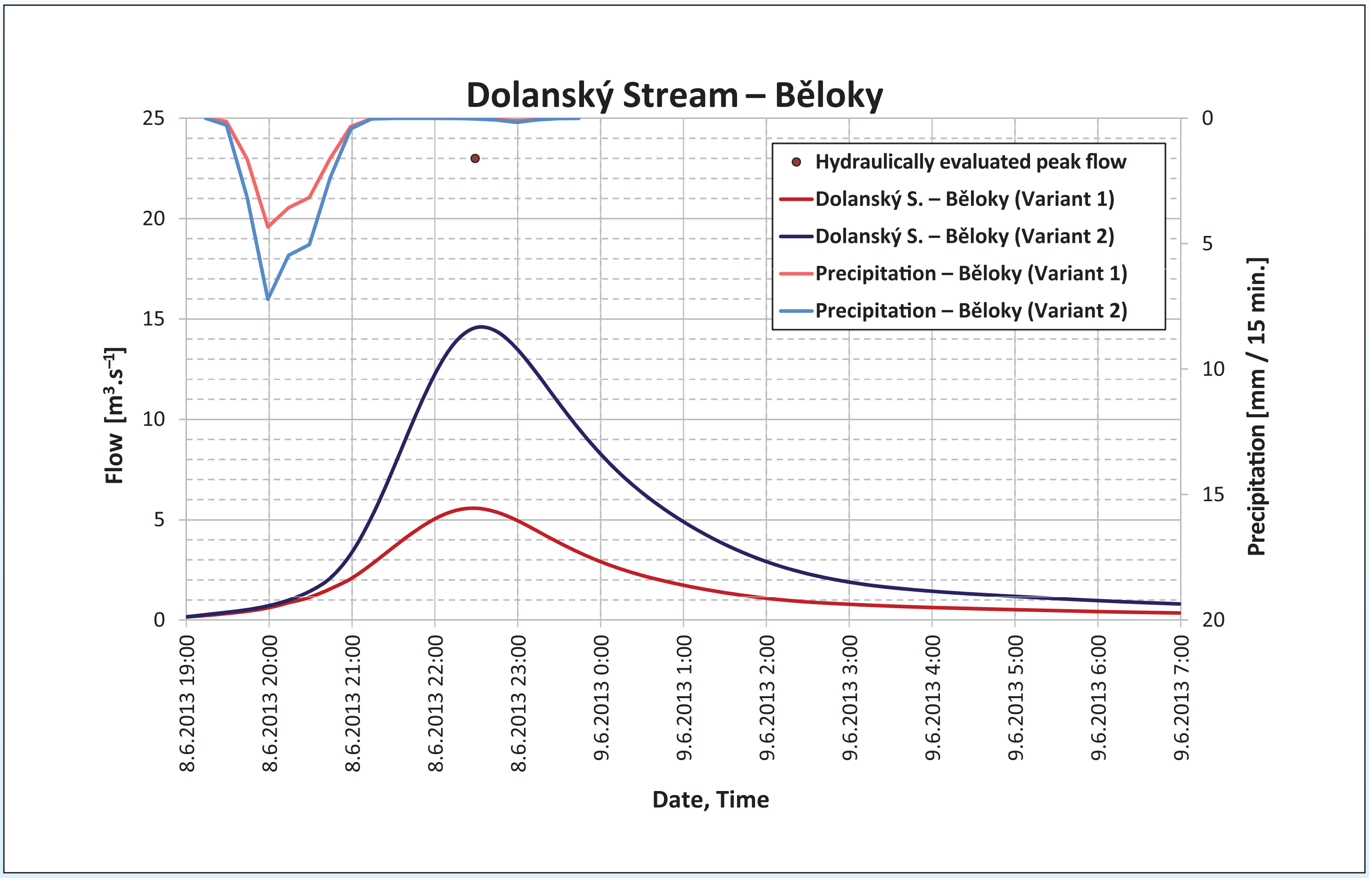

Fig. 2.2 Flood Hydrograph for Dolanský Stream in Běloky, Derived Using the Rainfall-Runoff Model.

and furthermore, water and mud from the surrounding fields and meadows rushed through the Dolanský stream bed, and also through fields, meadows, paths and roads towards Dolany. A similar situation occurred in the upper catchment area of the Sulovický stream, which flows via Hostouň and joins the Dolanský stream upstream of the villages of Běloky and Středokluky, which were also significantly affected by the flood wave from the Dolanský stream. Like in Dolany, local roads, sidewalks, channel bed, bridges and footbridges were damaged there. Water and mud rushed there over the bridge on the village square. The water threatened a large number of houses in the village. In several houses, it reached the residential area and elsewhere only flooded gardens, garages and cellars.

Fig. 2.3 Traces of Peak Level after Flood in Běloky on Dolanský Stream. (Source: official website of the village of Běloky).

Further downstream, the flood proceeded without major inflows and was gradually transformed, mainly due to innundation into the surrounding meadows and fields. The flash flood also hit the villages of Velké Číčovice, Malé Číčovice and Okoř. Thanks to information from firefighters and policemen who intervened in Dolany and its neighbourhood, the Okoř pond was drained just in time, and as such, it could partially catch and further transform the flood. However, the water still got into low-lying buildings, cellars and gardens.

The affected areas, together with the spatial distribution of precipitation on 8 June, are shown in Fig. 2.1. However, the data of maximum precipitation intensity are burdened with high uncertainty because in the core of precipitation there is no rain-gauge station, and therefore, it was not possible to significantly refine the estimated rainfall data from the weather radar.

Using the rainfall-runoff model, we processed the entire Zákolanský stream basin as far as the village of Okoř. The hydrograph for the profile of Běloky on the Dolanský Stream is shown in Fig. 2.2.

Kbelanský Stream and Hněvnický Stream – Nýřany and Other Villages

Flash floods also occurred in the Pilsen Region. The basins of the Kbelanský and Hněvnický streams were hit by rainfalls each day from 8 June to 10 June. On Saturday, 8 June torrential rains began to occur after 6:00 p.m. Precipitation lasted some two hours, and the headwaters of both the above-mentioned streams were the most affected areas. The most intense precipitation occurred from 6:30 p.m. to 7:00 p.m. CEST, when the rainfall in the catchment area amounted to approximately 15 mm. As per the radar estimates, the rainfall ranged from 15 to 25 mm in two hours. Since the catchment area was significantly saturated after previous rains, there was a significant surface runoff there. Water and mud rushed from forests, fields and meadows located north and west of the affected villages. In particular, Hněvnice situated on the Hněvnický stream, Kbelany and Rochlov situated on the Kbelanský stream, Blatnice on the Kbelanský and Hněvnický streams and Nýřany situated at the confluence of both the streams were affected. Water began to fall relatively quickly only in the evening.

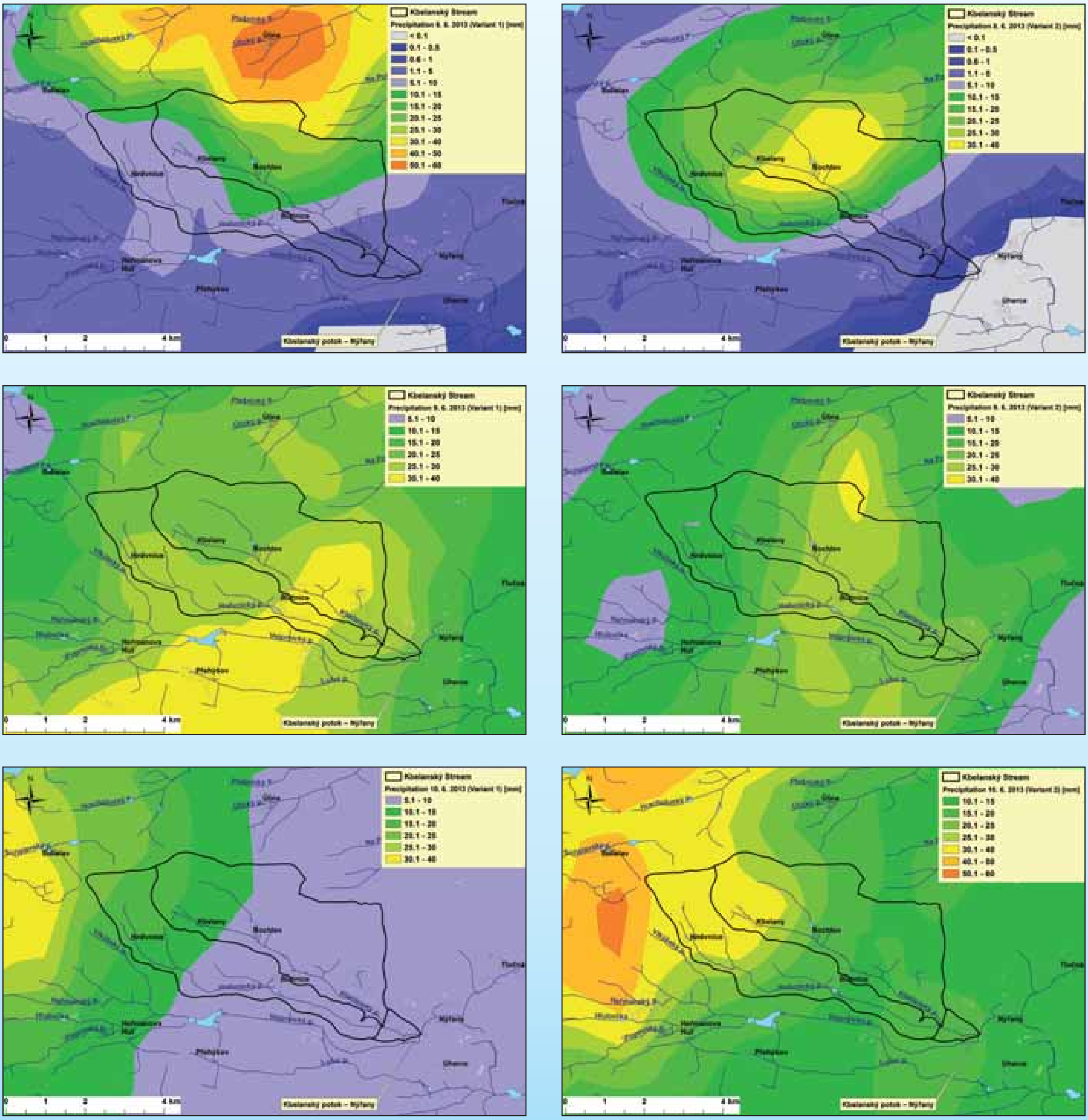

Fig. 2.4 Distribution of Precipitation (Variant 1 on the left, Variant 2 on the right) with Indication of Affected Catchment Area for 8 June, 9 June and 10 June 2013.

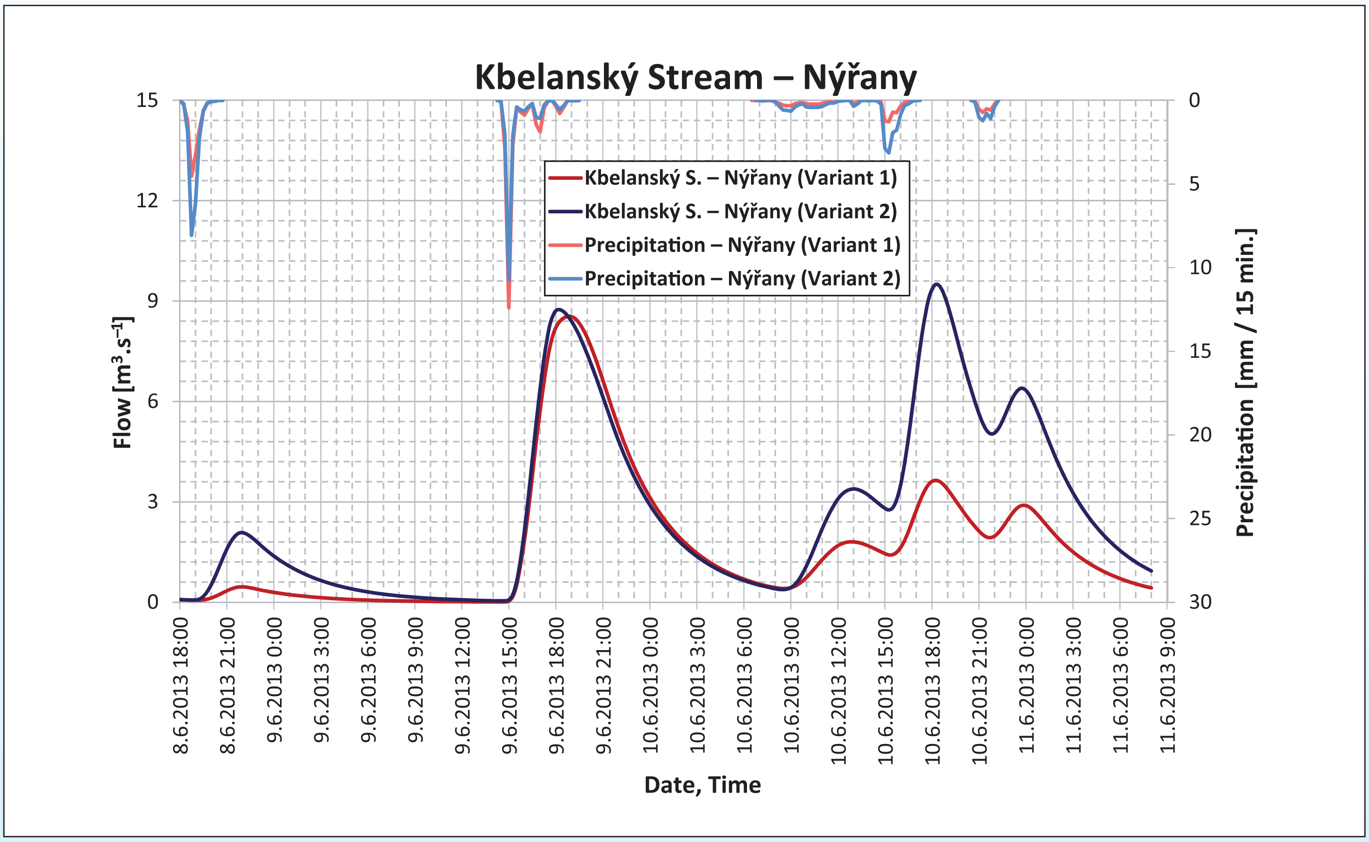

Fig. 2.5 Flood Hydrograph for Kbelanský Stream in Nýřany, Derived Using the Rainfall-Runoff Model.

Several houses, garages and cellars were flooded, and the whole gardens, paths and roads passing through the villages were often under water. In Rochlov and Blatnice, the local ponds were fully filled and later, they overflowed their banks.

On Sunday, 9 June, precipitation already began to occur before 3:00 p.m. and continued with variable intensity over the catchment areas of the Kbelanský and Hněvnický streams until the early evening hours, when only after 7:00 p.m., the precipitation began to subside. A total rainfall for the whole period amounted to an average of 18 to 26 mm in the individual catchment areas, and the most intensive rainfall occurred around 3:00 p.m., when 10 to 15 mm rained in 15 minutes. These rainfalls again hit especially the Kbelanský stream headwater and again caused a significant surface runoff.

On Monday, 10 June, precipitation occurred in the catchment area of the Kbelanský stream, as well as in the neighbouring catchment area of the Vejprnický stream throughout the day. The rainfall already started before 7:00 a.m. and continued with variable intense until the early evening hours (until approximately 5:00 p.m. CEST). The precipitation in the catchment area of the Kbelanský stream was not as intensive as in the previous two days, but torrential rains again occurred locally, especially in the western part of the stream basin. The basins of the affected streams were already very saturated from the previous days, and as such, the runoff response was again very strong.

A significant runoff situation also occurred in the Vejprnický stream basin on 10 June. Especially in its headwater area, i.e. Heřmanovský stream basin, there were torrential rains, which resulted in the filling and overflowing of the retention reservoir near Motorway D5. Because of the rushing water and mud, the motorway traffic had to be significantly restricted and for a time even stopped. Furthermore, water and mud flowed southeastward to the villages of Vlkýš and Heřmanova Huť, where the village squares, several houses, cellars, gardens and a farm were flooded. Downstream of the village of Heřmanova Huť, there were innundation to meadows and fields, where large water lagoons were formed. Part of the flood volume was also stored by the Přehýšovský pond, which was filled and partially overflowed, but its dam withstood the water onslaught. In the evening, the situation was also monitored in Nýřany, where the Vejprnický stream joins the Kbelanský stream. The situation did not calm down until the late night hours.

The affected area and spatial distribution of precipitation for 8, 9 and 10 June are shown in Fig. 2.4.

Using the Rainfall-Runoff Model, we estimated the flood wave progression in the Kbelanský stream basin. The hydrograph of the Kbelanský stream flow in Nýřany is shown in Fig. 2.5.

Vilémovský Stream, Liščí Stream – Šluknov Region

On Sunday, 9 June, torrential rains also occurred in the north of Bohemia. Early in the afternoon, the Šluknov region area was hit by strong thunderstorm with hails and heavy rainfall, whose intensity exceeded 25 mm in 15 minutes at some places. The total amount of rainfall during the episode, which lasted about 90 minutes, could even reach 90 mm at some places as per the radar estimates. Weaker precipitation still occurred on 9 June in the evening with an intensity of about 3–6 mm.h^{-1}. The affected areas, together with the estimated distribution of precipitation on 9 June, are shown in Fig. 2.6.

The torrential rains hit more or less all the villages of the Šluknov region, and a strong runoff response was registered mostly in the villages of Lipová, Vilémov, Jiříkov, Lobendava and Rožany. Water flowed from the surrounding forests, fields and meadows, and some houses and roads were flooded. The local pond in Rožany overflowed. A recently reconstructed, 300-years old half-timbered house in the centre of Lipová was flooded up to a height of one meter (Fig. 2.8).

Using the Rainfall-Runoff Model, we estimated the flood wave progression in the catchment area of the Vilémovský stream. The hydrograph of the Liščí stream (a right-bank tributary of the Vilémovský stream) in the village of Lipová is shown in Fig. 2.7.

Blšanka and Struhařský Streams – Lubenec, Kryry

On Saturday, 8 June, precipitation occurred in the form of showers and thunderstorms in the upper Blšanka stream catchment area. The first shower between 2:00 and 3:00 p.m. was of rather weak intensity, while the

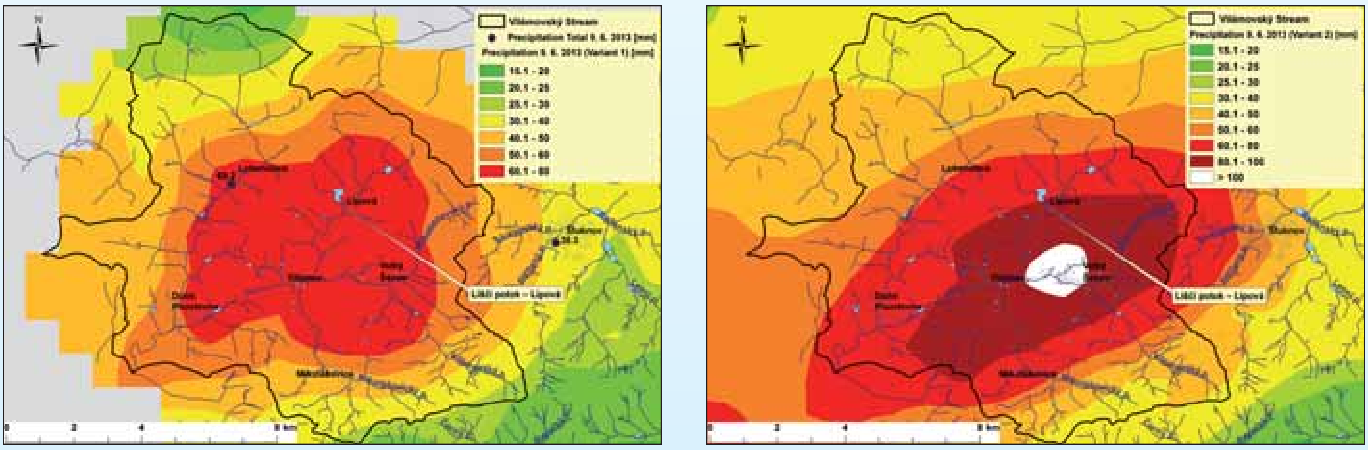

Fig. 2.6 Distribution of Precipitation (Variant 1 on the left, Variant 2 on the right) with Indication of Affected Catchment Area.

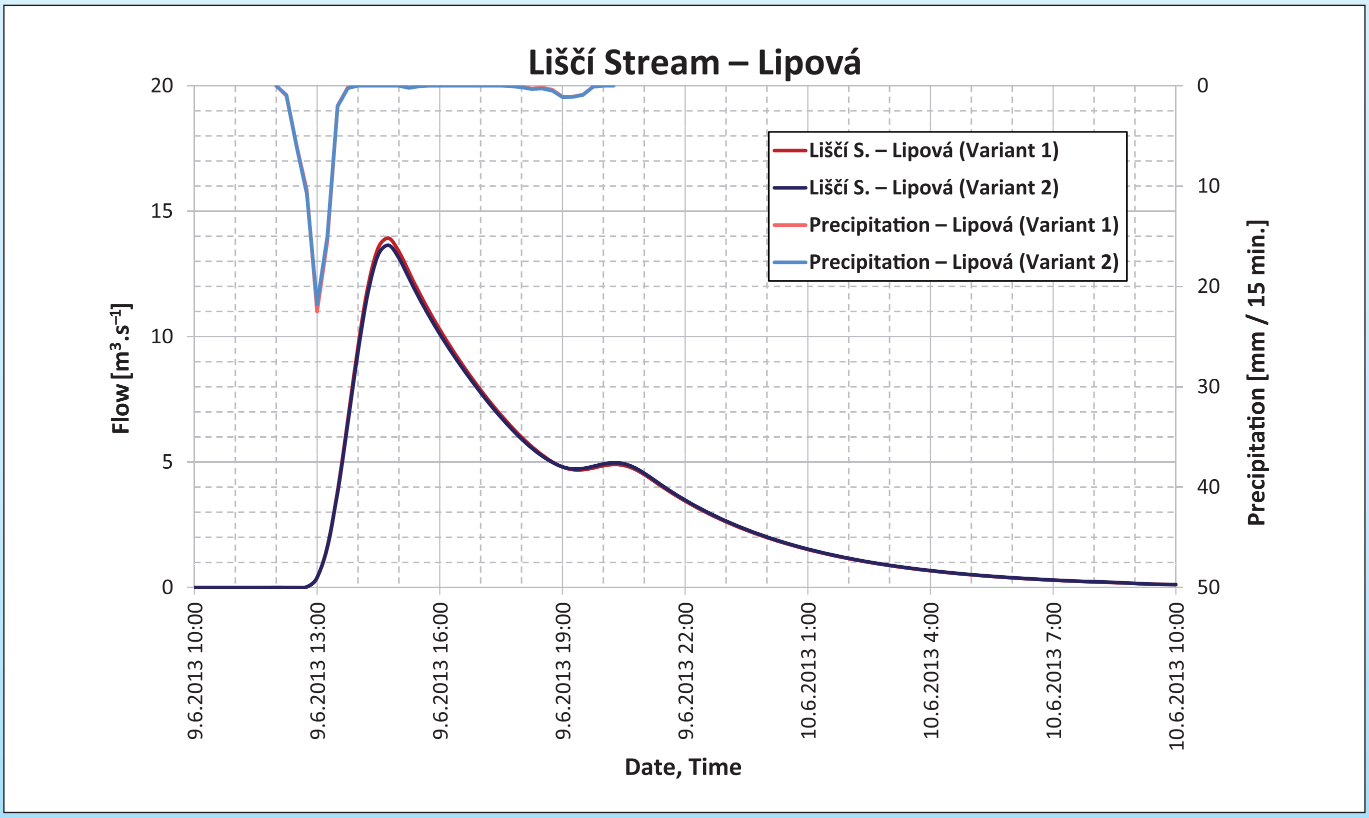

Fig. 2.7 Flood Hydrograph for Liščí Stream in Lipová, Derived Using the Rainfall-Runoff Model.

Fig. 2.9 Flooded Half-Timbered House in Village of Lipová (Source: Mopedos Torpedos Civil Association).

following one was much more intense. At some places, there was a rainfall of 20 to 30 mm within one hour, which locally caused an increased surface runoff in that catchment area. During the night from 8 June to 9 June, there was no precipitation, but the following rainfall hit the catchment area on Sunday, 9 June after 2:00 p.m. The most intense rainfall occurred between 3:15 and 4:30 p.m. CEST, when the rainfall ranged from 25 to 35 mm, of which 15 mm rained in 15 minutes, and at some locations, there was also quite a strong hail storm.

In response to the heavy rainfall, and especially due to the high saturation of the soil in the upper Blšanka stream catchment area caused by the previous rainfall, the water levels of the local streams rapidly rose in the afternoon, and water and mud were also rushing from the surrounding forests, meadows and fields above Lubenec. The flood from the Struhařský stream was transformed in the Lubenecký pond, which however later filled, and for a short period of time, water flowed over its dam. The other streams in the upper Blšanka stream catchment area flowed out of their channels and water flowed through fields, meadows, gardens and local roads.

The flood on the Blšanka stream progressed further to the villages located downstream of Lubenec. At first, it hit the village of Řepany, where a few persons had to be evacuated due to the risk of Lubenecký pond dam rupture.

Significant overflows of smaller tributaries of the Blšanka stream downstream of Lubenec, e.g. Ležecký stream, resulted in further increases of the Blšanka stream flow. The flood gradually hit the villages of Přibenice and Mukoděly.

The concentration of runoff from torrential rainfall in the catchment area of the Blšanka stream occurred upstream of the village of Kryry and downstream of the confluence with the Mlýnecký stream, whose catchment area was also hit by the torrential rainfall. The flood from the Mlýnecký stream was transformed by the Vidhostice reservoir. Another left-bank tributary of the Blšanka stream before the village of Kryry, i.e. Podhora stream, also overflowed its channels and caused problems especially in the village of Vroutek.

The strongly rain-swollen Blšanka stream in Kryry overflowed its banks and flooded the adjacent roads and hit most the lands and built-up area situated directly along its course. As per the local stream gauge reading, the Blšanka stream level rose up to 380 cm, which is more than two meters above the 2nd Flood Level.

In the evening of 9 June, no rainfall occurred anymore, but it again began to rain on Monday, 10 June in the afternoon, when from 2:00 p.m. to 6:00 p.m. CEST, there was further rainfall over the Blšanka catchment area upstream of Lubenec ranging on the average from 15 to 20 mm. However, due to the very strongly saturated catchment area, a fairly significant runoff response again occurred, and some affected villages (or their parts) were again flooded. The Blšanka stream in Kryry reached its peak flow at about 11:00 p.m. and its level rose to 320 cm.

The affected area, together with the daily precipitation total of 9 June, is shown in Fig. 2.10. The time-course of the flow was determined using the rainfall-runoff model at profile downstream of the village of Řepany, upstream of the confluence with the Ležecký stream, and is shown in Fig. 2.11. The figure also presents the hydrograph from the Stránky water-gauging station situated at the lower reach of the Blšanka stream.

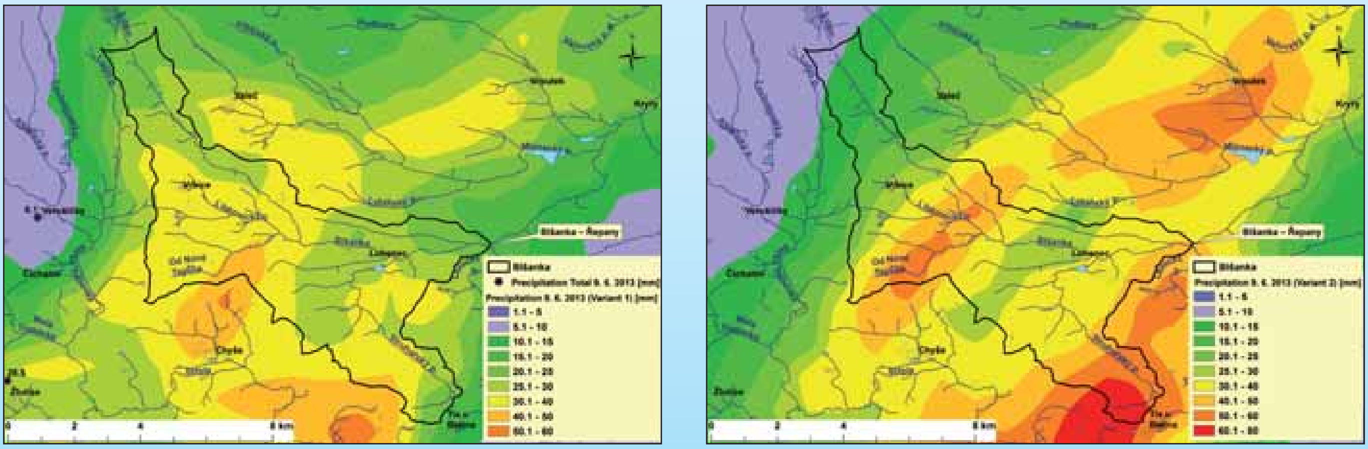

Fig. 2.10 Areal Distribution of Precipitation (Variant 1 on the left, Variant 2 on the right), with Indication of Affected Catchment Area.

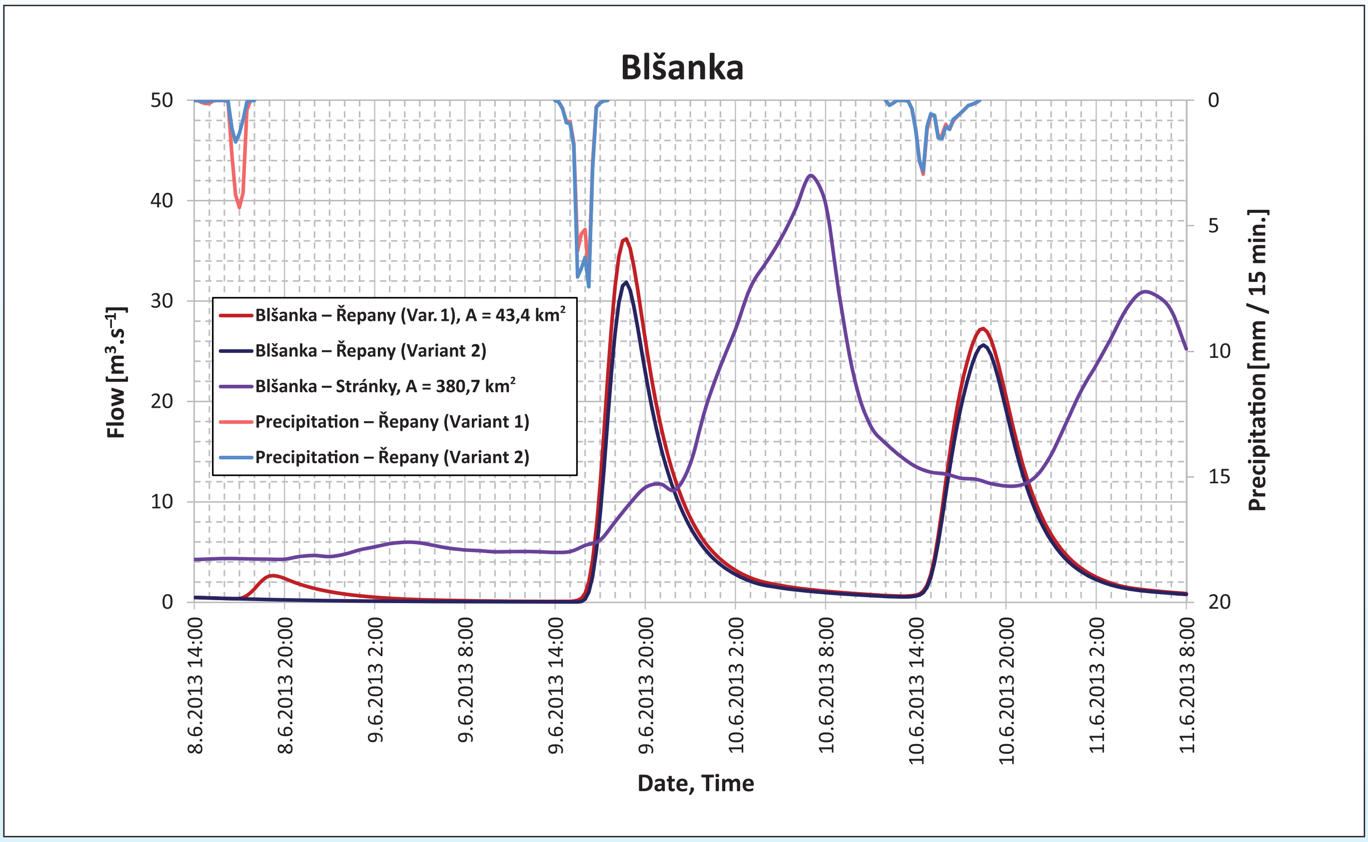

Fig. 2.11 Flood Hydrographs for Blšanka Stream downstream of Řepany, Determined Using the Rainfall-Runoff Model, and Observed Flood Hydrograph at Stránky Water Gauges.

Fig. 2.12 Flood-Swollen Blšanka Stream at Stránky Water Gauge (left) and Water Flowing over Safety Spillway of Lubenecký Pond on Struhařský Stream at the Edge of Village of Lubenec (right). (Source: Žatecký a Lounský deník).

Nivnička and Pivný Streams – Bystřice pod Lopeníkem

In the catchment area of the Nivnička stream, torrential rain began to occur at about 5:00 p.m. CEST on 10 June. It intensified very quickly and in approximately one hour (from 5:00 p.m. to 6:15 p.m.), the rainfall amounted to 30 to 50 mm. During the heaviest precipitation, the rainfall amounted to 15 to 20 mm in 15 minutes. Especially in the headwater area of the Pivný stream, an extremely large hail event occurred. The water levels of the Nivnička and Pivný streams, the latter flowing into the Nivnička stream in the village of Bystřice pod Lopeníkem, also began to respond very quickly to the heavy rainfall.

Water and mud flowed into the village of Bystřice pod Lopeníkem not only from the three main watercourses, Pivný stream, a nameless tributary of the Pivný stream and the Nivnička stream, but also in the form of surface runoff from the fields, meadows and forests near the village. In the course of time, the above-mentioned streams overflowed their banks and their channels failed to catch the torrents of water and mud.

More than ten houses, several cellars, garages and gardens were flooded, several bridge structures were damaged. Concrete panels controlling the stream bed and railing sections along such panels were torn out.

Downstream of Bystřice pod Lopeníkem, water and bed-load sediments rushed further along the Nivnička stream channels and through the adjacent lands to the Ordějov reservoir, which was partly drained due to the precipitation forecast. Thanks to that preventive measure, the flood volume could be caught and subsequently transformed.

The affected area with the spatial distribution of precipitation of 10 June is shown in Fig. 2.13. Using the rainfall-runoff model, we estimated the time-course of the flood at the Pivný and Nivnička streams. The modelled progression of the Nivnička stream flow rate in Bystřice pod Lopeníkem is shown in Fig. 2.14.

The unfavourable runoff situation in the catchment areas of the Nivnička stream and near Koménka stream was also worsened by the lower infiltration capacity of soils occurring in this area of the Carpathian Flysch.

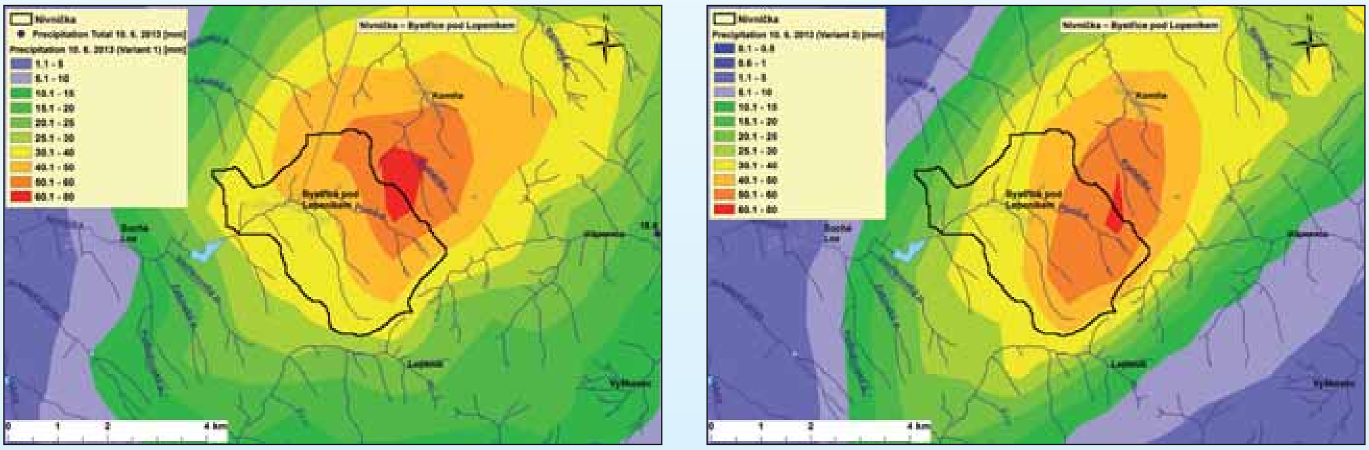

Fig. 2.13 Distribution of Precipitation (Variant 1 on the left, Variant 2 on the right) with Indication of Affected Catchment Area.

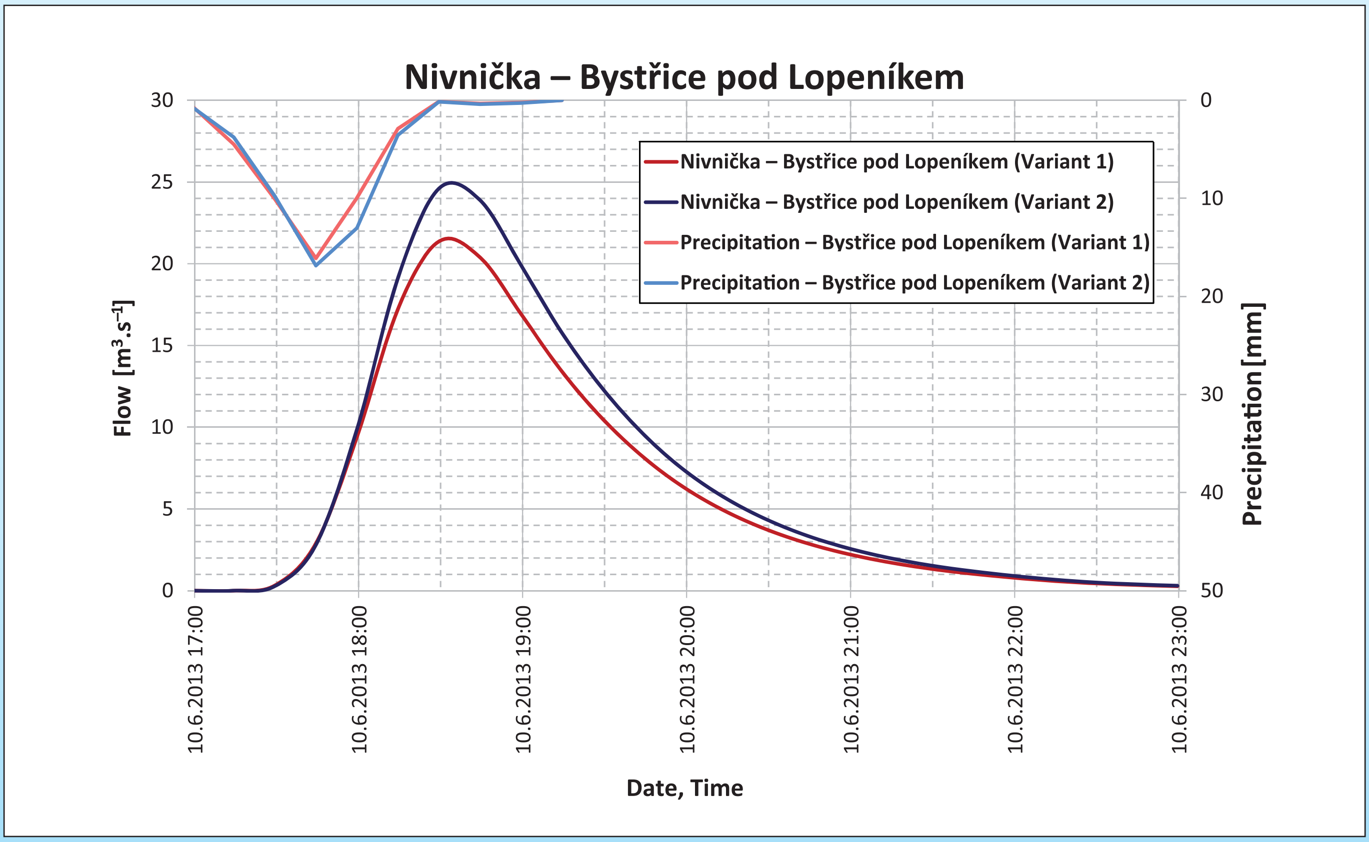

Fig. 2.14 Flood Hydrograph for Nivnička Stream in Bystřice pod Lopeníkem, Determined Using the Rainfall-Runoff Model.

Influence of Urbanization on Runoff

In the case of the Botič stream catchment area, the extensive changes in the built-up area and the way of how they could affect the runoff during floods were often discussed after floods. The catchment area as of the Hostivař reservoir reaches approximately 95 km^2 and over the last years, there have been significant changes in the use of the area due to the intense construction of residential buildings, logistics and shopping centre premises.

When evaluating the floods, changes in flood runoff were simulated for the current state of land use (i.e. as of 2013) and for the state of land use as of 1988 (Fig. 2.15). The change in the state of land use over the mentioned period of time mainly consisted in the conversion of farmland and meadows into urbanized areas or impervious surfaces. The average for the whole area is a 10% reduction in the area of arable land and grassland in favour of impervious surfaces, houses and gardens.

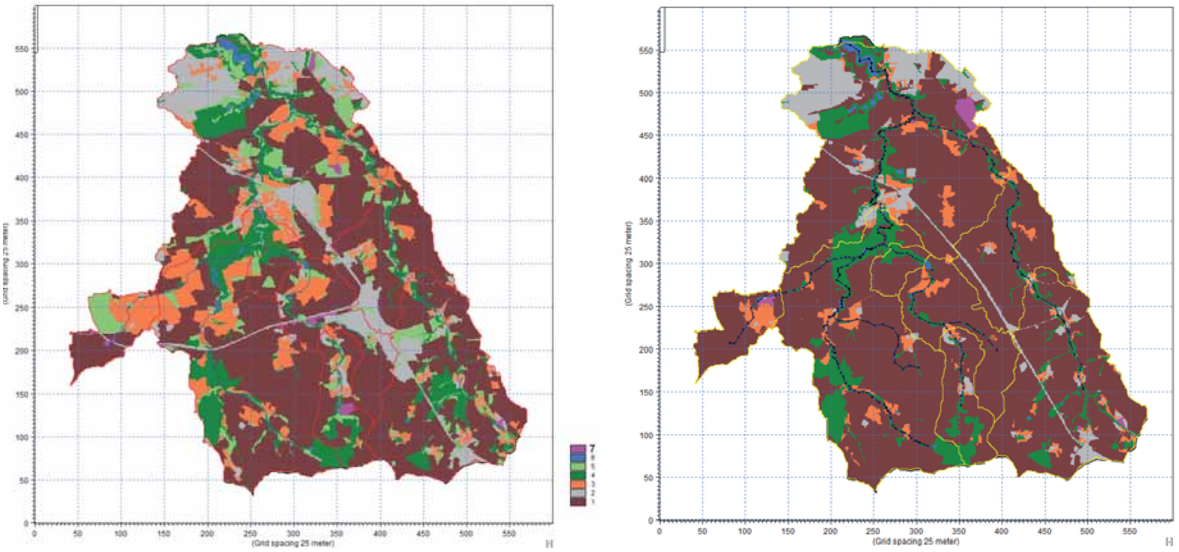

Fig. 2.15 Land Use (left: 2013 state, right: 1988 state). Symbols: 1+ 5 = arable land and grassland, 2 = impervious surfaces, 3 = houses and gardens, 4 = trees, bushes, forest, 6 = water, waterlogged area, 7 = bare soil and other, (source of aerial photographs: http://www.geoportalpraha.cz/).

The flood progression in June 2013 was simulated by DHI, a. s. using the calibrated distributed rainfall-runoff model MIKE SHE. The results show a relatively small change in the simulated peak flow and total runoff amount (Tab. 2.1). The biggest difference of 2 m^3.s^{-1} was simulated at the Dobřejovice profile, in whose catchment area the largest change in the state of land use was also identified. The differences in the total runoff for the flood episode are usually 2–3 %, which can be considered insignificant.

These results can be interpreted such that in this specific case, the retention capacity of soil was largely exhausted, due to the very rainy May 2013, as early as the beginning of rainfall, and as such, the impact of land use on the runoff was negligible.

Therefore, the episode was additionally simulated in June 2013 for both the states of land use, but for the low saturation of the catchment area at the beginning of the flood episode, i.e. under other, “drier” initial conditions. As expected, the values of simulated peak flows and total runoff were significantly smaller.

Tab. 2.1 Comparison of Peak Flows and Runoff Depths for the 2013 and 1988 States of Land Use (the state of saturation of the catchment areas considered as of 1 June 2013).

Hydrometric Profile	***Peak Flow Rate [m^3.s^{-1}]***		***Depth of Runoff from Interbasin [mm]***	
	2013 State	***1988 State***	***2013 State***	***1988 State***
Modletice	*8.2*	*7.7*	*97*	*91*
Dobřejovice	*14*	*12*		
Průhonice (CHMI)	*15*	*14*	*85*	*82*
Jesenice	*1.6*	*1.8*	*50*	*51*
Průhonice (Botič)	*34*	*34*	*76*	*78*
Kuří	*22*	*22*	*97*	*98*
Benice	*29*	*29*	*84*	*82*
Inflow to Hostivař Reservoir	*73*	*73*		

Obr. 2.16 Fluvial Erosion on the Hiking Trail above Horní Maršov (photo by Radovan Tyl).

3. FLOOD FORECASTING SERVICE

The flood forecasting service is assigned to inform the flood protection authorities about the hazard of flooding and its foreseeable development. This service is provided by the Czech Hydrometeorological Institute (CHMI) in cooperation with the River Basin Authorities (Povodí, s. p.). For this purpose, the CHMI and the River Basin Authorities operate the networks of water gauges and share data on water stages, flow rates, precipitation and water levels in reservoirs.

The CHMI operates hydrological forecasting models and issues alerts and information messages, and the River Basin Authorities also operate hydrological models to predict the inflow to the reservoirs and issue information messages for the needs of flood protection authorities of Regions and municipalities.

The forecasting service outputs in the form of warnings, alerts, forecasts and other information are provided to the flood protection authorities of different levels, are shared with other partners, including those in the neighbouring countries, and are also available to the general public.

At the end of May and in June 2013, numerous dangerous phenomena occurred in the territory of the Czech Republic. They mostly included thunderstorms, heavy rainfalls and floods. During three rainfall and flood episodes, a total of 20 warnings were issued to warn about the forecasted floods, 47 warnings about the occurrence of dangerous phenomena were issued to warn about the reaching of hazardous water levels and rainfalls intensities, and more than 100 hydrological information messages were released.

3.1 Integrated Warning Service System

In cooperation with the Meteorological Service of the Military Geographic and Hydrometeorological Office, the Czech Hydrometeorological Institute operates the Integrated Warning Service System for the coordinated issuance of alerts on dangerous hydrometeorological phenomena. According to established criteria, alerts are issued not only to floods, but also to various other kinds of extreme hydrometeorological phenomena (temperature, wind, storms, rainfall, frost, snow).

As a standard, two types of alert information are issued:

FAI – Forecast Alert Information, which is issued by the Central Forecasting Office if dangerous hydrometeorological phenomena are expected in the future, mostly based on the outputs of the meteorological models and consultations among meteorologists, in the case of flood events, also among hydrologists.

IODP – Information about Occurrence of Dangerous Phenomena, which is issued operatively in the event of an extremely dangerous degree of hazard, such as intense rainfall, severe thunderstorms, reaching the 3rd Flood level (Flooding). Issuing the IODP aims to immediately indicate the occurrence of an extremely dangerous phenomenon, and in some cases, also to predict its progression over the next period of several hours.

The CHMI distributes alerts to the flood and emergency authorities through the Operation and Information Centres of the Fire Rescue Service of the Czech Republic within the Integrated Rescue System. Alerts are also sent directly to other parties involved in the flood protection system, and for the general public, they are published at the CHMI website: http://www.chmi.cz.

3.2 Forecast Evaluation

Outputs of meteorological forecasting models are a basis for making decisions on issuing alerts to dangerous rainfalls. In doing so, the quantitative forecasting of precipitation is one of the most difficult tasks of numerical weather prediction. Although over the past decades, the forecasting quality has significantly improved, rain is an element that is still difficult to predict. The global prediction models used for medium-term weather forecasts, i.e. for a period longer than two days, can detect significant precipitation periods even more than a week in advance. However, it is still very difficult to predict the exact spatial distribution and totals of precipitation often even for the next few coming hours.

The spatial resolution of the model is a significant factor that influences the quality of precipitation forecasts. Whereas the global models, which cover the entire Earth and provide predictions for ten and even more days, have a resolution of 15 to 30 km, the local models, calculating precipitation forecasts only for a limited area with a forecast lead time of two to three days, have a resolution of approximately 5 to 7 km. If the resolution is more detailed, the models better reflect the effect of orographic barriers (windward sides of mountain slopes) and also some smaller spatial phenomena in the atmosphere. In its forecasting practice, the CHMI uses various models: global models of ECMWF(1), GME(2), GM UKMO(3), GFS(4) and local models of COSMO(5) and ALADIN calculated at the CHMI. Their outputs are a basis for an expert interpretation by the human forecasters, who prepare their own forecasts and make decisions on warnings alerts to dangerous precipitation.

In general, the reliability of individual forecast outputs should increase with an impending precipitation event. Therefore, outputs of regional models, which usually provide weather forecasts for a period of no longer than 72 hours in advance, are used to detect in greater detail the expected distribution and total of precipitation in a short-term time frame.

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(1) European Centre for Medium-Range Weather Forecasts, UK

(2) Deutscher Wetterdienst, Germany

(3) UK Metoffice, UK

(4) National Weather Service, USA

(5) Deutscher Wetterdienst, Germany

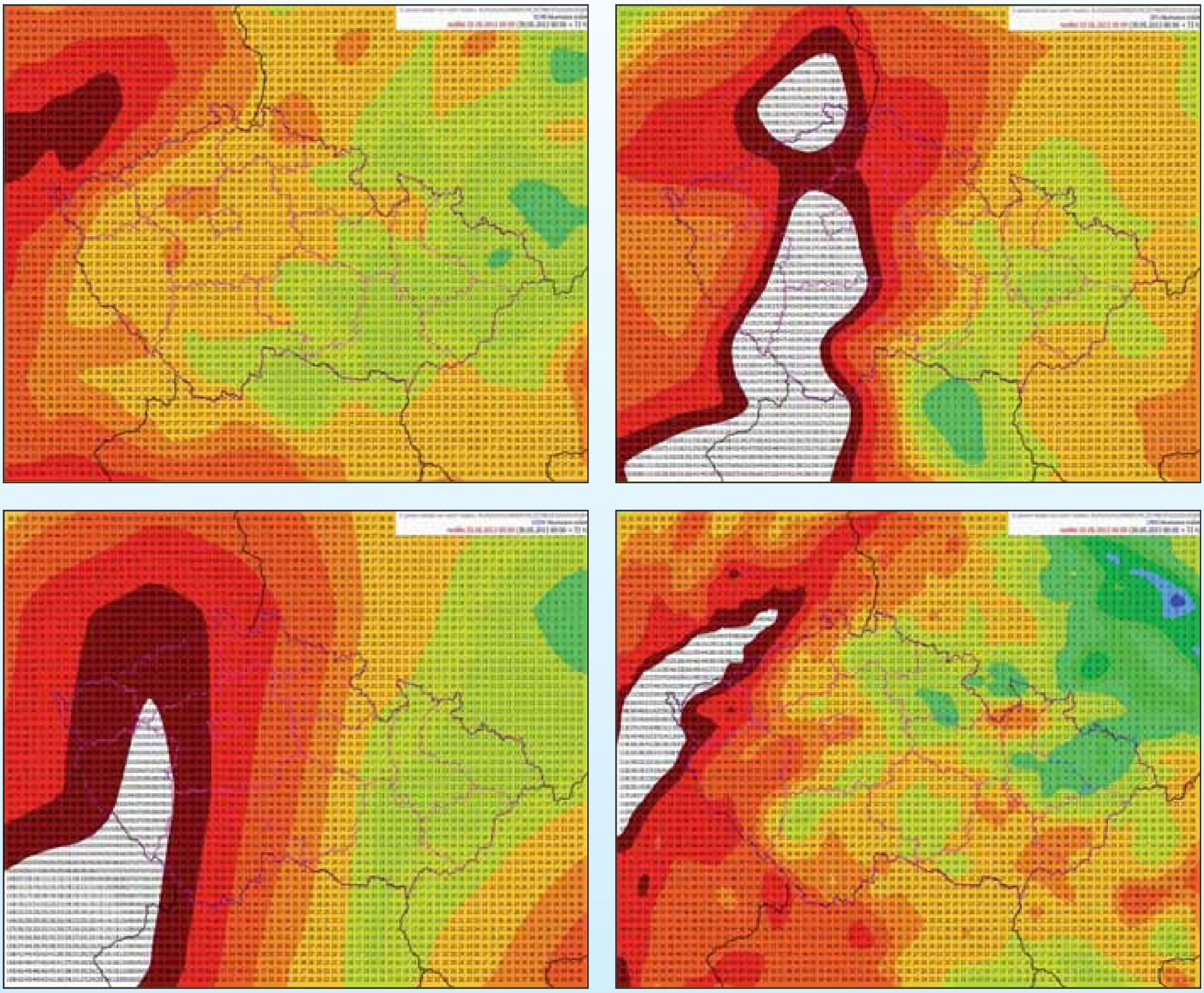


Fig. 3.1 Forecast of 72-Hour Rainfall Accumulation dated 30 May 2013, 02:00 a.m. CEST for the Period from 30 May 02:00 a.m. CEST to 2 June 2013 02 a.m. CEST as per the Models of ECMWF (top left), GFS (top right), GME (bottom left) and COSMO EU (bottom right).

Forecasts during the First Rainfall Episode

The model outputs of 30 May, 02:00 a.m. indicated a significant precipitation event in Central Europe at the turn of May 2013. Fig. 3.1 shows a forecast of 72-hour rainfall accumulation as per the models of ECMWF, GFS, GME and COSMO EU.

Except for the GFS Model, which forecasted quite close to the later reality that the core of the heaviest rainfall occured in the band over Bohemia, the models forecasted extreme precipitation for the western half of Bohemia or for the areas west and northwest of the Czech Republic. In terms of the rainfall total estimate, all the models forecasted that the maximum total rainfall amount would exceed 80 mm in the Czech Republic, and most of them even forecasted more than 100 mm (white colour) for a period of 72 hours.

The consensus of models that the precipitation would be located west of our territory over Germany also continued in the following days. The model outputs of 1 June, 02:00 a.m. still forecasted that the heaviest rainfall would occur in Saxony and Bavaria (Fig. 3.2). In that area, there were really heavy rainfalls, causing floods on the tributaries of the Elbe River and Danube River Basins. However at the same time, a convergence zone was created over the territory of the Czech Republic, which was indicated only by the model outputs of 1 June 2013, 02:00 p.m., and they thus provided a more accurate localization of the forecast of heavy rainfall.

Fig. 3.2 provides 24-hour precipitation forecasts from all the six models available at the Czech Hydrometeorological Institute. The comparison of forecasts of 24-hour rainfall totals with the actual rainfalls, determined as a combination of measurement using weather radars and rain gauges (Fig. 3.3), shows that the most accurate forecasts were provided by the regional models of ALADIN and COSMO EU, which relatively well expressed the rainfall distribution. However in terms of the final total, the rainfall forecast by these models was also underestimated by 20 to 40%, and in

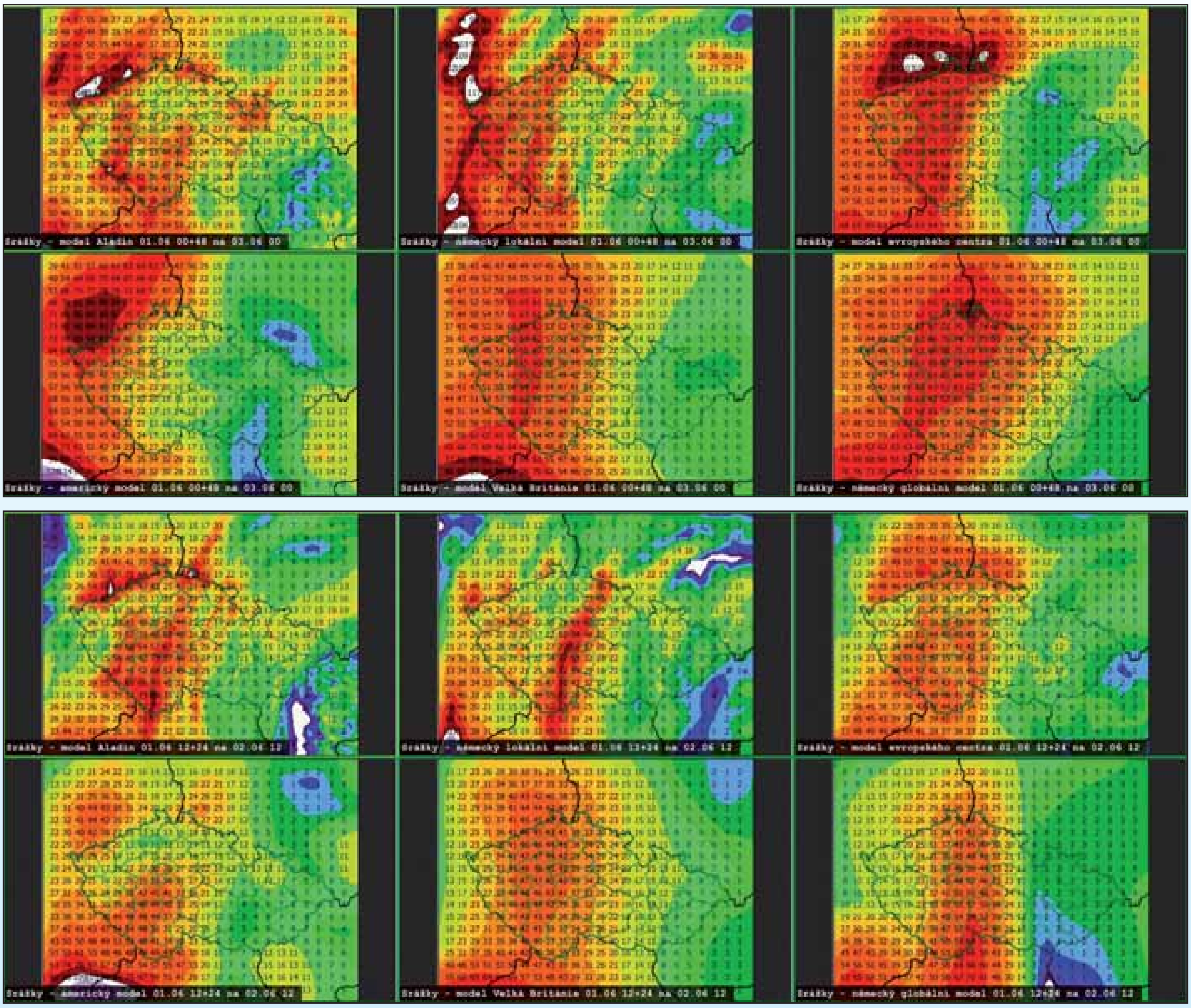


Fig. 3.2 Forecast of 24-Hour Rainfall as per Models (always from left to right and from top to bottom) ALADIN, COSMO EU, ECMWF, GFS, GM UKMO and GME – at the top, forecast dated 1 June 2013, 02:00 a.m. CEST, at the bottom, forecast of 1 June 2013, 02:00 p.m. CEST (up to 2 June 2013, 02:00 a.m. CEST and 02:00 p.m. CEST respectively).

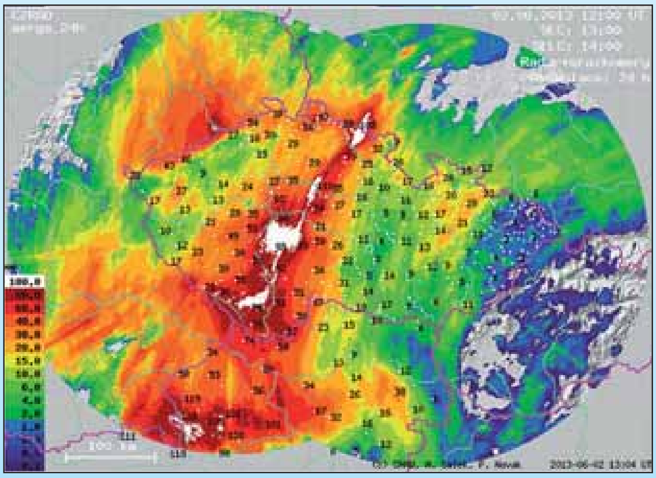


Fig. 3.3 Rainfall for the Period from 1 June 2013, 02:00 p.m. CEST to 2 June 2013, 02:00 p.m. CEST as a Combination of Radar Estimates and Measurement Provided by Rain Gauges.

respect of the areas with the heaviest rain, it was underestimated even more than twice.

In general, the meteorological models signalled periods of heavy rainfall in our territory and risk of flood occurrence. However, they significantly underestimated the rainfall intensity in the area of the main precipitation band. Subsequently, this fact was also reflected in the success of (i) hydrological forecasts of the runoff and (ii) alerts.

The hydrological forecasts mostly signalled flow increases with the possibility of reaching the Flood Levels. However, they mostly significantly underestimated the pace and size of the flood onset (Fig. 3.4).

For a comprehensive evaluation, the forecasts issued for the selected period were structured into categories in terms of success rate of forecasting the individual Flood Levels exceedances (Fig. 3.5). Such evaluated success rate of forecasts during the first flood wave in 2013 was greater than the long-term evaluation for the period from 2002 to 2013, but it is obvious that the

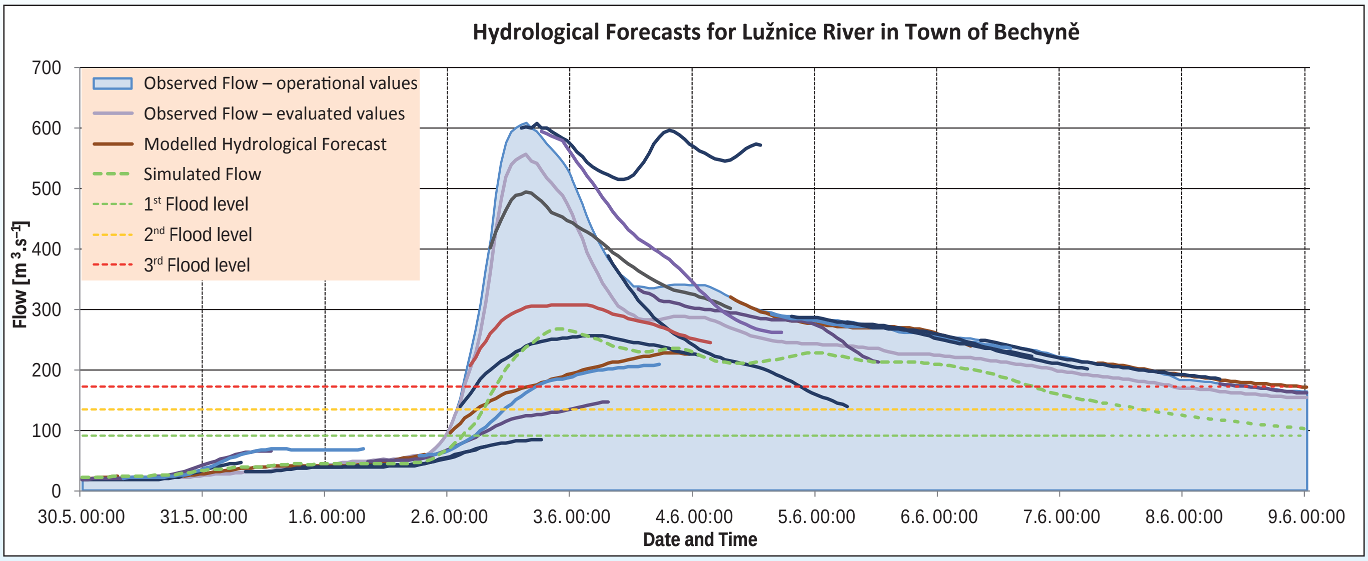


Fig. 3.4 Hydrological Forecasts for Lužnice River in Town of Bechyně and Backward Simulation of Flow Using the Model as per Actual Rainfall.

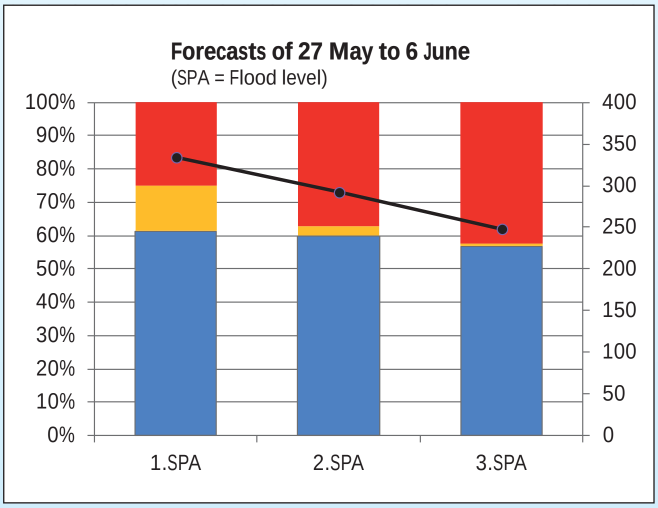


Fig. 3.5 Evaluation of Success Rate of Hydrological Forecasts of Exceedance of Flood Levels during First Flood Episode (blue = hit, yellow = false alarm, red = miss, the black line indicates the number of forecasts).

number of unpredicted cases also increased with the increasing Flood Level.

From the Graphs (Fig. 3.6), it follows that when the main flood episode was rising in early June, one third of the runoff volume forecasts was successful. However, almost one half of them slightly or strongly underestimated the water volume. The relatively high number of underestimated forecasts was caused by the combination of underestimated rainfall forecasts and also by the calculation of the hydrological model, which underestimated the runoff response for most basins. The reason for the hydrological model inaccuracy consisted in an inaccurate calibration for this specific type of flood. The model incorrectly assumed that water penetrates through soil into deeper horizons and complements the groundwater. However, the extremely saturated topsoil made the infiltration of further precipitation impossible and thus supported the rapid water runoff from the catchment area.

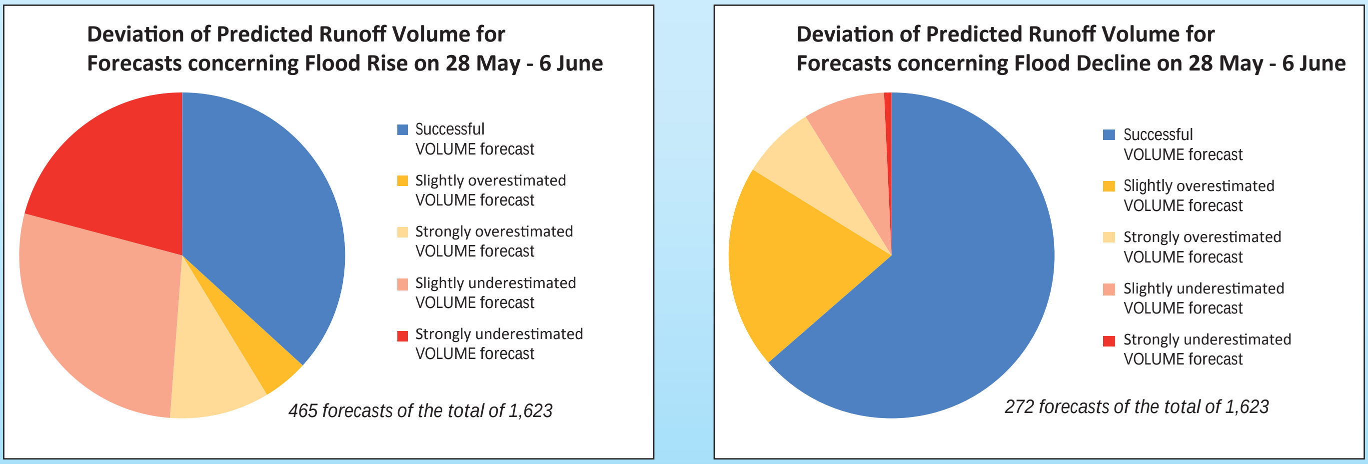


Fig. 3.6 Evaluation of Success Rate of Hydrological Forecasts of Flood Volume during First Flood Episode.

Forecasts for the Lower Vltava and Elbe Rivers

Forecasts of the Vltava River flow in Prague-Chuchle are prepared in close cooperation of the CHMI and Povodí Vltavy, s.p. (PVL). During floods, the hydrological forecast for the Vltava River is largely dependent on the outlook for the future outflow from the Vltava River Reservoir Cascade, which is prepared by the Operational Centre of Povodí Vltavy, s.p. This outflow outlook for 48 hours enters into the hydrological model, which produces a 48-hour forecast for the forecast profiles on the Vltava and Elbe Rivers. The Forecasting Office of the CHMI and the Operational Centre of PVL consult each other about the situation and both of them also issue a manual short-term forecast for Prague with a forecast lead time of 6 hours. Fig. 3.7 presents the forecasts of the Vltava River flow in Prague-Chuchle during the first flood episode in early June 2013, which forecasts were provided to the flood protection authorities (Flood Committee of the Capital City of Prague).

From the Graph, it is obvious that the modelled hydrological forecasts did not predict the rapid onset of the flood in Prague. Early in the morning of 2 June 2013, when the Crisis Management Team of the Capital City of Prague was activated, the hydrological forecast for the Vltava River did not even indicate any exceeding of the 2nd Flood Level. Only further forecasts, calculated on the basis of the data as of 7:00 a.m., which already took into account the actual rainfall and response to the rapid filling of the Vltava River reservoirs, predicted the exceeding of the 3rd Flood Level on the next day. The peak flow in Prague was reliably predicted by the forecast as of 7:00 a.m., 3 June 2013, i.e. with a lead time of approximately 24 hours.

On the contrary, the forecasts of the Elbe River flow in Ústí nad Labem (Fig. 3.8) predicted the onset of flood successfully and overestimated the peak flow. In this case, it was caused by the wilful non-consideration of effects of innundation in the Mělník and Litoměřice Regions with a view to providing possibly the most unfa-

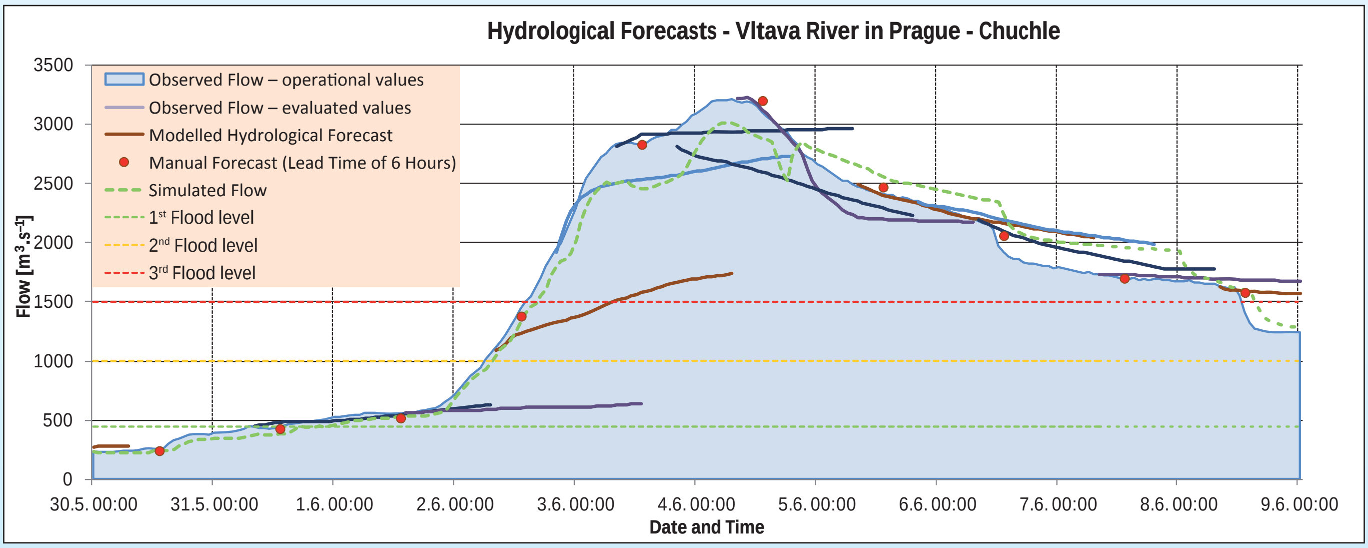


Fig. 3.7 Evolution of Predictions of Vltava River Flow in Prague-Chuchle.

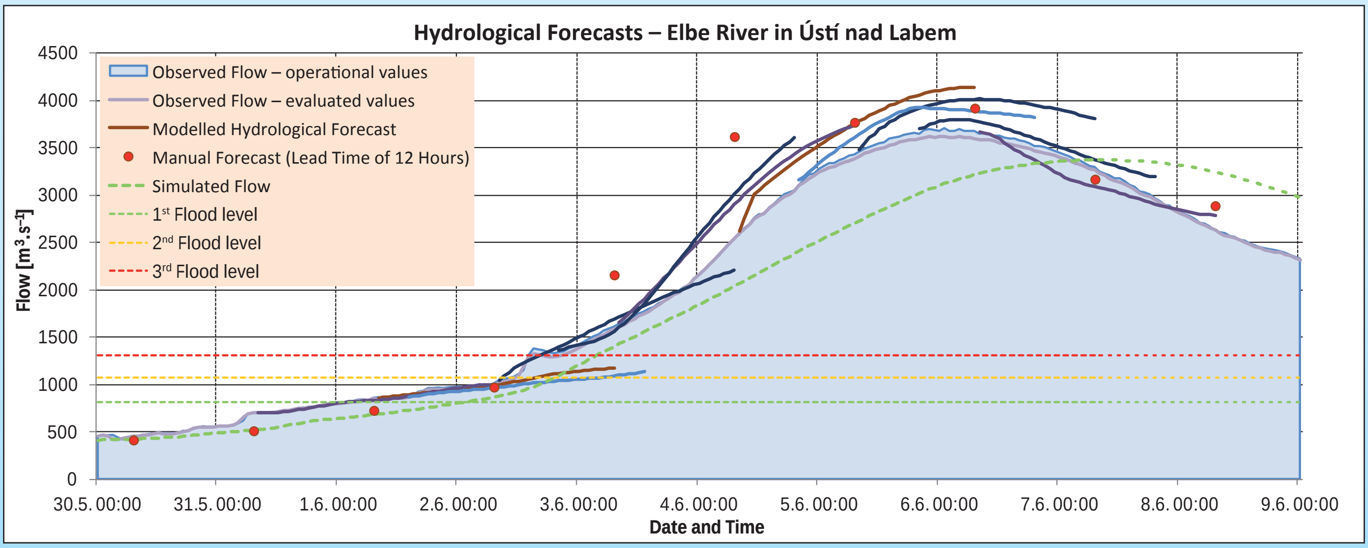


Fig. 3.8 Hydrological Forecasts and Backward Simulation of Flow Using the Model as per Actual Rainfall on the Elbe River in the Ústí nad Labem Profile.

Hydrological Forecasting in the Czech Republic

The Hydrological Forecasting Offices of the CHMI in the Elbe River basin use the AquaLog forecasting system as the basic prediction tool, which calculates, on the basis of data of the water-gauging stations and observed or forecast rainfall and air temperature data, the flow forecast for 165 so-called nodal points. Based on them, deterministic flow forecasts in one-hour steps are prepared for 120 forecast profiles with a forecast lead time of 48 hours. At the time of the flood, several ensemble forecast calculations were also performed experimentally, considering different variants of precipitation forecast.

For several hydrometric profiles on the lower river stretches, a simple forecast calculation is still also used on the basis of discharge travel time. This is a so-called manual forecast with a forecast lead time of no more than 24 hours, updated usually once a day.

In the case of normal situation, the CHMI Forecasting Offices at the Centre and Regional offices prepare a hydrological forecast once a day. The forecast is usually available between 9:00 a.m. and 10:00 a.m. During impending or ongoing floods, the forecasts are updated more frequently, depending on the progression of hydrological situation.

The issued model forecasts are published at the CHMI website: http://hydro.chmi.cz/hpps/.

Forecast Evaluation Method

For a comprehensive evaluation of the success rate of all hydrological forecasts issued by the CHMI, the categorical rating method was used. The method is based on the reduction of hydrological forecast (flow time series) to a single phenomenon. The exceedance of the threshold of the 1st, 2nd and 3rd Flood Levels, i.e. events related directly to the activities of flood protection authorities, was selected to be such a phenomenon. The evaluation then monitors whether a given phenomenon was or was not forecast and whether it occurred or not. Any forecast can be assigned to one of the following four categories: HIT (successful forecast), FALSE ALARM (false alert), MISS (missing alert), CORRECT REJECTION (correct no-event forecast).

		The phenomenon occurred	
		yes	*no*
The phenomenon is forecast	*yes*	*HIT*	*FALSE ALARM*
	no	*MISS*	*CORRECT REJECTION*

Contingency Table, Rating the Success of Forecasting the Exceedance of Flood Levels.

vourable variant of flood progression in order to adhere to the principle of staying on the safety side.

The above-mentioned underestimation of rainfall and runoff were also reflected in the alerts, which warned about the occurrence of rainfall and floods, but for some areas, they underestimated the level of danger. Especially at the beginning of floods, a problem consisted in the correct localization of expected rainfall. For example, even though a persistent heavy rainfall, that hit Central Bohemia south of Prague on 1 and 2 June 2013, was expected by Forecast Alert Information No. 43 of Friday, 31 May 2013, its localization was specified by the Forecast Alert Information to occur in the western area of Bohemia. Similarly, the greatest water level rises were expected by this Forecast Alert Information to occur in the northern border mountains.

The issued IODP (Information about Occurrence of Dangerous Phenomena) responded to the emerging exceedance of water levels corresponding to the 3rd Flood Level (flooding) in the individual reporting water gauges. In one case, IODP No. 22 also warned about an extreme danger that occurs in the exceedance of 50-year flow of the Kocába and Blanice Rivers, lower Lužnice River stretches and some other smaller tributaries in that area. There was only one IODP issued for extreme rainfall (IODP No. 17 of Sunday, 2 June 2013, 3:22 a.m. CEST). That IODP responded to the rainfall ranging from 40 to 50 mm in six hours in the border mountains and České Budějovice and Sedlčany Regions.

Forecasts during the Second Rainfall Episode

The next episode of significant precipitation in the territory of the Czech Republic took place from 9 to 11 June 2013. This was the period when primarily convective precipitation occurred, which could not be sufficiently forecast by the global models. A more accurate indication of potential occurrence of torrential rainfall was provided by the regional models of ALADIN and COSMO EU (see for example the forecast of 9 June, 08:00 a.m. in Fig. 3.9). Both the models relatively well estimated the pattern of rainfall distribution for the first day of the forecast, but the totals were locally underestimated, and

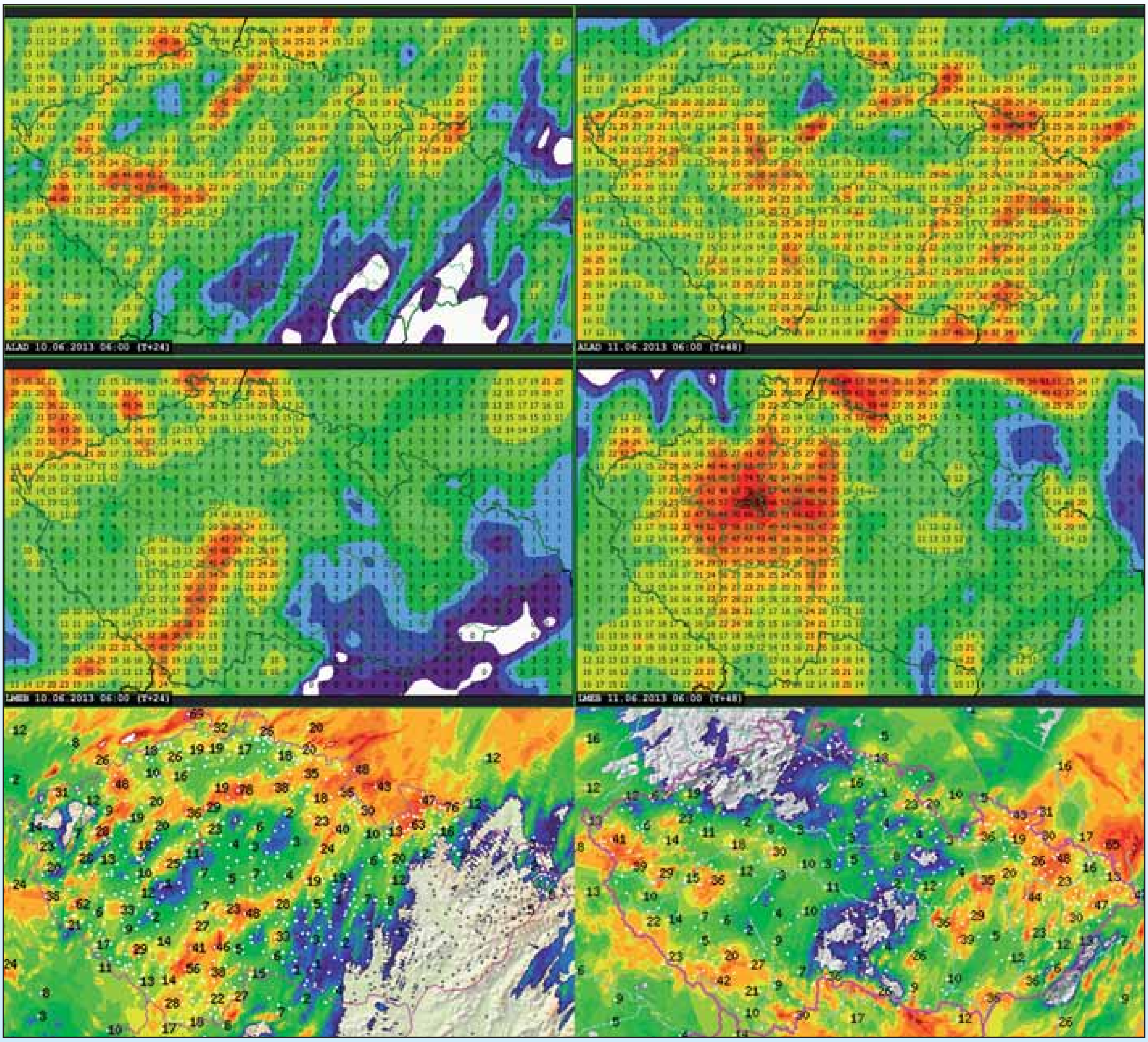


Fig. 3.9 24-Hour Rainfall Forecasts Using the Local Models of ALADIN (1st Line) and COSMO EU (2nd Line) dated 9 June 2013 08:00 a.m. CEST for 9 and 10 June 2013 from 08:00 to 08:00 a.m. CEST. The last line includes a rainfall estimate (combination of radar and rain gauge measurements).

the localization of individual precipitation cells was also inaccurate. Both of these tasks are however beyond the scope of the current techniques.

Due to the fact that the hydrological forecasting system of AquaLog was designed especially for predicting regional floods, the localized cases of flash floods on small streams were not depicted in the model.

Forecasts during Third Rainfall Episode

In the third precipitation episode, which came after a lapse of time in late June, the highest rainfall took place on 24 and 25 June, at that time over the large territory of Eastern Bohemia, Bohemian-Moravian Highlands and Southern Moravia. The rainfall was anticipated by the global models with a forecast lead time of several days (Fig. 3.10).

The forecasts of 23 and 24 June 2013 also gradually indicated a significant rainfall event over the territory of the Czech Republic, although the areas of greatest rainfall were mostly localized differently from those where the subsequent rainfall actually took place. The forecast of 48-hour totals of 24 June 2013, 02:00 a.m. (Fig. 3.11), using the COSMO EU Model, predicted local rainfall values of up to 130 mm in the area of the Bohemian-Moravian Highlands. The ALADIN Model predicted a local rainfall of above 100 mm in the areas of the Chrudim Region, in the north of Bohemia and in the Jizera Mountains. The localization of the actually recorded highest 48-hour totals for 24 and 25 June thus corresponded fairly well to the ALADIN Model outputs.

In the hydrological forecasts, the rainfall prediction was reflected by a certain overestimation of the runoff re-

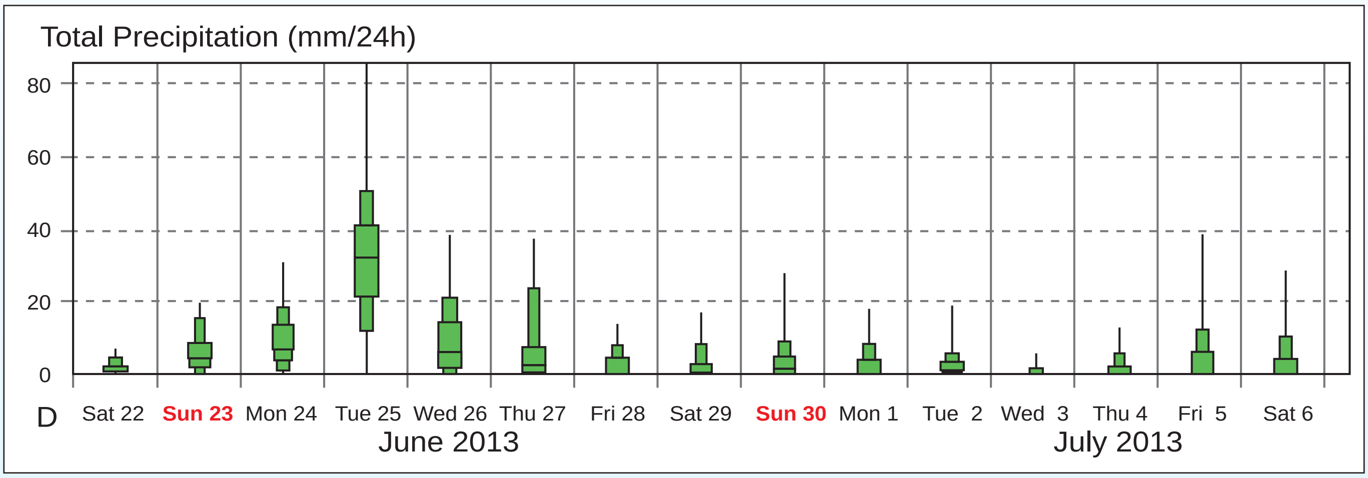


Fig. 3.10 Meteogram of Probabilistic Precipitation Forecast as per ECMWF of 22 June 2013, 02:00 a.m. CEST for the Town of Prostějov Located in the East of the Czech Republic.

sponse, where there were more frequent so-called false alarms about the exceedance of the Flood Levels, which did not subsequently occur (Fig. 3.12). Similarly, the flood volume was also rather overestimated (Fig. 3.13).

3.3 Problems of Hydrological Forecasts during 2013 Floods

The evaluation of hydrological forecasts issued during the flood in June 2013 again confirmed that the success rate of hydrological forecasts is directly dependent on the success rate of precipitation forecast in terms of its quantity and accurate localization. With respect to the catchment areas most affected by precipitation, the hydrological models themselves also significantly contributed to the overall forecast error, which was confirmed by the results of the flood re-simulation using the measured precipitation values. The cause of this phenomenon can be attributed to the imperfect calibration of models for this specific type of flooding in some river basins. Small streams were particularly affected by the flood. They often included the tributaries of larger rivers (Lužnice, Vltava, Sázava) and the intensity of flood on them was so significant that it also affected large streams on their lower reaches. From the said perspective, it was an exceptional flood event that had not been instrumentally recorded before, and as such, it was not used for the calibration of hydrological models. The precipitation nature was so specific that the model parameters derived for other floods were not appropriate for that event. Therefore, the flood evaluation also included the model recalibration, which responded to the above-mentioned findings by modifying the model parameterization.

Like in other extreme floods, at some gauges there were differences between the operationally indicated flow rates and the subsequently evaluated flows as a re-

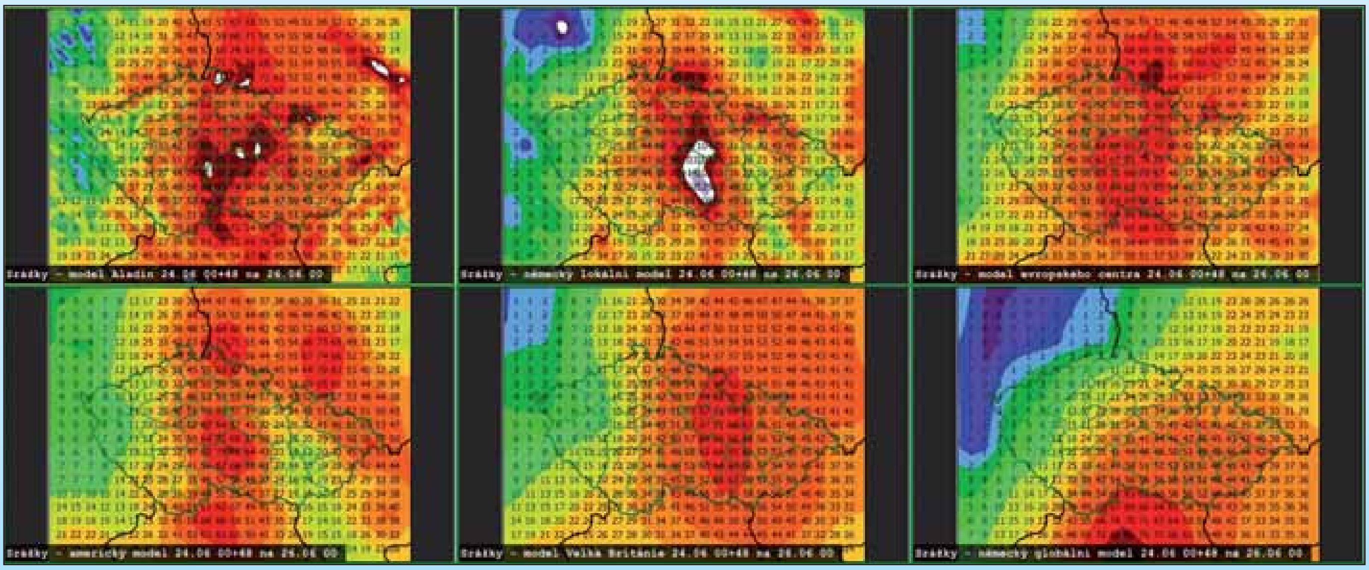


Fig. 3.11 Forecast of 48-Hour Rainfall Accumulation Dated 24 June 2013, 02:00 a.m. CEST for the Period from 24 June 2013, 02:00 a.m. CEST to 26 June 2013, 02:00 a.m. CEST (to the right and from up to bottom) based on ALADIN, COSMO EU, ECMWF, GFS, GM UKMO and GME Models.

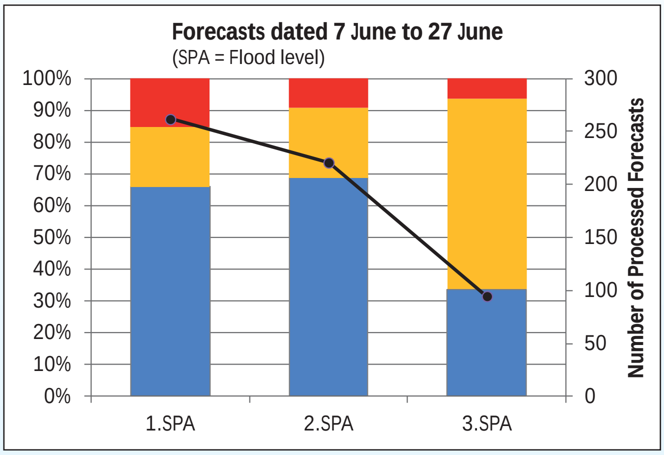


Fig. 3.12 Evaluation of Success Rate of Hydrological Forecasts of Exceedance of the Flood Levels during Second and Third Flood Episode (blue = hit, yellow = false alarm, red = miss, the black curve indicates the number of forecasts).

sult of the uncertainty of operationally used rating curves in the area of high water levels. This is influenced by the fact that on some streams, it was the largest-ever flood, which exceeded the parts of rating curves derived on the basis of hydrometric measurement and reached into their extrapolated section.

Even though in some other water gauges (e.g. Berounka River in Beroun, Vltava River in Prague, Elbe River in Mělník), it was not the largest recorded flood, however during the historically largest flood in August 2002, no hydrometric measurement was carried out at these profiles because no ADCP instruments were used at that time, and it was only the peak flow rate that was estimated. Thanks to numerous hydrometric measurements using the ADCP instruments at those profiles, the floods in June 2013 significantly helped to refine the rating curves in the areas of critical flood stages.

The above-mentioned inaccuracies in the rating curves during the flood negatively affected the forecast of flow at the given profiles, as well as the decisions on handling at the Vltava River cascade reservoirs, which followed the operationally indicated Vltava River flow data in Prague-Chuchle and Berounka River flow data in Beroun, where in both the cases the deviation of the operational flow rate from the evaluated flow rate reached approximately 200 $m^3.s^{-1}$.

The total categorical assessment of the success rate of all hydrological forecasts issued during June 2013 showed that the forecast success rate decreased with the increasing flow extremity. The exceeding of the Flood Levels 1, 2, 3 were not predicted in 20%, 25% and more than 30% of cases respectively. The exceeding of the 10-year flow was not predicted in almost half of cases. This fact subsequently resulted in a relatively good forecast of flood occurrence, but in an underestimation of its size.

3.4 Presentation of Forecasting Service Information

During the flood, the websites of the CHMI and River Basin Authorities were burdened with extreme traffic. Yet throughout the floods, the presentation of the Flood Warning and Forecasting Service (hydro.chmi.cz/hpps/) remained fully functional, accessible and updated. Due to the overloading, problems emerged in the access to the main website of the CHMI (www.chmi.cz), which were switched at critical moments over to a more economical version of the presentation of selected operational data.

In addition to the above-mentioned distribution of alerts and information messages provided by the Flood Forecasting Service of the CHMI and River Basin Authorities, the flood protection authorities were also informed through alternative internet presentations or SMS messages sent from automatic water-gauging stations with information on the exceeding of the Flood Levels (a total of almost 6,000 SMS messages were sent from the CHMI stations in June 2013).

Representatives of the CHMI and individual River Basin Authorities attended the meetings of Regional Flood Committees and Crisis Management Groups according to relevant territorial competences. At the meetings of Regional Flood Committees and Crisis Management Groups, the representatives of the CHMI and individual River Basin Authorities informed the meeting attendees about the flood progression and outlook of its further evolution, especially in view of the hydrometeorological situation or handling performed at the reservoirs.

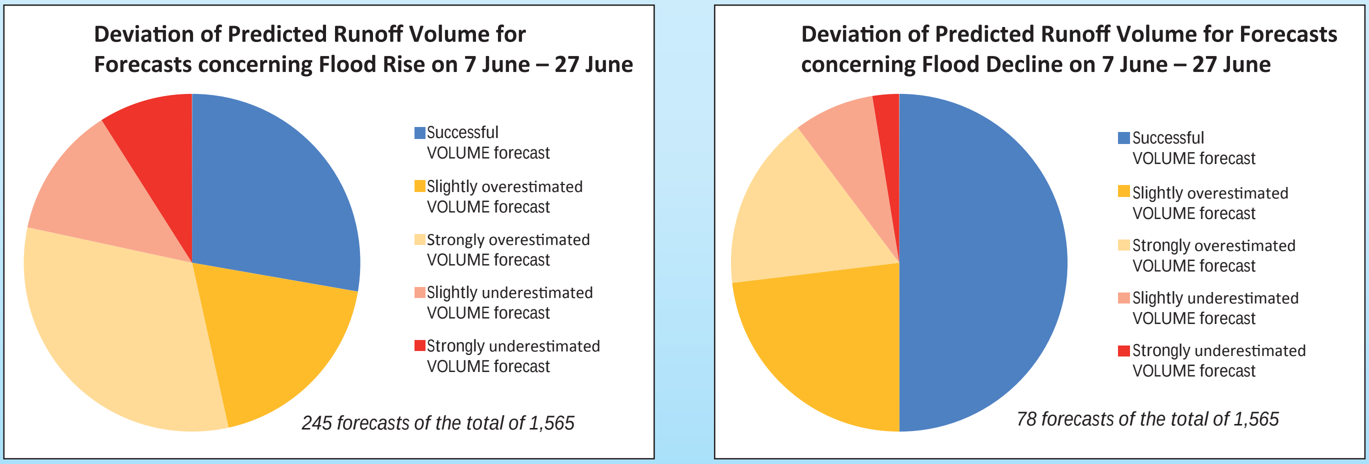


Fig. 3.13 Evaluation of Success Rate of Hydrological Forecasts of Flood Volume during Second and Third Flood Episodes.

4. FUNCTION OF RESERVOIRS AND FLOOD CONTROL MEASURES

4.1 Reservoirs Influence on Flood Progression

The flood progression in June 2013 was significantly influenced by the operations of water reservoirs, especially those in the Vltava, Upper Elbe and Ohře River basins. Within the flood evaluation, the function of 52 significant reservoirs was assessed. They mostly include multi-purpose water reservoirs containing a dedicated manageable flood control storage for capturing floods. Such storage was defined in 32 assessed reservoirs, and in the other cases, an unmanageable flood control storage or an additional empty conservation storage was available for capturing flood volume.

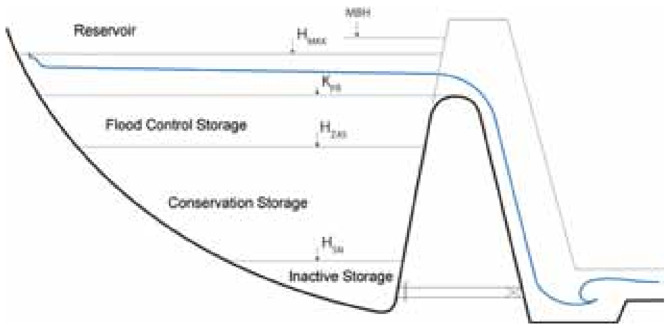
The selected reservoirs, which were significantly affected by floods in June 2013 or which significantly influenced the flood, are listed in Tab. 4.1. The inflows into the Orlík and Kořensko reservoir, as well as into the Hostivař reservoir on the Botič stream, were assessed as peak flows at the level of a 100-year flood. The inflow in the range of a 50 to 100-year flood was recorded at all the other reservoirs of the Vltava River Cascade and at the Vrchlice and Les Království reservoirs in the Elbe River basin. An inflow larger than a 10-year flood was also registered at the Husinec and Nýrsko reservoirs, as well as at the Újezd reservoir on the Bílina River. At the other reservoirs in the Vltava and Elbe River basins, there were smaller floods, and at the reservoirs in the Dyje River basin, there was a 5-year flood as a maximum.

When evaluating the reservoir function, it was found out that the defined manageable flood control storage of the reservoir was empty in all cases before the onset of the flood, and in some cases, a part of the conservation storage was also free. Reservoir operation was performed under the Operational Rules. At some reservoirs, some extraordinary operations were performed with the consent of the flood authority to better meet the needs of solutions of a given situation downstream of the reservoir.

The greatest reduction of the peak flow at the dam section was reached at the reservoirs of Lipno (64 %), Nýrsko (73 %), Švihov (52 %), Seč (53 %), Žlutice (51 %), Újezd (60 %). The flood progression was also significantly influenced by the reservoirs of Hracholusky, Labská, Les Království, Rozkoš, and in the Ohře River basin, by the reservoirs of Jesenice and Nechranice. Some reservoirs that control only small catchment areas, such as Přísečnice, Fláje, Obecnice and Pilská reservoirs, had a locally significant influence. The reservoirs in the Dyje River basin were burdened with relatively smaller floods and mostly transformed the inflow below the level of harmless outflow. The reservoir locations and transformation effects on the floods in June 2013 are shown in Fig. 4.1.

The transformation effect of most reservoirs in Bohemia was applied mostly during the first flood episode, and in the case of some reservoirs, also during the second flood episode (Hracholusky, České Údolí, Klabava, Žlutice and Újezd reservoirs). In Eastern Bohemia, the third flood episode was also significant (at the Labská and Les Království reservoirs), and at some reservoirs (Hamry, Seč, Pařížov), the third episode of floods only

Typical Structure of Storage of Multi-Purpose Reservoir



Level H_{SN} defines the inactive storage, which must be always full, mainly due to environmental reasons.

Level H_{ZAS} defines the conservation storage which shall be filled or drained depending on how the reservoir manages water and shall supply the flow downstream of the reservoir at the time of a low flow.

Safety Spillway Crest $K_{P\check{R}}$ delimits the manageable storage of the reservoir, whose part above the conservation storage is the so-called manageable flood control storage.

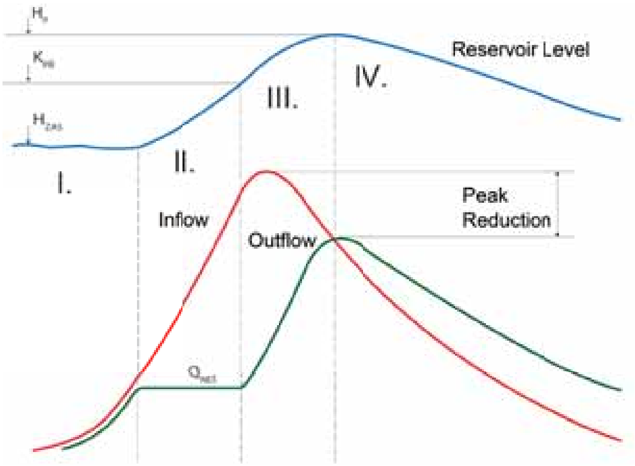
The height of the overflow jet on the safety spillway depends on the reservoir level and delimits the actually used unmanageable flood protective storage. In the event that the spillway contains a movable barrier (e.g. a flap or segment), the unmanageable storage is only above the upper edge of the barrier or is not delimited at all (Vltava River cascade reservoirs).

The maximum volume of the unmanageable flood protective storage is determined by the Level H_{MAX}, which is the maximum permissible water level in the reservoir, as approved by the water authorities. If possible, H_{MAX} must not be exceeded, and therefore, it is necessary to use all outlets, spillways and other equipment for water transfer. The reservoir storage structure is determined by the Operation Rules of the reservoir.

The Reservoir Safety Guidelines applicable to floods also defines the so-called Maximum Safe Water Level (MBH), at which the reservoirs is still considered safe.

How the flood goes through the reservoir

In the free volume of the reservoir, a part of the flood wave is captured and the peak flow mostly decreases. The rate of this decrease depends on the free storage in relation to the volume and shape of the flood hydrograph and to the reservoir operation.



Phase 1 – the reservoir level is maintained at the Level H_{ZAS} and the outflow from the reservoir is increased according to the inflow until it reaches the harmless outflow value $Q_{NEŠ}$, which does not cause any damage downstream of the reservoir. If the conservation storage is partly drained, it shall be refilled to the Level H_{ZAS}.

Phase 2 – the inflow continues to rise, and the outflow is maintained at $Q_{NEŠ}$ and the manageable flood control storage is being filled. After the level reaches the spillway level, it is still possible to maintain the outflow $Q_{NEŠ}$ by gradual closing of the bottom outlets for some time; however afterwards, the unmanageable state occurs.

Phase 3 – water flows over the spillway and the reservoir continues to be filled. The more the reservoir level rises, the greater the outflow is, but at the same time, a greater part of the flood volume is captured in the unmanageable flood control storage. Should the level reach the Level H_{MAX}, it is necessary to open all devices for it not to further rise.

Phase 4 – The water level in the reservoir peaks such that the outflow equals the declining inflow and the drainage phase begins. Both the inflow and outflow gradually decrease, and when the outflow drops to the Level $Q_{NEŠ}$, then it is usually maintained at this level to accelerate the drainage of the flood control storage.

If the inflow is reliably predicted, it is possible to optimize the reservoir function, usually by increasing the outflow in the initial phases of the flood, even above the Level $Q_{NEŠ}$. This saves the free flood control storage of the reservoir for the peak flood phase and a greater reduction of the peak flow is thus achieved. On the other hand, if the extremity of an expected flood is overestimated, the set outflow may be too high such that the flood control storage will not be fully utilized and the achieved decrease of the flood culmination will be smaller.

The peak flow reduction in the reservoir is propagated further down the stream, but its rate decreases with increasing inflows from the catchment area downstream of the reservoir.

took place. The Moravian reservoirs (Vír, Brno, Mostiště) also applied their influence during the third flood episode; the Dyje River reservoirs (Vranov, Znojmo, Nové Mlýny) applied their influence during all the three episodes, which were however quite small there.

Lipno I Reservoir

In view of the catchment area, the defined manageable flood control storage of Lipno I reservoir on the Vltava River is relatively large – 33.165 mil. m^3, and as such, it performs a significant transformation role during floods. Before the onset of the first flood episod, the reservoir still contained a 35 cm of empty conservation storage, which provided an additional volume of approximately 16 million m^3, considering the large area of the reservoir. The reservoir was burdened with a simple flood wave of a peak flow of 340 m^3.s^{-1}, which nearly approached the level of a 100-year flood (359 m^3.s^{-1}).

In the initial phase of the flood, the outflow from the reservoir was maintained deep below the harmless flow level (90 m^3.s^{-1}), whereas on the lower stretch of the Vltava River in Český Krumlov, there was a peak of the flood caused by high inflows from the catchment area downstream of the reservoir. After the flood reached its peak in the evening of 2 June 2013, some extraordinary handling was performed on the basis of a decision taken by the flood authority of the South Bohemian Region, and the amount of the harmless flow from the reservoir was exceeded. The outflow was gradually increased up to 100 m^3.s^{-1} and after the inflow and outflow were equalized on 5 June 2013, the outflow was further gradually increased up to 123 m^3.s^{-1}.

The maximum water level in the reservoir reached 725.33 m above sea level, i.e. 27 cm below the flood control storage level, i.e. Maximum Permissible Level approved by the water authority.

During the flood in June 2013, the transformation effect of the Lipno I reservoir was significant. The peak inflow of 340 m^3.s^{-1} into the reservoir was reduced by 217 m^3.s^{-1}; however by up to 260 m^3.s^{-1} at the time of peak inflow. As compared with the inflow peak time, the outflow peak time was delayed by approximately 4.5 days. Even

Tab. 4.1 Selected Reservoirs with Significant Flood Occurrence and Transformation Effect.

Reservoir	Watercourse	Catchment Area	Total Storage	Manageable Flood Control Storage	Maximum Inflow		Maximum Outflow	Peak Reduction	
		[km^2]	[mil. m^3]		[m^3.s^{-1}]	Return Period [years]	[m^3.s^{-1}]	[m^3.s^{-1}]	%
Vltava River Basin									
Lipno I	Vltava	948.2	309.50	33.17	340	50–100	123	217	63.8
Orlík	Vltava	12,106.0	716.50	62.07	2 160	100	1 950	210	9.7
Slapy	Vltava	12,956.8	269.30	–	2 020	50	2 010	10	0.5
Římov	Malše	488.5	33.64	1.55	180	10–20	140	40	22.2
Husinec	Blanice	212.5	5.64	2.82	126	20–50	97	29	23.0
Švihov	Želivka	1,178.5	266.56	–	104	2	50	54	51.9
Nýrsko	Úhlava	80.9	18.94	2.01	33.0	10	9	24	72.7
Hracholusky	Mže	1,609.4	41.71	4.58	110	2–5	57	53	48.2
Žlutice	Střela	213.7	12.80	1.30	41.0	10	20	21	51.2
Elbe River Basin									
Labská	Elbe	61.0	2.66	1.31	72	5	47	25	34.7
Les Království	Elbe	531.8	6.08	4.45	308	50	156	152	49.4
Rozkoš	Úpa	415.4*	76.33	19.80	60*	10*	10	50	–
Hamry	Chrudimka	56.8	2.50	1.16	20	5–10	12	8	40.0
Seč	Chrudimka	216.1	18.49	3.17	60	5–10	28	32	53.3
Pařížov	Doubrava	202.3	1.52	1.21	66	10–20	50	16	24.2
Vrchlice	Vrchlice	97.5	8.32	–	47	100	37	10	21.3
Ohře River Basin									
Skalka	Ohře	671.9	15.92	1.35	61	< 2	51	10	16.4
Jesenice	Odrava	411.0	52.75	3.49	58	5–10	29	29	50.0
Nechranice	Ohře	3,590.3	272.43	36.56	356	5	260	96	27.0
Újezd	Bílina	93.0	6.73	2.09	25	10–20	10	15	60.0
Morava River Basin									
Vír	Svratka	410.3	53.14	5.29	58	2–5	33	25	43.1
Dalešice	Jihlava	1,139.1	126.90	4.70	49	< 2	31	18	36.7
Mostiště	Oslava	222.9	10.99	0.61	22	2	17	5	22.7
Vranov	Dyje	2,211.8	122.66	11.16	118	< 2	83	35	29.7
Nové Mlýny	Dyje	11,853.1	130.33**	29.65**	336	2–5	277	59	17.6

* related to the profile of unloading from the Úpa River to the Rozkoš reservoir

** sum of volumes of all the three reservoirs of Nové Mlýny

though the reservoir was capable of maintaining the outflow at the harmless flow level of 90 m^3.s^{-1}, an increased outflow and faster drainage of the reservoir were preferred in view of the situation downstream of the reservoir, where a substantially larger flow had taken place before.

Orlík Reservoir

The Orlík reservoir, which is the most important reservoir of the Vltava River Cascade, has a delimited flood control storage of 62.072 million m^3. Like the other reservoirs of the Vltava River Cascade, it does not have any unmanageable flood control storage, which means that the flood control storage level of 353.60 m above sea level is also the Maximum Permissible Level approved by the water authority. Before the onset of the flood in June 2013, the whole flood control storage of the reservoir and a section of the conservation storage were empty, and as such, a total free volume of 121.5 million m^3 was available as of 1 June 2013.

The inflow into the reservoir began to sharply rise in the night from Saturday, 1 June 2013 to Sunday, 2 June

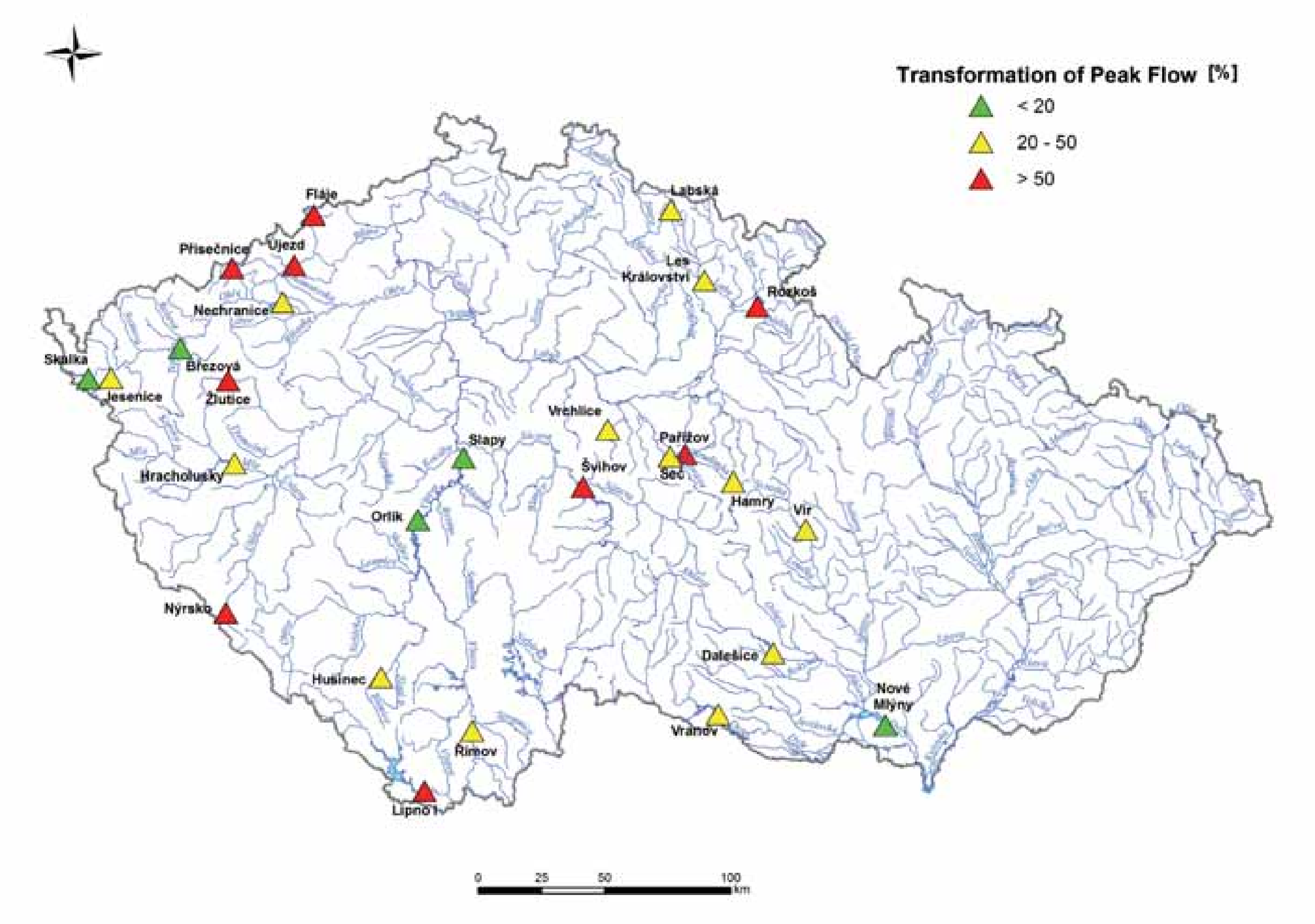


Fig. 4.1 Locations of Significant Reservoirs with Indication of Transformation Effects.

2013, and in roughly 24 hours, the inflow already reached its peak of 2,160 m^3.s^{-1}, i.e. practically the 100-year flood level.

The rising limb of the flood was very steep, which was caused, among other things, by (i) the distribution of causal rainfall, which hit the lateral inflows to the reservoir, and (ii) the atypically rapid progression of flood on the Lužnice River.

The outflow from the reservoir was controlled with regard to the situation on the Vltava River in Prague and progression of the Sázava and Berounka River flow. At the beginning the flood water was captured in the reservoir so as to maintain the stage in Prague allowing necessary flood protection measures to be taken. The outflow from the reservoir was robustly increased in the afternoon of 2 June 2013 and was further controlled for the Vltava River flow at Prague-Chuchle not to exceed 2,900 m^3.s^{-1}. On the next day, the peak of the flood from the Sázava River was eliminated by a temporary reduction of the outflow, but at the expected culmination of the Berounka River, the retention capacity of the reservoir was already exhausted. On 3 June 2013 at 5:30 p.m. CEST, the reservoir level reached 353.58 m above sea level, i.e. 2 cm below the Maximum Permissible Level, and the outflow from the reservoir had to be increased for the level not to rise any more. The maximum outflow of 1,950 m^3.s^{-1} from the Orlík reservoir occurred in the night from Sunday, 3 June 2013 to Monday, 4 June 2013, and the corresponding Vltava River peak flow in Prague reached 3,040 m^3.s^{-1}.

Further operations took place in the flood falling phase as required to improve the situation on the lower reaches of the Vltava and Elbe Rivers. At the same time and in accordance with the Resolution of the Central Crisis Management Group and Central Flood Committee on 7 June 2013, a free volume was being formed in the res-

Fig. 4.2 Lipno I Reservoir – Aerial View of 4 June 2013 (Source: Povodí Vltavy, s. p.).

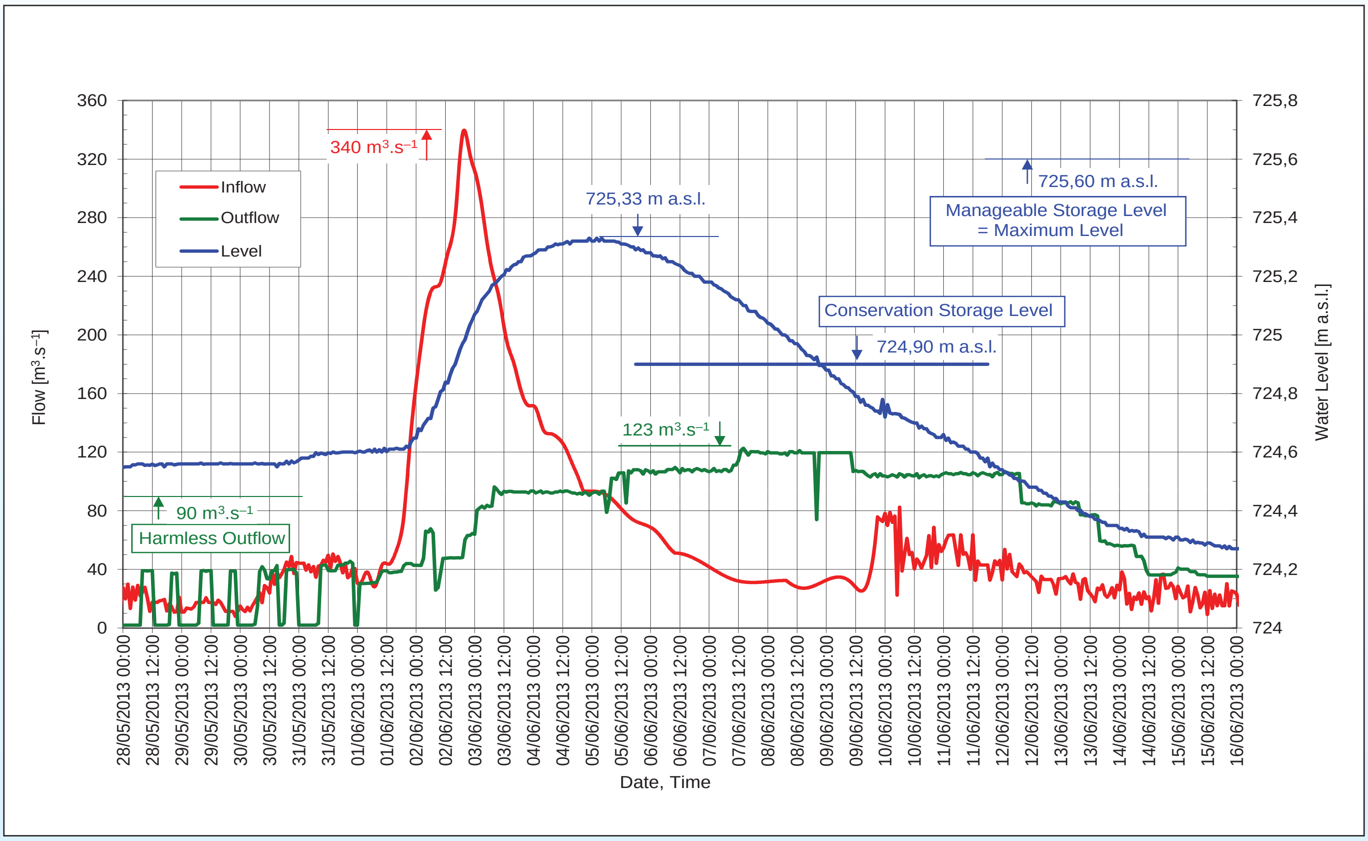


Fig. 4.3 Lipno I Reservoir – Time-Course of Reservoir Inflow, Outflow and Water Level.

ervoir considering the unfavourable precipitation forecast for the following days and the possibility of arrival of the second flood peak.

The retention capacity of the reservoir was used to the maximum extent possible, corresponding to the hydrological forecast, flood parameters, outlet and safety equipment capacity and situation on the streams down from the reservoir. The peak inflow of 2,160 m³.s⁻¹ into the reservoir was reduced by 210 m³.s⁻¹ (almost 10 %). However, the main effect of the reservoir consisted in delaying the onset of the flood on the Lower Vltava River stretch and providing time for the implementation of needed flood protection measures in Prague. Since the Maximum Permissible Water Level was almost reached in the reservoir, mobile flood barriers were constructed on the platform of the dam so as to protect the internal volume of the dam against potential flooding, (as was the case in 2002).

Slapy Reservoir

At the Slapy reservoir, there was a normal operating situation before the flood arrival, with the exception of the ongoing major overhaul of the right bottom outlet. Flood control storage was delimited in the reservoir, and the flood wave was not significantly transformed. Operations were managed in direct relation to (i) the handling operations carried out at the Orlík and Kamýk reservoirs and (ii) the inflow from smaller streams from interbasins. The peak inflow of 2,020 m³.s⁻¹ into the reservoir corresponded to the range of Q_{50} to Q_{100}. The maximum water level in the reservoir rose to 270.83 m above sea level, which was 23 cm above the Maximum Permissible Level approved by the Water authority. The exceedance was caused by a sudden increase of the inflow from the sub-basin between the Orlík reservoir and Slapy reservoir dam, to which it was not possible to respond in time.

According to the Resolution of the Central Flood Committee and Central Crisis Management Group of the Czech Republic of 7 June 2013, after the first flood peak was reached, the water level was lowered and a portion of the conservation storage was released to capture potential further increased flows. However, the effect of further

Fig. 4.4 Orlík Reservoir – Aerial View on 4 June 2013 (Source: Povodí Vltavy, s. p.).

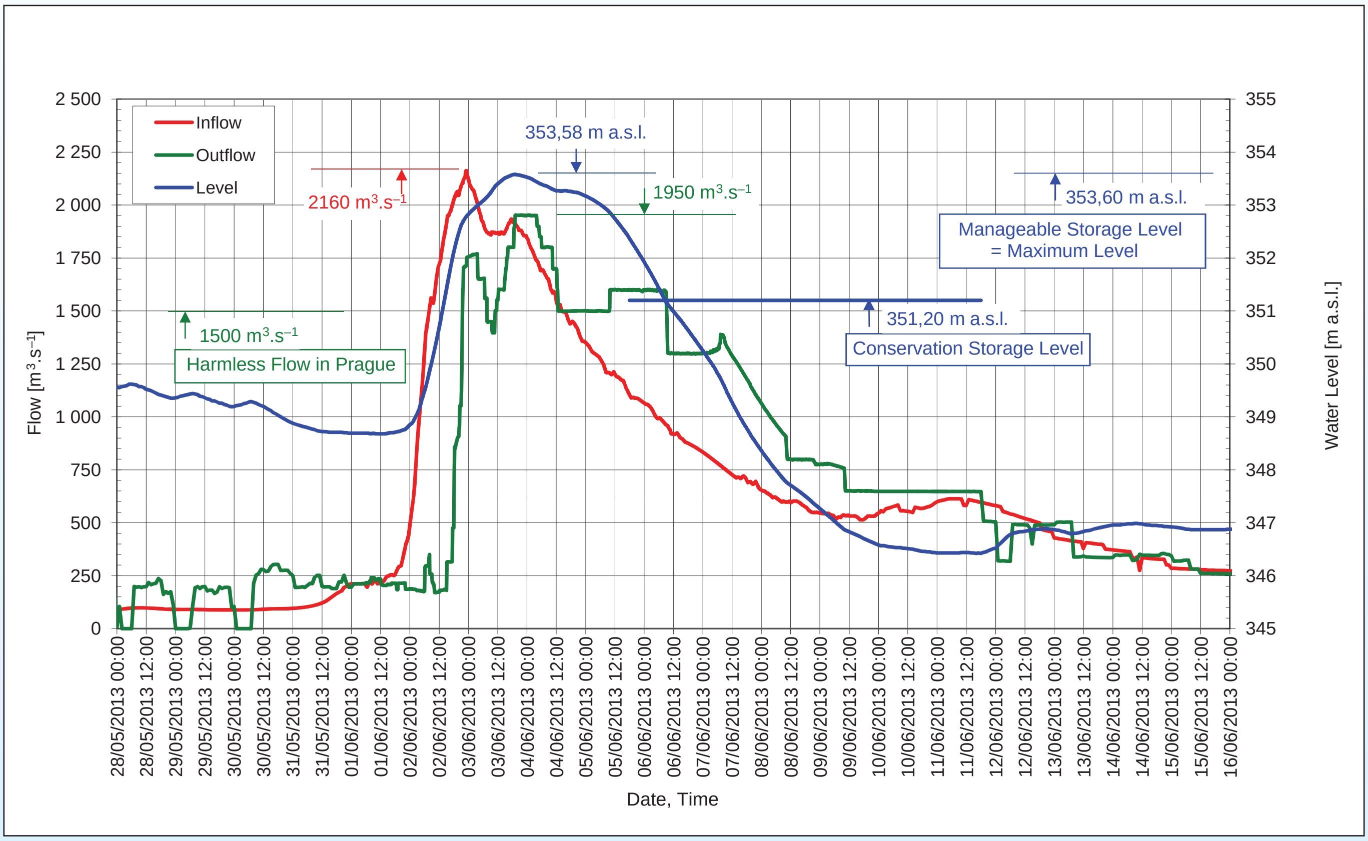


Fig. 4.5 Orlík Reservoir – Time Course of Inflow, Outflow and Water Level.

rainfall episodes did not anymore significantly manifest itself on the Vltava River. The overall retention influence of the Slapy reservoir in June 2013 was minimal.

The flood progression again confirmed that the protective effect of the Vltava River Cascade reservoir and other reservoirs, located in the river basin, on the Vltava River in Prague is limited when it comes to the large flood events.

Švihov Reservoir

The Švihov reservoir on the Želivka River is an important water reservoir whose main purpose is to supply drinking water to Prague, and a partial reduction of flood discharge is just a secondary purpose of this reservoir. The reservoir does not have any defined manageable protective volume nor is any harmless outflow defined for this reservoir. However due to the large surface area, the unmanageable flood control storage above the crest of the shaft spillway is quite significant and efficient. Before the beginning of the flood, the reservoir water level was 8 cm below the conservation storage level, i.e. the conservation storage was almost full.

The flood rise occurred in the night from 1 June 2013 to 2 June 2013 and reached its peak inflow of 104 $m^3.s^{-1}$ during the next night, i.e. approximately at the two-year flood level.

Operations for reducing the flood flows are limited in any reservoir without the manageable flood control storage. At the beginning of the flood, the outflow through the bottom outlets was increased up to 15 $m^3.s^{-1}$. After the conservation storage of the reservoir was filled, the level continued to rise, and the outflow through the shaft spillway gradually increased. However at the same time, an increasing portion of the flood volume was captured in the unmanageable flood control storage. After reaching an outflow of approximately 50 $m^3.s^{-1}$, the bottom outlets were closed, and an unmanageable state occurred.

The reservoir water level rose up to 377.61 m above sea level, meaning only 61 cm of the unmanageable volume were thus used. However, this was sufficient for the peak inflow of 104 $m^3.s^{-1}$ to be reduced to approximately one half (50 $m^3.s^{-1}$).

Fig. 4.6 Slapy Reservoir – Aerial View of 4 June 2013 (Source: Povodí Vltavy, s. p.).

Les Království Reservoir

At the Les Království reservoir on the upper Elbe River near Dvůr Králové nad Labem, the flood protection is the main purpose of the reservoir, and the structure of the reservoir storage, which varies throughout the year, corresponds to this purpose.

In summer, the defined manageable protective volume of the reservoir amounts to 4.449 million m^3, and in winter and ice-cover periods, it is slightly higher. In June 2013, the reservoir was significantly burdened with floods twice, during the first and third flood episodes.

Before the onset of the first flood episode in the night from 1 June to 2 June 2013, the reservoir had been partly drained by 1.6 m, and as such, there was an additional free storage of approximately 0.5 million m^3. However, the inflow rise was very steep, and even though the outlets were opened to the level of harmless outflow of 90 m^3.s^{-1}, the reservoir rapidly filled. Therefore early in the morning, the Regional Flood Committee of the Hradec Králové Region permitted extraordinary operation consisting in (i) an increase of the outflow from the Les Království reservoir over a harmless outflow up to 150 m^3.s^{-1}, and (ii) a temporary decrease of the outflow from the upstream Labská reservoir by 35 m^3.s^{-1}. The flood wave at the inlet to the Les Království reservoir reached a peak flow of 308 m^3.s^{-1} at the level of a 50-year flood, and the maximum outflow from the reservoir reached 156 m^3.s^{-1}. The maximum water level in the reservoir rose to 29 cm below the level of the safety spillway.

Fig. 4.7 Švihov Reservoir – Combined Structure with Shaft Spillway (Source: VODNÍ DÍLA – TBD a. s.).

The Les Království reservoir significantly influenced the flood on the upper reach of the Elbe River. The peak inflow, corresponding to a 50-year flood, was reduced by the transformation effect of the reservoir to approximately one half. Strict operation under the Rules without performing any extraordinary operation would have resulted in filling the manageable volume of the reservoir, and it is possible to estimate that with the given shape and volume of the flood hydrograph, the maximum outflow from the reservoir would have reached 180–200 m^3.s^{-1}.

The flood in the following precipitation episode on 25 June 2013 was substantially lower and its peak flow amounted to 74 m^3.s^{-1}. Before its onset, the conservation storage of the reservoir was partially drained by 1.15 m.

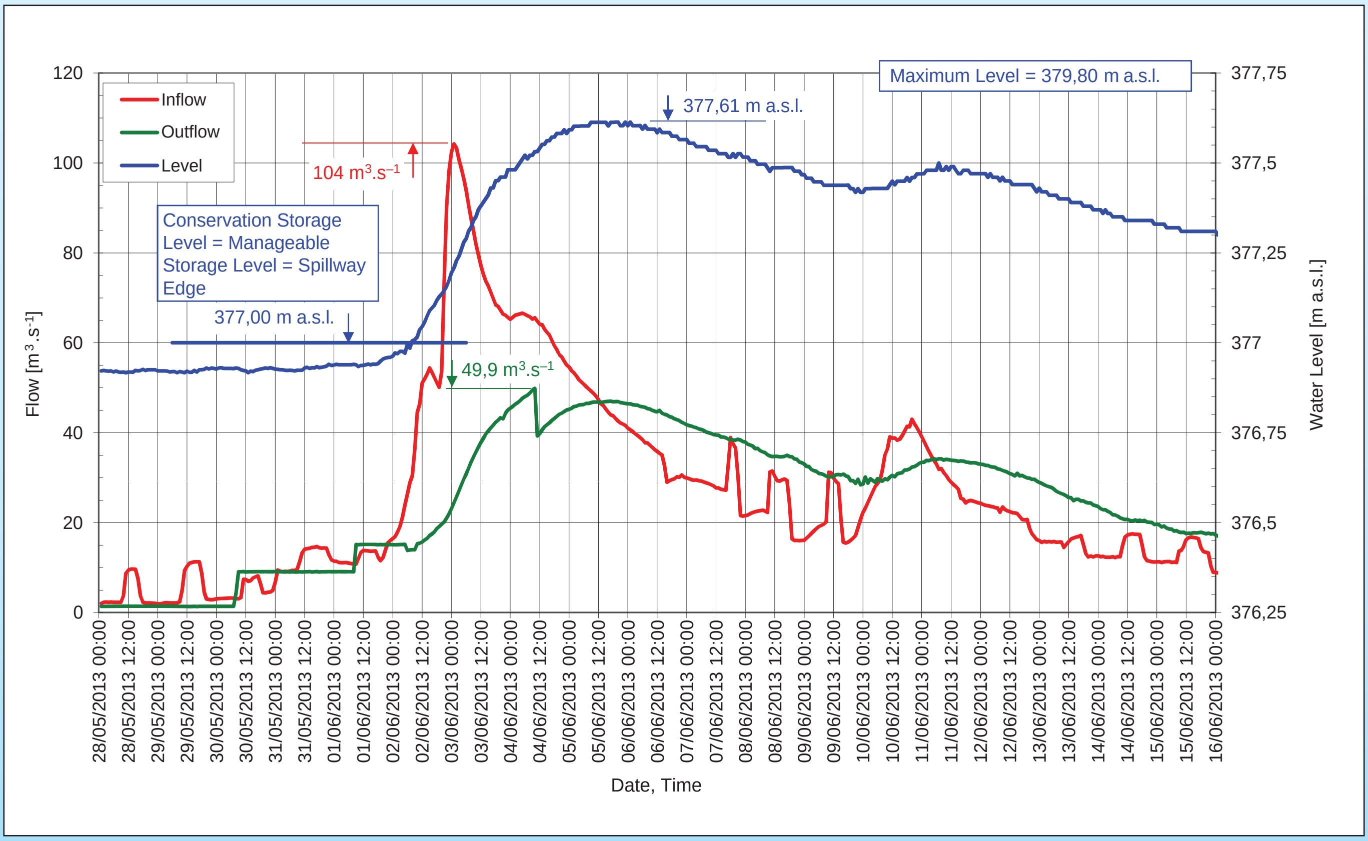


Fig. 4.8 Švihov Reservoir – Time-Course of Inflow, Outflow and Water Level.

Since the inflow did not reach even the harmless outflow level, it was decided not to fill the flood control storage of the reservoir in view of the situation downstream of the reservoir. The outflow from the reservoir was almost the same as the inflow and reached a maximum of 71 m^3.s^{-1}.

Fig. 4.9 Les Království Reservoir – Reservoir Filled up to Safety Spillway Level (Source: VODNÍ DÍLA – TBD a. s.).

Nechranice Reservoir

The Nechranice reservoir significantly influences the flow conditions on the Lower Ohře River. The delimited manageable flood control storage of the reservoir amounts to 36.562 mil. m^3, and considering the reservoir area, the reservoir also has a relatively large unmanageable flood control storage. The substantial limit of the protective effect of the unmanageable flood control storage however consists in the limited function of the safety spillway closure, where all three fields must be opened if the water level exceeds 271.90 m above sea level. This means that the unmanageable flood control storage cannot be used until the outflow is greater than approximately 890 m^3.s^{-1}, i.e. during the floods with an extremely small probability of occurrence (the value of Q_{100} untransformed by the reservoir reaches 753 m^3.s^{-1}). For common floods, the height of 271.90 m above sea level practically represents the Maximum Permissible Water Level in the reservoir.

The flood at the inlet to the reservoir gradually rose from 31 May to 3 June 2013, and in the evening, it reached its peak flow of 356 m^3.s^{-1} (5-year flood). The outflow from the reservoir was gradually increased to a harmless outflow of 170 m^3.s^{-1} (on 3 June 2013 in the morning). According to the estimate of the flood remaining volume, compared with the then free manageable protective volume, the outflow was gradually increased up to 260 m^3.s^{-1}. The maximum water level in the reservoir reached 271.72 m above sea level, i.e. 18 cm below the maximum level of the manageable volume.

The Nechranice reservoir had a significant retention effect during the flood in June 2013. By using almost the whole manageable protective volume, the maximum inflow of 356 m^3.s^{-1} was reduced by 27 %.

The harmless flow on the Lower Ohře River downstream of Nechranice was exceeded for a period of several days, and the Nechranice reservoir still significantly

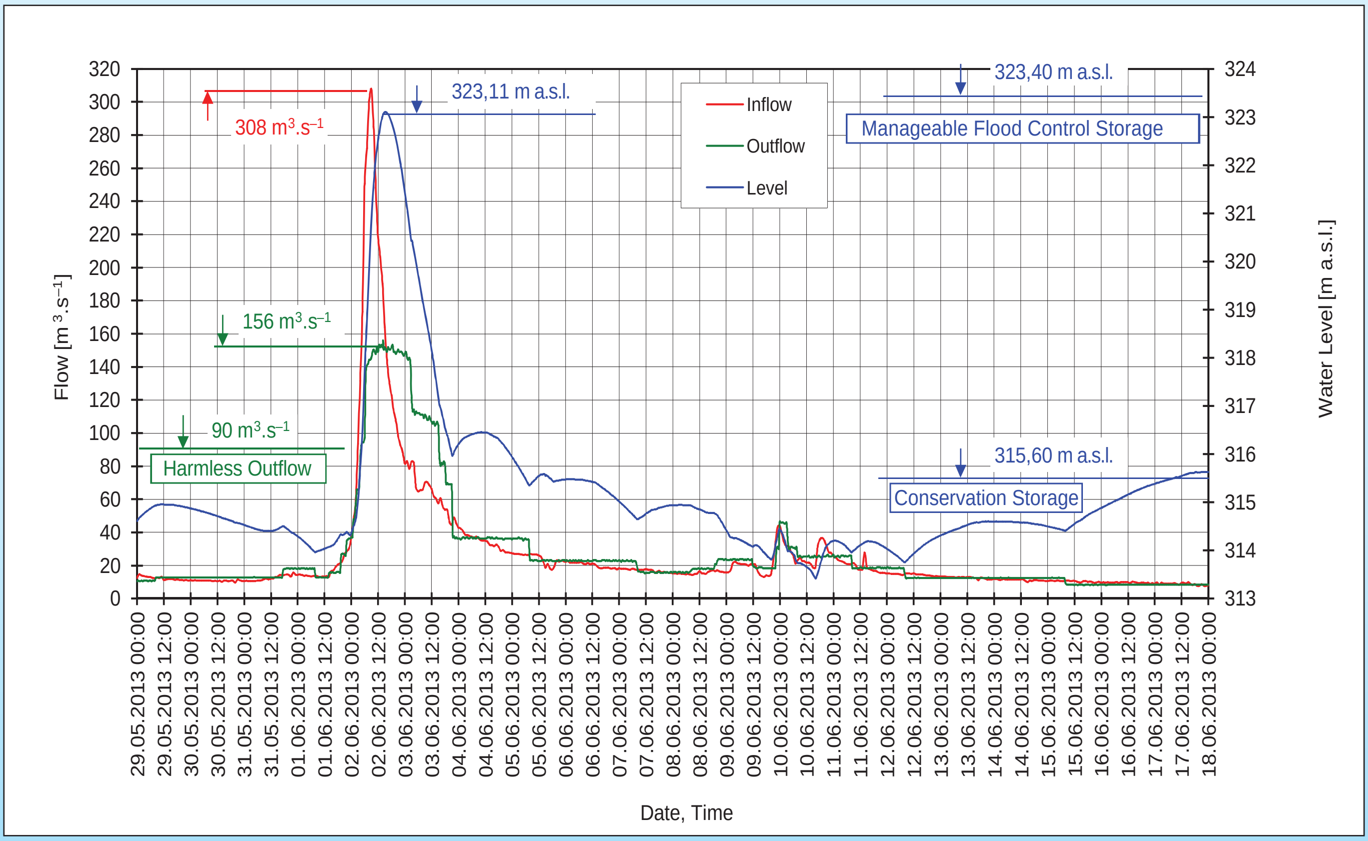


Fig. 4.10 Les Království reservoir – Time-Course of Inflow, Outflow and Water Level.

contributed to the mitigation of flood damage and partially protected the town of Terezín.

All major reservoirs safely transformed all floods in June 2013 and no events or phenomena that would jeopardize the stability and safety of reservoir dams were reported anywhere. At some reservoirs (Slapy, Štěchovice, Vrané, Hostivař), the Maximum Permissible Water Level approved by water authorities was exceeded; however, the Maximum Safe Level, which is defined in the expertises on safety of reservoirs during floods, was not exceeded anywhere. The Hostivař reservoir was closest (29 cm) to the Maximum Safe Level, and some extraordinary preventive measures were also taken there to establish the dam safety.

Fig. 4.11 Nechranice Reservoir – Aerial View of 5 June 2013 (Source: Povodí Ohře, s. p.).

4.2 Small Reservoirs

Any larger flood results in an accidental damage to some small reservoirs, especially ponds, where their owners or administrators do not pay enough attention to their safe condition and function during floods. When evaluating the floods in June 2013, 48 small reservoirs were assessed in terms of technical safety supervision. As a result of the floods, breakdowns of 14 small reservoirs were recorded, of which there were seven cases when the dam burst caused a special flood downstream of the reservoirs. Such breakdowns occurred at four ponds in the Central Bohemian Region, and in each of South Bohemian, Ústí nad Labem and Zlín Regions (Komňa na Koménce), there was one pond affected by such a breakdown. The most frequent reason for the breakdown was the pond dam overflow due to the insufficient capacity or clogging of the spillway or due to the fact that the spillway was not opened on time.

On the contrary, a number of small reservoirs captured a portion of the flood volume and positively influenced the flood progression. In particular, this applies to the ponds with a large innundated area, which formed an unmanageable flood control storage during the water level rise, such as Bezdrev and Rožmberk ponds, Máchovo lake, Žinkovský pond on the Úhlava River, Vavřinec pond on the Výrovka stream and also Jordán pond, which was empty and under reconstruction during the floods. Both

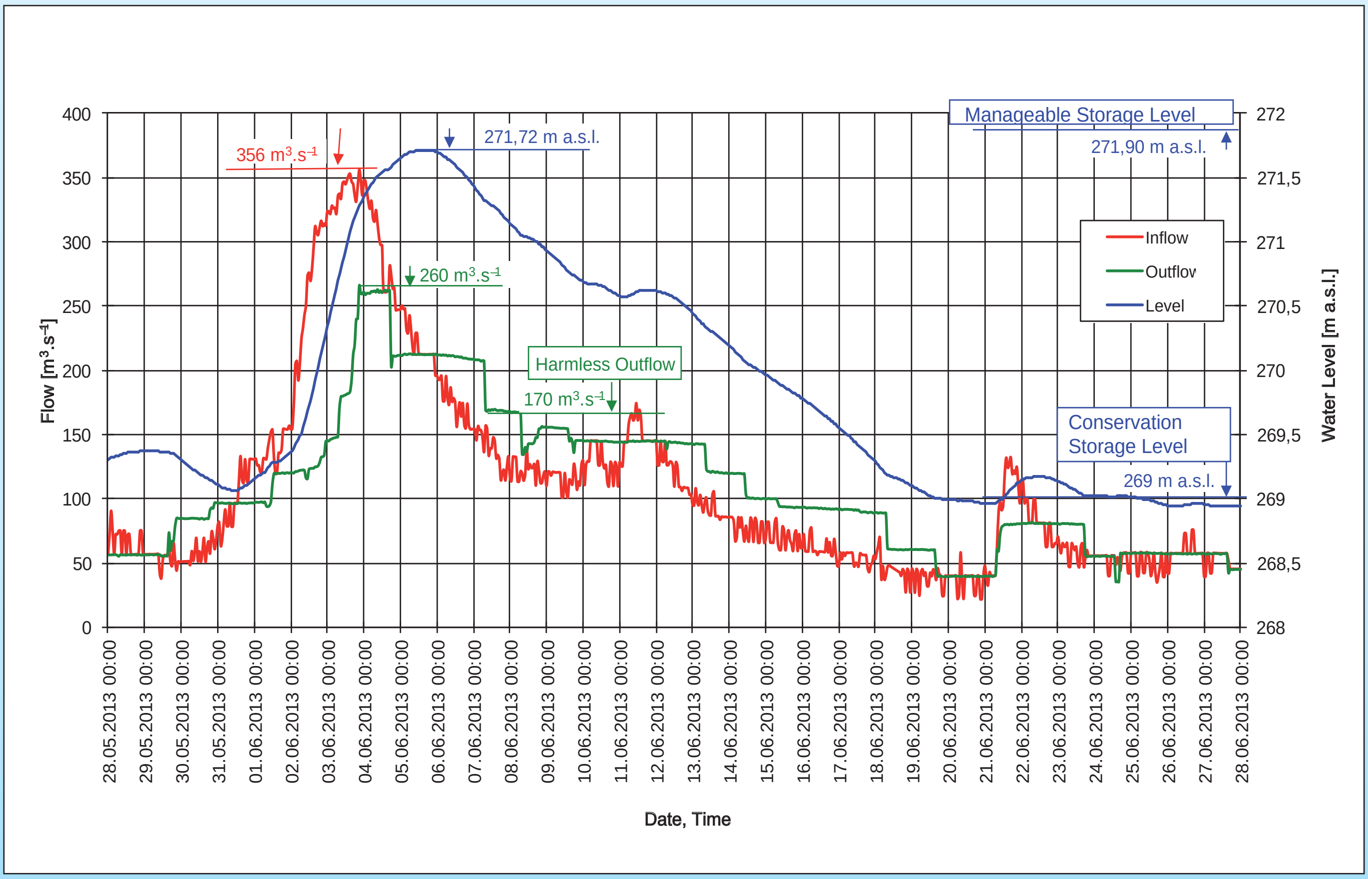


Fig. 4.12 Nechranice Reservoir – Time-Course of Inflow, Outflow and Water Level.

the assessed Onomyšl polders on the Onomyšl stream (in the Výrovka catchment area) and the Hamr-Rudý Sever polder on the Bílý and Zálužanský stream (in the Bílina catchment area) had positive effects. However, in all the cases, it meant only a local influence on the flood progression.

4.3 Flood Protection Measures

When evaluating the floods in 2013, a set of 69 flood protection measures applied to the affected watercourses was assessed. These were mainly linear flood protection measures and other related elements. The flood protection measures implemented after 2002 and possibly also related measures completed before were evaluated. The evaluation included the flood protection measures that were under construction in June 2013.

In the period between 2002 and 2013, a number of flood protection measures were implemented in the form of construction. In Prague itself, the construction was divided into 8 phases, which include linear structures with a total length of 17.5 km, of which almost 6.4 km are formed by mobile flood barriers. Phase 1, i.e. the mobile wall on the Smetana embankment and town quarter of Josefov, was already in service during the flood in August 2002 and protected the Old Town from flooding. After that flood, the design parameters of flood protection measures in Prague were adjusted for the 2002 water level with a safety margin of 30 cm.

After the 2002 flood, the preparation and implementation of other flood protection measures were accelerated in all regions of the Czech Republic. As compared with the past, an unusually large range of measures were supported by the funds from the State Flood Prevention Programme administered by the Ministry of Agriculture. Most funds were invested in the stabilization and enhancement of capacity of watercourses and dikes, as well as in the construction of retention volumes. Following the example of Prague, mobile flood barriers were quite frequently used also in other cities, which was probably influenced by offers made by manufacturers of such equipment. A number of those flood protection measures were completed or were under construction during the floods in June 2013, and within the evaluation of those floods, their functionality could be assessed.

Fig. 4.13 Dredging of Lateral Dam of Chotouchovský Pond on Polepka Stream, 2 June 2013 (Source: VODNÍ DÍLA – TBD a. s.).

Fig. 4.14 Mlékovický Pond on Bečvárka Stream – View of Area below Dam through Gap – 5 June 2013 (Source: VODNÍ DÍLA – TBD a. s.).

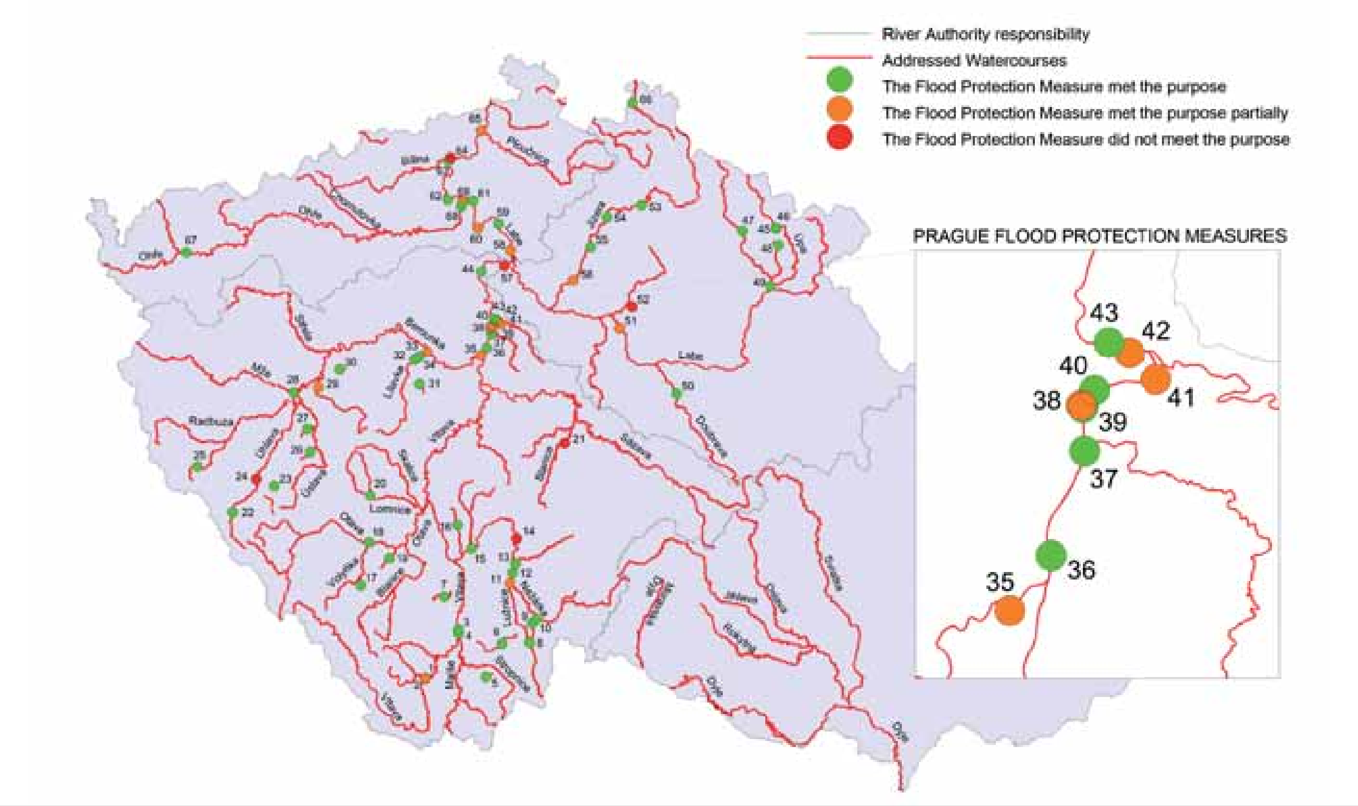


Fig. 4.15 Assessed Flood Protection Measures with Indication of Assessment Results.

The locations of the assessed flood control measures are shown in Fig. 4.15. Most of them, more specifically forty-four measures, are located on the streams administered by Povodí Vltavy, s. p. Twenty-two measures are administered by Povodí, s. p. and three measures are administered by Povodí Ohře, s. p.

Each flood protection measure was assessed in terms of compliance with the required level of protection or reasons for non-compliance. The flood control measures that were not completed at the time of the floods were registered separately. The summary results of the evaluation are presented in Tab. 4.2. Out of the total of evaluated flood protection measures, 45 measures were fully functional. In the case of 9 flood protection measures, there were malfunctions caused by various reasons or their design parameters were exceeded due to the flood magnitude. Fifteen measures had not yet been completed and thus fulfilled their purpose only partially.

The flood control measures that failed to protect a respective territory against damage are usually perceived negatively by the public and mass media. For an objective evaluation, it is however necessary to identify the reasons why it happened:

a) When designing the levees, flood barriers and walls, the technical capabilities of a relevant location and economic parameters of the construction are considered. At some locations, it is not possible, for example due to the subsoil nature, local constraints and hydraulic conditions, to construct a channel with a suf-

Tab. 4.2 Fulfilment of Function of Flood Protection Measures during Flood in June 2013.

Catchment Area	Number of Evaluated Measures	Completed Measures			Incomplete Measures
		Fulfilled Function of Protection	Reasons for Failures of Protective Measures		
			Exceedance of Design Parameters	Partial Fulfilment / Problems	
Elbe	22	11	2	2	7
Vltava	44	32	1	4	7
Ohře	3	2	0	0	1
Total	**69**	**45**	**3**	**6**	**15**

ficient capacity or levees or flood walls high enough to protect the area against a 100-year or larger flood. At other locations, the costs of any such construction would significantly exceed the value of protected property, and therefore, it is not economical to design such a level of protection. It may result in the implementation of flood protection measures at a lower level of protection, for example for a 20- or 50-year flood. If a larger flood hits, the flood levee will be overflowed and the area will be flooded. It however complies with the adopted measure, and the Flood Protection Plan of the relevant municipality must take it into account. The exceedance of the designed flow resulted in the levee overflow in Veltrusy and Hořín on the Vltava River, and in Mělník (Vinařství), Křešice, Roudnice, Ústí nad Labem-Střekov and partially in Děčín on the Elbe River in June 2013.

b) Where fixed levees or walls are not acceptable, especially in the national heritage sites, mobile barriers are designed and installed only before flood arrival. However, the protection using the mobile flood protection measures to a larger extent is operationally difficult and requires time and capacities so that the mobile flood barriers are installed on time. However, the flood arrival may be faster than the time required for the delivery and installation of mobile elements. Therefore, the town of Bechyně was flooded because water from the Smutná River came faster than a mobile wall could be built. Problems were also in Prague, where the length of mobile flood barriers is enormous, and as such, during the rapid-onset flood, there was a situation where some sections were built at the latest moment. The last section, i.e. Section 72 of Smíchov – Railway Bridge – North, was completed approximately 66 hours after the instruction for construction was released and 18 hours after the Vltava River reached its peak flow in Prague. It is necessary to add that the onset of flood in Prague can be even faster. The hydrologists and water managers have always pointed out the precedent flood of 1872, which occurred in the lower reach of the Berounka River basin and arrived in Prague within some 18 to 24 hours, which is too fast to complete the construction of mobile flood barriers.

c) During any flood, there are also technical problems of flood protection measures. Common problems are the function of backflow valves in the sewerage system (e.g. in Prague-Zbraslav and Radotín), materials leaking from the dikes or banks or their basement on Prague's Kampa Island, leaks (Dýšina and Nová Huť on the Klabava stream) or other technical failures (Roudnice nad Labem). Failures of this type are to be remedied immediately.

d) In Prague, the complex of flood protection measures as a whole has achieved its purpose, and the areas designated for protection were not flooded. The exceptions were only local problems caused especially by extreme flows in the tributaries of the Vltava River (Botič, Rokytka) or a malfunction of measures relating to the sewerage system. The most serious problem was the situation at the mouth of the Rokytka stream into the Vltava River in the area of Libeň ports, where the long-lasting flood inflow of the Rokytka stream exceeded the capacity of pumps (20 $m^3.s^{-1}$) designed for pumping the Rokytka stream water into the Vltava River in case of the closed flood gate. The Rokytka stream level thus rose higher than assumed for the engineering design of the pumping station.

e) A number of flood protection measures for the areas affected by floods were just under construction with various progress. Therefore, at some places, they could not fulfil their planned function (e.g. Český Krumlov, Planá nad Lužnicí, Zálezlice, left bank of the Elbe River in Ústí nad Labem); however at other locations, they have already partially or fully fulfilled their protective function (e.g. Veselí nad Lužnicí, Králův Dvůr, Beroun, Mělník, Terezín, Děčín).

Obr. 4.16 Mobile Flood Control Barriers along the Vltava River in České Budějovice (Photo by Libor Sváček).

Fig. 4.17 Mobile Flood Barriers along Lužnice River in Bechyně (Source: VRV a. s.).

Fig. 4.18 Mobile Flood Barriers in Prague downstream of Charles Bridge (Photo by Jan Kubát).

Fig. 4.19 Closed Outlet of Čertovka Channel in Prague (Source: VRV a. s.).

Fig. 4.20 Prague-Libeň – Pumping of Rokytka Stream Water to Vltava River (Source: VRV a. s.).

Fig. 4.21 Mobile Flood Barriers in Prague – Holešovice (Source: VRV a. s.).

5. FLOOD IMPACTS

5.1 Rescue and Emergency Works

Following the flood progression and degree of risk, the individual communities and municipalities with extended competence declared the states of Flood Activity, the local flood protection authorities and components of the Integrated Rescue System were activated and necessary actions were taken. However, the flood quite quickly grew into a crisis situation, where people's life, health and property were at risk, and the management of measures was gradually taken over by the crisis management authorities. The State of Danger under the Crisis Act was declared by the Lord Mayor of the Capital City of Prague at 09:45 a.m. on 2 June 2013 and by the Governor of the South Bohemian Region at 8:00 p.m. In the same evening at 09:00 p.m., the Government of the Czech Republic declared the State of Emergency for six Regions (South Bohemian, Pilsen, Central Bohemian, Hradec Králové, Ústí nad Labem and Liberec Regions) and the area of the Capital City of Prague. During the declaration of the State of Emergency, a joint meeting of the Central Flood Committee and Central Crisis Management Group of the Czech Republic was held. Similarly, meetings of lower-level crisis management and flood protection authorities were held.

Central coordination of rescue and first response recovery works was taken over by the Ministry of the Interior – General Directorate of the Fire Rescue Service of the Czech Republic, and all components of the Integrated Rescue Service, volunteer firefighter corps,

Tab. 5.1 Declaration and Withdrawal of State of Danger and Emergency.

	Declaration of State of Danger (Regional level)		Declaration of State of Emergency (National level)		Withdrawal
	Date	Hour	Date	Hour	Date (24:00)
Capital City of Prague	2 June 2013	09:45	2 June 2013	21:00	19 June 2013
South Bohemian Region	2 June 2013	20:00	2 June 2013	21:00	19 June 2013
Pilsen Region			2 June 2013	21:00	19 June 2013
Central Bohemian Region			2 June 2013	21:00	28 June 2013
Hradec Králové Region			2 June 2013	21:00	28 June 2013
Ústí nad Labem Region			2 June 2013	21:00	28 June 2013
Liberec Region			2 June 2013	21:00	12 June 2013

Fig 5.1 Intervention of Firefighters in Prague-Chuchle (Source: Prague - Velká Chuchle Municipality).

Police of the Czech Republic, municipal police teams, Army of the Czech Republic, Medical Emergency Service and others were engaged. During the floods, 19.5 thousand firefighters, 10 thousand policemen (excluding municipal police) and two thousand soldiers were deployed. To support the management and performance of rescue operations, helicopters of the Aviation Service of the Police and Army of the Czech Republic were also deployed.

During the June floods, more than 26 thousand people were evacuated in the territory of a total of 105 municipalities in seven regions and in the Capital City of Prague. Most people were evacuated in the Central Bohemian and Ústí nad Labem Regions, approximately 12 thousand people in each of them. In Prague, approximately 1,280 people were evacuated. A total of 20 thousand people were evacuated in a controlled manner with the participation of firefighters or policemen. The evacuated buildings also included buildings designed for recreation or short stays, such as the rock festival campsite in Pilsen, campsite in Karlštejn, outdoor school in Svatý Ján etc. It was also necessary to evacuate some social and medical service facilities, such as the Senior's Home in Beroun, Social Services Home in Zásmuky, Homeless Shelter in Litoměřice, Medical Emergency Service in Lovosice and Na Františku Hospital, which is located directly on the Vltava River embankment in Prague. Some animals in the Prague Zoo also had to be evacuated.

618 persons in jeopardy of life as a result of floods were immediately rescued. In connection with the floods, 51,100 emergency calls were received.

Flood events also bring along negative social phenomena, such as commitment of various crime types. In particular, this includes the looting of buildings in the evacuated areas or thefts. During the floods in June 2013, the Police of the Czech Republic recorded a total of 29 crimes in the period from 3 June to 17 June, which included 23 cases of looting, one case of physical assault, breach of duty in case of impending distress and four thefts. The vast majority of those crimes were recorded in the Ústí nad Labem Region.

5.2 Flood Damage and Social Impacts

During the floods in June 2013 or in direct connection with them, a total of 16 deaths were reported, of which 12 persons drowned and other 4 persons died as a result of the arisen situation. However, at least 5 deaths can be described as totally unnecessary because those were cases of undisciplined people who tried to kayak the swollen streams.

The floods affected in varying degrees almost 1,400 villages and towns in ten regions, including the Capital City of Prague. A total of 6,700 residential buildings (houses and blocks of flats) were hit, and subsequently, 66 buildings were scheduled for demolition. The most damaged residential buildings were located in the Central Bohemian and Ústí nad Labem Regions, and the destroyed buildings, which had to be later demolished, were located solely in the Central Bohemian Region (see Tab. 5.2). The public infrastructure of towns and villages, roads and transport structures were largely damaged.

Traffic disruption due to various traffic closures represents a significant impact of floods. During the floods in June 2013, a total of 92 traffic closures were registered, of which 84 occurred on roads and 8 on railway lines. Should the local roads in villages, which were flooded for a short period of time, be taken into account, the total number of closures would be probably much higher. Reduced traffic on both banks of the Elbe River in the section from Lovosice via Ústí nad Labem to Děčín and the road closures in Prague and its surroundings (e.g. Strakonická Street) undoubtedly ranked among the most

Fig. 5.2 Flooded Left-Bank Road in Ústí nad Labem (Source: FOTO STUDIO H s.r.o.).

Tab. 5.2 Overview of Damaged (Destroyed) Residential Buildings during Floods in June 2013.

Region	**Residential Houses**		**Family Houses**		**Total**
	damaged	**to be demolished**	**damaged**	**to be demolished**	
South Bohemia	50	0	547	1	**598**
Hradec Králové	11	0	579	1	**591**
Liberec	0	0	1	0	**1**
Pilsen	7	0	176	0	**183**
Central Bohemia	284	3	2,377	58	**2,722**
Ústí nad Labem	360	0	1,663	1	**2,024**
Capital City of Prague	145	0	451	2	**598**
Total	**857**	**3**	**5,794**	**63**	**6,717**

important traffic restrictions. Such closures were applied not only due to the direct flooding of roads, but also due to the construction of flood control measures. The Prague public transport system was also significantly reduced, especially due to the interruption of some tram and bus lines and closure of some underground stations. Of course, the navigation was also out of operation.

The flood affected or jeopardized 210 water pipelines supplying a total of 36.5 thousand inhabitants, of which in 87 water supply pipelines, it was restricted or completely forbidden to use water for drinking purposes. Moreover, individual wells and wells designed for municipal water supply pipelines were flooded.

The Flood Reports (especially those issued by the municipalities mentioned, that the drinking water sources were hit in a total of 102 communities affected by the floods (Fig. 5.3). Fortunately, there was no epidemic due to the contamination of drinking water.

The total flood damage (costs of recovery) was estimated at CZK 15.4 billion (see Tab. 5.3) of which almost more than a quarter of damage was recorded in the Central Bohemian Region, and significant damage was also incurred in the Capital City of Prague, Ústí nad Labem and South Bohemian Regions.

The structure and categorization of affected communities according to the amount of June 2013 flood damage are presented in Fig. 5.4. The list of the most affected towns and villages is provided in Tab. 5.4. Apart from Prague, the town of Terezín at the confluence of the Elbe and Ohře Rivers was the most affected by floods (Fig. 5.5), where the damage reached almost one billion Czech Crowns. In the case of other 9 communities, the damage exceeded CZK 100 million (4 municipalities in the Ústí nad Labem Region, 4 municipalities in the Central Bohemian Region and one municipality in the Liberec Region). Most other municipalities which showed damage during the flood evaluation incurred relatively smaller damage in the order of several million CZK or less.

Tab. 5.3 Total Damage Caused by Floods in June 2013 (‘000 CZK).

	Housing	**Transport Infrastructure**	**Engineering Works and Utilities**	**Water Structures and Streams**	**Agriculture, Forestry and Environment**	**Other**	**Total**
South Bohemia	62,162	788,849	126,819	413,504	543,861	77,452	**2,012,647**
Hradec Králové	86,524	340,554	10,121	308,662	40,378	85,507	**871,745**
Liberec	705	464,956	6,217	74,429	8,738	13,364	**568,409**
Pilsen	5,017	148,231	12,993	58,598	26,975	27,041	**278,855**
Central Bohemia	583,932	1,722,949	269,062	660,696	245,099	609,782	**4,091,519**
Ústí nad Labem	562,627	668,400	251,714	665,157	255,652	1,119,558	**3,523,108**
Capital City of Prague	289,744	362,615	1,562,526	265,150	70,022	1,291,427	**3,841,484**
Karlovy Vary							**20,128**
Pardubice							**161,000**
Vysočina							**17,144**
Total	**1,590,711**	**4,496,554**	**2,239,452**	**2,446,195**	**1,190,725**	**2,405,179**	**15,386,555**

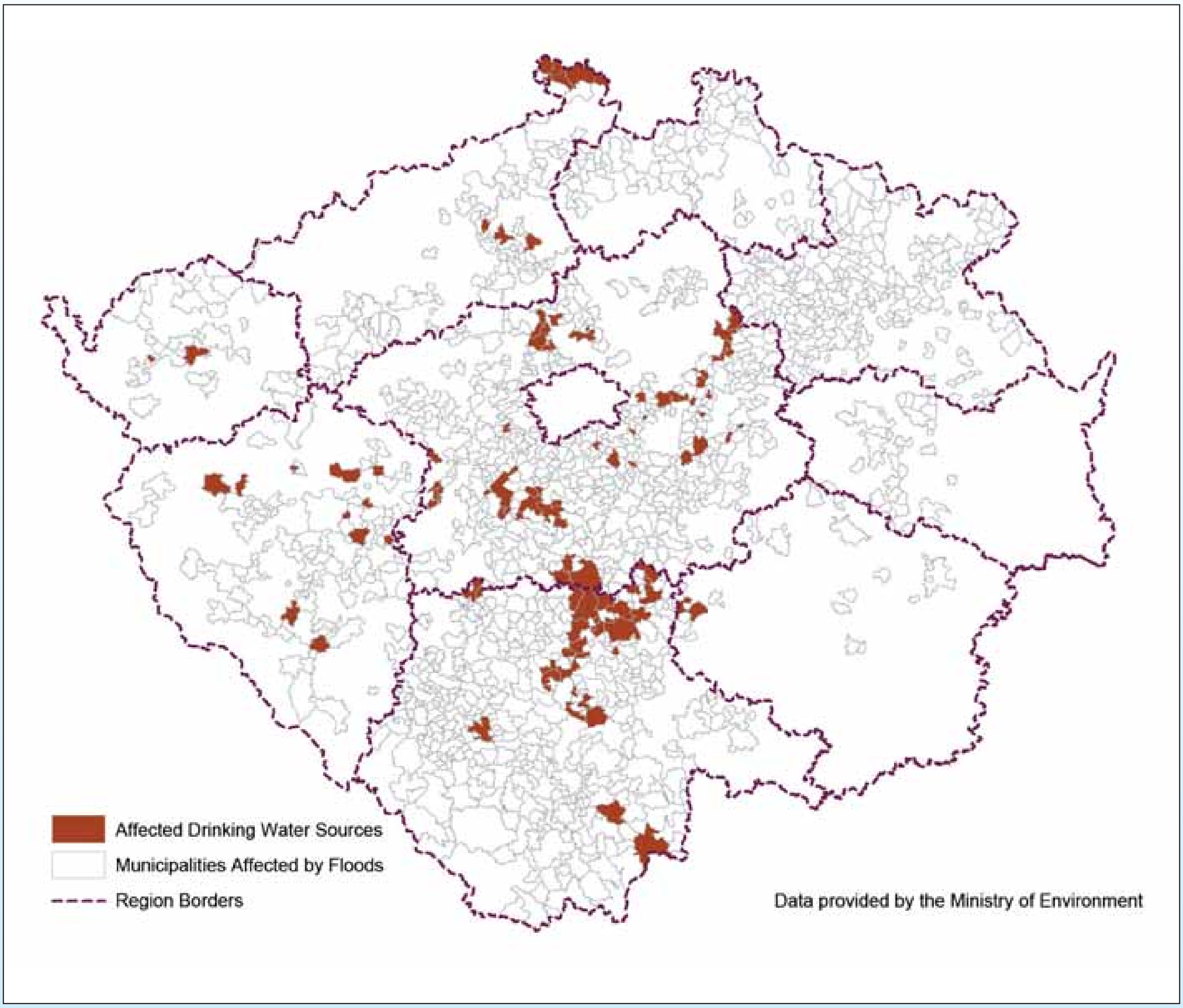


Fig. 5.3 Locations of Affected Drinking Water Sources, as Specified in Flood Reports.

Tab. 5.4 Overview of Municipalities Worst Affected by Floods in June 2013.

Municipality	Municipality with Extended Competence	Region	Total (‘000 CZK)
Prague	Prague	Prague	3,841,484
Terezín	Litoměřice	Ústí nad Labem	921,597
Kly	Mělník	Central Bohemian	265,900
Hořín	Mělník	Central Bohemian	243,360
Křešice	Litoměřice	Ústí nad Labem	231,553
Ústí nad Labem	Ústí nad Labem	Ústí nad Labem	182,898
Litoměřice	Litoměřice	Ústí nad Labem	151,756
Žatec	Žatec	Ústí nad Labem	140,030
Křižany	Liberec	Liberec	113,820
Dobřichovice	Černošice	Central Bohemian	105,500
Klecany	Brandýs nad Labem - Stará Boleslav	Central Bohemian	104,717

The largest damage was recorded in the transport infrastructure, amounting to a total of CZK 4.5 billion, which represents almost 30 % of all damage. A total of 4.5 thousand km of roads and 720 bridges were damaged. The second most affected sector was the water management, where the damage was estimated at nearly CZK 2.5 billion (16.1 %). More than one thousand kilometres of river channels and more than 350 water reservoirs and ponds were damaged. Flood debris of over 500 thousand m^3 were brought to channels and reservoirs, which will have to be removed.

Damage to engineering structures and utilities, incurred especially in Prague, was estimated at CZK 2.2 billion. Sewers were the most damaged municipal infrastructures (a total of more than two thousand kilometres). A total of 187 waste water treatment plants reported damage, and the waste water treatment process was affected by the floods at a total of 233 waste water treatment plants, including 29 large waste water treatment plants with an operating load of above 10,000 equivalent inhabitants. The waste water treatment plant operators already had experience with the previous floods, and all chemicals were secured duly in advance. According to available information, there was not any leak of activated sludge.

The floods affected some significant industrial plants, including chemical factories of Spolana, a. s., Lovochemie, a. s. and Spolek pro chemickou a hutní výrobu, a. s. However, no chemical leaks were registered at those sites.

In the area of education, health and social care, more than 180 school buildings and facilities, 22 health facilities and 29 social care homes were damaged. Dozens of cultural monuments were also damaged.

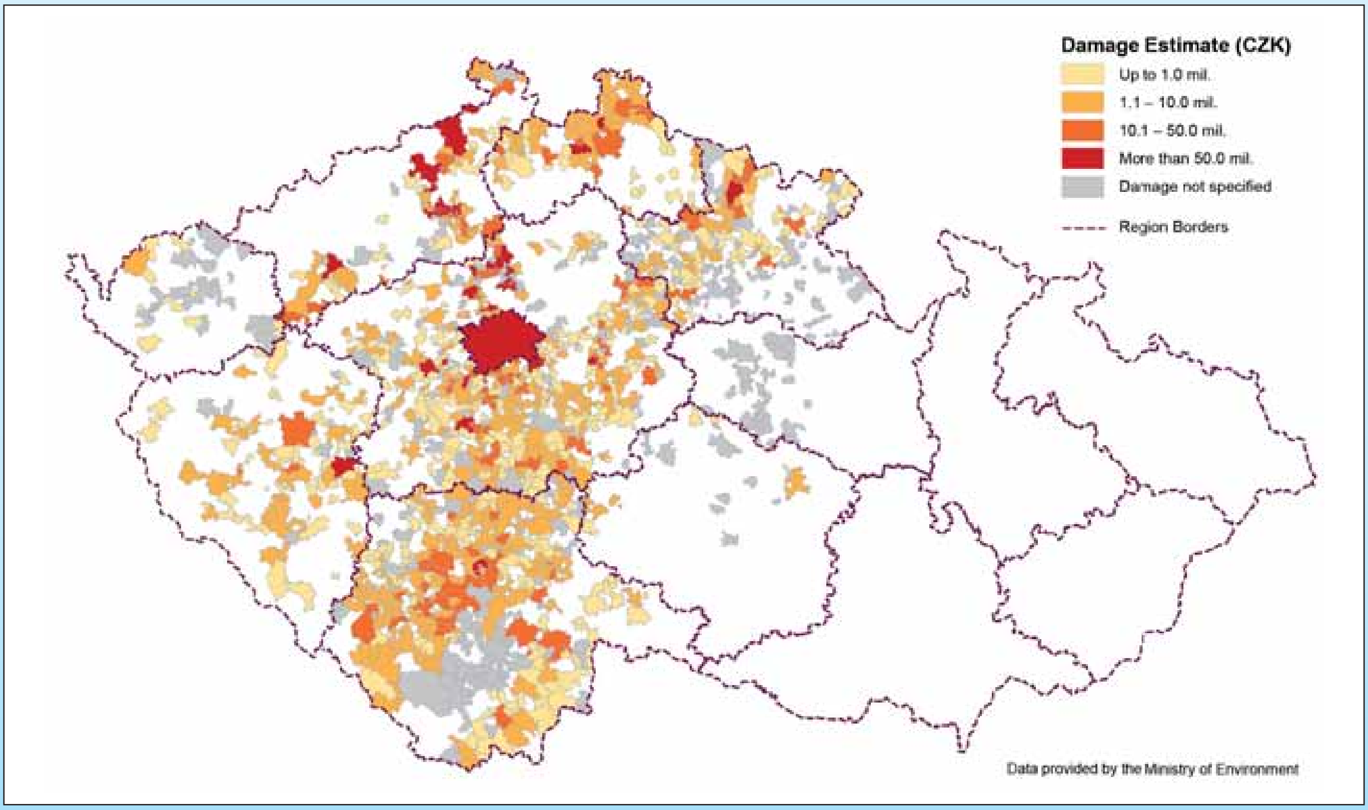
According to the Czech Insurance Association, after the floods in June 2013, a total of 38,227 insured events were reported with an estimated insurance benefit of over CZK 2 billion. Under the business insurance and crop and livestock insurance, there were a total of 6,191 insured events with an estimated insurance benefit of almost CZK 5.4 billion.

The costs of dealing with the crisis situation itself cannot be fully quantified; nevertheless, the costs of the Fire Rescue Service of the Czech Republic increased by CZK 70.6 million during the floods and immediate response of their effects. The Police of the Czech Republic quantified their costs of dealing with the flood situation to CZK 1.3 million.

There was also consumption of materials from the Administration of State Material Reserves and central inventories of the Fire Rescue Service of the Czech Republic. Subsequently, the Fire Rescue Service of the Czech Republic raised its requirement for the replenishment of materials and inventories because of their consumption during the floods in the amount of CZK 56.4 million; the Administration of State Material Reserves should be replenished in the amount of CZK 39.8 million.

5.3 Landslides

As a result of the extreme precipitation and floods, a large number of landslides and slope instabilities were also documented. After the flood, the Czech Geological Survey identified and assessed a total of 124 slope



Data provided by the Ministry of Environment

Fig. 5.4 Municipalities Affected by Floods in June 2013 and Estimated Damage in Their Areas.

Fig. 5.5 Flooded Town of Terezín, 5 June 2013 (Source: Povodí Ohře, s. p.).

instabilities, where most of them were identified in the Hradec Králové, Central Bohemian and Ústí nad Labem Regions. A total of 19 Category III slope instabilities (representing a high risk) were identified, and most of them were located in the Ústí nad Labem and Central Bohemian Regions. The extensive flow-type landslide near the village of Dobkovičky in the Ústí nad Labem Region, which disturbed the D8 Motorway construction at that location, was unambiguously the most significant recorded landslide.

The landslide occurred in the night from Thursday, 6 June, to Friday, 7 June 2013, when a flow-type landslide was formed on the southeastern slope of the Kubačka hill with an average width of approximately 200 m and a flow length of approximately 500 m on the slope. According to the study of archival data, it is clear that the landslide follows an older, already mapped slope deformation, which has dimensions similar to those of the newly formed landslide, and which is positionally located about 200 m down the slope. The head scarp of the landslide was localized in the area of the Dobkovičky quarry. As per the first rough estimate, the landslide mass volume reached 500,000 m^3. The overall cumulative horizontal shift in the axis of the landslide reached approximately 50 m. On 8 June, the landslide movement velocity reached one meter per hour, and on the next days, the landslide movement slowed down, and on 11 June at 02:00 p.m., the landslide practically stopped. The landslide was still active in autumn 2013. The railway line from Lovosice to Teplice was damaged by the landslide in the 200 m long section between the Dobkovičky and Radejčín railway stations. The construction of both lanes of the D8 Motorway was disturbed in the length of approximately 200 m.

Fig. 5.6 Aerial View of Dobkovičky Landslide on 11 June 2013 (Source: ČGS).

Fig. 5.7 Landslide Accumulation on D8 Motorway Body (Source: ČGS).

6. COMPARISON OF JUNE 2013 FLOODS WITH HISTORICAL FLOODS

At the outset of this Chapter, it is necessary to highlight probably the greatest hydrological paradox in the Czech Republic in terms of geography, where the catchment area and the average flow of the "main" reach of the Elbe River upstream of the confluence with its largest Czech tributary, i.e. the Vltava River, are roughly half. Even though this fact is determined historically and culturally, our ancestors were aware thereof and called the upper Elbe river upstream of the confluence with the Vltava River "Little Elbe" (Augustin 1891).

It is therefore quite logical that extreme floods on the Elbe River downstream of the confluence with the Vltava River are practically always caused by the swollen Vltava River, and the impact of inflows from the Upper Elbe River and Ohře River is not so significant. This is also true in the case of the evaluated floods of June 2013. Even though the information from the chronicle records of floods in Prague go back to the flood in the summer of 1118 and we know a lot of other extreme flood events that affected Prague and the whole Bohemia (e.g. floods in 1432, 1501, 1784 etc.), this Chapter focuses on comparing the causes, progression and extremity of floods of June 2013 with the floods that occurred in August 2002 and September 1890, which were also formed in the Vltava River basin and for which there are sufficient hydrometeorological data available.

6.1 Hydrometeorological Comparison of Floods of June 2013, August 2002 and September 1890

Since 1827, when systematic observations of water stages were commenced on the Vltava River in Prague, the flood in June 2013, as a summer-type flood, has ranked fourth, in view of the peak flow size. Besides the already mentioned floods in August 2002 and September 1890, the flood of May 1872 (with a peak flow of 3,330 $m^3.s^{-1}$) was also significant. However in comparison with the floods of September 1890 and August 2002, the flood of May 1872 was quite different due to the nature of causal precipitation and its progression. The peak flow was originally derived from the maximum water level upstream of the Charles Bridge. New findings however show that according to the height of flood marks at other locations in Prague and as compared with other floods, the peak flow would rather correspond to the flow ranging between 2,500 and 2,700 $m^3.s^{-1}$ (Daňhelka, Elleder et al. 2012). The water level before the Charles Bridge was increased due to accumulated flood debris, and as such, the estimated peak flow was probably overestimated. In such a case, the flood in June 2013 would rank third among the summer floods.

If we also include the winter-type floods in the flood list, then a probably larger peak flow was reached by the floods in March 1845 and February 1862 during the period of observation (Brázdil et al. 2005). The value of peak flow of the flood in March 1940, which is also larger with its size of 3,240 $m^3.s^{-1}$ than the peak flow of the flood in June 2013, is also burdened with great uncertainty due to backwater triggered by ice jams (Kakos, Kulasová 1990). According to the authors of the article, the actual flow rate was rather about 500 $m^3.s^{-1}$ less.

The flood of May 1872 will be mentioned only briefly. It is known that it was caused by extraordinarily extreme torrential rainfall over an unusually large area, which hit the catchment areas of the tributaries of the Berounka River between Pilsen and Prague, especially the Střela and Litavka Rivers. Due to the nature of the causal precipitation, the flood progression was very fast. In Beroun on the Berounka River, it had been the largest flood at least since the early 19th century. The extreme water inflow from the Berounka River accompanied by an enormous amount of flood debris caused Prague to record an approximately 50-year flow on the Vltava River. In terms of the causes and progression of this flood, it was however an event whose probability of occurrence cannot be reliably determined. The flood caused the loss of hundreds of people's lives and massive damage to property (Daňhelka, Elleder et al. 2012). On the other hand, it was one of the factors that influenced the decision on the establishment of the Hydrographic Commission of the Kingdom of Bohemia in 1875, which resulted in a large expansion of the network of rain gauges and water gauges.

What is also interesting is the fact that the 1872 flood is often mentioned by hydrologists and water managers as a memento towards the Prague flood protection, particularly with regard to its very rapid onset (18–24 hours).

The flood in July 1954 was also a large flood on the Vltava River in the 20th century. This event is known in particular for the flood progression in Prague being very significantly influenced by the Slapy reservoir, which was nearly finished at that time, but not yet completely filled. This resulted in a reduction of the peak flow in Prague to 2,260 $m^3.s^{-1}$ while an estimated nature flow was 2,920 $m^3.s^{-1}$ (see Bratránek 1956). In the same publication, it is mentioned that in the Slapy reservoir, the volume of 90 mil. m^3 was used for the flood transformation (the total volume of the Slapy reservoir is 269.3 mil. m^3). For comparison: the free volume in the Vltava River cascade reservoirs available before the onset of the 2013 flood reached a total of 180 mil. m^3, of which 121.5 mil. m^3 were available in the Orlík reservoir. What is also interesting is the mentioned rapid flood progression as a result of rainfall in a sub-catchment area close to the Slapy reservoir (Bratránek 1956), which is a certain analogy to the 2013 flood, when there were also extreme floods on the tributaries of the Vltava River in Central Bohemia.

Initial Saturation and Causal Precipitation

The spatial distribution of the Antecedent Precipitation Index for previous 30 days (API_{30d}), which expresses the state of soil saturation before the causal rainfall occurred, is shown for the events of June 2013, August 2002 and September 1890 in Fig. 6.1, 6.3 and 6.5. The common factor for all the events is a strong previous saturation, which significantly influenced the magnitude of subsequent runoff response, and in the event of August 2002, it was even made stronger by the effect of the first flood epizode in Southern Bohemia.

From the maps of spatial distribution of precipitation in Fig. 6.2, 6.4 a 6.6, it is obvious that in June 2013,

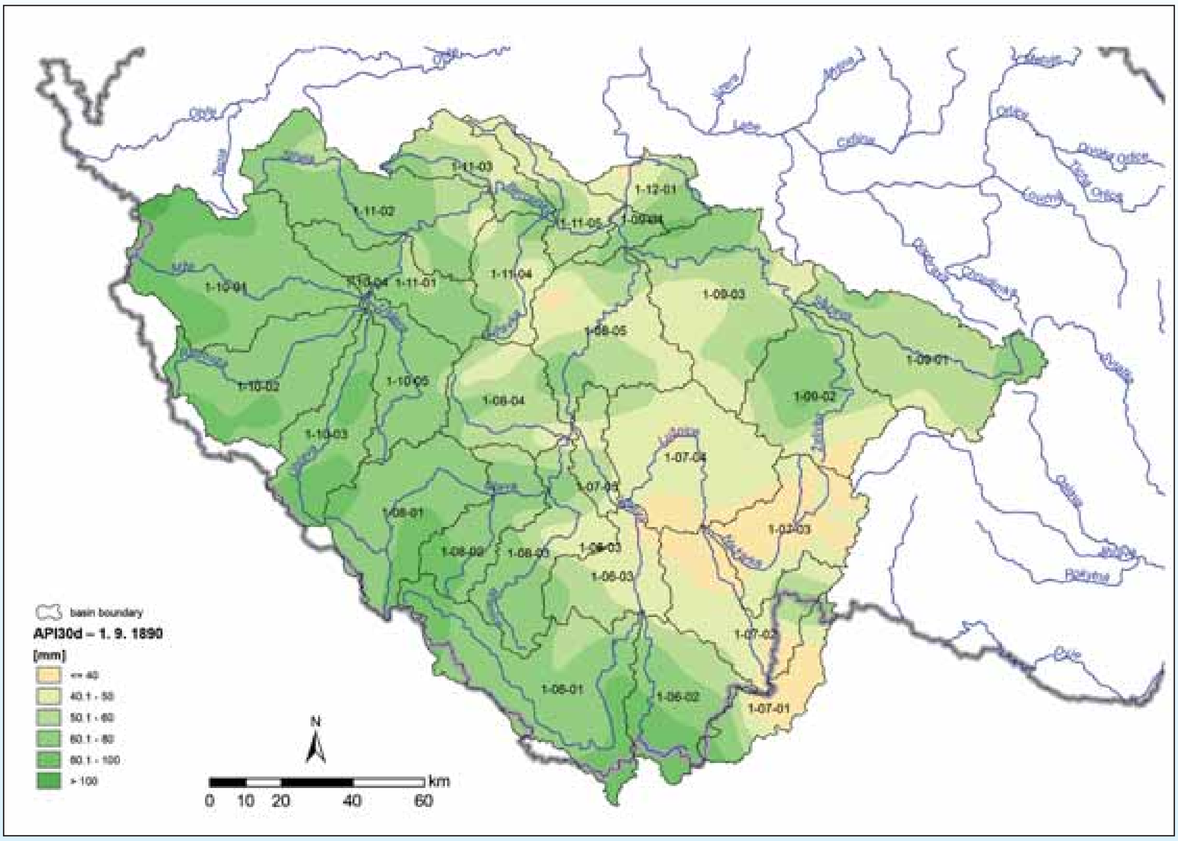


Fig. 6.1 Distribution of Antecedent Precipitation Index API_{30d} over the Vltava River Basin as of 1 September 1890.

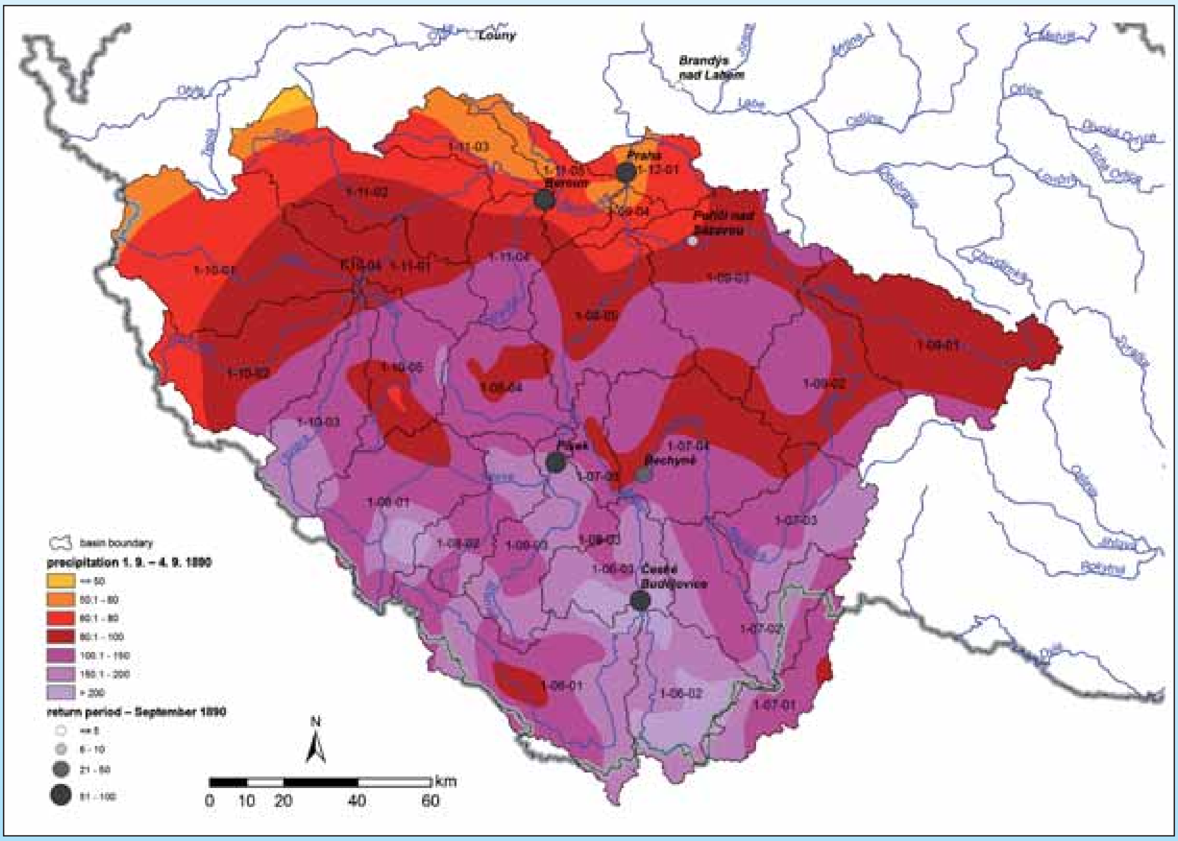


Fig. 6.2 Distribution of Rainfall Totals for the Period from 1 September to 4 September 1890 and Return Period of Peak Flows at Selected Profiles in the Vltava River Basin.

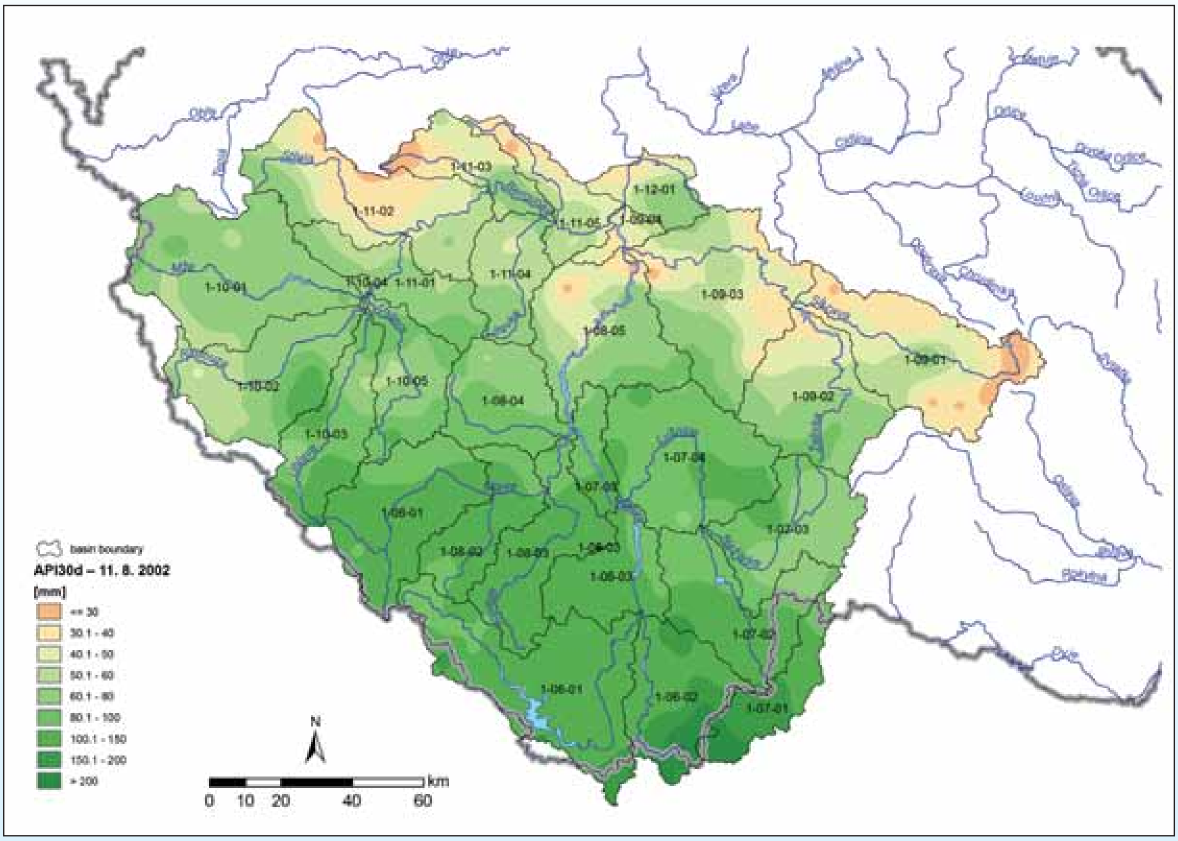


Fig. 6.3 Distribution of Antecedent Precipitation Index API$_{30d}$ over the Vltava River Basin as of 11 August 2002.

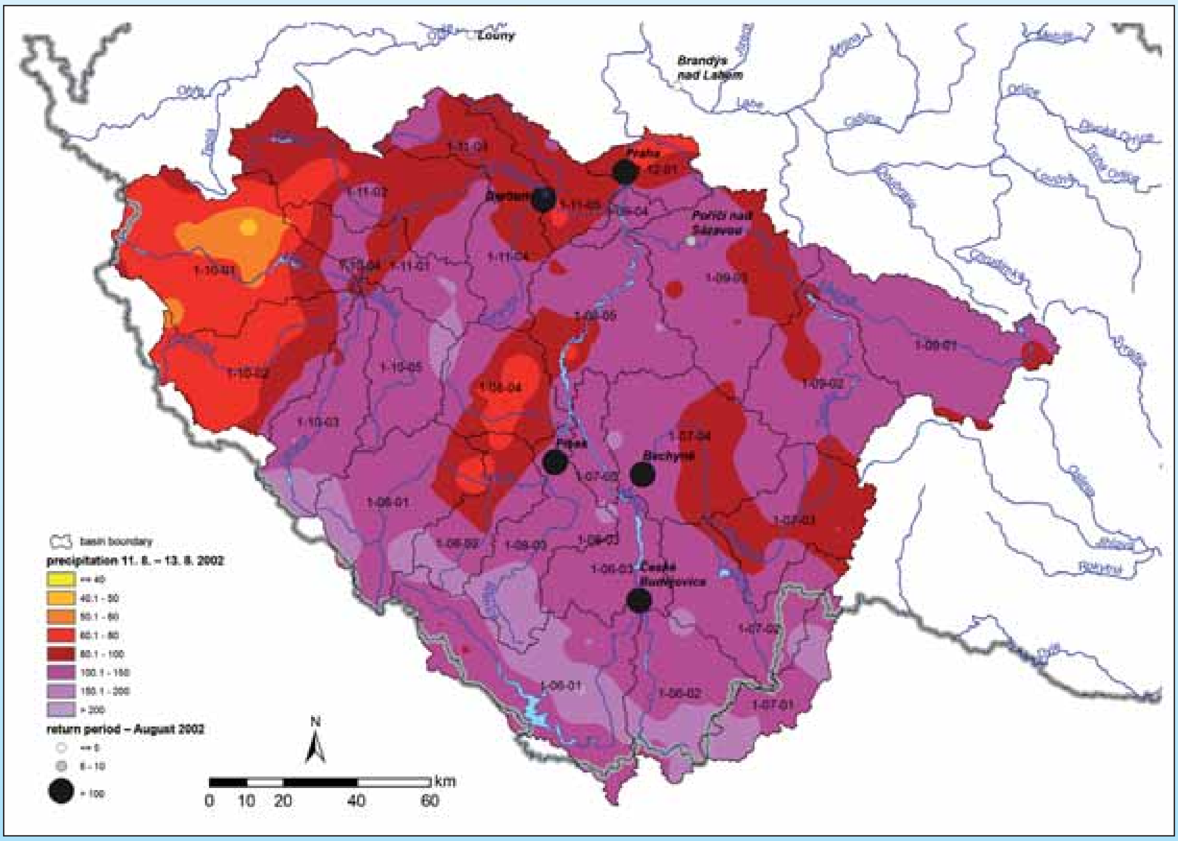


Fig. 6.4 Distribution of Rainfall Totals for the Period from 11 August to 13 August 2002 and Return Period of Peak Flows at Selected Profiles in the Vltava River Basin.

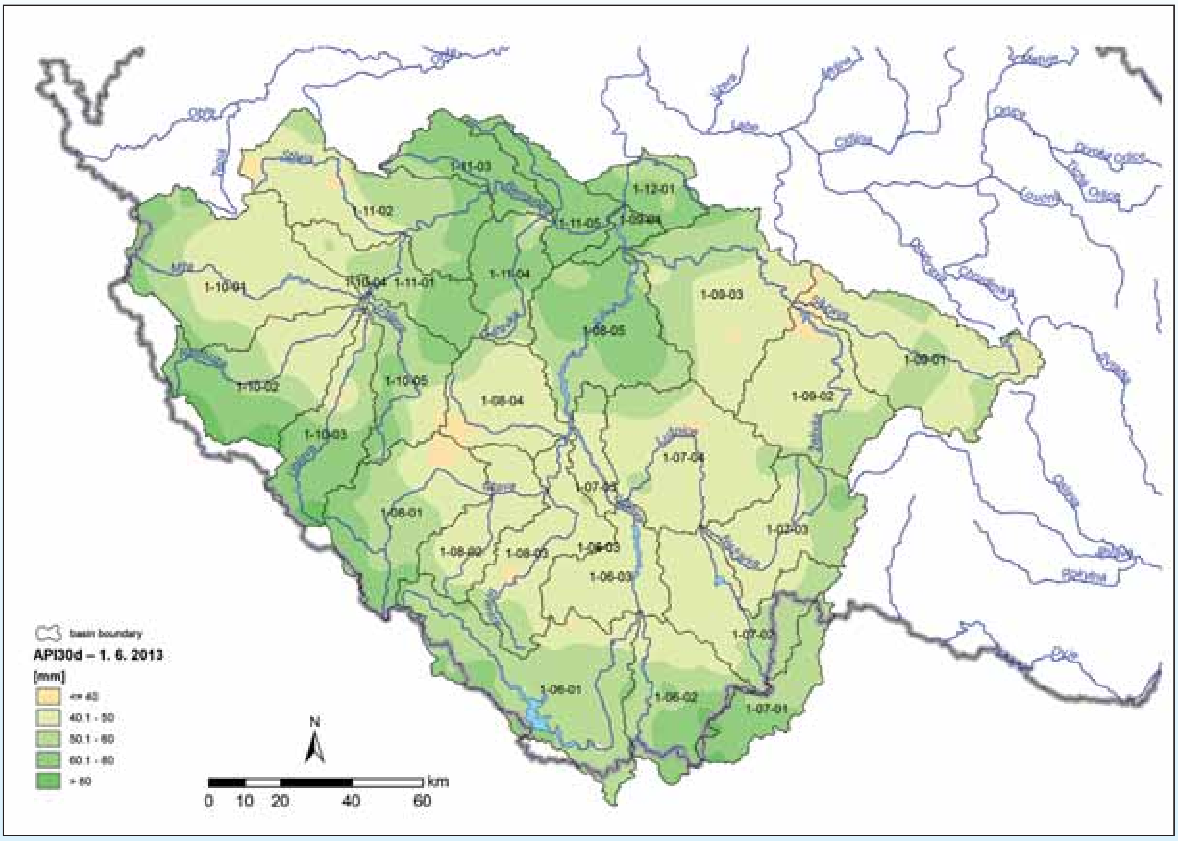


Fig. 6.5 Distribution of Antecedent Precipitation Index API_{30d} over the Vltava River Basin as of 1 June 2013.

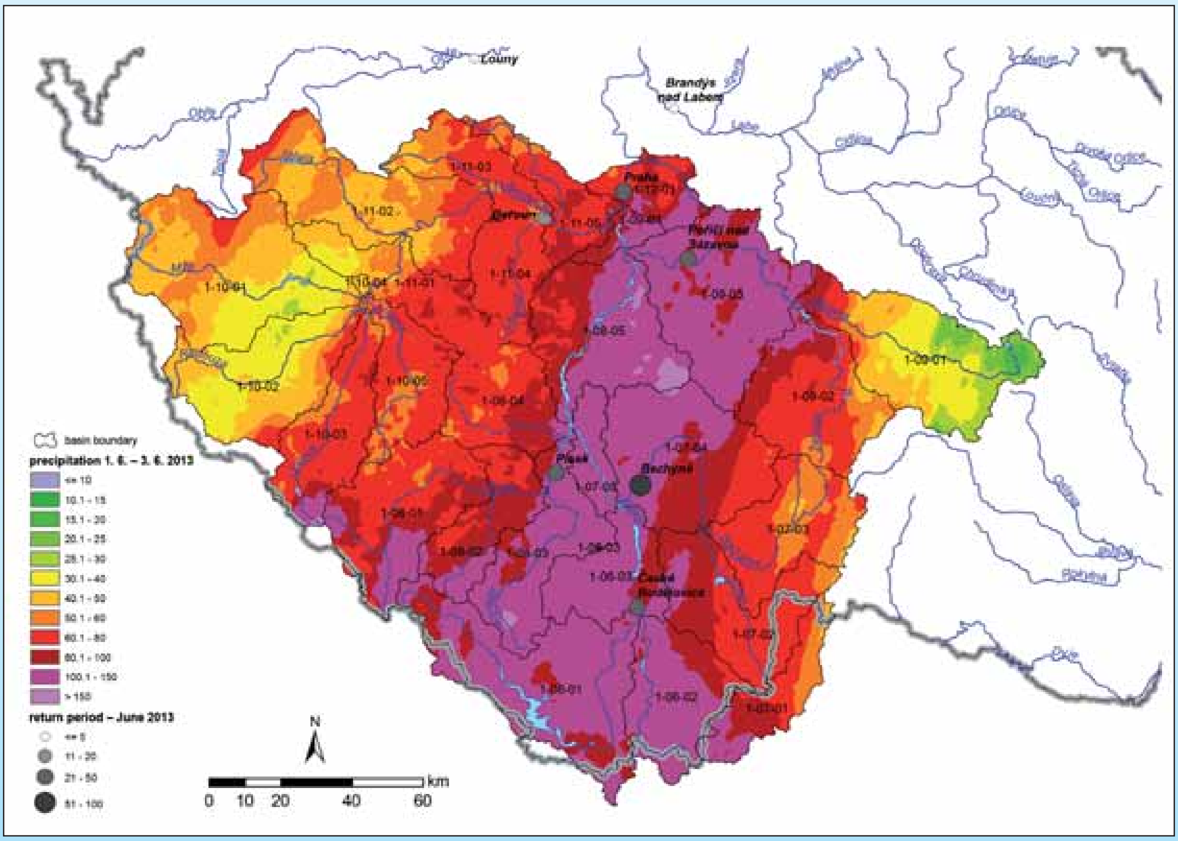


Fig. 6.6 Distribution of Rainfall Totals for the Period from 1 June to 3 June 2013 and Return Period of Peak Flows at Selected Profiles in the Vltava River Basin.

the nature of causal rainfall was different. While in September 1890 and August 2002 regionally extensive rainfall of stratiform nature prevailed, and was intensified by the influence of the windward slopes of the Šumava Mountains and Novohradké Mountains, in June 2013, there was a significant influence of convection and convergence on the clear line, where the rainfall was locally very intense and caused strong or even extreme flooding of smaller streams and then also faster runoff response on some larger rivers.

From the meteorological point of view, the synoptic situation in the case of floods in September 1890 and August 2002 was very similar, and in principle, it was of *Vb* type (see the box entitled "What weather conditions can cause floods in the Czech Republic?" in Chapter 1), while the situation in June 2013 differed from the previous events by the fact that a distinctive line of convergence was formed, on which convective precipitation fell.

Runoff Response

Tab. 6.1 lists peak flows and return periods at nine water gauges on main rivers. These profiles and return period are also symbolically indicated in the maps in Fig. 6.2, 6.4 and 6.6.

As shown in Table 6.1, the peak flows of the June 2013 flood were, as compared with the other floods, more significant on the Elbe River upstream of the confluence with the Vltava River, on the Sázava River at Poříčí nad Sázavou or Nespeky, and on the Ohře River in Louny. Due to the nature of causal precipitation during the June flood, smaller watercourses in Central Bohemia, especially the right-bank tributaries of the Middle and Lower Vltava River (Mastník, Brzina, Botič), tributaries of the Lower Lužnice River and Vlašim Blanice River substantially flooded.

It is necessary to mention that in 1890, there were no reservoirs of the Vltava River cascade, which influenced the progression of floods in 2002 and 2013. However with the extremity of their peak flows on the Vltava River, all the three floods exceeded the 20-year return period, which is the limit above which the transformation effect of the Vltava River cascade reservoirs on the Lower Vltava and Elbe Rivers already decreases (Peláková et al. 2012).

For selected water gauges, Figures 6.7 to 6.11 compare the flood hydrograph (in case of 1890, this is an approximate reconstruction) related to the beginning of their significant rise. The graphs show an obvious difference in the shape of the flood wave in June 2013 from the shape of floods in August 2002 and September 1890, which is primarily caused by the different rainfall duration, distribution and intensity in the individual flood episodes. In the case of floods on the Vltava River in Prague in August 2002 and especially in June 2013, the transformation effect of the Vltava River Cascade reservoirs is registered in addition to the other effects (Fig. 6.11).

In comparison with the floods in August 2002 and September 1890, the flood in June 2013 was less significant as to the extremity, but its onset was faster due to different causal rainfall at many sites. This however does not apply so much to some gauges on larger rivers, where the inflows from smaller streams were transformed and the flood progression was slower, for example on the Otava River in Písek (Fig. 6.8) or on the Berounka River in Beroun (Fig. 6.10). On the Sázava River (Fig 6.9), the effect of extreme inflow from the lower catchment area, especially that of the Blanice River, was reflected in the flood of June 2013, while in 2002 and 1890, rainfall hit the whole Sázava River basin, and therefore, the onset of flooding was gradual.

The way of flood formation in the Lužnice River basin is absolutely unique. The middle reach of the Lužnice is significantly influenced by the transformation effect of the Třeboň basin and pond system, while the valley of the lower reach is strongly incised, and the possibilities of transformation are minimal there. Therefore, the Lužnice River floods often have two peaks, where the first one represents the inflow from the tributaries draining the Central Bohemian Highland in the lower section of the catchment area, and the second peak comes with some delay from the upper section of the catchment area. At Bechyně water gauges on the Lužnice River (Fig. 6.7), the different nature of rainfall and its areal distribution manifested itself most significantly through a single peak of the 2013 flood from the lower section of the catchment area. The size and time of culmination of the flood in 1890 on the Lužnice river (see Fig. 6.7) was then influenced by the Svět pond dam rupture (Augustin 1891).

Tab. 6.2 indicates the time differences (in hours) in the occurrence of flood peak on the Vltava River in Prague and profiles on the main tributaries of the Vltava and Elbe Rivers.

Tab. 6.1 Comparison of Peak Flows and Extremity (Return Period in Years).

Stream (Gauges)	June 2013	August 2002	September 1890
Elbe (Brandýs nad Labem)	5	< 2	< 2
Vltava (České Budějovice)	20–50	500	50–100
Lužnice (Bechyně)	100	200–500	50
Otava (Písek)	20–50	200–500	50–100
Sázava (Poříčí nad Sázavou, Nespeky)	20–50	5–10	5–10
Berounka (Beroun)	20	200	100
Vltava (Prague)	20–50	200–500	100
Ohře (Louny)	< 2	<< 2	<< 2
Elbe (Děčín)	20–50	100	50–100

Tab. 6.2 Comparison of Relative Times of Peak Occurrence in Hours at Individual Profiles with Flood Peak Time on the Vltava River in Prague.

Stream (Gauges)	**June 2013**	**August 2002**	**September 1890**
Elbe (Brandýs nad Labem)	8	24	60
Vltava (České Budějovice)	–35	–21	–28
Lužnice (Bechyně)	–38	21	50 (26)
Otava (Písek)	–14	–24	–14
Sázava (Poříčí nad Sázavou)	–23,5	22	10
Berounka (Beroun)	–6,5	–12	–14
Vltava (Prague)	0	0	0
Ohře (Louny)	13,5	–4	20
Elbe (Děčín)	44,5	56	40 až 43

It is difficult to make an objective assessment of travel times of individual floods because while in 1890, there was practically no significant flood protective measure in effect, the progression of flood in 2002 was significantly influenced by the Vltava River Cascade reservoirs and the Nechranice reservoir on the Ohře River, and the progression of flood in 2013 was influenced, apart from the above-mentioned reservoirs, by other flood protection measures, especially by mobile and fixed dikes along the Lower Vltava River, at the confluence of the Vltava and Elbe Rivers and on the lower reach of the Elbe River downstream of the town of Mělník.

During the 2002 flood, the travel time between Prague and Děčín was 12 to 16 hours longer than the travel time of the floods in September 1890 and June 2013. The influence of flood protection measures (diking) on the rate of flood progression in June 2013 cannot be assessed because there are no relevant results available from the mathematical simulation models on the basis of which it would be possible to determine such influence. However, it is apparent that in June 2013 the structure of flood hydrographs at the confluences of watercourses differed from the structure in 2002. A larger proportion of the inflow from the Upper Elbe and Ohře Rivers, as compared with the inflow from the Vltava River, and the generally smaller inundations at the confluences of the Elbe River with the Vltava and Ohře Rivers and along the lower reach of the Elbe River probably caused a more

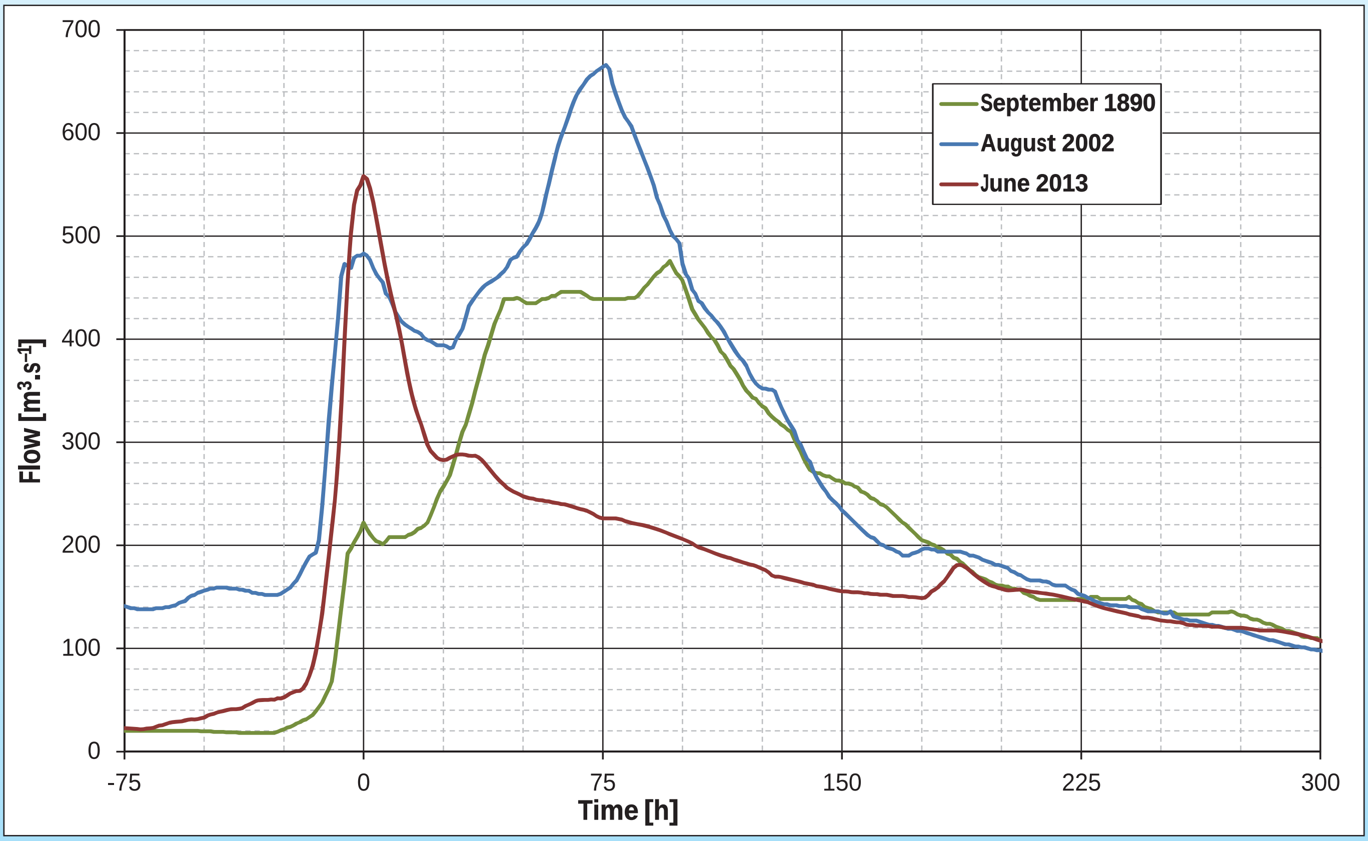


Fig. 6.7 Comparison of Flood Progression on the Lužnice River in Bechyně in 1890, 2002 and 2013.

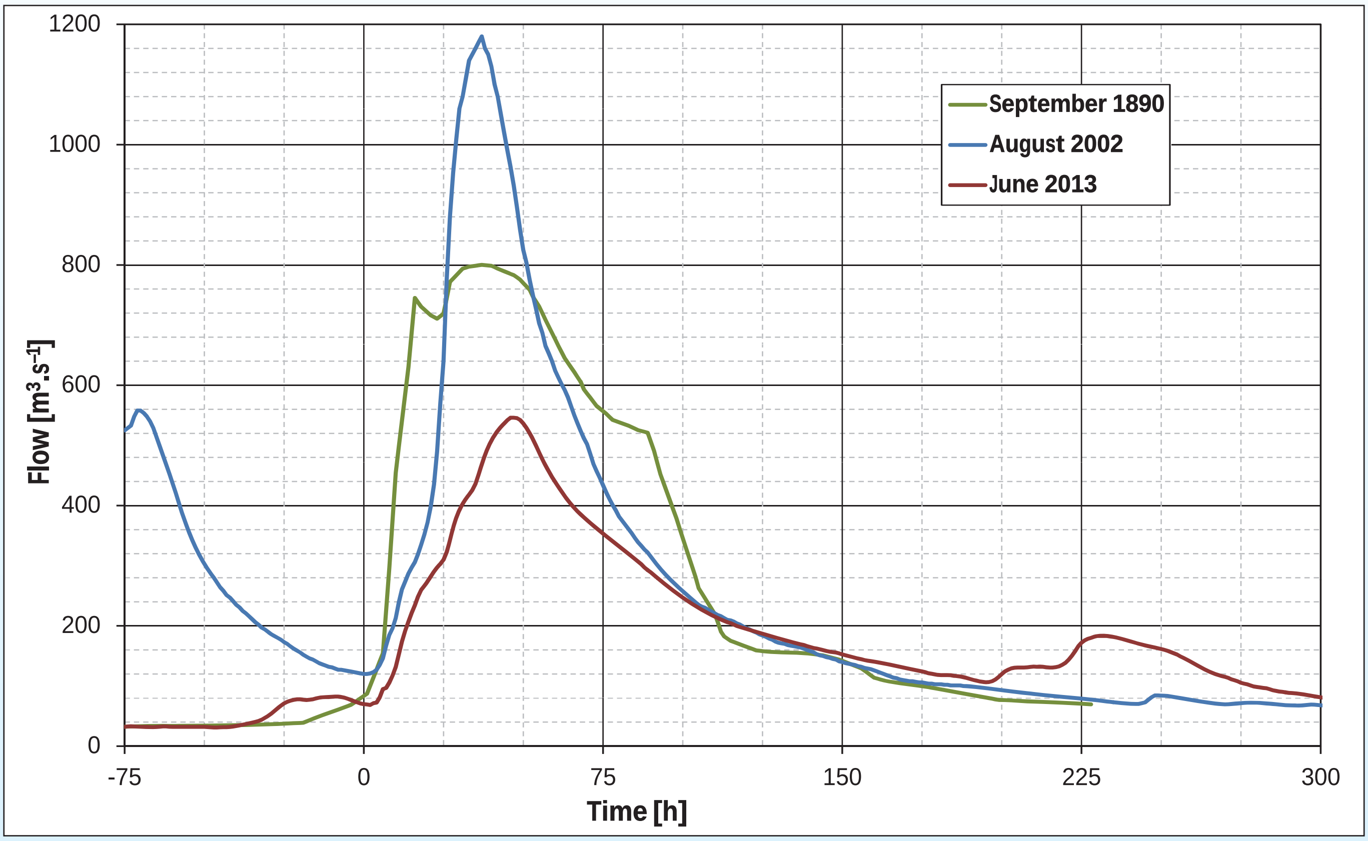


Fig. 6.8 Comparison of Flood Progression on the Otava River in Písek in 1890, 2002 and 2013.

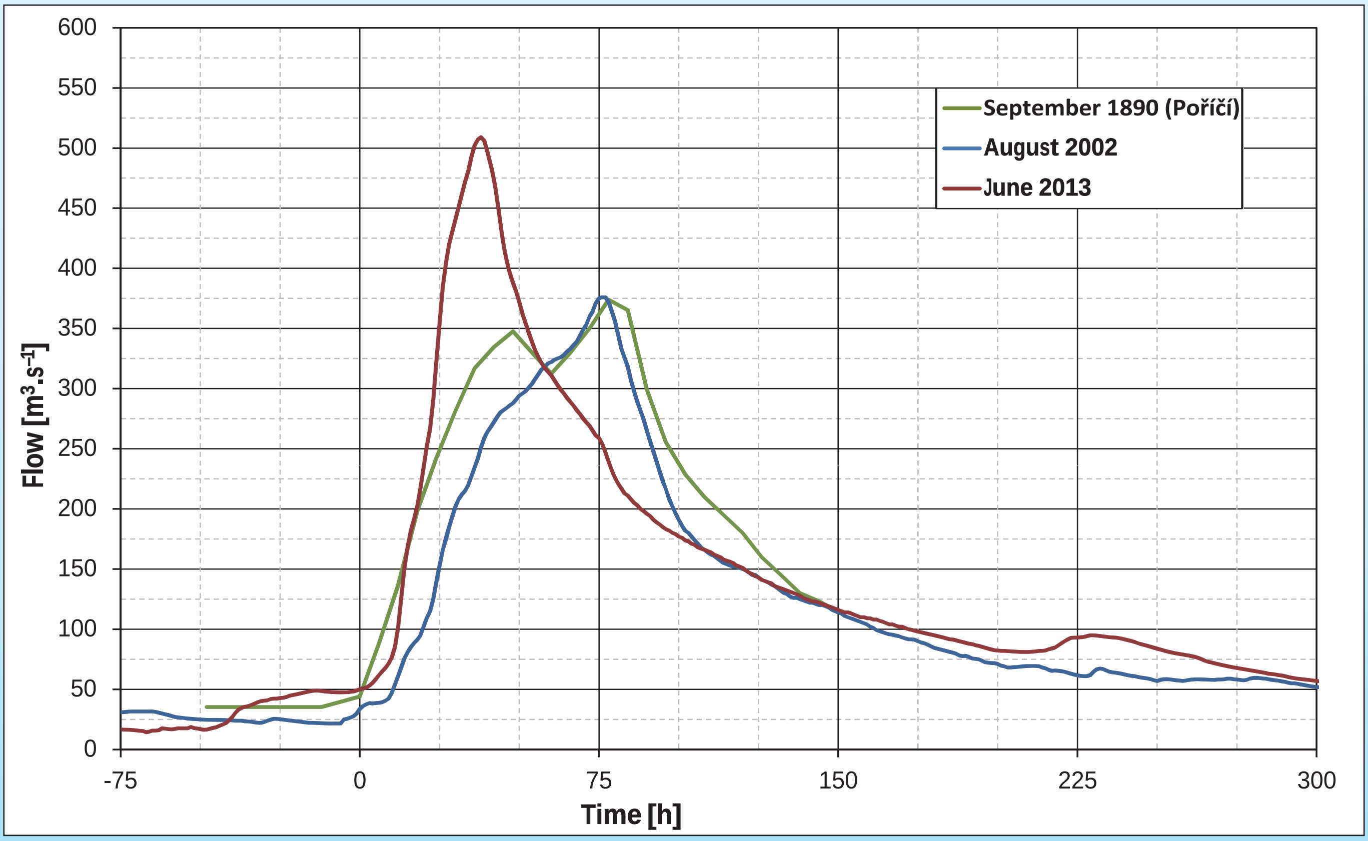


Fig. 6.9 Comparison of Flood Progression on the Sázava River in 1890 (Poříčí nad Sázavou), 2002 and 2013 (Nespeky).

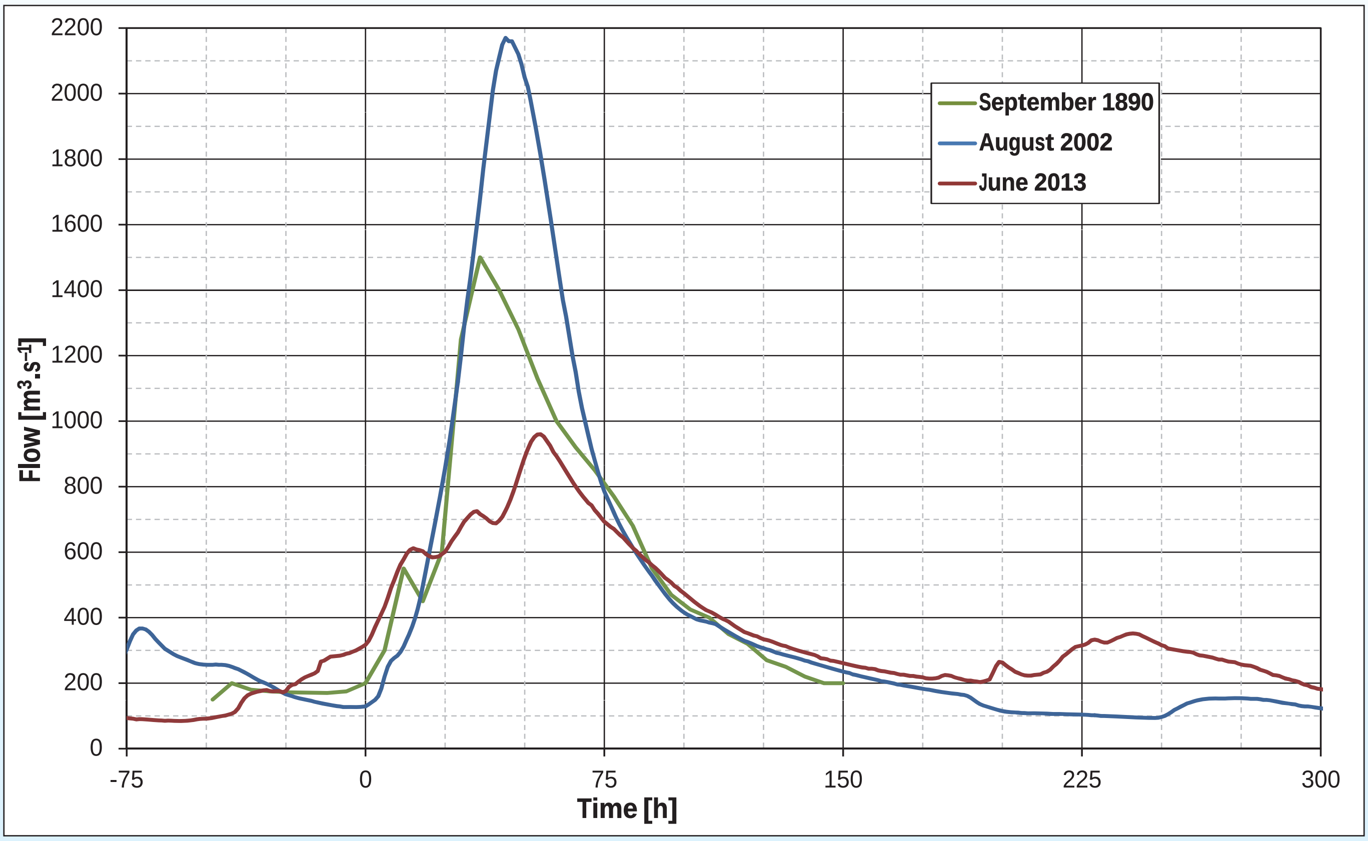


Fig. 6.10 Comparison of Flood Progression on the Berounka River in Beroun in 1890, 2002 and 2013.

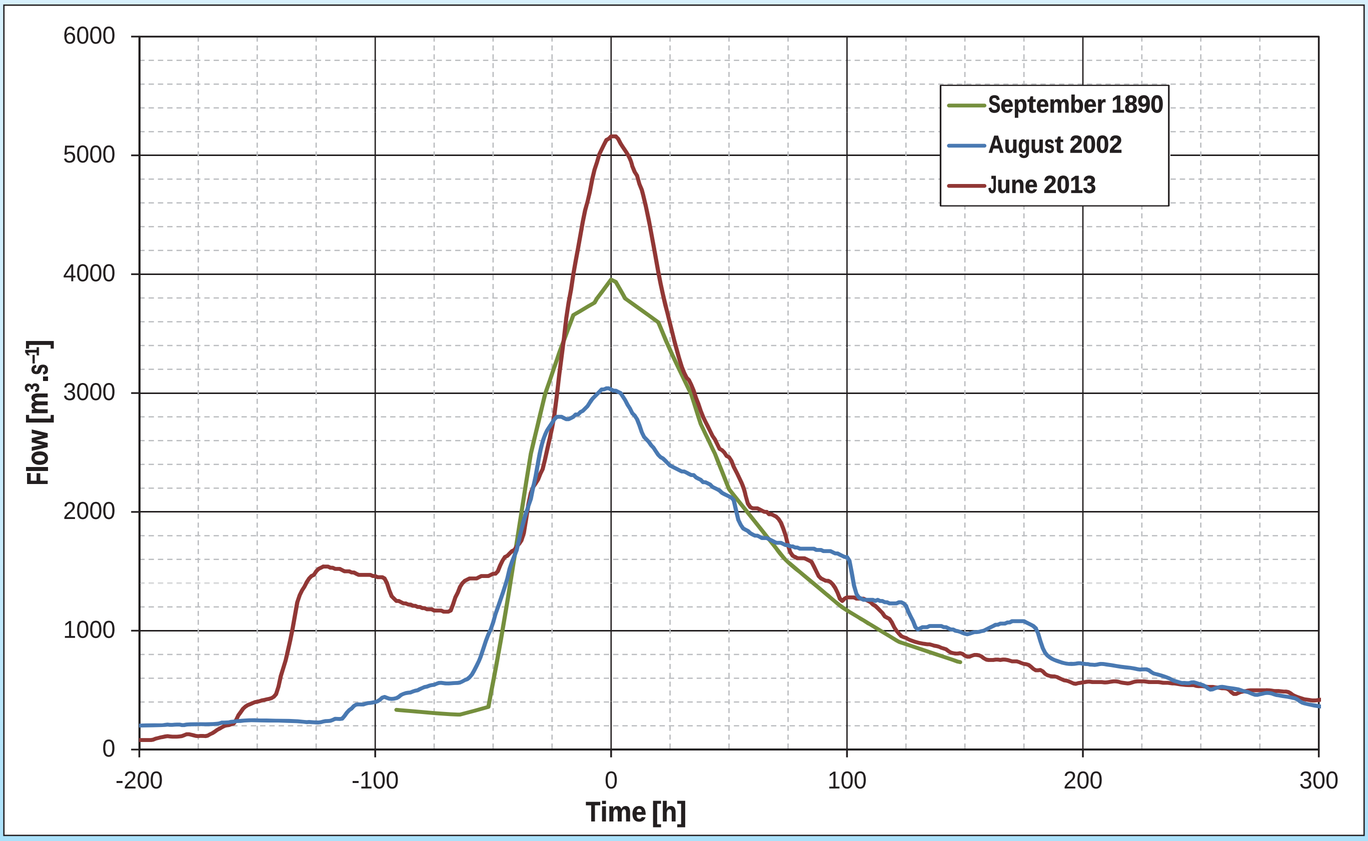


Fig. 6.11 Comparison of Flood Progression on the Vltava River in Prague downstream of the Confluence with the Berounka River in 1890, 2002 and 2013.

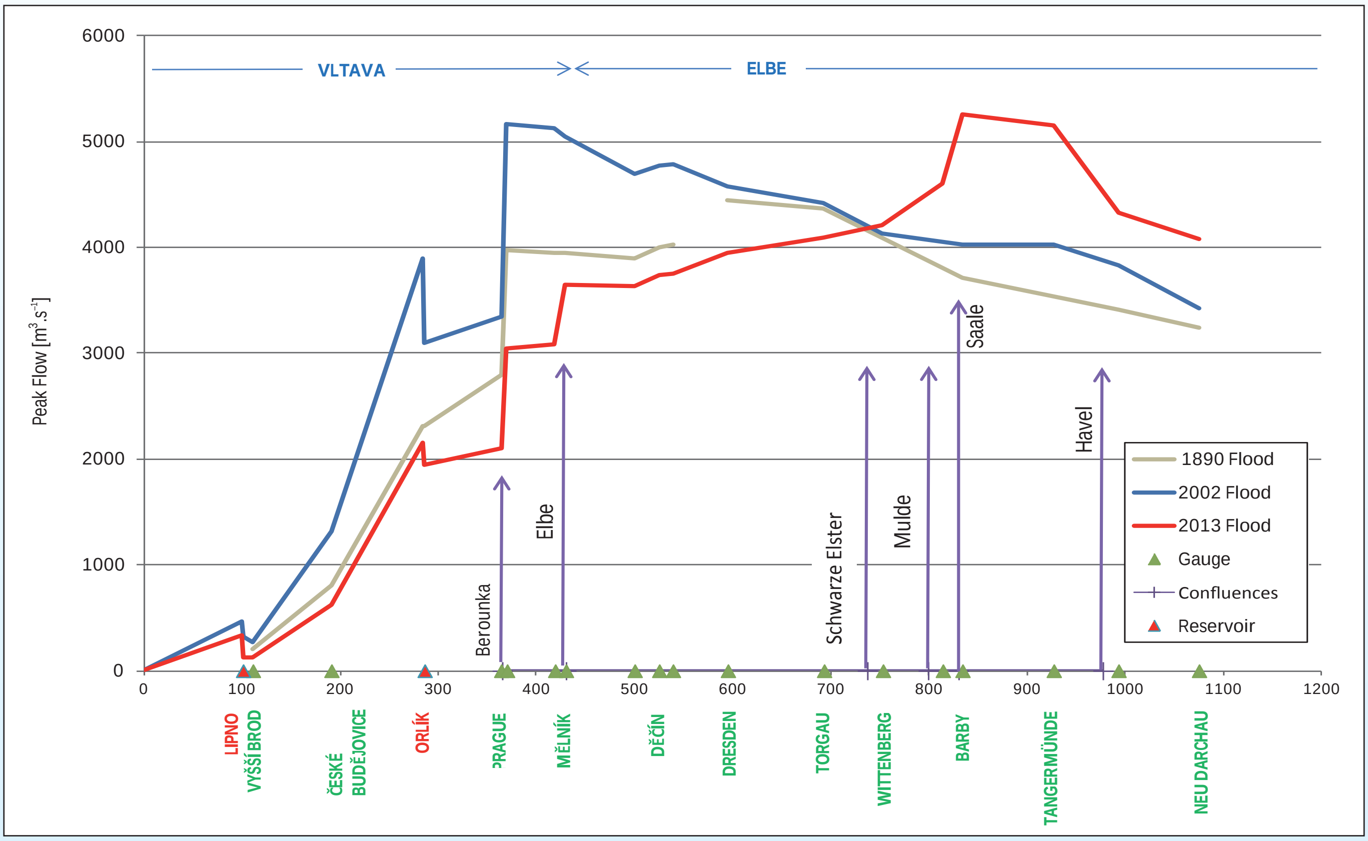


Fig. 6.12 Peak Flows during 1890, 2002 and 2013 Floods in Longitudinal Profile of the Vltava and Elbe Rivers.

rapid progression of the flood, and in comparison with the year 2002, there was no such a significant transformation of flood flows.

Based on the comparison of the progression of floods, the flood of August 2002 is clearly dominant, not only as to the peak flow magnitude, but especially as to its volume. The main contributors to this fact comprise the rainfall amount and very strong saturation of soil by water from previous rainfalls, which was enormous after the first flood eoisode in August 2002.

It is interesting to compare the magnitude of culmination of these three floods in the longitudinal profile of the Vltava and Elbe Rivers in the Czech and German territories, as shown in Fig. 6.12.

The 2002 flood peaked downstream of the confluence of the Vltava River with the Berounka River in Prague, and further down the stream, its peak mainly declined. The significant increase in the peak flow was caused by the concurrence of the flood peaks on the Vltava and Berounka Rivers. On the contrary, the Upper Elbe River inflow did not manifest itself at Mělník water gauge, where there was a strong backflow upstream of the Elbe River, and the flood was significantly transformed due to the innundation in the confluence area. The significant flood transformation on the Vltava River was also caused by the event that occurred at the Orlík reservoir, where an outage of the hydroelectric power plant (with a capacity of 600 $m^3.s^{-1}$) and insufficient capacity of the fully opened spillways resulted in exceeding the maximum permissible water level in the reservoir by 1.54 m. Such a formed retention volume, which was in principle illegal, contributed to the flood peak reduction of approximately 800 $m^3.s^{-1}$.

The measures taken at the Orlík reservoir dam should prevent the recurrence of a similar scenario in the future. However at the same time, it means that if an extreme flood of similar size should occur, the transformation effect of the Orlík reservoir would not be so significant.

The peak flow of the flood in June 2013 on the Vltava and then on the Elbe River continued to rise as far as the area of Magdeburg. In Bohemia, there was again a significant inflow from the Berounka River, and as compared with 2002, there were also significant inflows from the Sázava and Upper Elbe Rivers. In Germany, the Black Elster and Mulde Rivers, and in particular, the Saale River, were badly swollen, and their maximum levels exceeded the highest observed values there. This caused the Elbe River level in Magdeburg to be 67 cm higher than in 2002, reaching the highest level since the water level started to be measured in 1727.

The preserved records regarding the third largest summer flood in September 1890 are not so detailed and probably not reliable either, and as such, the records regarding the progression of the flood in the longitudinal profile are rather rough. In Bohemia, a strong influence of the Berounka River inflow is evident, while the Upper Elbe river inflow was disappearing, as was the case in 2002. The character of the flood on the German part of the Elbe River is similar to that of 2002. The graphic record of the flood progression between Děčín and Dresden is not continuous (Fig. 6.12) because the historical rating curves for the water gauges of Ústí nad Labem and Děčín were revised and modified in 2003 after analysing the old hydrometric measurements, including the peak values of historical floods on the Czech part of the Elbe River.

6.2 Comparison of June 2013 and August 2002 Flood Impacts

The flood event impacts in August 2002 hit the cadastral areas of 986 municipalities in 10 regions, representing an area of 17 thousand km^2 (Hladný et al. 2005). In these areas, a total of approximately 3.2 million inhabitants were living at the time of flooding. The Capital City of Prague was also significantly affected. During the flood, 17 people died and two more people died of its direct effects. In comparison with the floods in June 2013, more communities in the Pilsen Region and marginally also in the South Moravian Region were affected in August 2002. On the contrary, in 2002 the areas along the Upper Elbe River reaches, i.e. eastern areas of the Central Bohemian, Hradec Králové and Pardubice Regions were almost not affected by the 2002 flood. Damage caused by the flood in August 2002 was estimated at more than CZK 73 billion (Tab. 6.4).

The flood events in June 2013 resulted in damage totalling "only" CZK 15.4 billion, which represents a fifth of the 2002 flood effects. During both the events, the South Bohemian, Central Bohemian and Ústí nad Labem Regions and the Capital City of Prague were the most affected. The biggest difference in the damage caused by the flood events was recorded by the Capital City of Prague. In 2002, considerable damage was incurred for example during the subway (metro) flooding (approx. CZK 6 billion), while in 2013 minimal damage was recorded for this type of transport infrastructure.

The comparison of the shares of individual property categories in the total damage shows that the transport infrastructure had the largest share in the damage incurred during the floods in June 2013, almost in all the regions, except for Prague. On the contrary, the floods in August 2002 significantly affected the housing sector, especially on the lower reaches of the Vltava and Elbe Rivers, i.e. in the Central Bohemian and Ústí nad Labem Regions and Capital City of Prague.

Tab. 6.3 Comparison of Flood Effects in June 2013 and August 2002.

Affected Communities	**June 2013**	**August 2002**
Number	1,373	986
Area (km^2)	22 thous.	17 thous.
Population	3.9 mil.	3.2 mil.
Casualties	16	19

Tab. 6.4 Comparison of Flood Damage in June 2013 and August 2002 in Individual Regions.

Estimated Flood Damage (mil. CZK)		
Region	**June 2013**	**August 2002**
Capital City of Prague	3,841	26,914
South Bohemian	2,013	15,721
South Moravian	0	343
Karlovy Vary	20	77
Hradec Králové	872	0
Liberec	568	5
Pardubice	161	0
Pilsen	279	3,847
Central Bohemian	4,092	14,283
Ústí nad Labem	3,523	11,765
Vysočina	17	187
Total	**15,387**	**73,143**

Fig. 6.13 General Šiška Street, Prague, 4 June 2013 (Photo by Radovan Tyl).

7. FLOOD FORECASTING SERVICE DEVELOPMENT IN 2002–2013

Catastrophic floods are always an impulse to improve and expedite the development of flood protection in the affected area. This is caused by a greater focus of attention of the responsible authorities and public on flood issues, as well as by released funds to implement the measures. Basic system changes were made after the 1997 floods, when the Water Act was amended and new laws were passed in the area of crisis management and Integrated Rescue System, which already had positive effects during the floods in August 2002. As a result of experience, knowledge and actions arising from the 1997 and 2002 floods and thanks to the development of information technology, the Flood Forecasting Service, like other parts of the flood protection system, have undergone great changes.

7.1 Measurement and Observations

The process of making forecasts and providing alert information begins with meteorological and hydrological measurements and observations. As compared with 2002, the number of automatic stations with remote Near Real Time (NRT) data transmission to the centre had significantly increased by 2013, and a key turning point came in the form of transition from fixed telephone lines to the use of mobile data transmission networks.

It is necessary to realize that in principle, the gradual automation of rain gauge and water gauge stations, from which it was possible to obtain NRT information about current rainfalls and water stages, took place after the 1997 flood. Before that flood, rainfall information was only available from a limited number of professional meteorological stations, and the information on the water stage was obtained by phone from volunteer observers on a daily basis. The development of the number of rain gauge and water gauge stations within the Czech Hydrometeorological Institute is shown in Fig. 7.1 and 7.2.

In 2002, there was already a network of water gauges in service, equipped with automatic instruments communicating via telephone lines. During the flood, a disadvantage of that solution appeared to consist in the fact that the telephone networks and necessary electrical connections were disconnected when the office surroundings were flooded, and as such, the gauges remained unavailable. It was not either possible to obtain data with a frequency greater than one hour and the delay in data delivery reached tens of minutes. For example, during the flood culmination, the Prague forecasting office downloaded data from about twenty stations, where each modem connection attempt lasted several minutes and was successful only in a quarter to a half

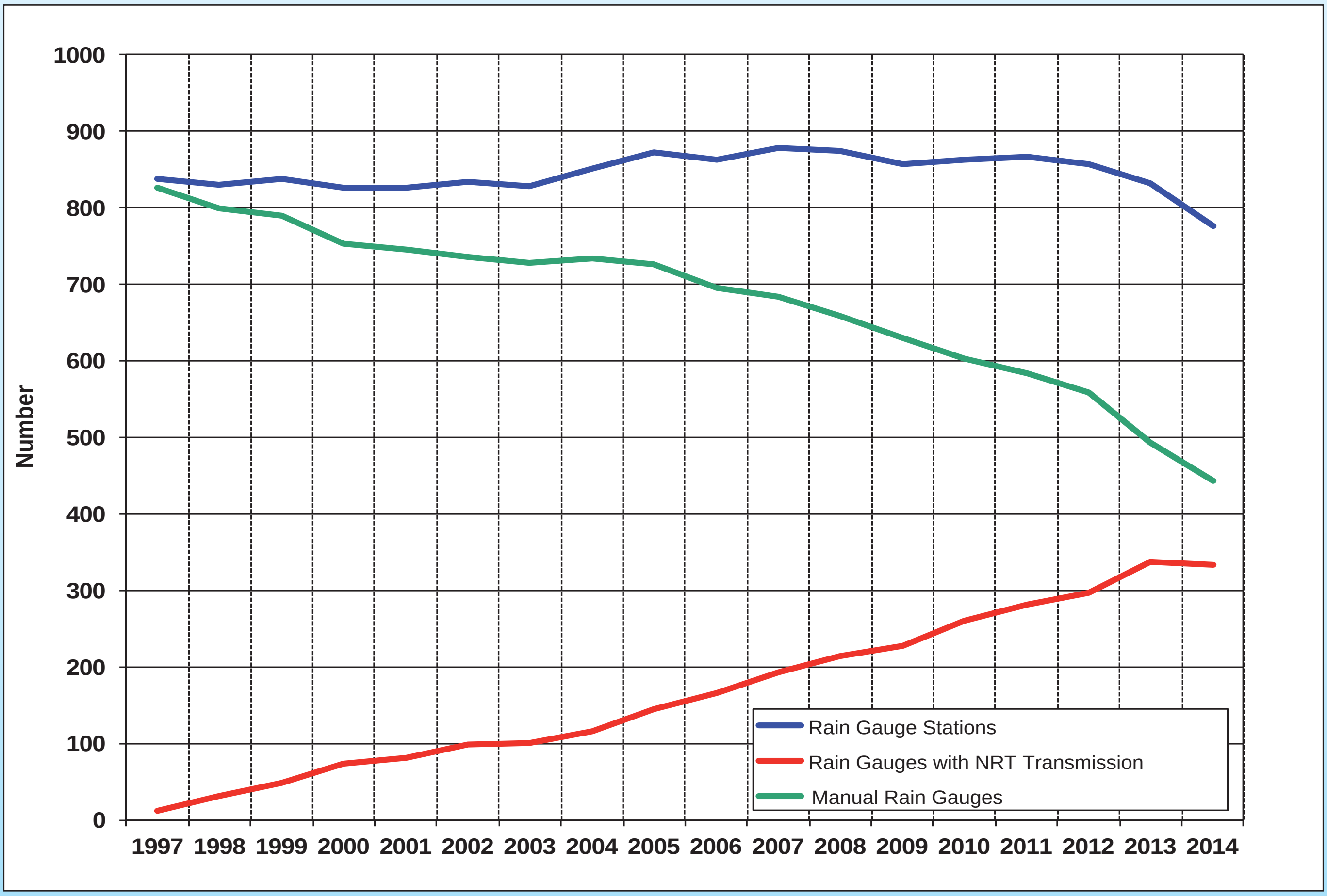


Fig. 7.1 Evolution of Number of Rain Gauge Stations of the Czech Hydrometeorological Institute.

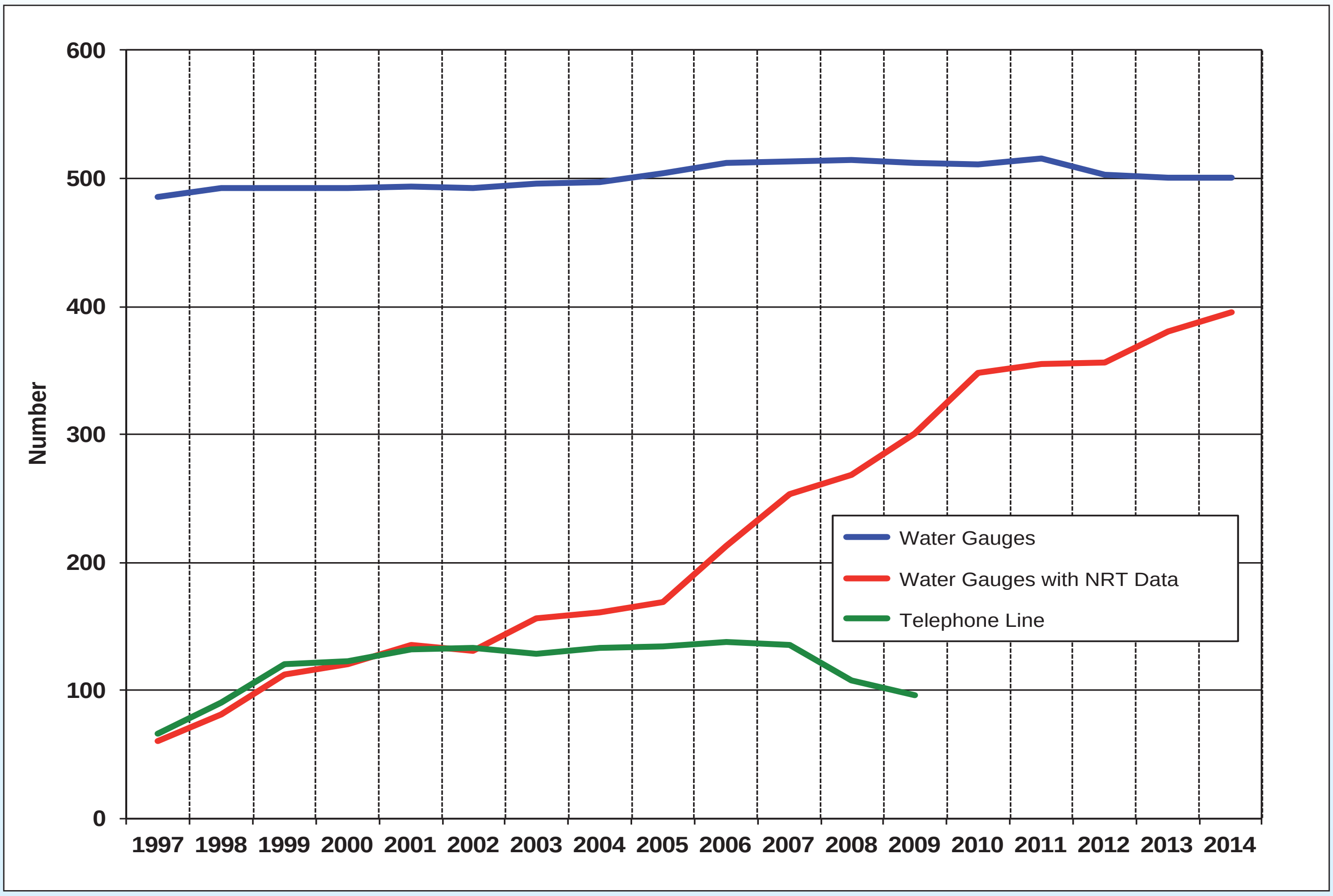


Fig. 7.2 Evolution of Number of Water Gauges of the Czech Hydrometeorological Institute.

of cases. Therefore, the data acquisition in hourly cycles was actually a continuous struggle with the overloaded and failing network. Reliable and regular information about measured rainfalls was basically provided only by the professionally operated stations (approximately 30 in the territory of the Czech Republic), and moreover, there were occasional reports from hydrometric stations and reservoirs. Images of meteorological radars were also available; however, they provided rather qualitative information on the distribution and intensity of precipitation, and did not quantify any precipitation totals.

The current situation, where data from hundreds of water and rain gauges are available once every ten minutes with a minimum delay is thus qualitatively incomparable with the situation in 2002. The data availability allows the hydrologists in forecasting offices, flood protection authorities and public to basically continuously monitor and immediately evaluate the flood progression. Current information on rainfalls and flows allows the flood progression to be better forecast and the flood peak times to be better estimated. Our ability to record on time the risk of flash flood events has also significantly improved.

Apart from speed, the current solutions for data transmission via mobile networks are also much more reliable. Interruption of telephone lines or power supplies was the most frequent cause of measurement failures in 2002. Lower vulnerability was therefore achieved mostly by using devices that operate independently of terrestrial networks. The communication via telephone lines was replaced by the mobile network, and the reduced input power of instruments allowed switching to battery power.

Many water gauges were also structurally modified so that buildings and measuring instruments would withstand larger floods. For example, in the Upper Vltava River basin upstream of the Orlík reservoirs, where more than one half of water gauges experienced longer measurement failures in 2002, all the instruments remained in service during the flood in June 2013, even at the stations that were partially flooded.

The water gauges located at the flood reporting profiles of the Flood Forecasting Service, whether they are operated by the Czech Hydrometeorological Institute or Povodís (River Basin Authorities), were preferably automated. For example, at the flood reporting profiles of category A and B in the Elbe River basin, a total of 85 stations, available only through dial-up connection up to that time, were automated in August 2002. In 2013, more than 200 stations already used the mobile data transmission system (see Fig. 7.4). In addition, the state-of-the-art water gauge allows an SMS alert to be automatically sent to hydrological forecasting office and possibly also to other users, including flood protection authorities, if the Flood Level is exceeded.

Fig. 7.3 Reconstructed Station Slověnice on the Chotýšanka Stream. The Station remained functional during the flood in June 2013 with the peak exceeding the 100-year flow rate.

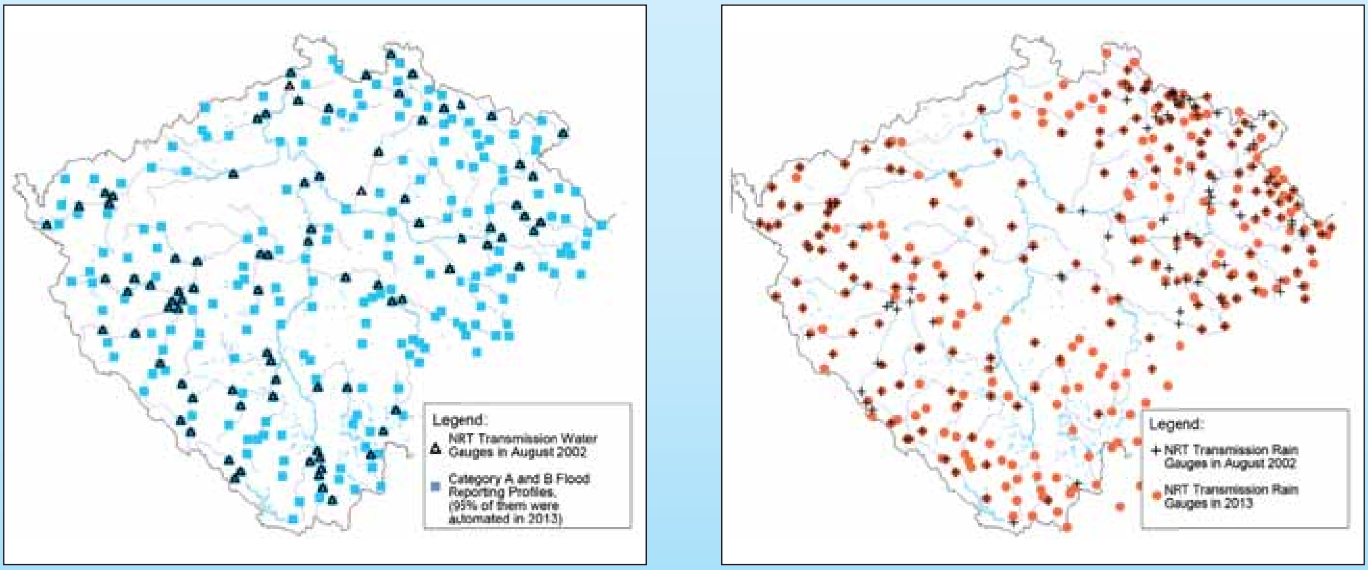


Fig. 7.4 Automated Water Gauges in the Elbe River Basin in 2002 and 2013 (left). Automated Rain Gauges Used for Hydrological Forecast Calculation, in 2002 and 2013 (right).

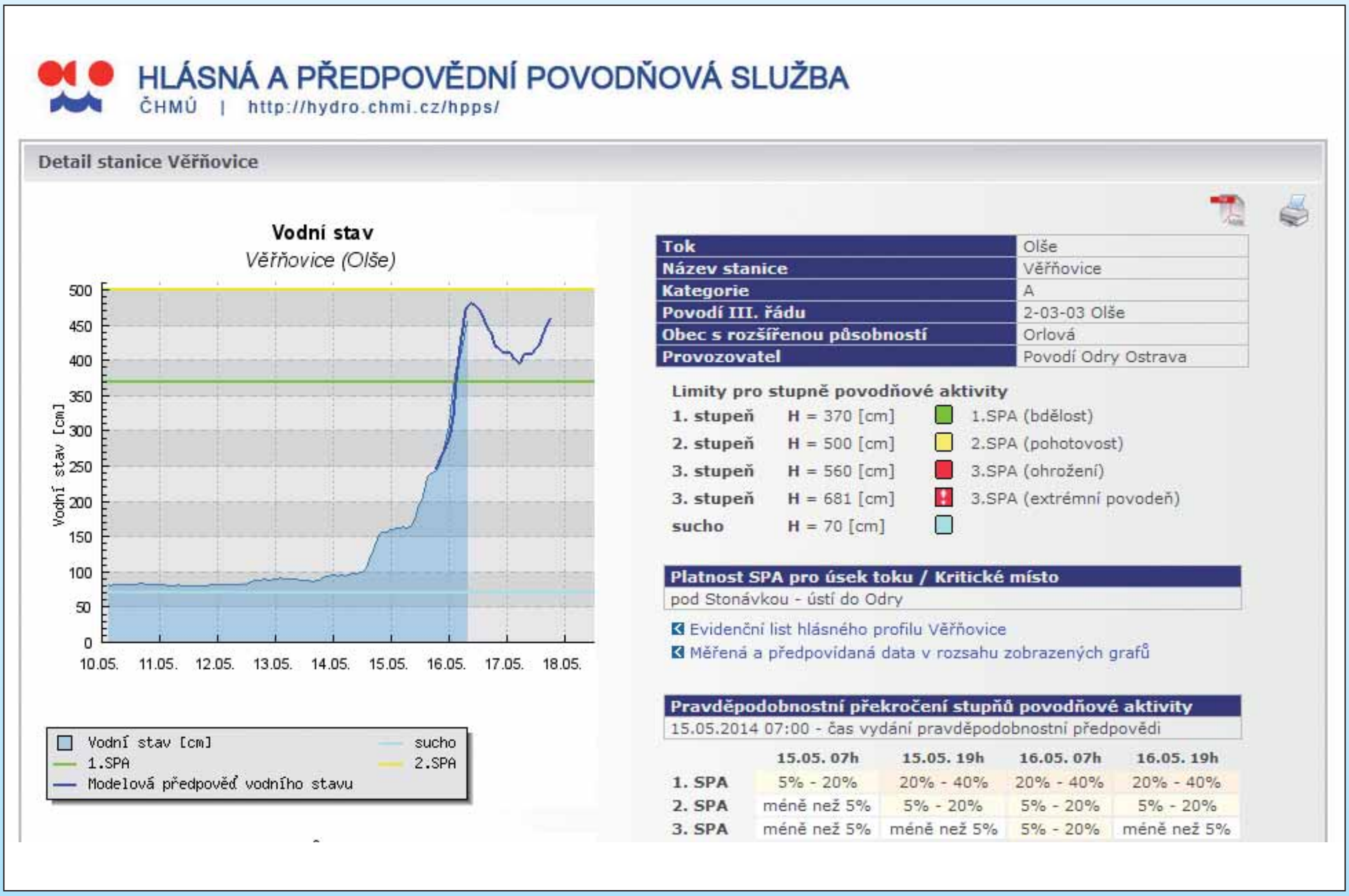
Information from meteorological radars has also undergone significant development. The spatial resolution increased from 2 to 1 km and the scanning frequency increased to five minutes. In particular however, a software extencion was created on the radar images, which significanty improved their presentation. The radar data were on-line coupled with the data of automatic ground rain gauges, which enables an automatic correction of radar precipitation estimates to be carried out in real time. The application thus provides so-called combined rainfall information on both the immediate rainfall intensity and the rainfall total for a selected time interval. Moreover, the nowcasting methods (i.e. radar echo movement extrapolation) were also applied, which are particularly important for predicting further movement of torrential rainfalls and convective cells.

The snow gauge observation network has also been upgraded. A total of eight automatic snow-gauge stations were built to continuously measure the depth and water content of total snow cover. The data enable a significantly better calculation of the snow cover water storage. Manual measurement of snow is performed at climatological stations, and at selected climatological stations, such measurements are performed in open space, as well as in forests.

The water gauges operated professionally by the Czech Hydrometeorological Institute or Povodí (River Basin Authorities) at the flood warning water gauging profiles of Categories A and B form a basic framework of the reporting network, which is locally complemented by other stations of the Local Warning Systems (LWS), established by some communities and cities. They aim at activating the local flood protection authorities in the event of locally limited extreme precipitation and flash floods that are not captured by the national network. A great development of the LWS took place after the flash floods in June and July 2009 with financial supports from the funding programme administered by the Ministry of the Environment. The communities usually associate the LWS installation with the establishment of a local wireless radio to alert the population.

7.2 Forecasts and Warnings

In 2002, the forecasting offices of the Czech Hydrometeorological Institute were at the beginning (in the first year) of the live operation of hydrological forecasting models, the AquaLog Model in the Elbe River basin and the HYDROG Model in the Morava and Odra River basins. The models started to become a major tool of hydrological forecasts. They are prepared every day,



Tok	Olše
Název stanice	Věřňovice
Kategorie	A
Povodí III. řádu	2-03-03 Olše
Obec s rozšířenou působností	Orlová
Provozovatel	Povodí Odry Ostrava

Limity pro stupně povodňové aktivity

1. stupeň	**H** = 370 [cm]	🟩	1.SPA (bdělost)
2. stupeň	**H** = 500 [cm]	🟨	2.SPA (pohotovost)
3. stupeň	**H** = 560 [cm]	🟥	3.SPA (ohrožení)
3. stupeň	**H** = 681 [cm]	!	3.SPA (extrémní povodeň)
sucho	**H** = 70 [cm]	☐	

Platnost SPA pro úsek toku / Kritické místo

pod Stonávkou - ústí do Odry

Evidenční list hlásného profilu Věřňovice

Měřená a předpovídaná data v rozsahu zobrazených grafů

Pravděpodobnostní překročení stupňů povodňové aktivity

15.05.2014 07:00 - čas vydání pravděpodobnostní předpovědi

	15.05. 07h	**15.05. 19h**	**16.05. 07h**	**16.05. 19h**
1. SPA	5% - 20%	20% - 40%	20% - 40%	20% - 40%
2. SPA	méně než 5%	5% - 20%	5% - 20%	5% - 20%
3. SPA	méně než 5%	méně než 5%	5% - 20%	méně než 5%

Fig. 7.5 Example of Presentation of Observed Data and Hydrological Forecast for Olše River at Věřňovice <http://hydro.chmi.cz/hpps>. In the right bottom corner, there is an evaluation of results of the probabilistic forecast, which indicates the probability of exceeding the individual of Flood Levels during 12-hour forecast intervals.

and during floods, even several times a day. The basic parameters of forecasts, i.e. lead time of 48 hours and time step of one hour, remained the same until 2013 because in our conditions, an extension of the lead time is largely limited by natural factors, especially by the runoff concertation times.

In order to achieve a two-day forecast lead time, the hydrological models must include a quantitative precipitation forecast, whose reliability significantly decreases for a longer period. However, progress has been made in increasing the number of forecasting locations. In 2002, the forecasts were computed for 91 locations in the Elbe River basin, and in 2013, there were already 162 such locations. Forecasts of water stages and flows are presented for selected forecast water gauges at the Czech Hydrometeorological Institute website.

The structure of the used hydrological models also underwent changes. In the case of the AquaLog Model, the input data processing module was completely redesigned and a more detailed division into computational patches was carried out. Moreover, the module computing the soil freezing and its impact on the runoff was added and the evapotranspiration computation procedure was changed. In the period between 2002 and 2013, the rainfall-runoff model was recalibrated twice for the individual catchment areas, using new data from past floods. All these changes were positively reflected in the long-term statistics of the model success rate in the simulation of hydrological processes. A generally easier operation of the model and the data availability allowed the hydrological forecast during the flood in June 2013 to be updated up to four times a day, depending on the rainfall forecast availability.

The success rate of hydrological forecasts, especially for the next day, undoubtedly depends on the rainfall forecast reliability. In this area, some progress has also been made since the 2002 floods. The ALADIN Meteorological Model resolution was increased from 9 to 4.7 km, the Model is computed with updated inputs four times a day, and the forecast time was extended to 54 hours. The meteorologists have outputs available from other numeric models, including the Model of the European Centre for Medium Range Weather Forecasting (ECMWF), which forecasts precipitation for the next ten days and can warn about dangerous weather situations and probability of dangerous precipitation events with a longer lead time. However, the quantified precipitation forecast and areal localization of precipitation still continue to be limiting factors in flood forecasting.

Since 2010, so-called probabilistic hydrological forecasts have also been tested. Their benefit consists in estimating the variance of forecasted flows and probability of their deviation from the basic, deterministic predictions. The probabilistic prediction is obtained by the hydrological model running repeatedly over the sixteen-member ensemble of rainfall forecast variants produced by the ALADIN Model. Even though the computation of these forecasts was in a test run during the June 2013 flood, its outputs were already partially used when assessing the likelihood of reaching the Flood Levels. Since 2014, the computation of probabilistic forecasts has been a part of the forecasting offices operations and their evaluated results are published at the CHMI website (Fig. 7.5).

Since 2002, the method for issuing warnings and alerts has undergone several modifications to reach the current form of the Integrated Warning Service System, which produces warnings and alerts in a uniform way for all types of dangerous hydrometeorological situations, i.e. apart from floods, also for windstorms, thunderstorms, extreme temperature and precipitation, and in winter, also for snow and ice phenomena. The introduction of two alert categories was a major change: (i) Forecast Alert Information, which warns of an expected occurrence of dangerous phenomena in the next period, and (ii) Information about Occurrence of Dangerous Phenomena (IODP), which is issued when such a phenomenon really occurs. If possible, the IODP describes its next progression in the affected area. As a standard, the alerts include recommendations to mitigate the potential consequences of the phenomenon occurrence. In relation to the flood service system, a significant change was brought by an amendment to the Water Act, which newly provides that if the Flood Forecasting Service releases flood warning, 1st Flood Level (i.e. flood watch) shall automatically take place in a given area.

7.3 Information Distribution on the Internet

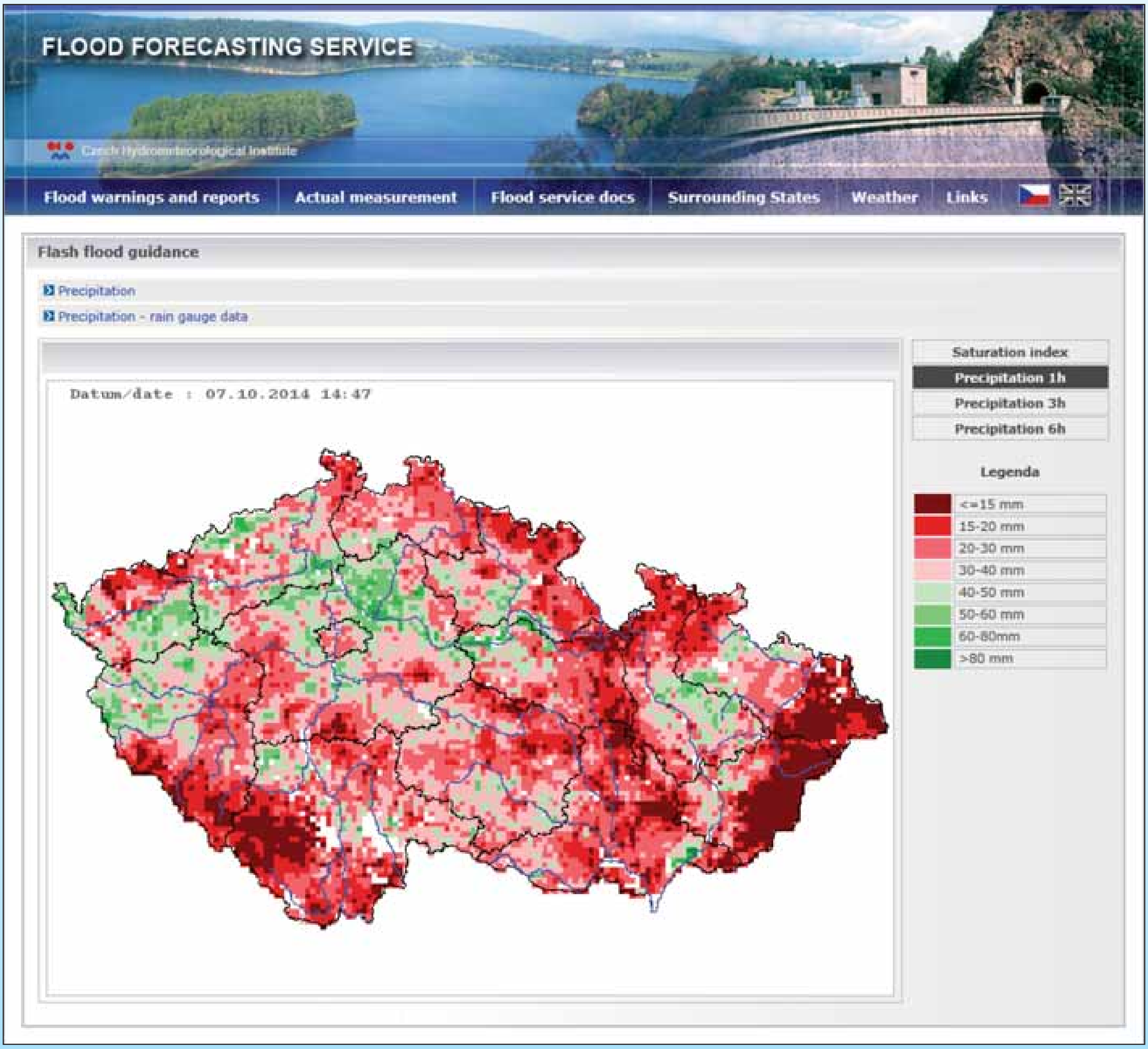
Another major qualitative change compared to 2002 is represented by the significant development of the Internet and services provided by the CHMI and River Basin Authorities through the internet. The internet presentation of the Flood Forecasting Service of the CHMI at <http://hydro.chmi.cz/hpps/> contains continuously updated record sheets of the flood reporting profiles, current data from meteorological and hydrological stations, meteorological model forecasts, hydrological forecasts and much more information. The Water Management Information Portal <http://voda.gov.cz/portal/> covers the websites of the state-owned enterprises of Povodí (River Basin Authorities), which contain current data from the monitoring networks of Water Management Operation Centres, including information from the reservoirs. In each region, current data from the water gauges are exchanged between the CHMI and River Basin Authorities, and with respect to the other data, both the presentations complement one another, and therefore, the public can monitor both the websites according to specific interest.

The CHMI website also presents completely new products of the Flood Forecasting Service which were introduced in the period between 2002 and 2013. In particular, this includes the so-called Flash Flood Guidance. Based on the output of a simple hydrological model, into which the precipitation field from combined precipitation information enters, the application provides information about the soil saturation in individual areas, as well as about the soil capability to retain further precipitation by specifying the dangerous precipitation total that may cause a flood response (Fig. 7.6). In summer, the application is calculated every day and is used for evaluating the risk of flash flood occurrence.

Another new feature of the website in winter is the presentation of water amount in snow cover, whose evaluation is currently carried out in a modern way in the GIS environment. It allows a spatial representation of the water content of snow cover and snow water volume for the individual river basins. The results are a valuable tool for the needs of water reservoir management in the spring.

At the Flood Forecasting Service website, those interested can find useful information even outside flood periods, e.g. evaluation of current flow probability with respect to historical data and groundwater. Issued warning information of the Integrated Warning Service System is also publicly presented on the internet, although this does not affect the main method of distribution of alerts to the flood authorities, which goes through the operation and information centres of the Fire Rescue Service of the Czech Republic.

However, all the above-mentioned improvements in the information area are only an impetus and tool for the correct human behaviour and activity. We therefore believe that the most significant change since 2002 consists in experts, meteorologists, hydrologists, as well as flood and emergency authorities and population gaining experience from major flood events, which will allow them, along with better information, to make quick and effective decisions in critical situation.



Datum/date : 07.10.2014 14:47

Fig. 7.6 Example of Flash Flood Guidance Presentation – Threshold for Rainfall Total for a Period of One Hour, Which Would be Dangerous in Terms of Flash Flood Occurrence.

8. CONCLUSION

In the previous chapters of this publication, you had a chance to get acquainted with the main results of the assessment of causes, progression and effects of the floods that hit the territory of the Czech Republic in June 2013. As we have pointed out in the introduction, the results presented herein are not complete, and we admit that they are more focused on hydrological aspects of floods and the Czech Hydrometeorological Institute activities. Readers can obtain more detailed information, even from other areas of the evaluation, from the Final Summary Report or individual reports of the Project, all of which are posted at the CHMI website.

The floods in June 2013 were undoubtedly extreme, as to their extent and effects. Within the evaluated major floods which have occurred in the Czech Republic since the end of the last century, the June 2013 flood ranks third, behind the floods in July 1997 and August 2002 (see Tab. 8.1). In terms of the magnitude of peak flow of the Vltava River in Prague and of the Elbe

Tab. 8.1 Significant Recent Floods in the Czech Republic.

Flood	Flood Type	Affected Area	Return Period	Flood Effects	Flood Documentation
July 1997	Summer regional flood, two flood epidoses	The whole Odra (Oder) and Morava River basins, part of the Upper Elbe River basin	100 to 500, exceptionally >500	CZK 62.6 billion 50-60 casualties	Comprehensive Project (CHMI), River Basin Authorities Reports
August 2002	Summer regional flood, two flood epidoses	River basins of the Vltava and Berounka Rivers, Lower Elbe River	200 to 1,000, at some locations >1000	CZK 73.1 billion 17-19 casualties	Comprehensive Project (Water Research Institute - WRI), River Basin Authorities Reports
June 2013	**Summer regional flood, two flood epidoses + flash flood epidose**	**River basins of the Vltava and Berounka Rivers, Lower Vltava River, Elbe River**	**20 to 50, exceptionally >100**	**CZK 15.4 billion** **16 casualties**	**Comprehensive Project (CHMI), River Basin Authorities Reports**
August 2010	Summer flood with flash flood elements	River basins of the Smědá, Lužnice, Nisa, Ploučnice and Kamenice Rivers	50 to 100, >100, exceptionally >1000	CZK 10.1 billion 5 casualties	Comprehensive Project (CHMI), River Basin Authorities Reports
June / July 2009	Flash floods	Nový Jičín, Jesenice, Děčín Regions	100, >100, at some locations >>100	CZK 8.5 billion 15 casualties	Comprehensive Project (CHMI)
March / April 2006	Spring flood, snow melting and rain	River basins of the Dyje, Morava, Sázava, Lužnice Rivers and others	50 to 100, exceptionally >100	CZK 6.0 billion 9 casualties	Comprehensive Project (WRI), River Basin Authorities Reports
May / June 2010	Summer regional flood, two flood epidoses	Odra and Morava Rivers basins	20 to 50, exceptionally >100	CZK 5.1 billion 3 casualties	Comprehensive Project (WRI), River Basin Authorities Reports
March 2000	Spring flood, snow melting and rain	Upper Elbe and Jizera Rivers basins	50 to 100, exceptionally >100	CZK 3.8 billion 2 casualties	CHMI Report, River Basin Authorities Reports
July 1998	Flash flood	Dědina, Bělá streams (right-bank tributaries of the Orlice River)	>100	CZK 1.8 billion 6 casualties	CHMI Report, Povodí Labe (River Basin Authority) Report

River in Děčín, the 2013 floods occupied most likely the third place among the summer floods over the period of instrumental observations since the first half of the 19th century, more specifically, behind the 2002 and 1890 floods.

Every larger flood brings knowledge and experience that can be used to improve the flood protection system in the following events. Draft measures have already been formulated in the reports of projects aimed at evaluating the floods that occurred in 1997, 2002, 2006, 2009, 2010, and undoubtedly, much has already been done to improve the flood prevention and protection. The overall level of Flood Management Planning, work performed by flood and emergency authorities and the functionality of information systems have improved.

With the support of the State Flood Prevention Programmes, a number of structural measures were taken to increase the flood protection level at specific locations. Following the issue of European Directive 2007/60/EC on the assessment and management of flood risks, a Preliminary Flood Risk Assessment was made and areas with significant flood risks were identified in the Czech Republic. In these areas, flood risks were mapped, and in 2014 and 2015, Flood Risk Management Plans are being and will be developed respectively. Activities are coordinated within the international river basins of the Elbe, Odra and Danube Rivers.

The Final Summary Report of the June 2013 Flood Evaluation Project also includes a proposed set of measures, which was discussed and approved by the Government of the Czech Republic through its Resolution No. 570 dated 14 July 2014. The adopted proposal contains a number of measures in the area of legislation, flood prevention, flood warning and forecasting service, activities of flood and emergency authorities, reservoirs operation and maintenance, flood documentation, as well as preparation and implementation of structural measures. When comparing them with the conclusions of past floods, we can find out that some proposed measures are repeated, which suggests that problems in these areas persist. On the contrary, undeniable progress has been achieved in other areas. When the reader takes this publication in his hands after a longer period of time and compares the information presented herein with reports on new, future floods, which will certainly occur again, he will be able to judge by himself to what extent our ability to cope with adverse effects of floods has changed.

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