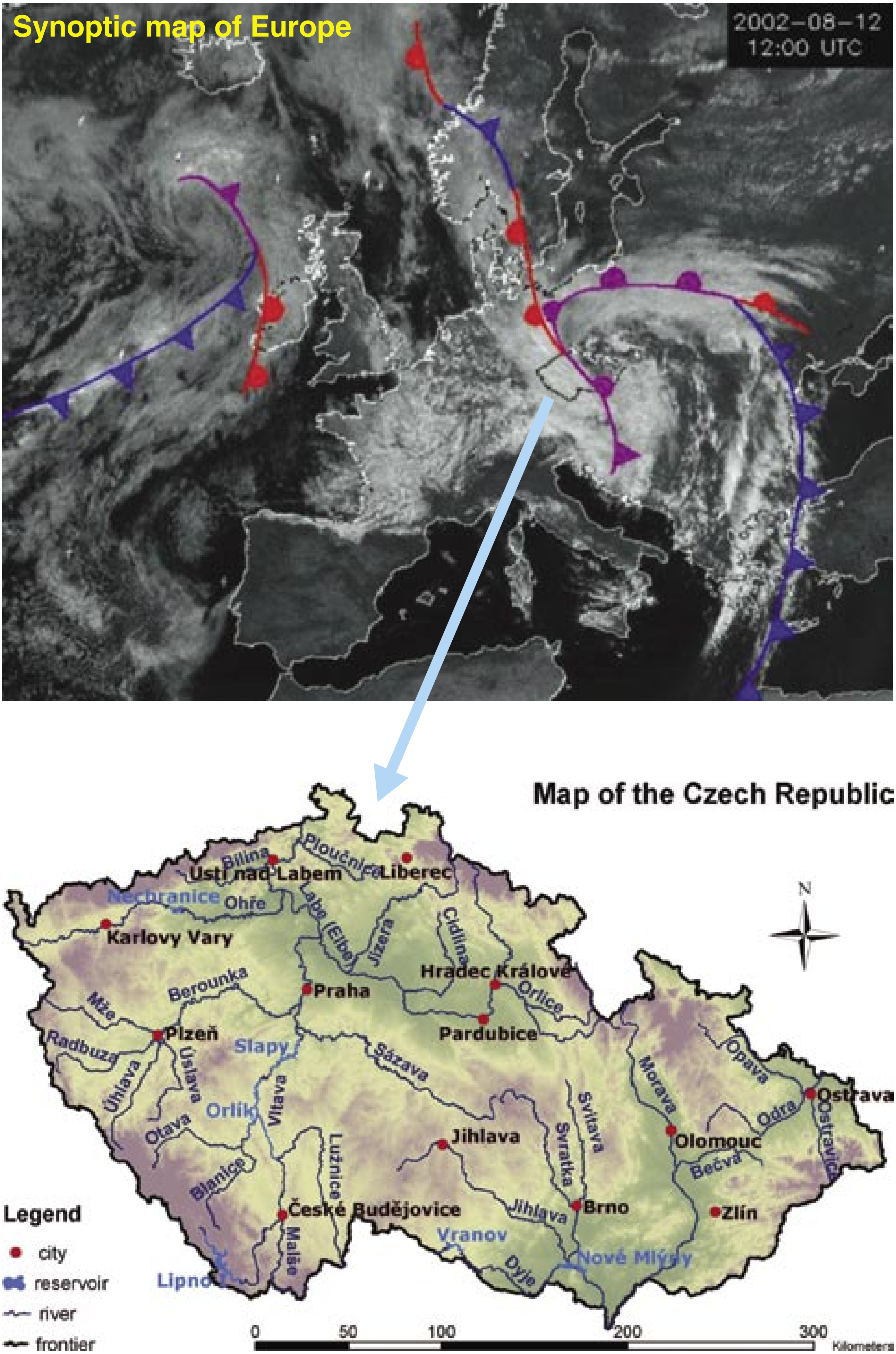
Ministry of Environment
of the Czech Republic

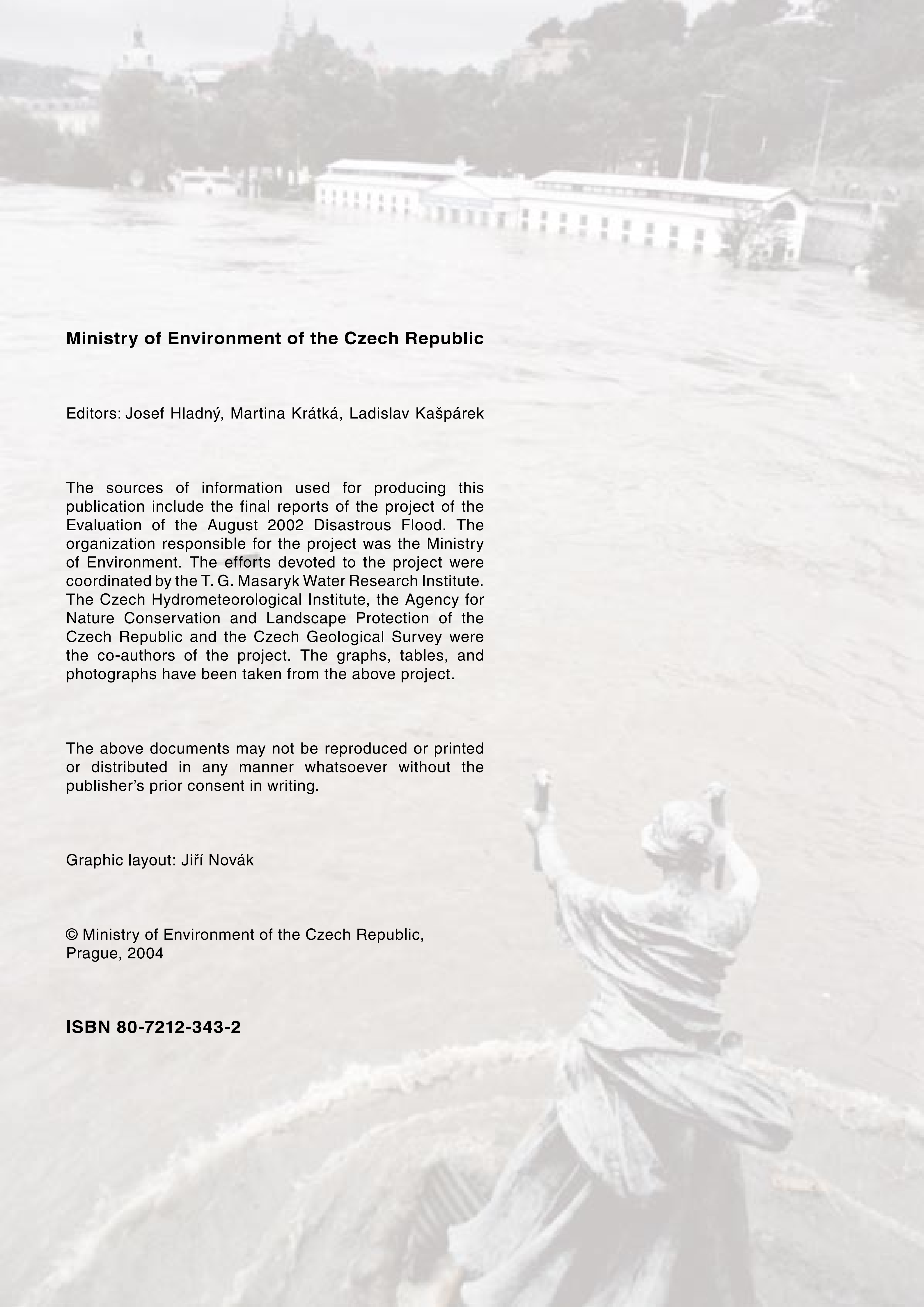
August 2002 catastrophic flood in the Czech Republic

VÚV TGM

T. G. Masaryk
Water Research Institute


Synoptic map of Europe
2002-08-12
12:00 UTC
Map of the Czech Republic
Ústí nad Labem
Liberec
Bílina
Ploučnice
Nechranice
Ohře
Karlovy Vary
Labe (Elbe)
Jizera
Cidlina
Hradec Králové
Orlice
Pardubice
Praha
Berounka
Mže
Plzeň
Radbuza
Úhlava
Úslava
Slapy
Sázava
Orlík
Vltava
Otava
Blanice
Lužnice
České Budějovice
Malše
Lipno
Jihlava
Svratka
Svitava
Brno
Vranov
Dyje
Nové Mlýny
Morava
Olomouc
Bečva
Zlín
Opava
Odra
Ostrava
Ostravice
N
Legend
city
reservoir
river
frontier
0
50
100
200
300
Kilometers

August 2002
catastrophic flood
in the Czech Republic



Ministry of Environment of the Czech Republic

Editors: Josef Hladný, Martina Krátká, Ladislav Kašpárek

The sources of information used for producing this publication include the final reports of the project of the Evaluation of the August 2002 Disastrous Flood. The organization responsible for the project was the Ministry of Environment. The efforts devoted to the project were coordinated by the T. G. Masaryk Water Research Institute. The Czech Hydrometeorological Institute, the Agency for Nature Conservation and Landscape Protection of the Czech Republic and the Czech Geological Survey were the co-authors of the project. The graphs, tables, and photographs have been taken from the above project.

Graphic layout: Jiří Novák

ISBN 80-7212-343-2

FOREWORD

The flood damage the Czech Republic has suffered over the past seven years has amounted to what from the historical perspective is a staggering CZK 142 billion (i.e. approximately EUR 4.6 billion). Thousands of homes, buildings, and various operations have been destroyed or heavily damaged. Hundreds of thousands of people had to be evacuated and, most tragically, 92 people perished. The overall harm inflicted on the quality of the environment is a clear signal that Central Europe is growing more and more vulnerable to extreme floods. Also, the indirect consequences of floods are evidence of the increasingly extensive and negative chain reaction in the socio-economic sphere (damage to physical and mental health of the population, growing rate of unemployment, damage to trade and markets, etc.). Budgets are also growing more sensitive to the consequences of huge floods: even if a flood does not hit the whole country at once, making up for and remedying the losses caused by it usually affects the whole country's economy. The two most recent disasters, the 1997 and 2002 floods, bear this out.

In particular, the August 2002 flood, where losses totalled more than CZK 73 billion, demonstrated again that very careful attention needs to be devoted to each and every one of such disasters; on the basis of a thorough interdisciplinary assessment of the disaster we need to expand our knowledge of how to protect ourselves as efficiently as possible against the harmful effects of these extreme natural phenomena.

In view of the experience from the previous disastrous floods in 1997, the Czech Government has allocated the required funds for these purposes, and instructed the Ministry of the Environment to organise and implement a project entitled *Evaluation of the Disastrous Floods of August 2002*. Most of the country's specialist technical and research institutions have been involved in this. The project's Steering Committee, composed of representatives of the relevant Ministries, self-governing bodies from the afflicted regions (Regional Authorities), and managers of the respective catchments, has monitored and directed the efforts.

The purpose of the project was to coordinate and align unique interdisciplinary activities focused on the evaluation of the August 2002 floods. In this publication, we want to impart the outcomes of the project to professionals at large. Some results of the projects were actually used as early as the course of carrying out the project to formulate the principles of international co-operation, for example in the *Flood Control Action Plan for the River Labe Catchment*, approved by the International Commission for Protection of the River Labe in October 2003, and in the *Action Plan for Flood Control in the River Odra Catchment*, approved by the International Commission for Protection of the River Odra against Pollution, in December 2003. The project outcomes may also serve as one of the sources of information for the European Commission in developing its European policy for protection against floods.

At this place, I wish to express thanks to all those who have contributed to the project and its implementation, and all those who tackled or helped to manage their own flood situation in August 2002 or participated in the efforts to reclaim and regenerate the afflicted areas.

Ambrozek

Libor Ambrozek
Minister of the Environment
Czech Republic

CONTENTS

INTRODUCTION

This publication represents a contribution from the Czech Republic to the global efforts dealing with reducing damage from natural disasters. It summarizes results of the project on Evaluation of the August 2002 Catastrophic Flood in the Czech Republic initiated by the Government of the Czech Republic.

The project was carried out by more than one hundred experts representing ten different scientific disciplines. The main responsible institution was the T. G. M. Water Research Institute; a substantial input to the project was provided by the Czech Hydrometeorological Institute, the Agency for Protection of Landscape and Nature, the Czech Geological Service and a number of other institutions. Apart from identification of meteorological causes of unusually heavy precipitation, analysis and modelling of dynamics of flood waves and evaluation of function of information, warning and forecasting systems, also impacts of the flood on the environment were studied, including changes in water quality during and after the flood, geological changes in alluvial plains and groundwater aquifers, effects of water reservoirs on development of flood situation in the river network, experience from activities of flood management authorities during critical conditions, harm to public health, impact of the flood on social conditions in the affected areas, estimates of flood damage, establishment of a storage centre on information about the flood situation, mapping of inundation and their depths etc.

The flood affecting mainly the Vltava River Basin in the Czech Republic ranks among events with return periods of duration of a century. We are convinced that the knowledge we collected about it may be useful also in other countries. It was also the main reason for a decision to publish the results of the project in an English version.

Let me allow at this occasion to express by sincere thanks to all who, in a major or lesser extent, contributed to evaluation of the August flood disaster and helped with the preparation of this publication.

Jan Bouček
Coordinator of the Government Project on
Evaluation of the August 2002 Catastrophic Flood

1 METEOROLOGICAL CAUSES OF THE FLOOD

Circulation during summer season of 2002 across the Atlantic and the European continent was significantly of the meridian type. Zone streaming appeared sporadically and lasted usually shortly. Pressure lows and front systems, which moved along the southern trajectory across Mediterranean into the Central Europe, brought along unusually strong precipitation. This strong precipitation was appearing in Mediterranean during whole summer season and in Central Europe in August in particular.

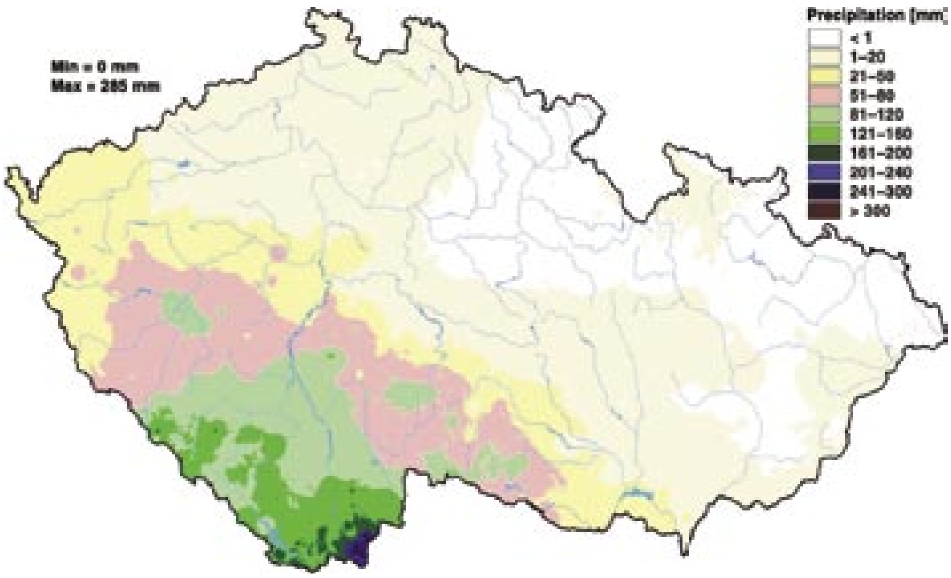


Figure 1.1 Map of precipitation in the period from 6th to 7th August 2002

1.1 Meteorological situation

On 5 August 2002 a pressure low evolved over the west Mediterranean, the front system of which drifted towards north-east and by 6 August it moved above the east Alps. This day it started already to affect also south Bohemian region by intensive long persisting rain and locally by rainstorms. On Wednesday 7 August it started to move south-east and heavy precipitation in the Czech Republic ended on Thursday 8 August at morning hours.

Another pressure low moved across British islands south-east on 9 August. On 10 August evening it regenerated above north Italy and started to drift with its front system towards north. During 11 August it reached the Czech territory and during 12 August it was slowly moving towards Poland. Intensive persistent precipitation hit gradually from south the whole territory of the Czech Republic. Due to orographic intensification the peak precipitation intensities were recorded in mountain ranges and highland regions. During Monday 12 August even short intensive precipitation appeared within storms along the front line (the Vltava,

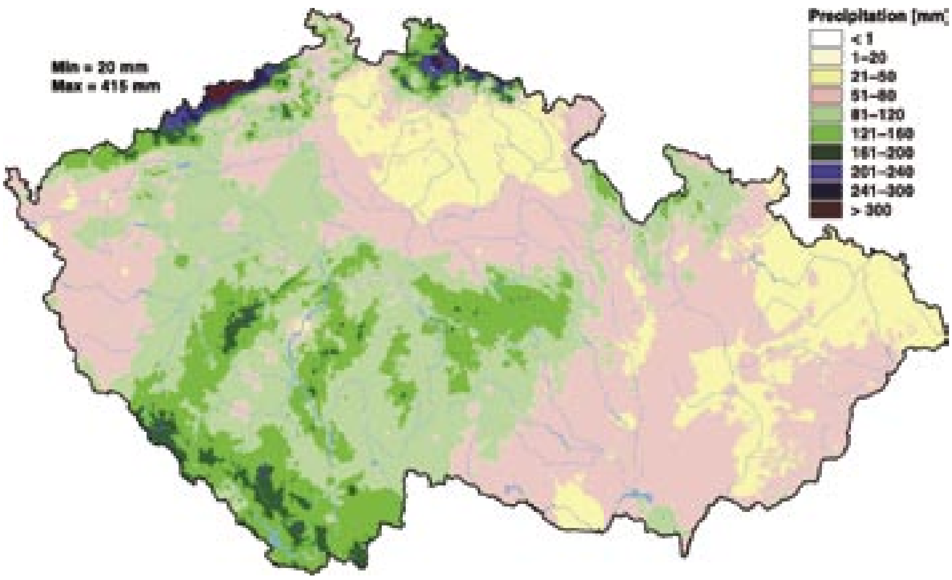


Figure 1.2 Map of precipitation in the period from 11th to 13th August 2002

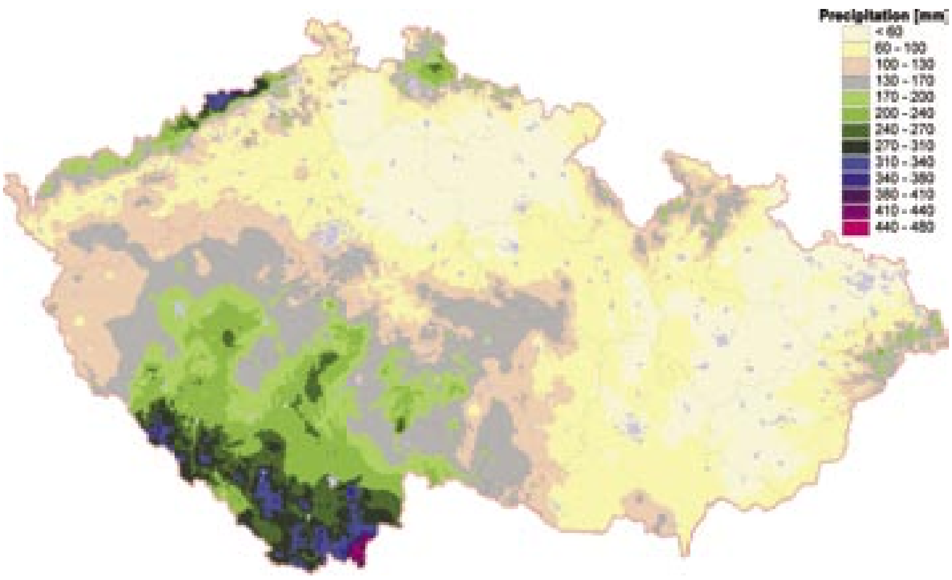


Figure 1.3 Map of precipitation in the period from 6th to 15th August 2002

Table 1.1 Areal precipitation derived for individual regions in the Czech Republic in the period from 6th to 15th August 2002

Region	Area [km²]	Precipitation (mm) in individuals days (August 2002) and sum for the total period [1]										
		6.8	7.8	8.8	9.8	10.8	11.8	12.8	13.8	14.8	15.8	6.-15.8
Středočeský and Praha	11,510	8.4	13.4	1.1	0.1	0.1	24.9	**50.1**	13.7	0.2	0.7	112.7
Jihočeský	10,050	51.5	55.1	2.6	0.2	0.6	45.4	**70.2**	4.3	0.1	0.1	**230.1**
Plzeňský	7,553	31.3	38.9	1.7	0.4	3.9	32.7	**68.4**	0.5	0.1	0.3	178.2
Karlovarský	3,301	18.2	15.3	6.2	0.0	4.1	33.1	**48.1**	0.3	0.1	0.1	125.5
Ústecký	5,328	5.7	3.0	1.6	0.0	0.1	24.8	**76.0**	9.8	0.1	0.4	121.5
Liberecký	3,143	4.1	2.0	0.0	0.5	0.9	7.4	29.7	**55.7**	0.2	0.1	100.6
Královéhradecký	4,738	0.6	0.0	0.0	0.8	2.6	9.9	14.8	**33.1**	3.9	0.3	66.0
Pardubický	4,521	0.1	1.1	0.0	1.4	0.9	19.0	8.8	**52.0**	3.6	0.1	87.0
Vysočina	6,929	23.7	9.2	0.3	2.4	0.0	24.6	**42.0**	32.2	0.4	0.2	135.0
Jihomoravský	7,036	13.4	3.9	0.0	0.7	0.0	**31.5**	8.8	21.7	1.8	0.2	82.0
Olomoucký	5,120	0.6	1.2	0.0	2.8	1.6	21.8	4.7	**39.3**	5.1	0.8	77.9
Moravskoslezský	5,509	0.1	0.2	0.0	5.7	2.9	17.9	2.7	**25.9**	16.4	4.9	76.7
Zlínský	3,939	0.5	1.2	0.1	2.0	0.3	23.1	3.9	**29.7**	8.9	4.0	73.7

[1] values in bold indicate maxima

Sázava, middle Elbe and Dyje river basins). On Tuesday 13 August precipitation activity over the Czech territory started slowly to weaken from southwest and it ceased during 14 August.
Movement of the two successive significant pressure lows within short time period brought extreme floods in Central Europe. Both of the lows hit by their back (rear) side (the rainiest sector) the territory of the Czech Republic. In addition, both moved only very slowly, causing prolongation of the period of persistent precipitation.

1.2 Distribution of precipitation

During the first precipitation event on 6 and 7 August (Figure 1.1), the total volume the precipitation was 2.4 km³ while during second event in the period from 11 to 13 August it was 6.7 km³ (Figure 1.2).
Figure 1.3 shows spatial distribution of total precipitation in the period from 6 to 15 August. The highest 10-day precipitation totals exceeding 400 mm occurred in the Novohradské Mountains in southern Bohemia in boundary belt with Austria and in eastern top parts of the Krušné Mountains at the boundary with Germany. Precipitation exceeding 300 mm occurred in substantial part of the Šumava (mountains), in the remaining parts of the Novohradské Mountains, including their foothills, and in high parts of the Jizerské Mountains.
Strong precipitation belt affected also territories of other countries (Italy, Austria and Germany).
The total volume of precipitation which fell from 6 to 15 August 2002 on the territory of the Czech Republic was enormous, amounting to almost 9.7 km³, most part of which fell in Jihočeský and Plzeňský region (Table 1.1).
In August 2002, mean areal precipitation on the territory of the Czech Republic was at a level of 225% of long-term mean. In Jihočeský region, it was even 381% of the mean.

1.3 Extremity of precipitation

In August 2002, some of the stations recorded precipitation which was at a level of the highest precipitation totals recorded since the beginning of the observation on the territory of the Czech Republic.
The daily precipitation totals recorded at rain-gauge stations in August 2002 were compared with daily totals derived for return period of 100 years. Precipitation occurring on large areas reached levels between 0.4 and 1.1 of the 100-year values. At some localities, however, the extreme storm precipitation reached 1.6 of the 100-year values (the Novohradské Mountains, ridges of the Krušné and Jizerské Mountains). The most extreme precipitation totals exceeding by a factor of three 100-year value fell in the vicinity of Cínovec.

1.4 Saturation of the basin

For an assessment of saturation of the basin and its capacity to retain additional rainfall water, antecedent precipitation index (API) was used. This parameter, which was calculated from precipitation during 30-day period before causal rainfall, uses weights, which give less significance to those daily precipitation values which are more distant in time. The point values of API30 were calculated for 6 August (beginning of the first precipitation event)

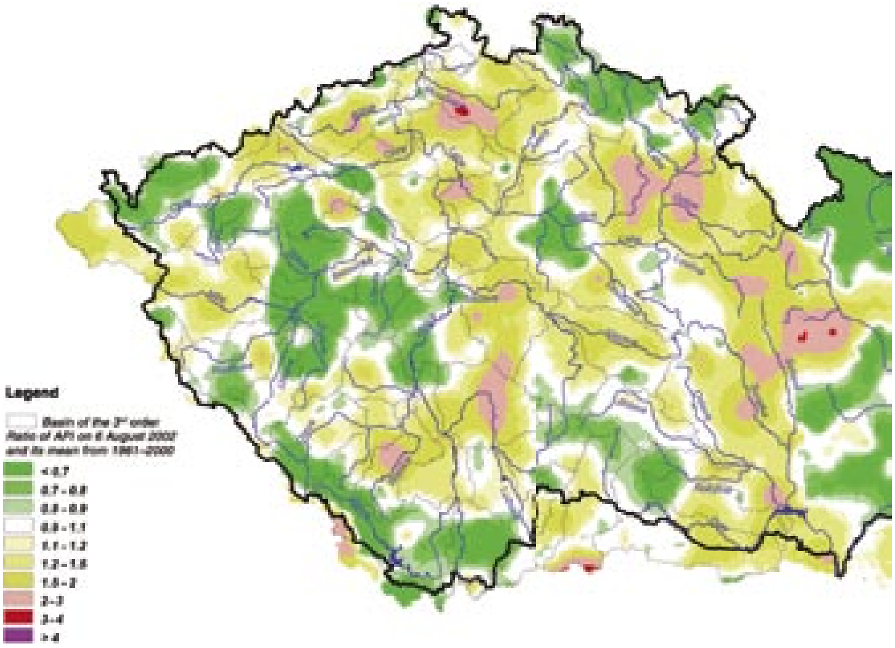


Figure 1.4 Ratio of antecedent precipitation index (API30) on 6th August 2002 and its standard value

and for 11 August 2002 (beginning of second event) and they were subsequently interpolated by using a geographical information system. For the assessment of the situation in 2002, also long-term means of API30 values were calculated for identical days (6 and 11 August) from daily precipitation time series 1961 – 2000. The results of the comparison of the values from 2002 and the long-term means are shown in maps in Figures 1.4 and 1.5.
Before the first precipitation event, the saturation of the basin was mostly between 80% and 120% of the standard value. Consequently to the first precipitation event, the basin saturation before the second event in eastern and western Bohemia reached 200% to 400% of the standard or exceptionally even more. The most saturated basins before the second precipitation event included those of the Upper Vltava, Malše, Otava, Blanice and Upper Dyje (in Austria) Rivers and these basins also experienced the most intensive precipitation during the second event. Consequently to the first precipitation event, the basins were highly saturated and their remaining retention capacity was insufficient for significant reduction of the flow during the second event. Such conditions were in natural basins as well as in those partially urbanised.

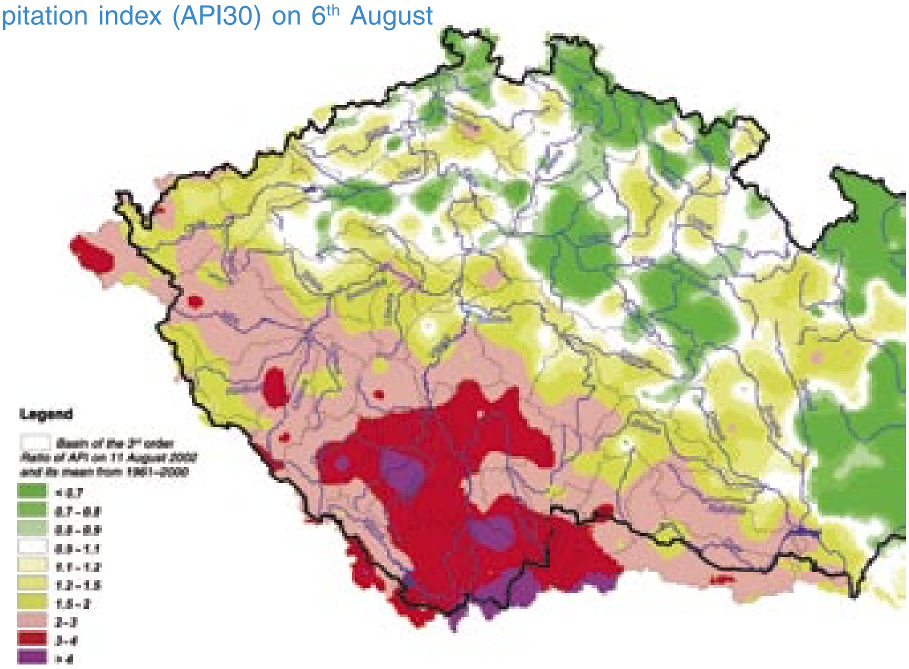


Figure 1.5 Ratio of antecedent precipitation index (API30) on 11th August 2002 and its standard value

2 METHODS FOR ESTIMATION OF FLOOD FLOWS

Estimation of flood flows was extremely difficult because water stages exceeded those observed in historical observation at many river sites. This was associated with extensive flooding of flood plain areas and large morphological changes of the channels. In addition, at some of the sites the water gauging stations and naturally also water stage records were totally damaged. In more favourable cases, important parts of the flood hydrographs were missing in water stage records. Values of the maximum water stages had to be verified also in stations where the water stage records were available because these sites were not accessible during the flood and the records might be incorrect.
Another widely occurring problem associated with assessing extreme flood flows was in fact that rating curves, which had been derived from water flow measurements, were not available for high water stages. Due to relatively great flow velocities, transported objects and frequent inaccessibility of water gauging stations, it was impossible to conduct relevant measurements during the flood. The rating curves therefore had to be extrapolated by using indirect methods.
Several measurements of surface water flows could be made for the Vltava River at Prague, of which one full measurement was carried out on 14 August 2002 immediately after the occurrence of the maximum flows. This contributed to availability of more accurate estimates

of the flows for Prague. In the period form 7 to 23 August 2002, 130 water flow measurements were carried out on rivers affected by the flood. The flow on 19 August 2002 was the highest of those measured by using current meter in history of the Czech Republic. This maximum flow of 2,180 $m^3.s^{-1}$ was measured in the Elbe River at Děčín for the water stage at a level of 743 cm. For many river sites, the flood flows were assessed in cooperation with companies that were involved in hydraulic modelling of flows and morphological changes in river channels. The results were compared with those of water balance assessment of runoff volume, which was carried out by Czech Hydrometeorological Institute (CHMI).

2.1 The use of hydraulic models

Several one-dimensional (1D) hydraulic models of non-steady flow (HEC-RAS, Hydrocheck and MIKE 11) were used for estimation of maximum discharges. The simulated peak flows were derived for 30 water gauging stations.
This modelling approach is normally associated with uncertainty originating from the fact that some of the model parameters (mainly roughness coefficient) cannot be derived exactly. It was therefore necessary to verify and refine rating curves, which were derived by using the modelling approach.
Two-dimensional (2D) hydraulic models were used for those sites where complexity of the flows did not allow the use of one-dimensional models. These sites were located in downstream reaches of rivers where the water widely overflowed the banks into flood plain areas. The results of the modelling do not provide only the maximum flows, but the whole flood hydrographs.
The flood hydrographs, which were derived for several sites of the river, could be used for estimation of the flood routing along its longitudinal profile. Complicated flows occurred mainly in the Vltava River downstream from Prague and the Elbe River downstream from Mělník. For example, the flood hydrographs were derived for the Vltava River at Vraňany and the Elbe River at Mělník, which are localities where the water gauging stations were completely damaged by the flood.

2.2 Knowledge from simulation of the flood flows

The fast increase in water stages in the Elbe River subsequently to backwater effects and high inflows from the Vltava River was a causal factor of backwater flows in the Elbe for a distance of 8 km upstream from this confluence. In results of the simulation, these backward flows and relevant water depths were indicated in the period between 13 and 14 August 2002.
The water from the Blanice River, which is a left hand side tributary of the Otava River, was frequently diverted into raceways whose length reached several kilometres. The flood flows of the mainstream were consequently decreased by retention effects of these channels. This fact was also substantiated by results of the mathematical modelling. An important role during the flood was also played by bridges and connected transverse structures mainly in the downstream reaches of the rivers and their flood plain areas. Such transverse dams which were consequently formed had transformation effects on the flood flows.
Several bridges were completely damaged on the Berounka River, mainly in localities where local morphological conditions did not allow inundations and consequent decrease in dynamic impacts of water flow on the transverse structures. The results of mathematical modelling of the Berounka River reach downstream from Beroun contributed to a comparative analysis of maximum flows of the highest known historical flood from 1872 and the flood in 2002.

3 HYDROLOGICAL ASSESSMENT OF THE FLOOD

The two precipitation events were reflected also in two flood waves, of which the second one was mostly larger (Figures 3.1 to 3.5, Tables 3.1 and 3.2).

3.1 Flood evolution in large basins

Extremity of this flood was predominantly high in middle and large basins and exceptionally in small basins, if they experienced high intensity rains.
The return period of the flood was increasing with an increase in basin area because the flood waves, which simultaneously developed in neighbour basins consequently to high precipitation, coincided in confluences of river network. This was an important causal factor of all floods occurring in large areas particularly during the second flood wave.


The confluence of the Vltava and Otava Rivers in the Orlík reservoir

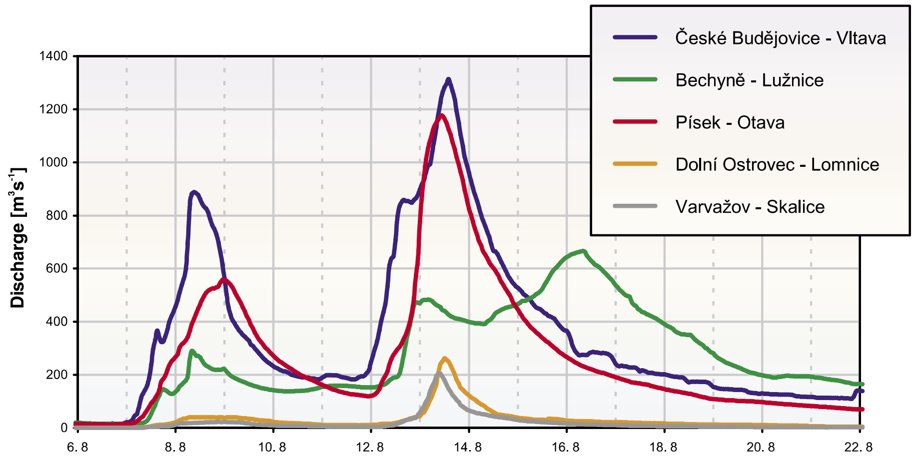


Figure 3.1 Flood hydrographs of the tributaries of the Orlík Reservoir

Hydrological conditions during the first flood wave

The first precipitation event on 6 and 7 August was reflected in occurrence of relatively large floods mostly in southern Bohemia. In basins of rivers draining the Novohradské Mountains, the intensive precipitation caused catastrophic floods, mainly of the Malše River and its tributary the Černá River, where the return periods of maximum flows exceeded locally 500 years. The flood runoff from precipitation in the spring area of the Vltava River in Šumava (mountains) was retained mainly by the retention capacity of Lipno I reservoir. The flood wave of the Vltava River reached therefore its extremity downstream from its confluence with the Malše River at České Budějovice, where the return period of the maximum flow was close to 1000 years. The extreme flood wave was gradually transformed along the longitudinal profile of the Vltava River because the flows of the downstream tributaries (the Otava and Berounka) were relatively small and large part of the flood was retained in a cascade of reservoirs on the Vltava River. Consequently, the return period of the flood in Prague was at a level of only 5 years.

The first precipitation event affected also partially the Dyje River basin, however, the flood wave in this basin was retained in the Vranov reservoir.

Hydrological conditions during the second flood wave

Consequently to the first precipitation event, the basins were saturated by water and therefore unable to retain new precipitation during the second event, which was reflected in catastrophic flood runoff volumes and maximum flows in the most affected regions. The extremely high runoff volume of the second flood wave could not be retained by reservoirs of the Vltava River cascade and therefore also the maximum flows could not be reduced. The calculations showed that only Lipno I and Orlík reservoirs affected significantly the maximum flows during the second flood wave by reducing these discharges by 150 $m^3.s^{-1}$ (Lipno I) and 800 $m^3.s^{-1}$ (Orlík). However, maximum permitted water stage in Orlík reservoir was exceeded by more than 1.5 m.

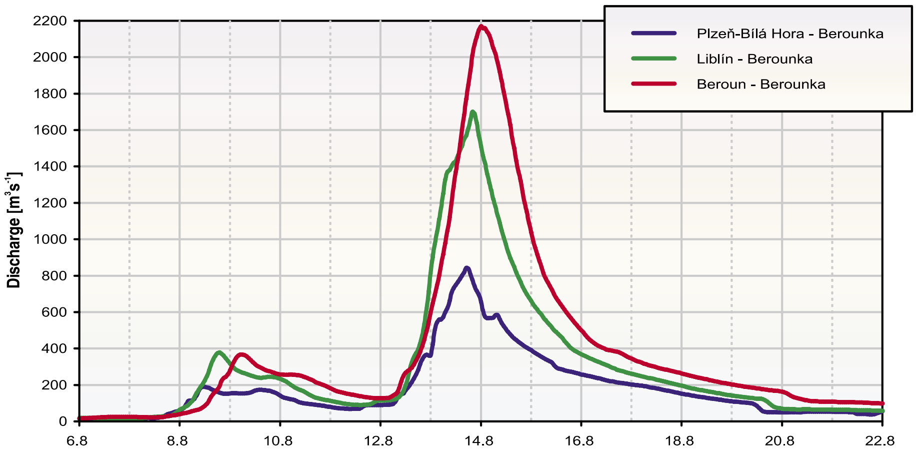


Figure 3.2 Flood hydrographs of the Berounka River

Maximum flows of the two flood waves at the confluence of the Berounka and Vltava River upstream from Prague coincided, which was the causal factor of the catastrophic flood in the capital. For the Lower Berounka River, it was the highest recorded flood after that in 1872. For the Vltava in Prague, it was the largest flood in terms of both the calculated maximum flow and historical bench marks of water stages. Rereturn period of the maximum flow of 5,160 $m^3.s^{-1}$ (14 August 2002) is 500 years.

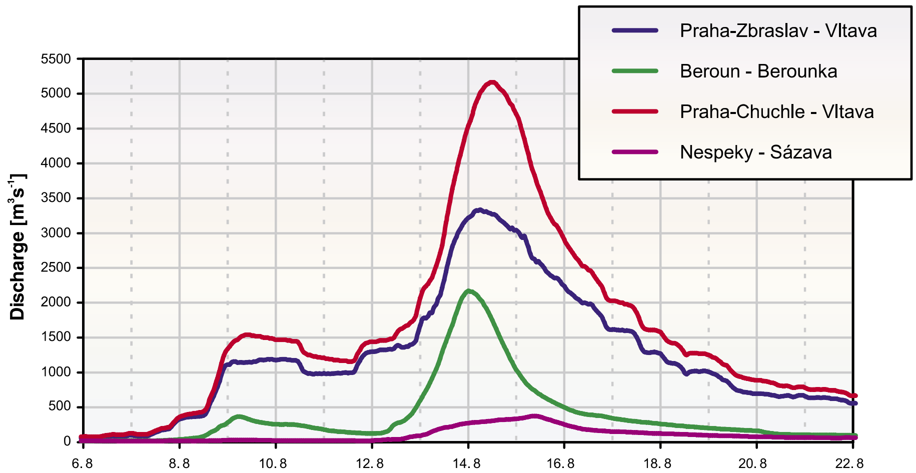


Figure 3.3 Flood hydrographs of the Vltava, Sázava and Berounka Rivers

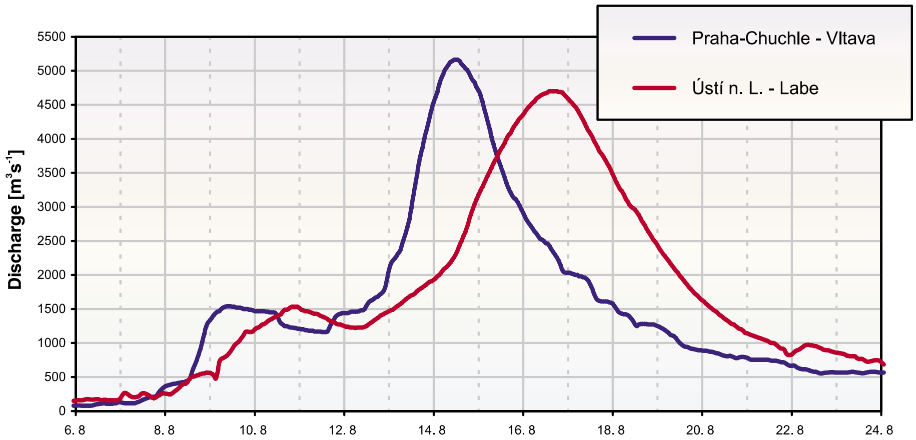


Figure 3.4 Flood hydrographs of the Vltava and Elbe Rivers

In its travel in the Vltava River downstream from Prague and in the Elbe River, the flood wave was spread widely in flood plain areas, which was reflected in a gradual decrease in the maximum flow. Another factor contributing to this fact was that the flows of the Elbe River upstream from Mělník and of its tributaries, the Ohře, Bílina and Ploučnice, did not contribute significantly to the total flow of the Elbe River. The flood flow in the downstream reaches of the Elbe River at Hřensko culminated on 16 August and the maximum discharge of 4,780 m^3.s^{-1} had a return period over 100 years.

As a consequence of extreme precipitation, large floods occurred also in the Dyje River basin, particularly on the territory of Austria. During this event, the Vranov reservoir could not reduce significantly the flood flows,

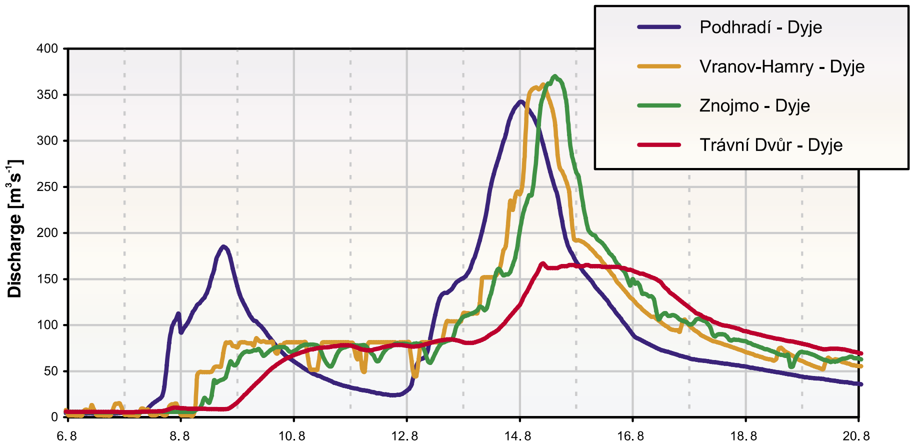


Figure 3.5 Flood hydrographs of the Dyje River

which were transformed only in lower reaches of the river consequently to the effects of flood plain areas and to retention of high part of the flood in a system of Novomlýnské reservoirs.

Of about 200 reporting water gauging stations in the Czech Republic, the water stages at 74 exceeded limits for declaration of second degree of flood protection activity (emergency) and the third degree (danger) was reached at 63 stations. Map of degrees of flood protection activities is shown in Figure 3.6.

3.2 Flood evolution in small and ungauged basins

Flood waves at sites whose basin area is small are not significantly transformed by retention capacity of river channels and their flood plain areas, and their maximum flows are suitable for derivation of non-transformed specific values, which are useful for derivation of effects of retention capacities in basins on flood flows. The assessment was therefore focused on those small watercourses which are ungauged or whose water gauging stations were damaged, particularly in areas which experienced extreme precipitation. These areas were located specifically in the Jizera Mountains, the Krušné Mountains and basins of Upper Vltava and of tributaries of the Berounka River.

The results of the assessment include maximum flows, specific maximum runoffs and causal precipitation totals for about 60 sites.

The flood flows were derived mainly from geodetic measurements of cross sections and subsequent hydraulic calculations.

Specific events occurred in basins of the Polečnice River and Křemžský Brook (left-hand side tributaries of the Vltava River at Český Krumlov), which experienced 3 large floods in summer 2002 during a period of 1 month. It is notable that maximum flows of all these 3 events

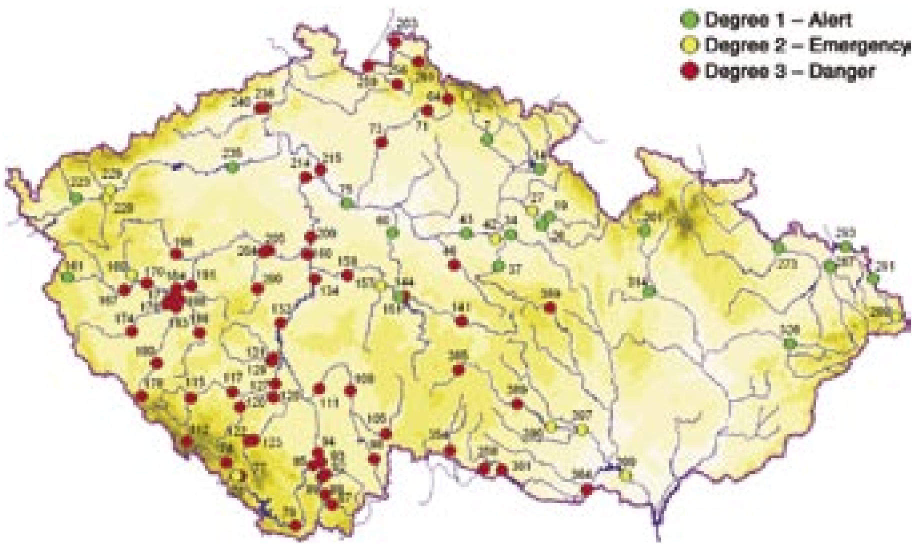


Figure 3.6 Map of degrees of flood protection activities declared during August 2002 flood for sites of reference water gauging stations

The upper reaches of the Bystřice Brook

exceeded that officially considered to be 100-year flood. The flood flows of the Bystřice Brook, which is a mountain stream in the Krušné Mountains, transported large quantity of sediments, gravel and boulders whose diameter reached 0.5 m. The flow from basin area of 9 km^2 at site located only 6 km downstream from the water divide reached 33 m^3.s^{-1}. This local flood impacted mainly Dubí small town (located at the State boundary close to Teplice town), which experienced the flood in its full magnitude. Two-day total of the causal precipitation observed at Cínovec station (close to Dubí) was 380 mm.

3.3 Influence of dams and weirs on flood flows

Before the first flood wave, the retention capacities of all of the large reservoirs were empty, which represents volume of 175 millions m^3, and due to relatively dry period before the flood also storage capacities of most of the reservoirs were partially available, which provided additional retention capacity of 175 millions m^3. The magnitude of the flood was extremely high and therefore the majority of the reservoirs reduced significantly the maximum flows during the first flood wave, however, they mostly could not affect the flows during the second wave, which was mostly greater.

The Bystřice Brook flooding Dubí town

3.4 Effect of the cascade of reservoirs on the Vltava River

The Vltava Cascade affects significantly the runoff regime since 1954, when a part of a flood was retained by Slapy reservoir whose construction was closely before completion. The floods are mainly affected by Orlík reservoir, which was put into operation in 1968. In the period from 1955 to 2001, the Vltava River experienced floods whose return period did not exceed 20 years and therefore the effect of the Vltava Cascade was examined for only relatively small floods. The effect of the reservoirs in terms of reduction of maximum flows of the Vltava River at Prague varied for individual floods from relatively small values to 800 m^3.s^{-1}.

The August 2002 was therefore the first event when the Vltava Cascade experienced extreme conditions. In terms of retention capacities before the flood, 45 millions m^3 was available in Lipno I reservoir and 126 millions m^3 in Orlík reservoir. The first flood wave from the upper part of the Vltava River basin was therefore fully transformed in the Lipno reservoir. The Orlík reservoir reduced the maximum flows in the lower Vltava River so that the flow relevant to the third degree of the flood protection activity (danger) was not exceeded and therefore the flood did not cause practically any damages in Prague.

The water retained in the reservoirs was released before the second flood wave and therefore the retention capacities of the reservoirs were available at a level of 23 millions m^3 in Lipno I reservoir and 104 millions m^3 in Orlík reservoir. However, the retention capacities were rapidly flooded during the second wave and maximum water stages permitted for individual reservoirs were exceeded for a number them. These conditions formed additional uncontrollable volume, which retained part of the flood.

Table 3.1 Maximum water stages and maximum flows during the first flood wave

Data bank num.	Site name	River name	Basin area [km²]	Mean flow Qa [m³.s⁻¹]	Maximum flow and associated data					
					Day	Time	Water stage [cm]	Discharge [m³.s⁻¹]	Specific runoff [m³.s⁻¹.km⁻²]	N [1)] [years]
1110	Březí	Vltava	1,824.6	20.0	8.8	5:00	266	332	0.182	20
1120	Kaplice	Malše	259.0	2.14	8.8	1:00	353	257	0.992	200-500
1125	Líčov	Černá	126.1	1.56	8.8	5:00	382	213	1.690	500
1126	Pořešín	Malše	437.9	4.05	8.8	2:00	457	434	0.992	500-1,000
1130	Římov	Malše	494.8	4.42	8.8	5:00	396	385	0.779	200-500
1140	Pašinovice	Stropnice	398.7	2.45	8.8	18:00	426	182	0.457	200
1150	Roudné	Malše	961.2	7.26	8.8	9:00	446	562	0.585	200-500
1151	České Budějovice	Vltava	2,847.6	27.6	8.8	9:00	548	888	0.312	500-1,000
1290	Hamr n. Nežárkou	Nežárka	981.2	12.3	10.8	3:00	361	93.7	0.095	2
1330	Bechyně	Lužnice	4,046.3	23.6	8.8	8:00	396	289	0.072	10
1380	Sušice	Otava	536.2	10.5	7.8	20:00	165	109	0.203	2-5
1430	Němětice	Volyňka	383.4	2.95	8.8	5:00	284	126	0.292	20-50
1450	Blanický Mlýn	Blanice	85.6	0.949	8.8	0:00	228	47.5	0.555	50
1500	Heřmaň	Blanice	839.6	4.65	8.8	23:00	272	191	0.228	50-100
1510	Písek	Otava	2,912.8	23.4	8.8	23:00	527	558	0.192	20-50
1520	Dolní Ostrovec	Lomnice	390.7	1.67	8.8	8:00	210	41.1	0.105	5
1530	Varvažov	Skalice	366.8	1.50	8.8	21:00	169	23.1	0.063	1-2
1799	Lhota	Radbuza	1,174.9	5.32	9.8	6:00	243	57.8	0.049	2
1801	České Údolí	Radbuza	1,263.4	5.49	8.8	7:00	240	59	0.047	1-2
1820	Klatovy	Úhlava	338.8	3.44	8.8	6:00	290	28.8	0.085	2
1830	Štěnovice	Úhlava	897.3	5.82	8.8	6:00	211	52.5	0.059	1-2
1860	Bílá Hora	Berounka	4,015.6	20	9.8	2:00	362	155	0.039	1
1870	Koterov	Úslava	734.3	3.53	8.8	7:00	286	123	0.168	5-10
1880	Nová Huť	Klabava	358.8	2.15	8.8	12:30	205	41.7	0.116	2
1910	Liblín	Berounka	6,454.3	30.1	8.8	18:30	297	378	0.059	2
1980	Beroun	Berounka	8,283.8	35.6	9.8	5:00	332	367	0.044	2
2001	Praha-Chuchle	Vltava	26,719.9	148	9.8	11:00	303	1,540	0.058	5
2210	Ústí n. Labem	Labe	48,556.9	293	10.8	20:00	653	1,530	0.032	1-2
4290	Janov	Mor. Dyje	517.5	2.63	7.8	21:00	274	40	0.077	5

[1)] return period of maximum flow

The inflow into Orlík reservoir was rapidly increasing, which was reflected in fast filling of the retention volume and consequently when all of the spillway gates were fully opened, the outflow from the reservoir was uncontrollable. The inflow into the reservoir culminated on 13 August at midday at a level of 3,900 m³.s⁻¹. At about that time, the operation of a hydropower station was interrupted due to flooding and consequently the capacity of installations for realising water from the reservoir was reduced by about 600 m³.s⁻¹. The capacity of the spillway gates and bottom outlets was insufficient for safe flood regulation and the water level increased by 1.57 m above maximum permitted value. Maximum outflow from the reservoir was 3,100 m³.s⁻¹. The flood flow hydrographs are shown in Figure 3.7.

Other reservoirs of the Vltava Cascade downstream from the Orlík did not affect significantly the flood flows.

Table 3.2 Maximum water stages and maximum flows during the second flood wave

Data bank num.	Site name	River name	Basin area [km²]	Mean flow Qa [m³.s⁻¹]	Maximum flow and associated data					
					Day	Time	Water stage [cm]	Discharge [m³.s⁻¹]	Specific runoff [m³.s⁻¹.km⁻²]	N [1)] [years]
0490	Přemilov	Chrudimka	204. 4	2. 22	14. 8	7:00	225	60.6	0.297	5-10
0590	Nemošice	Chrudimka	851.9	5.99	15. 8	4:00	263	91.6	0.108	2-5
0640	Spačice	Doubrava	198.4	1.56	13. 8	19:00	250	86	0.433	20-50
0660	Žleby	Doubrava	382.7	2.87	14. 8	4:00	305	127	0.332	20
0845	Jablonec n. Jizerou	Jizera	181.0	5.70	13. 8	17:00	377	202	1.116	10
0910	Železný Brod	Jizera	791.0	16.6	13. 8	21:00	457	433	0.547	10-20
1018	Předměřice	Jizera	2,158.4	24.3	15. 8	4:00	497	270	0.125	2-5
1040	Brandýs n. Labem	Labe	13,111.4	99.3	15. 8	11:00	367	530	0.040	1-2
1090	Vyšší Brod	Vltava	998.6	13.4	13. 8	9:00	370	265	0.266	20-50
1110	Březí	Vltava	1,824.6	20.0	13. 8	10:00	410	706	0.387	> 1,000
1120	Kaplice	Malše	259.0	2.14	13. 8	7:00	353	257	0.992	200-500
1125	Líčov	Černá	126.1	1.56	13. 8	6:00	357	178	1.412	200-500
1126	Pořešín	Malše	437.9	4.05	13. 8	9:00	441	399	0.912	200-500
1130	Římov	Malše	494.8	4.42	13. 8	8:00	413	414	0.837	200-500
1150	Roudné	Malše	961.2	7.26	13. 8	11:00	465	695	0.723	1,000
1151	České Budějovice	Vltava	2,847.6	27.6	13. 8	14:00	652	1,310	0.460	> 1,000
1290	Hamr n. Nežárkou	Nežárka	981.2	12.3	14. 8	4:00	474	220	0.225	> 1,000
1310	Klenovice	Lužnice	3,143.0	19.7	15. 8	17:00	529	625	0.199	100-200
1140	Pašinovice	Stropnice	398.7	2.45	13. 8	5:00	492	250	0.627	> 1,000
1330	Bechyně	Lužnice	4,046.3	23.6	16. 8	8:00	640	666	0.165	1,000
1380	Sušice	Otava	536.2	10.5	12. 8	17:00	287	350	0.652	100
1430	Němětice	Volyňka	383.4	2.95	12. 8	16:00	321	199	0.519	200
1450	Blanický Mlýn	Blanice	85.6	0.949	12. 8	8:00	334	202	2.360	> 1,000
1500	Heřmaň	Blanice	839.6	4.65	13. 8	1:00	427	443	0.528	> 1,000
1510	Písek	Otava	2,912.8	23.4	13. 8	11:00	880	1,180	0.405	500-1,000
1520	Dolní Ostrovec	Lomnice	390.7	1.67	13. 8	12:00	361	263	0.672	> 1,000
1530	Varvažov	Skalice	366.8	1.50	13. 8	10:00	406	203	0.556	> 1,000
1539	Radíč	Mastník	268.2	0.599	13. 8	14:00	274	71.2	0.265	50-100
1546	Štěchovice	Kocába	308.8	0.574	13. 8	17:00	211	78.7	0.255	50
1610	Zruč n. Sázavou	Sázava	1,419.8	9.92	14. 8	16:00	426	197	0.139	5-10
1625	Poříčí n. Želivkou	Želivka	780.1	4.79	14. 8	21:00	294	89	0.114	5
1632	Soutice	Želivka	1,187.0	6.97	14. 8	12:00	248	78	0.066	1-2
1672	Nespeky	Sázava	4,037.2	23.4	15. 8	9:00	473	378	0.094	5-10
1690	Zbraslav	Vltava	17,816.7	110	14. 8	6:00	1,042	3,340	0.187	200-500
1730	Stříbro	Úhlavka	296.8	1.20	13. 8	14:00	233	53.8	0.181	20
1740	Stříbro	Mže	1,144.8	6.69	13. 8	18:00	290	131	0.114	10

Data bank num.	Site name	River name	Basin area [km²]	Mean flow Qa [m³.s⁻¹]	Maximum flow and associated data					
					Day	Time	Water stage [cm]	Discharge [m³.s⁻¹]	Specific runoff [m³.s⁻¹.km⁻²]	N 1) [years]
1761	Hracholusky	Mže	1,609.6	8.28	14.8	0:00	370	124	0.077	5
1790	Staňkov	Radbuza	699.9	3.70	13.8	8:00	360	213	0.304	100-200
1799	Lhota	Radbuza	1,174.9	5.32	13.8	12:00	432	360	0.306	200-500
1801	České Údolí	Radbuza	1,263.4	5.49	13.8	15:00	580	339	0.268	200
1820	Klatovy	Úhlava	338.8	3.44	13.8	6:00	362	159	0.469	200-500
1830	Štěnovice	Úhlava	897.3	5.82	13.8	12:00	513	398	0.444	1,000
1860	Plzeň-Bílá Hora	Berounka	4,015.6	20.0	13.8	17:00	799	858	0.214	100-200
1870	Koterov	Úslava	734.3	3.53	13.8	7:00	371	459	0.625	> 1,000
1880	Nová Huť	Klabava	358.8	2.15	13.8	7:00	294	266	0.741	200
1900	Plasy	Střela	775.5	3.05	13.8	6:00	210	48	0.062	1-2
1910	Liblín	Berounka	6,454.3	30.1	13.8	20:00	703	1,710	0.265	500-1,000
1960	Čenkov	Litavka	157.0	0.86	13.8	2:00	235	88	0.561	50-100
1964	Hořovice	Červený p.	74.8	0.325	13.8	0:00	127	40.4	0.540	20
1973	Beroun	Litavka	628.7	2.58	13.8	7:00	375	210	0.334	50
1980	Beroun	Berounka	8,283.8	35.6	13.8	23:00	796	2,170	0.262	500-1,000
2001	Praha-Chuchle	Vltava	26,719.9	148	14.8	11:00	782	5,160	0.193	500
2030	Vraňany	Vltava	28,048.2	151	14.8	20:00	829	5,120	0.183	500
2040	Mělník	Labe	41,824.7	252	15.8	13:00	1,066	5,050	0.121	200-500
2101	Stará Role	Rolava	127.9	2.38	13.8	4:00	261	39.3	0.307	5
2140	Karlovy Vary	Ohře	2,855.9	25.2	13.8	6:30	253	274	0.096	2-5
2190	Louny	Ohře	4,982.8	36.3	14.8	7:00	422	175	0.035	> 1
2210	Ústí n. Labem	Labe	48,556.9	293	16.8	14:00	1,196	4,700	0.097	100-200
2230	Chotějovice	Bílina	621.7	4.30	13.8	20:00	250	24.1	0.039	20
2260	Trmice	Bílina	963.5	6.50	13.8	22:00	297	59.2	0.061	20
2400	Děčín	Labe	51,103.9	309	16.8	19:00	1,230	4,770	0.093	100-200
2453	Hřensko	Labe	51,392.4	313	16.8	22:00	1,228	4,780	0.093	100-200
3200	Hrádek	Lužická Nisa	353.9	5.41	14.8	5:00	315	137	0.387	5-10
3230	Frýdlant	Smědá	132.4	3.09	13.8	20:00	261	219	1.654	20-50
4290	Janov	Mor. Dyje	517.5	2.63	14.8	0:00	303	46.8	0.090	10
4300	Podhradí	Dyje	1,750.7	8.50	14.8	0:00	476	343	0.196	200
4320	Vysočany	Želetavka	368.0	1.08	13.8	1:00	233	51	0.139	50
4340	Vranov	Dyje	2,223.9	9.74	14.8	9:00	378	364	0.164	100
4350	Znojmo	Dyje	2,491.4	10.3	14.8	14:00	462	375	0.151	100
4370	Trávní Dvůr	Dyje	3,448.5	11.6	14.8	9:00	516	168	0.049	10
4420	Dalečín	Svratka	367.0	3.34	14.8	4:00	216	87.6	0.239	10
4650	Dvorce	Jihlava	307.3	1.98	14.8	2:00	242	44.1	0.139	20
4805	Ladná	Dyje	12,276.8	41.6	15.8	15:00	408	318	0.026	5-10

The maximum permitted water stage in the Orlík reservoir was exceeded by more than 1.5 m

Verification of effects of the Vltava Cascade of reservoirs by using a simulation model

AquaLog hydrological modelling system was used for development of a detailed model of basins and reservoirs of the Vltava Cascade. The model was applied for verification of correctness of the observed or derived inflows into and outflows from the reservoirs. In further step, the model was used for simulation of 23 variants of initial filling and operation of the Orlík reservoir and their effect in terms of reduction of maximum flow of the August 2002 flood in Prague. Apart from 3 unrealistic variants, the difference between the simulated and real maximum flow was in an interval from +387 to -390 $m^3.s^{-1}$, which is maximally 7.5%. These results are at a level of possible accuracy of the modelling and its input data. They show that for such extreme flood there was no alternative operation of the Vltava Cascade which would reduce significantly the maximum flows in Prague during the second flood event.

The simulation included also derivation of probable flood hydrographs for an alternative that the dams had not been constructed. With respect to complexity of the problem and lack of data, it was necessary to apply high simplifications and therefore the results of these simulations can provide only approximate information. It can be deduced that reservoirs on the Vltava River did not affect significantly the velocity of the wave movement in the Middle Vltava and no acceleration was identified by the effects of the reservoirs in contrast to the original assumptions. This indicates that the flood waves from the Vltava and Berounka Rivers would coincide at the confluence also under natural conditions not affected by the reservoirs. However, sufficiently accurate derivation of the maximum flow in Prague could be based only on the development of a complex hydraulic model of the confluence of the Vltava and Berounka Rivers. Variability of possible values of the maximum flow in Prague is less than real accuracy of the simulation.

3.5 Balance assessment of the precipitation and runoff totals

Extremity of the flood can also be demonstrated by using values of runoff coefficients, which are ratios between quantity of water which outflows at a closing gauged site of a basin and quantity of rainfall on the basin area.

The runoff coefficients are logically high in those basins which have experienced high precipitation. The highest values have been derived for the Malše River basin, where direct runoff involving both flood waves amounted to 70% of the basin rainfall volume. For individual waves, it was 65% for the first one and 90% for substantially lower precipitation causing the second flood wave. The runoff coefficient for the second wave reflected high saturation of the basin as a consequence of the first event.

The spillway of the Orlík dam on the Vltava River

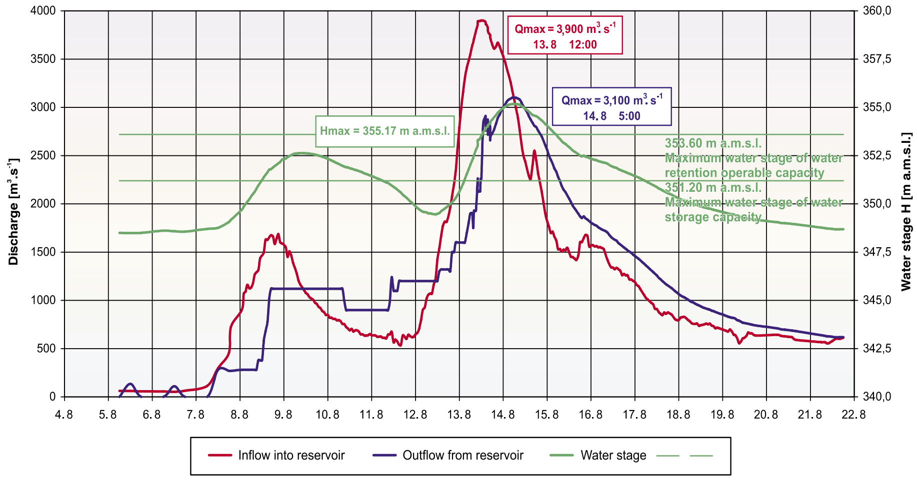


Figure 3.7 Flood hydrographs of August 2002 flood in Orlík Reservoir

The values of runoff coefficients were decreasing for larger basin areas and associated lower basin precipitation depth. The runoff volume was less than 50% of the whole precipitation amount for the Vltava River at Prague and less than 40% for the Elbe River at Ústí nad Labem. In absolute values, of the total precipitation at a level of 5.2 km³ on the Vltava River basin 2.5 km³ discharged at Prague-Chuchle river site.

4 ASSESSMENT OF FLOOD EXTREMITY

The assessment of extremity of August 2002 flood was firstly focused on probable return periods of maximum flows and runoff volumes at gauged sites of the river network. Subsequent assessment was focused on changes of statistical characteristics of maximum flow time series after involving the new flood peaks. From these series and their characteristic, design values are derived for the purposes of water management planning, construction activities, operation and also protection of the environment.

4.1 Return periods of maximum flows and runoff totals

The assessment of probable return periods of the maximum flows and runoff volumes was carried out by using their annual series, which alternatively involved and did not involve the new flood events from 2002 (Table 4.1). Figure 4.1 shows that the return periods which have been derived for the maximum flows from the series involving the August 2002 flood are shorter. In terms of design parameters, the consideration of August 2002 would be mostly reflected in an increase in their values, for some of them even by 40% (Figure 4.2).

Data from two water gauging stations, the Vltava River at Prague and the Elbe River at Děčín, were used for the assessment of return periods of the runoff volumes. Series of mean daily flows (period 1901–2002 including values reconstructed for 1890 flood and period 1851–2002 were available for Prague and Děčín, respectively) were used for derivation of runoff volumes coupled with given duration in number of days. It was derived for Prague that the probable return period of August 2002 flood runoff volume was approximately 200 years or between 200 and 500 years if only data from summer floods were used. For Děčín, these return periods were 50 years and 100 years respectively.

4.2 A comparison of 2002 flood with extreme historical events

Occurrence of extreme catastrophic floods is very irregular in the Czech Republic. Historical records, which are available e.g. for the Vltava River at Prague since 1827 or for the Elbe River since 1845, show that extreme floods were relatively frequent in second half of 19th century. This frequency was subsequently gradually decreasing and regional

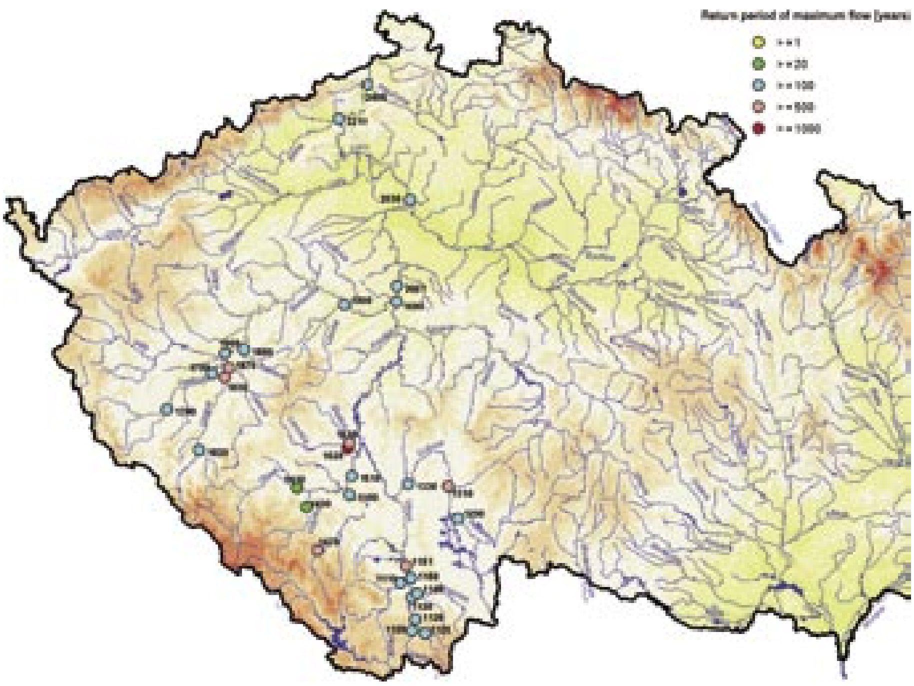


Figure 4.1 Map of return periods derived for August 2002 flood at sites of water gauging stations for an alternative when the flood was taken into account in the return period assessment (the stations are indicated by their database numbers)

Table 4.1 Maximum flows during the August 2002 flood and their return periods (N)

Data bank num.	Station name	River name	Basin area [km^2]	Maximum flow [m^3.s^{-1}]	Historical floods and annual series used for preceding assessment	Original return period N [years]	Historical floods and annual series used for new assessment	N derived from data exluding 2002 flood	N derived from data involving 2002 flood
1110	Březí	Vltava	1,824.6	706	1888, 1941-1960	> 1,000	1888, 1890, 1899--1928, 1941-2002	200	100-200
1120	Kaplice	Malše	259.0	257/250	1965-1985	200-500	1888, 1949, 1965-2002	200-500	200
1125	Líčov	Černá	126.1	213/178	–	200-500	1888, 1967-2002	200	100-200
1126	Pořešín	Malše	437.9	434/399	–	200-500	1882-1938, 1978-2002	500-1,000	200-500
1130	Římov	Malše	494.8	414	1888-1975	200-500	1888, 1890, 1899-2002	200-500	100-200
1140	Pašínovice	Stropnice	398.7	250	1910-1985	1,000	1888, 1890, 1910-2002	200-500	200
1150	Roudné	Malše	961.2	695	1888, 1910-1975	> 1,000	1888, 1890, 1897-2002	1,000	200-500
1151	České Budějovice	Vltava	2,847.6	1,310	1875-1960	> 1,000	1875-2002	1,000	500
1290	Hamr n. Nežárkou	Nežárka	981.2	220	1912-1985	100-200	1912-2002	200	100-200
1310	Klenovice	Lužnice	3,143.0	625	1890, 1910-1985	> 1,000	1890, 1910-2002	1,000	500-1,000
1330	Bechyně	Lužnice	4,046.3	666	1879-1985	1,000	1879-2002	500	200-500
1410	Katovice	Otava			1890, 1900-1985		1890, 1899-2002	100-200	50-100
1430	Němětice	Volyňka	383.4	199	1888, 1899-1985	200	1888, 1899-2002	100-200	50-100
1470	Podedvorský Mlýn	Blanice			1951-1985		1937-2002	1,000	500-1,000
1500	Heřmaň	Blanice	839.6	443	1888, 1926-1985	> 1,000	1888, 1890, 1926-2002	500	200-500
1510	Písek	Otava	2,912.8	1,180	1874, 1887-1985	500-1,000	1887-2002	500-1,000	200-1,000
1520	Dolní Ostrovec	Lomnice	390.7	262	1899-1985	> 1,000	1895, 1899-2002	1,000	1000
1530	Varvažov	Skalice	366.8	203	1890, 1899-1985	> 1,000	1890, 1899-2002	1,000	500-1,000
1690	Zbraslav	Vltava	17,816.7	3,340*	1845, 1936-1985	200-500	1845, 1936-2002	200-500	200-500
1790	Staňkov	Radbuza	699.9	213	1845, 1901, 1931-1985	100-200	1845, 1901, 1931-2002	100-200	100
1799	Lhota	Radbuza	1,174.9	360	1845, 1901, 1914-1985	200-500	1845, 1901, 1913-2002	1,000	200-500
1820	Klatovy	Úhlava	338.8	159	1931-1943, 1952-1985	200-500	(1845), 1931-1943, 1952-2002	200-500	100-200
1830	Štěnovice	Úhlava	897.3	398	1913-1985	1,000	(1845), 1913-2002	1,000	500
1860	Plzeň-Bílá Hora	Berounka	4,015.6	858	1887-1985	100-200	(1845), 1887-2002	100-200	100-200
1870	Koterov	Úslava	734.3	459	1913-1985	> 1,000	(1845), 1913-2002	1,000	500-1,000
1880	Nová Huť	Klabava	358.8	266	1950-1985	200	1950-2002	200	100-200
1980	Beroun	Berounka	8,283.8	2,170	1872, 1890-1985	500-1,000	1872, 1890-2000	200-500	200
2001	Praha-Chuchle	Vltava	26,719.9	5,160	1845, 1890, 1899-1983	500	1827-2002	200-500	200-500
2040	Mělník	Labe	41,824.7	5,050	1845, 1852-1985	200-500	1845, 1852-2002	200-500	200
2210	Ústí n. Labem	Labe	48,556.9	4,700	1845, 1877-1985	100-200	1845, 1851-2002	100-200	100-200
2400	Děčín	Labe	51,103.9	4,770	1845, 1851-1985	100-200	1845, 1851-2002	100	100

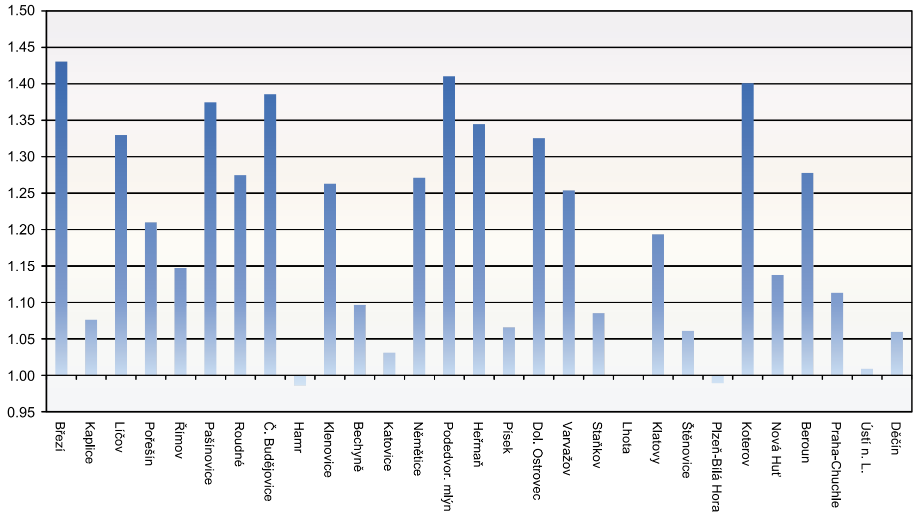


Figure 4.2 Ratios of Q100 derived from flood series involving and not involving the August 2002 flood

of floods until 2001. The maximum flows since 1954, when Slapy dam was put into operation, are affected by the retention capacities of the cascade of reservoirs on the Vltava River. Historical documents indicate that the Vltava River at Prague experienced 45 significant floods (the oldest is from 819) in the period before regular observation, which began in 1827. Information available on these floods is however insufficient for relevant hydrological studies. It was estimated that August 2002 flood could be the most extreme event in Prague since 1432.

extreme precipitation events were relatively rare during second half of 20th century. During recent years, however, the Czech Republic experienced two extreme floods, which affected also neighbour countries. Floods in July 1997 in the Morava, Odra and partially also Upper Elbe River basins and in August 2002 in the Vltava, Lower Elbe and Dyje River basins were historically extreme events in terms of the flooded areas, water stages and their catastrophic consequences.

Maximum flow of the August 2002 flood in Prague is the highest peak discharge which has been derived in available hydrological studies. This discharge probably also exceeded that of 1784 flood, whose maximum flow was recently derived. This fact is indicated by bench marks of maximum water stages from August 2002, historical floods in 1784 (two bench marks on a left-hand side bank of the Vltava River at Prague – close to bridges Legií and Karlův) and historical floods in 1845 and 1890. It is, however, necessary to take into account that the hydraulic conditions in Prague have significantly changed since the occurrence of the historical floods and therefore the elevations of flood bench marks do not necessarily lead to correct conclusions.

Annual maximum flows of the Vltava River at Prague are shown in Figure 4.3, which illustrates an obvious decrease in the frequency

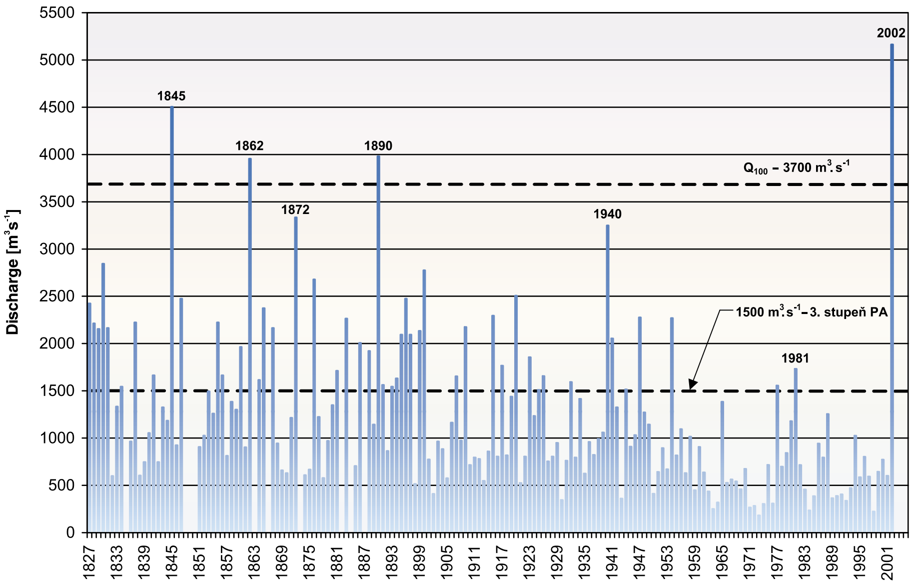


Figure 4.3 Maximum flood flows of the Vltava River at Prague in the period 1827–2002

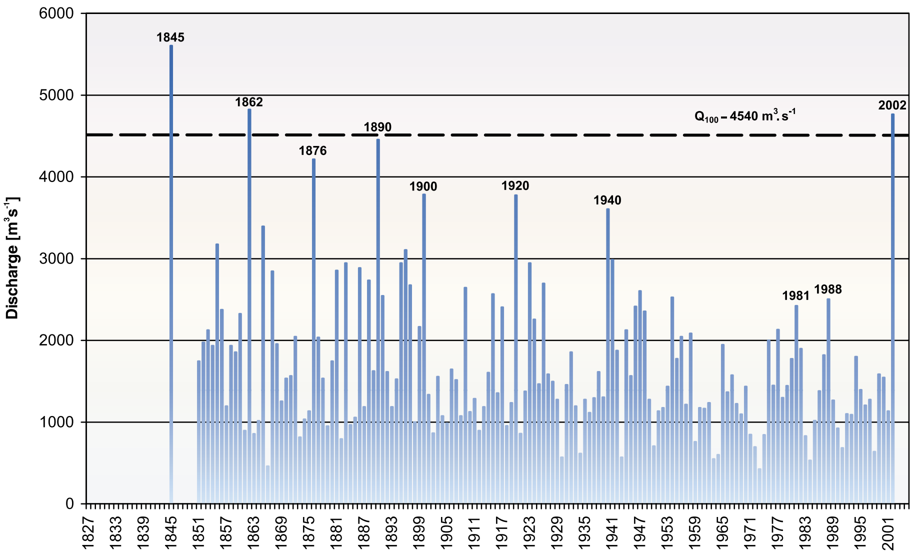


Figure 4.4 Maximum flood flows of the Elbe River at Děčín in the period 1845–2002

Marks of extreme water stages from the period 1862 to 2002 in Křešice village on the bank of the Elbe River

Maximum flood flows of the Elbe River at Děčín are shown in Figure 4.4, which illustrates that the maximum flow of the August 2002 flood was less than those of the floods in 1845 and 1862. Both of these floods, however, occurred in March from snow melting in the whole basin of the Elbe on the Czech territory. The biggest summer flood which was recorded and assessed in the period before 2002 occurred in 1890. Identically to situation in 2002, this flood was caused mainly by flood flows from the Vltava River. The order of the floods of the Elbe River in terms of their magnitude is substantiated also by historical flood bench marks on rock below the castle in Děčín. Differently from conditions in Prague, the floods in Děčín are probably not significantly affected by changes in hydraulic conditions originating from construction activities.

The occurence of a possible near future flood, whose extremity would be similar to that in August 2002, cannot reliably be estimated. Historical records, however, give examples of grouping of years when the Vltava River basin experienced large summer floods (1872, 1890, 1897, 1899).

Comparison of 2002 flood with similar situations in 1890 and 1997

All of these events were extreme summer floods, which were caused by regional precipitation. The meteorological conditions were also very similar. The intensive precipitation on the Czech territory originated from slowly advancing pressure low from northern Italy. Different conditions included duration of individual precipitation events. In 2002, a three-day precipitation occurred subsequently to a two-day event after a short period of 3 days, in 1997 two five-day precipitation events were separated by a period lasting for 10 days, and in 1890 a four-day event occurred 5 days after three-day precipitation.

For extremity of maximum flows, the most unfavourable combination of synoptic conditions occurred in August 2002, when the second and more substantial precipitation fell within a short time interval of 8 days from the beginning of the first event and when these two events affected the whole basin of the Vltava River. The situation in 1890 (24 and 26 August and 1 to 4 September) was similar to that in 2002, however, the August precipitation was significantly lower. In 1997, the two precipitation events were separated by a longer period without precipitation.

The results of the studies also indicated that, in the couples of the precipitation events in 1890, 1997 and 2002, the probability of the occurrence of the individual events was not extremely low. The extremity of the situation in August 2002 was in the fact that the high-total precipitation occurred shortly after the first precipitation event. It is not however impossible that such situation could repeat in future.

4.3 Probable maximum precipitation

In accordance with definition by World Meteorological Organisation, the probable maximum precipitation (PMP) is the maximal possible precipitation

A road bridge across the Elbe River in Ústí nad Labem town was nearly flooded

Počaply village in the flood plain area on the left-hand side of the Elbe River

totals over basins of different size and of given duration did not exceed 68% of the PMP values. The highest percentages were derived for duration of precipitation of 2 and 3 days for the Vltava River basin upstream from confluence with the Malše River and for the Malše River basin. Similar values of ratios between basin precipitation and PMP were derived also for the July 1997 flood, both for basins located in southern and middle Bohemia and basins in Moravia, for which the derived PMP values are higher. The maximum values of the ratio were derived for duration of 4 and 5 days, i.e. for duration longer as compared to that in 2002. Precipitation totals from individual stations included a value which exceeded

total for an area of given size and given geographical location, for given season and given duration of the precipitation event. In estimating PMP, climate changes are not taken into account. The PMP value is therefore an estimate of upper limit of extreme precipitation.

The Institute of Physics of Atmosphere of the Czech Academy of Sciences estimated PMP for selected basins and these values were compared with maximum precipitation totals in August 2002 and in July 1997. The results of the assessment were valuable. The 2002 precipitation

PMP. This value was observed at Cínovec station (on German territory), where the daily precipitation total from 12 August 2002 was 312 mm and the PMP value was 277 mm. This fact indicates that estimates of PMP in boundary regions should be refined by using results of measurements made in neighbour countries. For 2002 flood, the basin precipitation values are generally relatively highly below estimates of PMP. The results therefore show that, even if inaccuracy of the PMP estimates is accounted for, precipitation which would exceed that in 2002 is a possible realistic event.

5 WARNING AND FORECASTING SERVICE

In accordance with stipulations of Water act, activities of warning and forecasting service were carried out by Czech Hydrometeorological Institute (CHMI) in cooperation with River Basin Authorities and participants involved in a flood warning system, which is organised by flood management bodies. Data, information, forecasts, notifications, monitions and news issued by CHMI had a key importance in the flood protection system. They were used for initiation of the activities of its individual bodies, declaration of individual degrees of flood protection activities, warning services and other activities.

Terezín town in the flooded area on the confluence of the Elbe and Ohře Rivers

The Otava River overflowing a bridge from the 13th century in Písek town

5.2 Forecasting possibilities by hydrological service of CHMI

In standard conditions, hydrological forecasts are issued with frequency of 1 day for 19 forecasting river sites in the Czech Republic (in the area that was flooded, these sites included the Berounka River at Beroun, inflow into Orlík reservoir, the Vltava at Prague-Chuchle, and the Elbe at Mělník, Ústí nad Labem and Děčín). Frequency of the issued forecasts was increased during the flood. These forecasts were derived by using a method of corresponding discharges and their travel times. Time advance of the forecasts is limited by geographical dimensions of the basins, which are relatively small in the Czech Republic, and therefore its range is between 6 and 24 hours.

Since 2002, hydrological forecasting methods have included also hydrological models, which were derived and calibrated during recent years for basins of majority of main rivers in the Czech Republic. During the August 2002 flood, pilot operation of these models was initiated in all of the regional forecasting offices and these models were used for deriving forecasts for 48 hours. Each regional office of CHMI operated a part of the model covering its basins.

5.1 Forecasting possibilities by the meteorological service of Czech Hydrometeorological Institute (CHMI)

Meteorological forecasting was based on data on actual weather conditions (results of observations in meteorological stations, data from aerological sondes, satellite and radar measurements and other data) and results from numerical forecasting models. The mostly applied model was ALADIN, which provides short-term weather forecast for 1 to 2 days. In addition, the meteorological service used also output from foreign meteorological models, involving local models for short-term forecasts and global models for middle-term forecasts for a period limited by 10 days. The middle-term forecasting models have less resolution in terms of space and time than the short-term models and their uncertainty is higher.

The first indication of dangerous meteorological situation was derived from results of the global models. Subsequent development of the phenomena, their intensity and spatial distribution were refined from results of local models, which are more capable to identify orographic effects. Additional improvements of the forecasts were based on data from meteorological stations and radar measurements. The output from the models is also essential information for forecasting of precipitation. Final conclusions, however, have to be made by meteorologists who use their knowledge and experience.

5.3 Assessment of forecasts

In August 2002, the derivation of the forecasts by using both classical and modelling approaches was complicated by lack and insufficient accuracy of some of the data that are necessary for hydrological forecasting. The causal factors of these problems included failures

A broad flood plain area at the confluence of the Elbe and Ohře Rivers

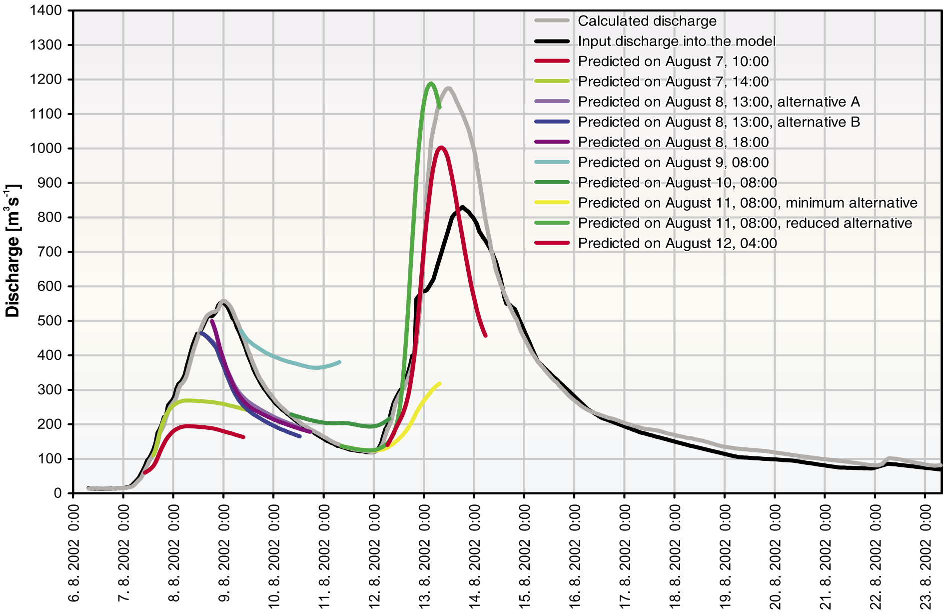


Figure 5.1 Flood hydrographs forecasted by using a hydrological model for the Otava River at Písek

in data collection from some reporting stations, uncertainties in rating curves (water stage-discharge curves) in their parts of high water stages, inaccuracy in precipitation forecasts and in estimates of future operation of reservoirs. In spite of these problems, the hydrological forecasts were relatively good and their errors were between acceptable limits (the errors mostly did not exceed 10% of the real values of the forecasted variables). Real values during the first flood wave in the Vltava and Malše River basins exceeded significantly those forecasted by the hydrological forecasting model. This fact was stemming from inaccurate output from meteorological models, which underestimated significantly real precipitation totals in given areas.

On 11 August 2002, the Central Forecasting Office of CHMI in Prague together with Regional Forecasting Offices in České Budějovice and Plzeň derived alternative forecasts of flows for the second flood wave dependably on alternatives of meteorological forecasts of precipitation.

The maximum alternative of the forecasted precipitation would result in sharp and fast increase in river flows in south-western Bohemia. For the minimum and most favourable alternative (precipitation at a level of about 50% of the maximum alternative), the simulated response of rivers would be less by one order of magnitude. The real development of the flood was close to the maximum alternative (Figure 5.1). The results showed that the model was suitable for simulation of possible development of floods in large basins (areas of thousands km²). For smaller rivers and basins, high uncertainty in the forecasted precipitation totals and their temporal and spatial distribution did not allow the model to predict acceptably the flood wave with significant time advance. The effect of uncertain temporal and spatial distribution of the forecasted precipitation was partially eliminated by size of large basins.

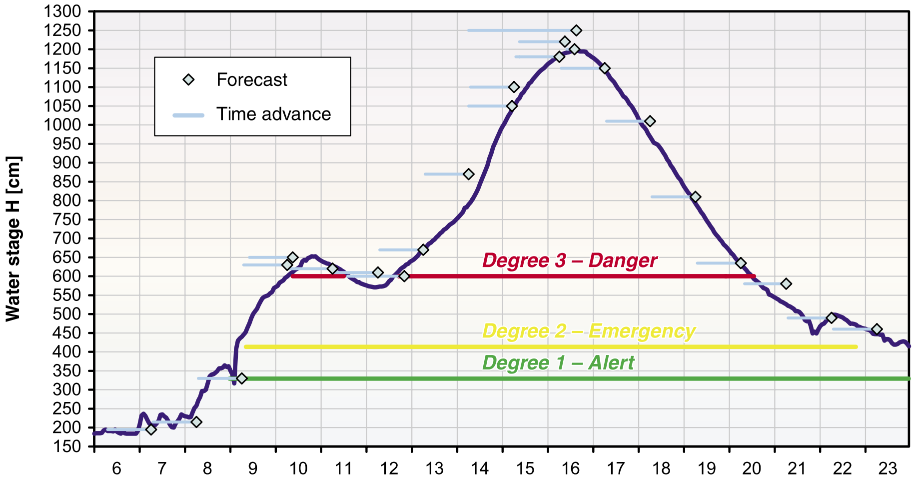


Figure 5.2 Water stage predictions derived for the Elbe River at Děčín

For the Vltava River at Prague and the Lower Elbe River, the development of the flood was forecasted by Central Forecasting Office in Prague. Derivation of these forecasts was highly complicated by lack of information on hydraulic conditions in the Vltava River cascade of reservoirs (data on inflows and outflows for individual reservoirs) and by uncertainty in rating curves for key water gauging stations (Beroun and Prague-Chuchle).

The services in providing information and forecasts of flows for Prague-Chuchle water gauging station had even to be interrupted and data on water stages only were used. The forecasts for this site were concentrated mainly on expert predictions of water stages and their time of occurrence. As compared to situation in Prague, conditions for forecasting flows and water stages for the Lower Elbe were more favourable and also time advance of the forecast was longer (Figure 5.2). During the flood, the Central Forecasting Office issued 59 reports involving description and forecasts of development of hydrological and meteorological conditions.

These reports were provided to crisis management bodies, mass media and they were available also from internet. Additional ten special reports were prepared for meetings of Central Crisis Management Board and one special report was prepared for Crisis Management Board of Prague. In accordance with concluded agreements, successful cooperation was also ensured in the area of providing information on flood development on the territory of the Czech Republic for the purposes of flood management bodies of neighbour countries and their basins affected by the flood.

6 RELATIONSHIPS BETWEEN FLOOD AND QUALITY OF SURFACE WATER AND GROUNDWATER

For the explanation of impacts of the flood on quality of surface water and groundwater, Ministry of the Environment initiated implementation of a special monitoring of changes in water quality in the period during and after the flood (Figure 6.1).

6.1 Assessment of surface water quality in the period during and after the flood

For a detailed assessment, values of identical parameters were available as results of sampling and analyses made for selected river sites. These parameters included concentration of dissolved substances, suspended solids, nitrate and ammonium nitrogen, total phosphorus, adsorbable organic halogens and nonpolar extractable oil substances. Additional parameters included pH of water, chemical oxygen demand, concentration of dissolved oxygen and number of thermotolerant coliform bacteria. For selected sites, the assessment included also total quantity of polluting substances in conjunction with corresponding discharges.

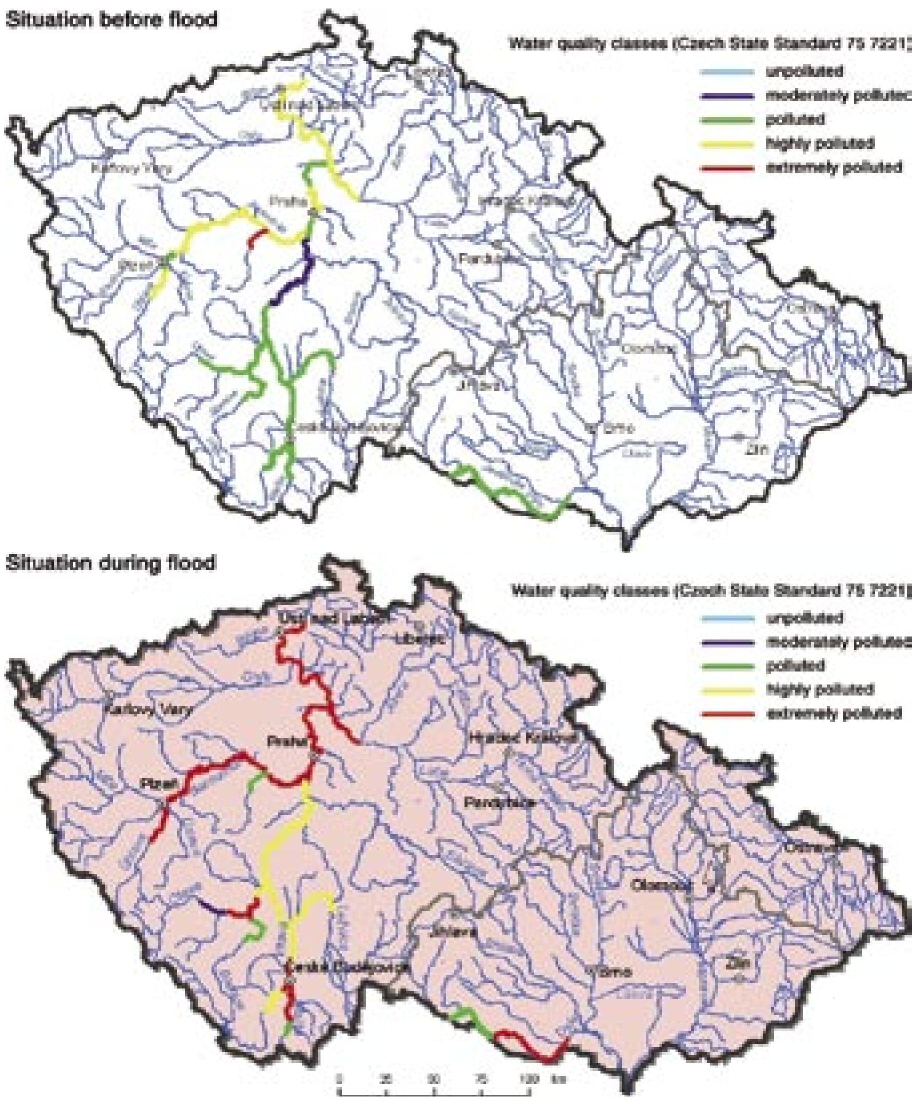


Figure 6.1 Maps showing water quality in the affected area before and after the flood

The assessment of analyses of the results of the special flood monitoring of water quality show that limits specified in Government Order 82/1999 Coll. for pollution of surface waters were exceeded only rarely, which suggest a general conclusion that impact of the August flood on surface water quality was not catastrophic and its duration was relatively short.

An increase in concentration of parameters of specific organic pollution and heavy metals (Fe, Mn, As, Al, Pb and Cr) in the flooded area originated mainly from washouts from fields, flooding of sewerage systems, waste water treatment plants, localities of industrial plants and agricultural farms. An increase in some heavy metals and chlorinate hydrocarbons could stem also from resuspension of contaminated river sediments. An increase in concentration of pesticides was probably associated with washouts of chemical fertilisers from agricultural lands. Releases of oil substances from insufficiently safe storage facilities caused short-term increases in concentrations of nonpolar extractable oil substances to levels exceeding their permissible pollution limit. The most frequent violation of the limits was observed for faecal pollution indicated by a number of thermotolerant coliform bacteria. This was mostly a consequence of washouts from waste water treatment plants and releases of untreated waste waters into watercourses.

At the end of the assessed period, i.e. at the end of September 2002, values of most of the observed parameters were close to those corresponding to standard conditions not affected by the floods. Exceptional situation was in thermonuclear coliform bacteria whose numbers were still high (mainly at river sites downstream from large towns) consequently to insufficient function of waste water treatment plants.

Knowledge from few specific analyses of water samples from flood plain areas indicates that chemical composition of this water in terms of most of its parameters was repeatedly transformed consequently to transformation processes involving dissolution, extraction, concentration by evaporation, bacterial processes, photosynthesis, and other processes. Very intensive process in flood plain areas was also biological succession (similar process to that in stabilisation tanks of waste water treatment plants).

Chemical Factory Spolana Neratovice on the Elbe River bank was flooded by the backwater from the Vltava River

6.2 Assessment of changes in groundwater quality

The assessment was focussed on a comparison of results of analyses of samples from regular sampling made in autumn 2002 (conditions after the flood) with results from preceding years including those from spring 2002 (conditions before the flood). For the assessment, data from selected observation sites (springs and boreholes) situated in the flooded areas or their close vicinity (3 km as maximum) were used. The assessment included data from 60 sites.

It is obvious from the results that groundwater quality was significantly changed, mainly in parameters indicating organic pollution, i.e. in chemical oxygen demand (both CODCr and CODMn), concentration of organic carbon, absorbance at 254 nm (A254), and also in colour and turbidity. The most affected areas included basins of the Lužnice and Dyje Rivers and some parts of the basins of the Vltava and Elbe Rivers.

6.3 Impact of the flood on contamination of substrates in flood plain areas

The assessment included analyses of 54 samples from those localities in flood plain areas, which were flooded for long period of time after the flood (high probability that contaminating substances could penetrate into the subsurface layers) and 6 samples of water from dead river branches. For many of the samples, the results of the analyses indicated occurrence of some persistent organic pollutants, whose concentration exceeded limits of one or both standards laid down in Guidelines of Ministry of the Environment (Official Journal of Ministry of the Environment No. 8, 1996). For majority of the samples, the increased concentrations did not exceed the level indicating that natural background concentration was exceeded in substrates of the flood plain areas.

6.4 Releases of dangerous substances in the flooded areas

Data collected by Czech Environmental Inspectorate show that no less than 20 accidents associated with release of dangerous substances (chemical substances, oil, wastes from landfills, and other substances) occurred in the flooded area.

The data showed that the most significant source of the contamination was Spolana chemical plant in Neratovice, whose locality was flooded and the water washed high quantity of chemical substances, oil substances, oils and other pollutants. Consequently to a release of 80 tons of chlorine into water environment, concentration of chlorinated substances increased, which was reflected e.g. in doubling concentration of adsorbable organic halogens in the Elbe River at Děčín. As a consequence of washouts of oil substances, also concentration of nonpolar extractable substances increased. Releases in chemical substances were reflected also in an increase in concentration of ammonium nitrogen, 1,2 dichloroethane and lead in the Elbe River at Obříství. This increase however was not associated with releases from Spolana.

The Vltava River at Kralupy nad Vltavou town, flooded and polluted

6.5 Impact of damaged waste water treatment plants and old ecological loads on water quality

In the flooded area, the flood damaged 124 waste water treatment plants, of which 88 were small (capacity less than 10 000 population equivalent) and 36 large (p.e. exceeding 10 000, involving plants in Prague, České Budějovice, Ústí nad Labem, and Spolana and Setuza plants). The contaminated water from the damaged plants was the main factor of water pollution of all big and many small receiving rivers.

Information on the old ecological loads was obtained from a database of a System of old ecological loads and from information on accidents during the floods in 2002 provided by Regional Environmental Inspectorates.

Impacts of washouts from these sources on water quality was assessed by comparing results of analyses from the nearest monitoring sites in the periods before and after the flood with pollution limits laid down in Government Order 82/1999 Coll.

The most critical flooding of old ecological loads was detected in a locality of Spolana chemical plant in Neratovice, particularly in its installations for amalgam electrolysis (mercury) and dioxin installations. The flooding of these installations was reflected in an increase in mercury and dioxin in water and sediments, however, it was reported by Czech Environmental Inspectorate that this increase was of a local importance except for contamination of Libiš locality.

7 GEOLOGICAL CHANGES PROVOKED BY THE FLOOD IN FLUVIAL PLAINS AND ADJACENT SURROUNDINGS

In many parts of fluvial plains hit by the flood in August 2002 changes of river channels, erosion zones, appearance of enclosed depressions and new sedimentation accumulations were manifested. In unfavourable geological and inclination conditions adjacent slopes were also endangered by landslides after strong precipitation. Hydrogeological conditions also changed, together with groundwater regime in hydraulically linked collectors. Previous human economic activities played also its role in relation to morphological changes of the fluvial terrain, including raw materials mining from deposits in these areas. All of these geological changes provoked by dynamic effects of the August 2002 flood were necessary to evaluate.

Alluvial sand with ripples

7.1 Examination of geological changes in fluvial plains

In view of the extent of affected area only pilot regions could be selected for evaluation of geological and geomorphological changes within the project.

For identification of stratigraphy of fluvial deposits a range of techniques were applied, such as archaeological dating (settlements at different fluvial levels of varying age), pollen analysis of organic sediments deposited in dead stream branches and flow less depressions and radio-carbon dating (14C – indicates age of separate flood deposits and allows historical reconstruction of the biggest floods). Accumulation area of the Vltava River downstream from Kralupy nad Vltavou was modelled using geo-radar, allowing to apply a geophysical technique for determining thickness, composition and type of fluvial sediments. Results of petrographic, geochemical and pollen analyses were subsequently interpreted digitally using basic topography and relevant database to produce an orthophotomap within a Geographical Information System (GIS).

Aerial photographs taken after the flood, which registered all of the geological changes taking place in the fluvial plains, provided substantial data in collecting important information on dynamic development of the plain. This material, together with former aerial photographs and orthophotomap amended by topographic data retrieved completely new findings useful mainly for landscape planning.

A landslide as a consequence of flood on the upper reaches of the Bystřice Brook

7.2 Impacts of the flood on hydrogeological conditions of fluvial plains

Within the project mainly risks of diffuse pollution of groundwater were assessed using several categories:

(1) A separate category in flood risks was represented by porous highly permeable gravel sand deposits of the fluvial plain linked hydraulically with surface water stream specific by very high risk of pollution of shallow groundwater circulation.

(2) High to very high risks of pollution were represented by gravel sand or loamy sandy deposits, partially surrounding fluvial plains of significant watercourses or depressions filled in by Deluvium loamy sand material without hydraulic link to a surface water stream. Solidified largely fissured permeable sediments were also included into this category.

(3) An important additional type of risk of pollution of hydrogeological structure and groundwater collector was represented by large low permeable cover layers or continuous top aquitard with protective effect against transport of pollution from surface.

(4) As a part of the evaluation, a morphological analysis of fluvial sediments of flood plains focused on determination of a rate of possible pollution was also included. Higher risks of pollution were possible to identify at reaches with hollow topographical shapes of the fluvial plain. In depressions conditions for diminution of the cover Holocene layer of a collector were created during flooding due to loss of its upper layer by flow dynamic effects. Subsequently, changes in vertical permeability took place leading to bigger "opening" of the collector.

Additional criterion for evaluation of risks posed to groundwater resources was estimation of water management significance of the area according to the type of flow capacity of the hydrogeological structure (collector). Resulting level of vulnerability was assessed as a summary of partial risks, i.e. intensity of pollution according to the type of water saturation, characteristics of the aquifer and covering layers, and water management significance of the region.

The result of the evaluation is presented in a form of a specific hydro-ecological map allowing to select possibilities for protection of groundwater resources according to the type of hydrogeological structure and type and size of the anthropogenic vulnerability (extreme flood → type of water saturation → characteristics of hydrogeological structure → degree of risks → vulnerability of water resource → selection of preventative measures).

7.3 Impacts of the flood on mineral deposits

Gravel, building sand, brick clay, ceramic clay, peat etc. is exploited in many places in the regions of fluvial plains hit by flooding. It was demonstrated that regarding to flooding, mining activities in inundated areas had both

A fresh deposit of sand in the flood plain area of the Černá River

The cracked sandpit in the upper Lužnice River basin

positive effects (increased retention capacity of landscape to contain part of the flood water in excavation voids) as well as negative effects (unexpected change of water flow and subsequent damages to infrastructure, property and the environment, effects to quality of exploited material, possible decrease of retention capacity of landscape in absorbing precipitation water particularly in case of peat extraction). The project was therefore concerned with pilot regions of fluvial plains of the Lužnice River and its tributaries among the localities: Tábor – Stráž nad Nežárkou – Suchdol nad Lužnicí – Soběslav, as deposits in this region were relatively most severely hit with subsequent negative effects (for example Majdaléna sand pit).

The necessary approximate analyses were focused on effects of the flood to technological quality of raw materials exploited in the pilot region, and also on reclamation measures linked with the adopted exploited sites, mining plans and preparation of exploitation from exclusive deposits, and, on the other hand, on effects of the mining and subsequent activities on flooding. Plans for reclamation of exploited deposits of mineral raw materials were also evaluated in view of development of the flood and possibilities for affecting the flooding. Retention capacities of deposits or, rather, their existing or future sites in the region (including peat extraction) were also estimated.

The results should help in future – in case of similar extreme flood – to evaluate economic losses in the construction and mineral raw material mining sectors immediately after flooding of the deposits, and estimate losses in relation to infrastructure and property due to lack of measures against flooding of mining sites (unsuitable exploitation plan, reclamation plan etc.), remedial actions in case of pollution of fluvial plain by mining activities and similar activities.

8 RELATIONS BETWEEN LANDSCAPE AND THE FLOOD

There is mutual influence between landscape and flood. The August flood undoubtedly affected, by its dynamic impacts, river channels of the river system in inundated zones of the landscape terrain. On the other hand, question of a degree of influence of landscape on a flood event of such an extremity became a subject of differing views.

8.1 Evaluation of extremity of the flood on the basis of occurrence of fluvial soils

Soils of a fluvial group are one of the indicators of a range of inundations and also of surface extent of accumulation activities of a watercourse during the recent roughly eight thousand years. Spatial dimensions of

Bank vegetation along riverbed in the agricultural alluvial plain of the Radbuza River

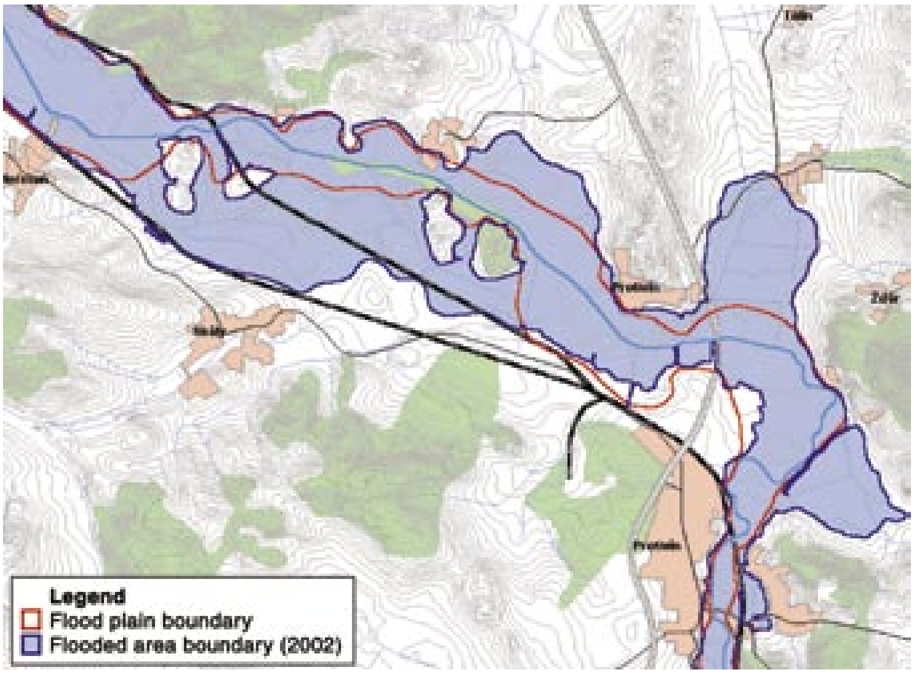


Figure 8.1 Flooding outside boundaries of flood plain area (confluence of the Otava and Blanice Rivers)

these processes are closely linked with development of fluvial plains. Knowledge of fluvial soils and fluvial plains can therefore help in reconstructing past flood events and also indicate approximate extremity of the flood in August 2002.
There are, however, certain limitations of such indicators. They do not appear in erosion zones of river valleys and are affected by man-induced impacts (mining activities and other changes of landscape).
From comparison of boundaries of fluvial plains, or range of fluvial soils, and the extent of inundations in 2002 slight differences appeared for upper, middle and lower reaches of watercourses. The upper reaches in the pilot Otava basin experienced flooding, but corresponding fluvial plains were not completely inundated. On the other hand, majority of fluvial plains of the middle and lower reaches were completely inundated, at some places, together with bottom parts of the neighbouring lateral slopes of the valley (Figure 8.1). Ambiguity of the fact that fluvial plains of the upper reaches were not completely inundated can be explained by either lower extremity of the August local precipitation in comparison with historic events or by river training (deepening, reduction of channel roughness etc.), inducing faster runoff of water from landscape.

The rail embankment forms a barrier to flow which is reflected in water level rising above this obstacle

Another significant finding represented non inundated areas of fluvial soils with land modified by man (roads, large modification of the landscape topography etc.). These cases would not however always lead to a definite conclusion that non inundated fluvial soils at boundary of large fluvial plains originated from flood events larger than the flood in August 2002. In view of stream-channel training their flow capacity could be changed.
For other watercourses under study in few cases inundation was larger than the extent of fluvial soils, namely for the Vltava above České Budějovice and at the confluence of the Vltava with the Elbe also for the Elbe at Terezín. This phenomenon is undoubtedly, apart from the extremity of the flood, a result of man-made modifications of the fluvial plain (road embankments) and permanent gradation (build-up) of fluvial plains at lower watercourse reaches due to accumulation of material from deforested erosion prone areas (it is a process lasting for already 3 thousand years).
It can be concluded that boundaries of fluvial soils mostly corresponded to the boundaries of maximum inundation in 2002. This proves that although the flood in 2002 was an extreme event, it was not uncommon. So as current boundaries of fluvial soils could develop, similar large inundations had to occur several times in past.

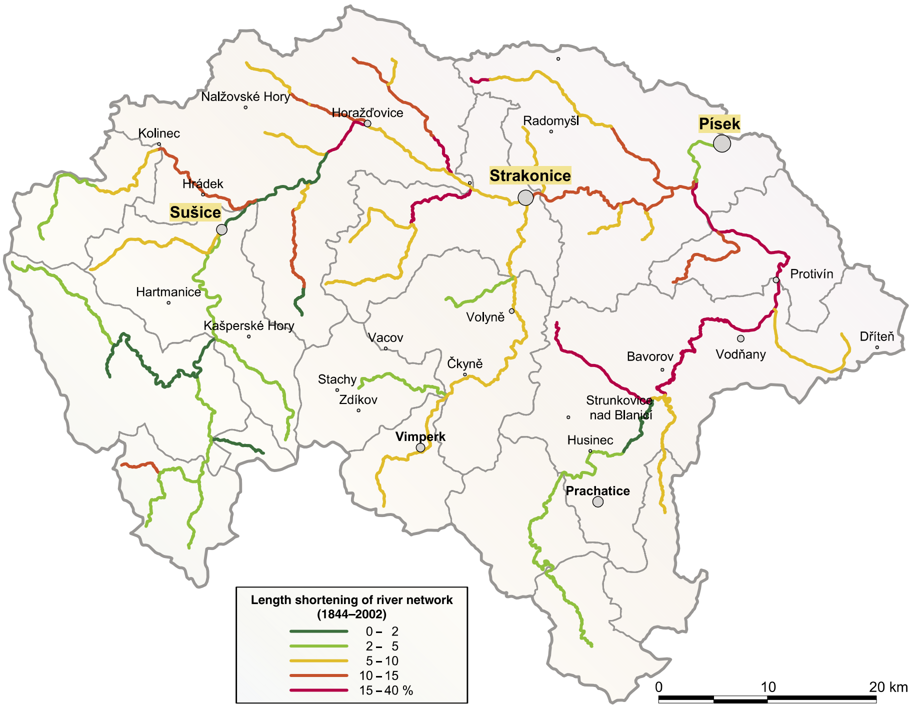


Figure 8.2 Length shortening of river network in the Otava River Basin during period 1844–2002

8.2 Identification of sites with improper land use in inundated areas

Assessment of land use was focused on river reaches with wide fluvial plain, i.e. with large potential for inundation. In addition, presence of land modifications was also observed (dikes, roads, embankments etc.). By comparing the maximum inundation and current state of man-made changes of the fluvial plain, unused retention areas were identified at some watercourses.

Level of recorded damage corresponds well with degree of man-made modifications of fluvial plains, with highest in the Berounka River fluvial plain. The highest degree of modifications (rate of urbanised areas, longitudinal modifications above the level of fluvial plain, backfill sites and mining areas) was identified at the Berounka fluvial plain between Beroun and confluence with the Vltava River with surface area of 2276 ha. Of this area 32% is significantly modified by man (housing and industrial urbanisation, land with leisure buildings, embankments etc.).

8.3 Landscape changes as a possible factor affecting development of flood

Landscape changes in the pilot Otava River basin were analysed in view of their impact on the August flood. If was found that during the latest 150 years the forest land cover increased by 10% and during the latest 50 years extent of arable land decreased. In this river basin the extremity of the flood in 2002 cannot therefore be linked with effects of deforestation, at least regarding the period from the industrial revolution until now.

It follows from comparison of length of watercourses of the river network of the Otava River basin during the latest 150 years that their length was shortened by 9%. There are however considerable differences between upper and lower reaches of watercourses. Some of the lower reaches were shortened up to 60% while mountainous parts were not substantially changed mainly due to their morphology and minor land use demands (Figure 8.2).

Analysis of land use based on the Landsat TM and CORINE Land Cover geo-database demonstrated unsuitable composition of fluvial plain vegetation cover. Arable land represents a dominant element covering 44% of the total area. Together with other agricultural land it covers 63% of the fluvial plain area, with forests covering only 11%.

It follows from the special mapping of river channel modifications in the Otava River basin that 43% of the total watercourse length is modified. The changes introduced modifications of cross and longitudinal sections with the use of alien materials for reinforcing riverbanks or bed or for straightening of the course (Figure 8.3).

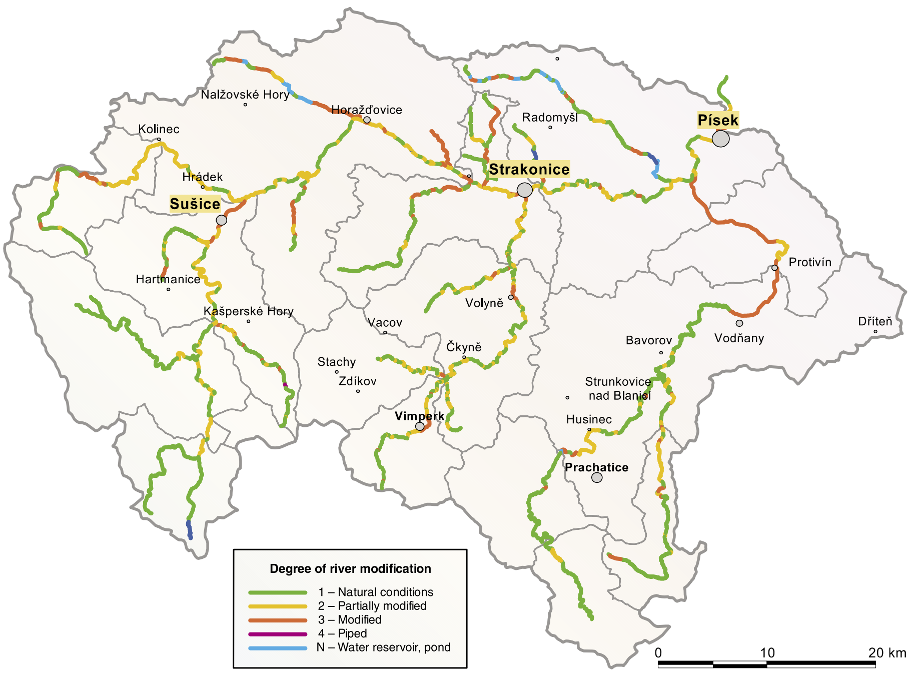


Figure 8.3 River channel modification in the Otava River Basin

8.4 Pilot study of measures for increasing retention of water in landscape

An extreme rainfall-runoff process of the August 2002 flood was simulated for small basins of the Boletický (12.7 km^2) and Třebonínský (10.3 km^2) brooks, as well as hydrological balance of the vegetation period of 2002. Next, hydrological comparison with "normal" year 2001 was carried out. The tools included techniques of mathematical modelling. Parameters obtained served for scenario simulations allowing to obtain guidance on mitigation of harmful effects of possible floods in future and on proposals of flood protective measures in landscape. By applying a scenario of increased proportion of permanent grassland by 10% it was confirmed that maximum discharges on small watersheds would decrease by 5 to 15% (according to periodicity of occurrence).

8.5 Flood and rehabilitation measures

An analysis of relations between rehabilitation and floods was focused on two basic factors, first on development of floods in relation to existing rehabilitation structures (degree of damage) and secondly on self-rehabilitation effects of floods.
Rehabilitation measures completed on some of the small watercourses were nearly unaffected by the flood. Cross and longitudinal sections of rehabilitated channels were usually post-formed. Segmentation of channels to pools and streaming reaches was accentuated, riverbank shelters multiplied.
Similar changes took place also on modified and partially modified watercourses, which could be considered as a spontaneous approximation to the natural status parameters. In comparison with so far rather modest results of rehabilitation plans implemented in the Czech Republic within the Programme for rehabilitation of river systems, the self-rehabilitating effects of the August flood was significant. Watercourses experiencing flood waves changed in view of their cross and longitudinal segmentation (layers of alluvia and riverbank rips). In particular, in more natural river sections the changes were positive and did not call for strong remedial measures.

8.6 Evaluation of a role of riverbank vegetation cover

On a basis of monitoring of riverbank vegetation cover affected by the August flood the following conclusions were drawn:
In agriculture landscape it is necessary to use as flood prevention measures stabilisation effect of riverbank vegetation, having a range of other irreplaceable ecological functions. Its retention effect is incomparable to similar effects of a number of artificial structures in the channel or alluvial plain.
Herbal covers should not be regarded as riverbank vegetation, fulfilling only fraction of positive ecological functions of woody covers. Nor accompanying vegetation behind upper edge of river channels can be regarded as such.
Stability and the stabilisation function of riverbank vegetation covers are maintained only with permanent care, represented by removal of woody plants endangered by pulling up or ailing, damaged or overageing etc. and also by substitution planting or support to natural rejuvenation.

8.7 Impact of the flood on special protected nature areas

Based on mapping of changes of natural habitats in special protected areas it was found that the flood did not affected adversely ecosystems close to natural conditions. Negative changes in number and vitality of a subject of protection was always small-scale and it usually concerned ruderal vegetation of early successive stages on modified (disturbed) areas. The flood strongly affected interests of nature protection at only few artificially created ecosystems (ponds, sites in mining areas), where either dams were damaged or galleries collapsed. A common feature in protected alluvial ecosystems was appearance of riverbank rips, individual pull up of trees and accumulation of flood sediments. Positive aspects of flood were related to either above changes in the landscape allowing emerging of new biological habitats (for example nesting of common sandpiper on gravel alluvia, a number of new nest sites of kingfisher) or to increase of groundwater level at peat biotopes. The only species significantly affected by the flood was pearl mussel. A major part of population was flooded away. On the other hand, new biotopes were created suitable for certain pearl mussel life phases.


Floodplain forests at the confluence of the Elbe and Vltava Rivers

9 SAFETY OF WATER STRUCTURES DURING FLOOD

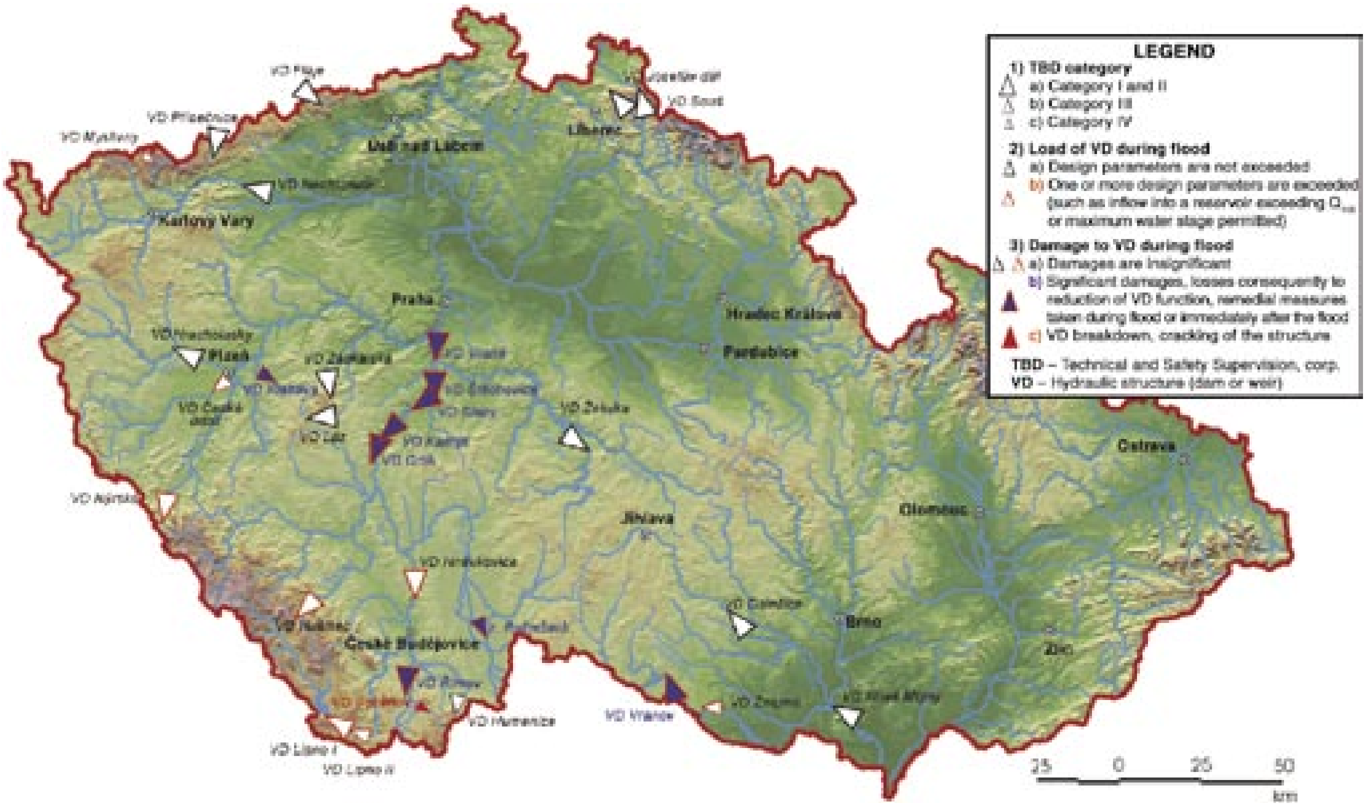


Figure 9.1 Dam safety during the 2002 flood

Water structures (WS) of I to III category (hydraulic structures mainly dams and weirs according to classification adopted in the Czech Republic) were evaluated in view of their safety, defined, for concrete conditions of each WS, in the Programme of technical-safety inspection. For this purpose regular and special measurements and observations of WSs were used, carried out during flood situation or immediately after in the framework of control and flood inspections. In addition, on a basis of an authorisation by the Central Crisis Management Board, all significantly affected dams under maintenance of the state river basin companies were inspected in view of their technical status and safety on 18 August 2004. For less significant structures of IV category, the basis for evaluation was, apart from findings and records by operators of WSs, inspection carried out during flood or immediately after the flood and also results of examination of technical status of WSs.

The Lipno reservoir on the Vltava River exposed to a discharge of 320 $m^3.s^{-1}$

9.1 Significant water structures

Out of 27 significant WSs more than half (15 WSs) were exposed to extreme load and operational requirements during the August flood (Figure 9.1). Seven WSs passed the flood without any substantial damage, mainly due to appropriate design and construction conditions and subsequent real reserves – particularly in the capacity of flood overflowing facilities. Eight WSs, mainly at some of the sites of the Vltava Cascade, experienced large damage by the flood due to destructive effects on construction as well as ground structures below the dam, and due to loss of function of inundated facilities.

The Římov reservoir on the Malše River

In spite of extreme load, the dam structures and operational equipment of the WSs were stable and fully operational during the flood.

Extreme flood load and major damage
Eight WSs belonging to the evaluated group were relatively significantly damaged during the August flood due to extreme load. Damage was caused mainly on functional structures of the dams and incorporated facilities, on channels downstream the dams or due to high losses of function subsequent to restriction of full operation of WSs. Gradually all degrees of flood activity were reached and imposed at the site downstream the water structure.
During the flood situation some of the observed parameters surpassed temporarily limit values similarly to the previous group of WSs, in addition, some of the measurements were not possible to take due to high water level. The situation at the Římov WS and a related danger required imposing the first degree of flood activity corresponding to the so-called special flood. Subsequent inspections together with measurements of deformation and geodetic measurements did not, however, showed any harmful changes on the construction elements. To eliminate incurred damage restoration measures were suggested.

Flood load below design parameters
A group of twelve water structures only rarely experienced surpassing given limit values. It usually related to intensity of water level increase in the dam reservoir or to amount or tendency of increase of observed leakage or groundwater levels in observing boreholes. Increase of the values was usually short and did not present any danger or loss of functionality of principle WS frames. Conditions corresponding to the degree of danger of so-called special flood were not achieved at these WSs.

Extreme flood load without major damage
Seven WSs were not affected by loss of gain due to limitation of full operation and there was neither significant damage on dam facilities or incorporated equipment of the technical-safety inspection. No costly repairs had to be carried out during or after the flood. During the flood situation some of the observed parameters, such as water level in the reservoir, total inflow into the reservoir or outflow from the reservoir, water level in some of the observing boreholes and water pressure at the bedrock base behind the injection sealing of some of the concrete dams, surpassed temporarily given limit values. However, no phenomena linked to the danger of appearance of the so-called special flood were experienced. At all of these water structures or downstream river reaches second or third degrees of flood activity were imposed according to the situation.

9.2 Water structures of IV category and fishponds
The number of small water reservoirs, mainly his-

The spillway of the Římov dam on the Malše River torical fishponds in the Czech Republic is estimated at about 20 000. Due to local storms rupture appears on one to five dams during a year.

During the August flood many fishpond dams were overflowed, particularly in the second wave from 13 to 14 August. According to inspections, more than 100 dams of fishponds bigger than 5 ha were overflowed. Regarding smaller fishponds with area up to 5 ha, overflowing happened at 300 cases. Accidents due to rupture of the dam were experienced on the total of 23 fishpond dams. Other 84 fishponds (dams, operating facilities) were seriously damaged.

About 75% of overflowed dams resisted rupture, even in spite of partial local surface erosion, in particular owing to:

- Favourable parameters of the dam structure (max. height up to 4 m, width of the top over 4 m, suitable inclination of the free slope reaching max. 1:2, good grassing of the free slope and minimum number of trees or other obstacles leading to development of erosion, reinforced top of the dam, for example asphalt roadway, etc.),
- Emergency spillway at the end of the barrier, where the dam is lowest or operational establishment of an emergency spillway (forced opening of the dam at its end saved, for example, 10 fishponds with area over 5 ha),
- Quality soil used for the dam structure capable to resist water erosion for long period.

The Orlík dam on the Vltava River

9.3 Protective dikes or dams

It was found by an inspection that the following factors or circumstances decreased safety of the damaged or destroyed protective dikes or dams during extreme flood load:

- Insufficient size or non-existence of unloading and flood-way facilities,
- Uneven elevation line of the top of the dam (preferred site of probable overflowing),
- Insufficient height of bank reinforcing, designed to significantly lower flows, as shown during the flood in August 2002 (erosion of upper parts of earthfill dams or dikes above the reinforcing took place),
- Using stones of small sizes for reinforcing of banks insufficiently capable to resist dynamic water pressure (grouted stone reinforcing suffers from bottom water inflow leading to soil erosion under the reinforcing with subsequent destruction),
- Non-maintained vegetation on the free slope,
- Ride-up free bottom of dams or dikes at the edge of agricultural fields used as a road,
- Undesirable activities of animals, particularly beavers, foxes (holes), wild boars (deep digging of soil dams),
- Dynamic effects of large flowing objects, contributing to damaging of water side of protective dams or dikes.

The stilling basin of the Orlík dam damaged by the flood

10 FINDINGS AND SUGGESTIONS RESULTING FROM ACTIVITIES OF FLOOD MANAGEMENT BODIES

Reports from affected districts and regions served as a basis for analysis of activities of members of flood protection bodies. A report for the Prague municipality and reports by the river basin companies were among the background material.


České Kopisty village in the flood plain area of the Elbe River

10.1 Effect of previous experience on dealing with flood situation in August 2002

Firstly, system changes undertaken as a consequence of flood situation in 1997 helped in coping with managerial, rescue and cleanup activities after the flood. By adopting legislative regulations in the field of flood protection, rescue systems and crisis management, former multiplicity of procedures within the state administration was removed. Subsequently, the flood in 1997 speeded up and improved preparation of flood management plans. Merging of fire and civil protection bodies and establishment of managing and operational structures in a form of regional Fire Rescue Brigades (FRB) for dealing with rescue flood activities brought a positive effect.

10.2 Analysis of composition of flood commissions and crisis management bodies

Occasionally the reports by flood management bodies of district authorities called for better specification of a scope of responsibilities of mayors and their flood related activities, mainly in small municipalities. In assessing the requirement it can be stated that increasing rights and responsibilities of municipalities was welcomed and fully applied during the flood. Problems with composition of district commissions or crisis management bodies did not appear.

10.3 Improvement of applicability of legislative, regulative and methodological tools in relation to flood risks

The necessary improvement is seen in enforcing steps stemming from proposed legislative changes based on experience from summer floods in 1997 and 2002, in amending relevant regulations and methodological guidelines and in improvement of logistical measures. The aim is to speed up activities and prevent discrepancy in assessment.

The FRB report also required to specify precise rules and instructions for distribution and accounting for of humanitarian aid received either within the Czech Republic or from abroad.


Karlín district of Prague was completely flooded

10.4 Accessibility of headquarters of flood management commissions during flood

In some cases buildings serving for management and organisation of protection and rescue activities were inundated during the flood, concerning often buildings of the police, FRB, river basin companies etc. It follows that there is a necessity to ensure suitable workplaces,


The flood in streets of Písek town

buildings or rooms for headquarters of flood management commissions or crisis management bodies and their operating units outside inundated zones.
Often the flood management plans consider using of school buildings as emergency lodging of evacuated people. As the flood appeared during summer holidays, in some cases there were problems with ensuring entrance to the buildings. It is therefore necessary that flood management plans take into account such a possibility and ensure accessibility to emergency lodging in every situation throughout the year.

10.5 Prior public information on flood risk

It appeared that in view of possible early delivering information on development of flood situation in a local or wider scale it is very useful to notify through proper means – notice boards, maps, diagrams, eye-catchers – characteristic water levels in selected water gauging sites significant for a given area. To ensure functional flood warning service and warning of public, proper selection of sites for placing water gauges and of marks of levels of flood activity is necessary. These activities should be carried out not only in zones already hit by the flood, but also elsewhere, as a part of preventive measures. In zones hit by the flood placing of the flood bench marks is necessary to ensure passing the information to future generations.
After the flood in August 2002 measurements of maximum water levels were carried out in the affected area (about 1100 sites) and at a number of sites fixed bench marks are being planned.

10.6 Communication between flood management bodies at all levels, components of the Integrated Rescue System and public

During the flood events a number of problems were encountered regarding mutual communication between municipalities and supervising bodies (flood management commissions or crisis management bodies) and also with components of the Integrated Rescue System (IRS). Often the reason was insufficient equipment of municipalities by modern telecommunication equipment, mainly concerning service mobile phones.
Often problems with insufficient information on telephone numbers and names of contact points appeared. Such situations had to be dealt with often only during the flood operations, which meant loss of time. In this regard it will be necessary to consider current possibilities of computer-oriented communication (for example internet) and limits of its use (for example electronic mail). Separate assessment should consider also functionality of networks of mobile systems, mainly in view of possibility of damage to fixed phone lines or disruption of communication during the flood situation.
Another suggested requirement concerned completion of digital radio system for all IRS and FRB components and their linking with relevant bodies of the state administration within an integrated telecommunication system of the Ministry of Interior of the Czech Republic.

A flooded housing estate in Kralupy nad Vltavou town

This category includes also modification of responsibilities of commercial operators to ensure setting communication priorities to selected subscribers including determination of priorities of transfer between operators.

10.7 Preventive measures

At the beginning of the flood situation no current inventories of available technical and transport vehicles were at disposal for operational use or sufficient information on storage of fuels and materials. It means that also these phases of preparation on flood situation should inherently, in future, make a part of a logical, functional and effective system.

District flood management bodies stressed the role of preventive flood risk measures, regarding mainly landscape planning and, in particular, delineation, updating and designation of inundation areas and their active zones.

10.8 Determination of damages and financing of preventive and continuous activities during flood events

The exact evaluation of flood damage in its full extent was not in the Czech Republic under a responsibility of any state authority. Only cost estimates for renewal of property are used, prepared by the Ministry of Regional Development in co-operation with Ministry of Finance. In some cases duplicity of information appeared or alternatively no damage estimates were made (damage incurred by inhabitants and indirect damage).

After subsequent expert evaluation of disastrous effects of the flood, using data on possible future risks and on design of protection measures it was showed that it would be better to work with more detailed data on smaller land units. It is therefore important to have available information on damage not only in summary for regions and districts, or maybe for ministerial sectors, but also in the detail of municipalities.

10.9 General evaluation of activities of flood management commissions in view of previous development phases

Evaluation of activities and functioning of flood management commissions in the Czech Republic in recent decades can be described, in a simplified way, in five development phases. Each of these can be characterised according to causes predominantly affecting development of the flood protection activities:

I phase – before the flood in July 1997: Underestimation of a possibility of occurrence of extreme flood due to previous long period without large floods. General unpreparedness to the situation given by effects and impact of extreme natural phenomenon.

II phase – during the flood in July 1997: Occurrence of extreme flood event. Major part of the state territory was affected without sufficient preparation of endangered part of the public. Enforced improvisation resulted in operational management.

III phase – from July 1997 to August 2002: Efforts for remedial actions and renewal of buildings and facilities. Apart from financial aid from the state to cope with flood damage, firstly in the history of the Czech Republic an inter-discipline analysis of harmfulness of a flood event was carried out, causes of these disasters were studied, effective legislative, administrative and partially economic tools for enforcing preventive measures in some of the areas of human activities were being sought (although not within the scope of requirements of integrated protection against extreme events).

A street in the Dubí town was damaged by flood

IV phase – during the flood in August 2002: Certain similarity with II phase with significant reduction of improvisation during operational activities. Flood forecasting service improved significantly technologically, transfer of information among participants of flood management was less satisfying. There was improvement in operational management of flood management commissions and later of crisis management bodies and in activities of Integrated Rescue System (FRB units, voluntary fire brigades, army, medical service etc.). Relatively more effective management of flood situation was achieved where maximum use of subsidiarity principle was applied (i.e. using local responsibilities, local decision making, human and material resources).

V phase – after the flood: Again efforts for remedial actions and renewal of buildings and facilities. The state aid is concentrated not only on coping with flood damage, but also follows programmes of renewal of landscape, so that financial means are used at the same

A house damaged in Dubí town

time to improve protection of land and buildings against future floods. Much attention is again paid to causes of the event, its explanation and this time also to analysis of risks, application of findings into various fields of economic and social life, such as landscape planning, building code, analysis of function of water structures and water management systems, searching for critical spots in flood risk zones, analysis of origin and development of flood events, proposals for flood protection measures in view of technical, environmental, economic, social, land-administration, information and logistic aspects within concrete local, regional and countrywide conditions.

11 SOCIAL AND ECONOMIC CONSEQUENCES OF THE FLOOD

State administration, non-governmental organisations and individual citizens, foreign humanitarian organizations and governments of other states showed great sympathy with territories affected by August 2002 flood disaster and contributed significantly to compensation of the highest damages and social problems. For this purpose, the attention was also paid to identification of regional differences in flood damages in individual areas and associated problems. The estimated flood looses were compared with data of Czech Association of Insurance Companies on compensation of flood damages. For the first time, also data on epidemiological impact of floods on health conditions of population were collected and analysed.

11.1 Regional characteristics of the flood

Consequences of August 2002 flood were compared with those of a flood which experienced Moravia, Silesia and Eastern Bohemia in July 1997 (Table 11.1). The results of the comparison allowed us to specify some important proposals for improvement of the flood protection system. Consequences of July 1997 flood included 60 losses of lives in the Czech Republic while 2002 flood was associated with 19 fatalities. Total direct flood damages were at a level of 62.6 milliards Czech Crowns (CZK) or 2.5 milliards USD in 1997 and 73.14 milliards CZK (2.9 milliards USD) in 2002.

The assessment of 2002 flood involved temporal and spatial analyses of causal factors and consequences of the flood. The results of multi-criterion analysis included identification of 16 mostly affected regions which were used for detailed analyses of there systems of protection against impacts of floods. The assessment included additional 4 regions, which were less affected.

The following is review of problems, which were identified and measures proposed.

Table 11.1 Comparison of consequences of floods in 1997 and 2002

Measure of flood consequence	1997 flood	2002 flood
Affected area calculated as a sum of flooded territories administrated by affected municipalities	11,000 km^2	17,000 km^2
Percentage of total territory of affected districts	38.5 %	43%
Number of affected municipalities	558	986
Number of affected regions	8	10
Number of affected districts	34	43
Number of fatalities	60	19
Number of affected inhabitants in affected districts	2,855,000	3,200,000
Percentage of affected inhabitants of the total population in affected districts	63%	66%

Necessity of delineation of areas at risk to be flooded
Delineation of flood risk areas is the main component of a system for maximum possible elimination of flood damages. Water authorities recently delineated officially about 50% of flood risk areas attached to important rivers. Inconsistent regulation of construction activities associated with recreation and prohibition of other construction activities is permanent problem of regional planning and its implementation.

Underestimation of flood flows of small watercourses
Underestimation of flood flows of small watercourses in flood protection plans in municipalities and private buildings was reflected in local problems associated with flood protection systems. In this conjunction flood protection measures and plans do not always sufficiently include possible flooding of lower reaches of tributaries originated from backwater effects of main watercourses. Municipalities were also flooded through their sewerage systems, which were not equipped by elements for protection against backward flows.

Effects of flood occurrence seasonality
Experience from August 2002 flood showed that the flood protection plans have to take into account temporal high density of population in recreation areas during holiday seasons. These plans should therefore include adequate capacities for evacuation of affected population.

Lack of instructions for situations when flood risk exceeds protection effects of flood measures
Extremely high flows in densely urbanized areas of towns and municipalities including Prague capital and extensive floods in middle and lower reaches of watercourses were causal factors of time and operational requirements for rescue activities. Flood rescue measures for conditions of emergency declared by the Government were organised in situation when magnitude of flood disaster exceeded highly potentials of all existing flood protection measures. The future review of flood protection and emergency plans should employ the acquired experience and measures that were developed and include instructions for behaviour of population endangered by such extreme flood conditions.

Forecasts for improving efficiency of flood protection systems
The flood events substantiated the fact that an improvement of time advance of flood forecasting can significantly contribute to a decrease in flood damages. It was demonstrated in econometric studies from abroad that the flood damages can be decreased dependably on flood magnitude by introducing suitable preventive measures, which include well managed forecasting system. Important aspects include also participation of population, which should be aware of importance of its disciplined behaviour and prompt actions. The extremity of floods deteriorates naturally capabilities for decreasing flood damages.

Table 11.2 Economic losses according to type of assets

Assets	Immovable assets [CZK]	Movable assets [CZK]	Sum [CZK]
State assets	8,064,864,000	573,192,000	8,638,056,000
Assets of regions	3,456,986,000	337,081,000	3,794,067,000
Assets of municipalities	7,665,540,000	829,849,000	8,495,389,000
Persons in business	6,011,750,000	7,499,639,000	13,511,389,000
Physical persons not in business	7,809,319,000	2,718,869,000	10,528,188,000
Legal persons not in business	894,431,000	138,703,000	1,033,134,000
Some corrections	190,000,000	38,777,000	228,777,000
Total estimate for Prague	26,914,396,000	–	26,914,396,000
Sum	**61,007,286,000**	**12,136,110,000**	**73,143,396,000**

Data from Ministry of Local Development

Table 11.3 Economic losses according to their regional distribution

Region	Celkem [CZK – rounded]
Jihočeský	15,721,000,000
Plzeňský	3,847,000,000
Středočeský	14,283,000,000
Ústecký	11,765,000,000
Praha	26,914,000,000
Karlovarský	77,000,000
Liberecký	5,000,000
Vysočina	187,000,000
Jihomoravský	343,000,000
Sum	**73,142,000,000**

Problems with declaration of degrees of flood protection activity
Declaration of degrees of flood protection activities was reflected in the operations of the Integrated Rescue System (IRS). Actions of unites (especially of professional and volunteer fire units) were based mostly on local information on flood development and they were only subsequently be informed by relevant flood management commissions. Such situations occurred mainly in regions affected by fast development of flood. These problems indicate necessity for coordination of information systems including requirements for higher reliability and promptness of transfer of information between individual flood control commissions, crisis management bodies, IRS units and population during flood rescue activities.

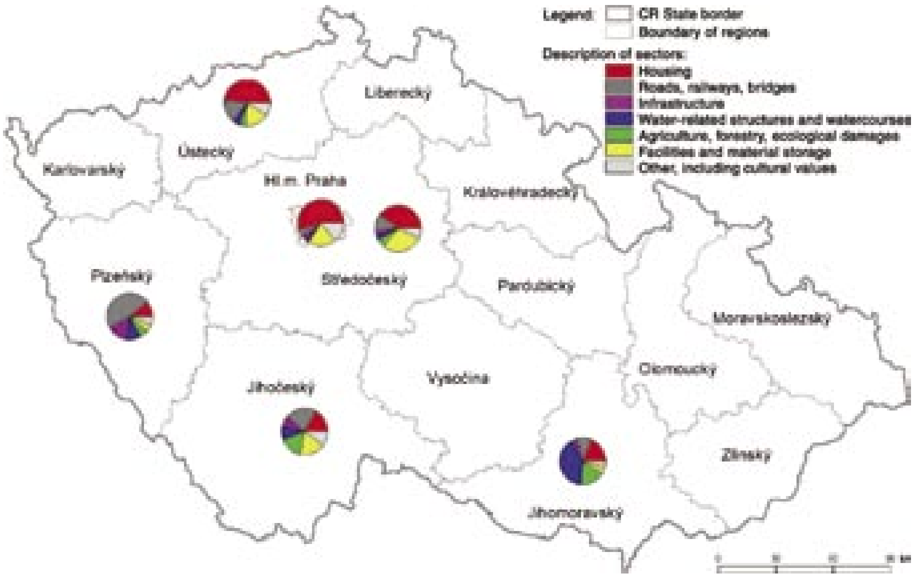


Figure 11.1 Flood damages according to sectors in individual regions in the Czech Republic

Problems of traditionally designed protection for flood return period of 100 years
In many cases, the 100 year flood (Q100), which was used for designing majority of flood protection measures, was highly exceeded. Operational measures (dikes from sandbags, mobile flood protection walls, etc.), which were taken during flood situation for additional improvement of flood protection, could not be as efficient as sufficiently designed flood protection measures.
Local decreases in flow capacity of watercourses consequently to jamming of bridges and sluices by inflowing material were other factors affecting unfavourably the flood damages. Majority of problems were associated with unsuitable location or insufficient dimensions of such structures in flood plain areas or other conditions deteriorating flood flow conditions. Future measures will have to include development of an inventory of these critical localities and economic assessment aimed at making decisions about higher protection of structures or improvement of river flow capacities for floods whose return period exceeds of 100 years.

11.2 Damage on health of population affected by floods

Important factors included also impacts of floods on health conditions of population and risks associated with infections and epidemics. Health consequences of August 2002 flood were assessed for a pilot area of former Český Krumlov district. The assessment was based on combination of information from public inquiry and health documentation of family practitioners.
The results of the assessment show that 41% of the inquired inhabitants were affected by the floods. Of the affected population, 9% lost their dwellings, and property of 31% of the population was highly damaged. The analyses show that consequences of the flood affected significantly health conditions of the population and total quality of lives of the inhabitants. Of the affected population, 42% had a feeling of health deterioration, of which 46% immediately during the flood, 39% during 6 weeks after the flood and 13% during a half year period. The health deterioration continued for 73% of this population even after 1 year following the flood. Occurrence of infectious and parasitic illnesses which would be associated with the flood was not substantiated.

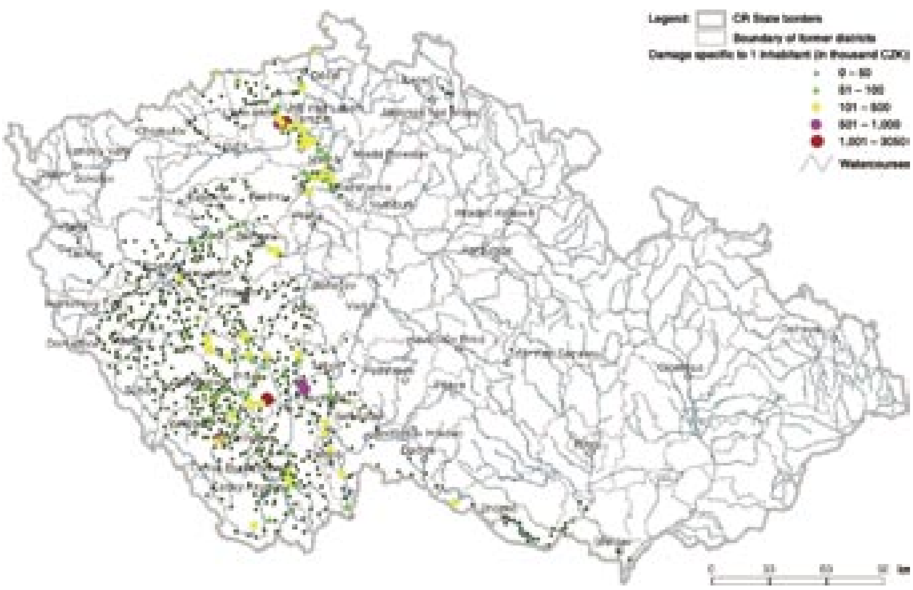


Figure 11.2 Flood damages specific to 1 inhabitant of affected municipalities

11.3 Review of flood damages according to data of the Ministry for Local Development

Data specified in a governmental document on Proposal for an integrated strategy for restoration of areas affected by the floods show that the total damages to properties amounted to 73.14 milliards CZK (Table 11.2 and 11.3) as at

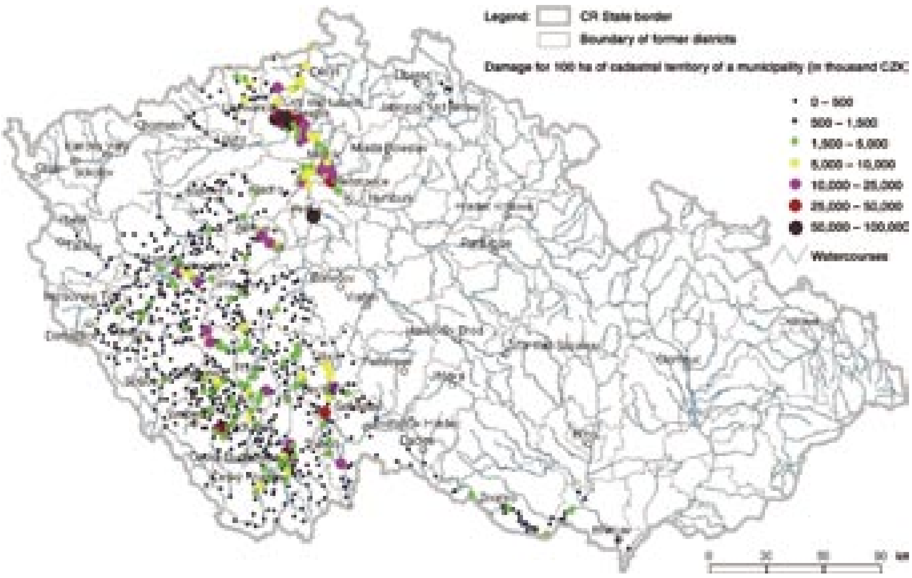


Figure 11.3 Flood damages specific to 100 hectares administrated by affected municipalities

3 December 2002. In this document, the highest damages were reported for routes and bridges (around 6.2 milliards CZK), buildings, halls and structures (6 milliards CZK), Prague underground (6 milliards CZK), machinery, installations and transport means (3.7 milliards CZK), family houses (3 milliards CZK), railway infrastructure (2.4 milliards CZK), other structures (2.1 milliards CZK) and watercourses (1.3 milliards CZK). Damages to individual sectors in particular regions are shown in a map in Figure 11.1, damages specific to 1 inhabitant of municipality are shown in Figure 11.2, and damages specific to 100 hectares administrated by a municipality are given in Figure 11.3.

The documents concerning the flood include a Review of preliminary estimates of costs of restoration of properties necessary for insuring basic functions in territory affected by natural or other disaster in Prague capital and individual affected districts. This review was prepared in accordance with requirements laid down in a Decree of Ministry of Finance.

11.4 Flood damages to family houses and flats

Public inquiry method was used for collecting data on house ages, extension of damages to the structures and localisation of the structures in flood plain areas. The data were used for derivation of total damages to family houses and flats for 986 affected municipalities (Figure 11.4). These damages are at a level of 6 to 7 thousand new family houses. In terms of a number and portion of affected houses and flats, the flood affected mostly South Bohemian, Pilsen and Ústí nad Labem regions. The analysis also showed that important components of regulations, prohibitions and conditional approvals issued by water authorities in approving family houses and other structures include necessity of coordinated actions, which would contribute to participation of all bodies of local, regional and national administration in taking rescue protective and preventive measures.

Two questionnaires distributed as a component of the inquiry in the areas exposed to flood danger provided good data in terms of their information and statistical values. One of the questionnaires included 7 questions related to conditions in municipalities affected by the August 2002 flood, while the other was focused on the municipalities mostly affected in 1997. Some of the answers were almost unambiguous, while other were less informative but all of the answers provided good background for development of a strategy and also for a proposal of direct flood protection measures. The individual respondents did not necessarily be aware of the fact that they preferred integrated conception.

11.5 Compensation of flood damages by insurance companies

In accordance with Act on the Insurance System and in cooperation with insurance companies, data were collected on insurance compensations, on approaches of population in property insurance in municipalities and towns affected by floods, and on population assessments of services provided by insurance companies. The fact that interest of the population in insuring its property has been increasing since 1997 is positive information. On the basis of data collected from the inquired households, it was reported for damages associated with August 2002 flood that family houses were affected in 64%, their internal equipment in 54%, other properties in 62%, recreational houses in 14% and vehicles in 11%.

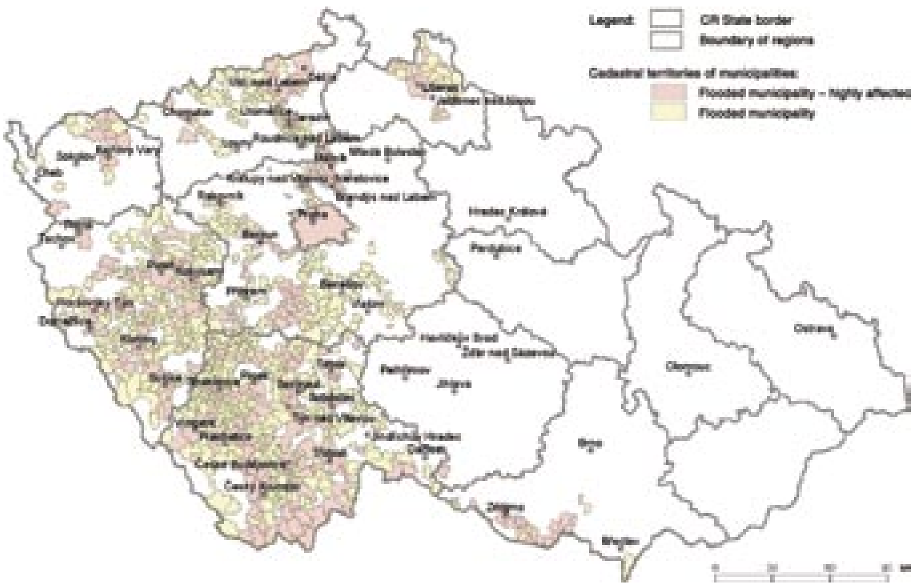


Figure 11.4 Municipalities affected by August 2002 flood

12 INFORMATION BACKGROUND MATERIALS AND MAPPING DOCUMENTATION OF THE FLOOD

The aim of the project was also to ensure preparation and controlled use and archiving of geographical data from affected areas. To fulfil this objective the project included and implemented information data store on the flood in August 2002, atlas of the maps documenting the flood, orthophotomap of inundated (flooded) areas with the line of maximum inundation and digital model of river valleys in the regions affected by the flood.

12.1 Data store of information on the flood

In principle it concerns a system of hardware and software instruments, as well as organisational measures allowing transfer of data, correct checking and storage of data, availability of identical data to all the project participants, access to data, possibility of their presentation and distribution computerised way for final users and recipients. Hardware means of the data store are located in the T. G. Masaryk Water Research Institute premises in Prague. The data store was used during the project and serves subsequently as an additional information source on the flood in August 2002 for the state and public authorities.

12.2 Atlas of maps

The set of maps documenting the August flood in 2002 is developed in a digital form and comprises three basic parts:

(1) Orthophotomap with incorporated layer of maximum inundation, marks of ecological loads and marks of maximum level of inundation,

(2) Orthophotomap of the area affected by the flood with incorporated layer of inundation classified according to water depths,

(3) Qualitatively classified inundation lines based on the Basic Map of the Czech Republic 1:10,000

12.3 Quantitative characteristics of inundation (flooded area)

These data were derived from the geometric shape of inundation and its projection on the elevation model, map of administrative regions and land use map. Three dimensional tasks were solved using GIS. All of the lines in two-dimensional coordinate system in the affected areas were acquired from the relevant water management administrators of river basins, i.e. river basin companies.

12.4 Digital elevation model of the landscape affected by the flood

In the whole area affected by the flood the contour line model of elevation of the Principal Base of Geographical Data (ZABAGED) was transformed into a model structure of triangular irregular network (TIN) and a regular square grid (GRID) with 10 m size of a square. It is an area covered by 2,724 map sheets of the Basic Map of the Czech Republic 1:10 000.

A differential elevation model was created for the affected area based on the elevation data from ZABAGED and improved by elevation measurements from aerial survey photographs in selected parts of the area affected by the flood.

12.5 Orthophotomap of the affected area

A colour orthophotomap with resolution of 0.5 m was created in the coordinate system of the Uniform trigonometric cadastral network (S-JTSK) for an area of 8 190 km². It is deposited in the data store in a composition of map sheets of the State map 1:5 000 derived. Mapping compositions based on the orthophotomap are also attached with classified inundation area according to water depths, with ecological loads and bench marks of maximum water levels reached during the flood. An example of such a composition is given in Figure 12.1.

12.6 Multimedia outputs of the projects

Outputs of the project were documented and published using multimedia means and public information products. Some of them are accessible through internet.

A mobile aerial video recording of the state of alluvial plains after the August flood in 2002 for all significant watercourses is also among the outputs of the project.

Technical results of the project Assessment of the extreme flood in August 2002 are also presented by means of a short video film.

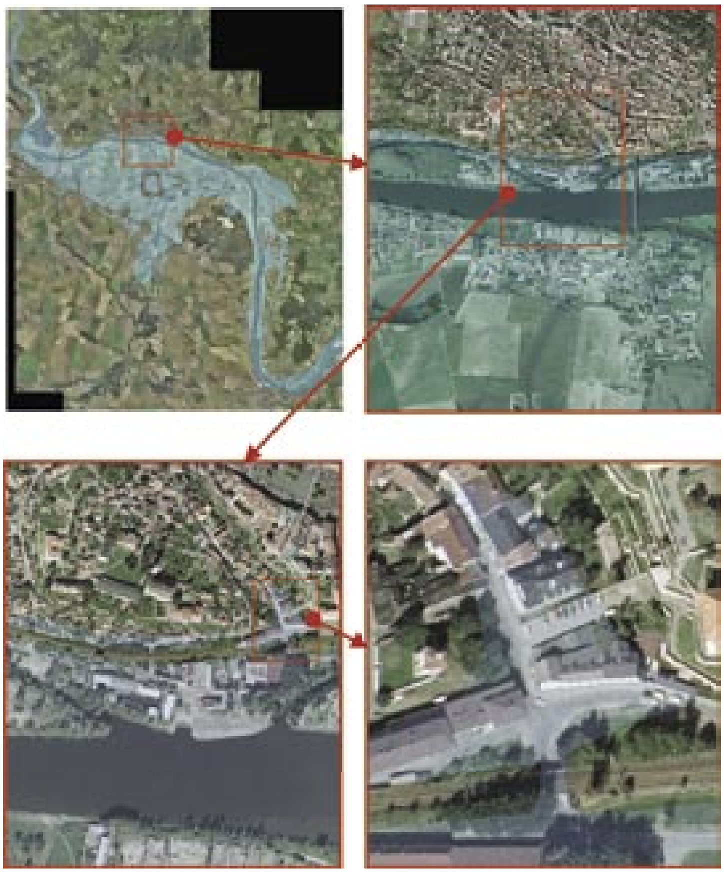


Figure 12.1 Flooded area in an orthophotomap in different scale

SUMMARY AND CONCLUSIONS

- The August 2002 flood was one of the biggest natural disasters on the territory of the Czech Republic during past few centuries.
- It hit mainly the Vltava River Basin and the Elbe River downstream of the Vltava tributary. It appeared shortly after occurrence of a flood disaster, which affected the Morava, Odra and Upper Elbe River Basins in the year 1997. The public was surprised by the event, although appearance of several subsequent floods during short time periods is not a rare exception in a historic flood record (cf. occurrence of floods on the Elbe River in 1888, 1890, 1896, 1897 and 1899).
- The main meteorological cause of the August flood was movement of two deep pressure lows along southern trajectory across Mediterranean to Central Europe, bringing a sequence of two waves of heavy precipitation during a relatively short time span. It was again confirmed that meteorological situations from southern or south-western sector can, under certain conditions, bring very strong or extreme floods to the region of Central Europe and therefore also to the territory of the Czech Republic.
- Both precipitation waves hit mainly the Vltava Basin between 6 to 7 August and 11 to 13 August 2002. Average precipitation depth over the Vltava Basin by Prague (26,720 km^2) was 193.9 mm, runoff depth was 92.5 mm and maximum rainfall depth reached 450.5 mm at the Pohorská ves station in South Bohemia. Both precipitation waves hit the same territory with only short interruption by 3 days, leading to nearly total saturation of the landscape before fall-out of the second, heaviest amount of precipitation.
- At many sites the biggest discharges were reached within the whole period of observation. Return periods surpassed usually 100 years, few times even 1000 years.
- The first runoff wave was usually significantly transformed in river stretches with influence of large reservoirs. It was apparent mainly on the Vltava River in Prague. During the second runoff wave the retention capacities of reservoirs were quickly filled up and their effect on the second more substantial runoff phase of the flood was minimal. Only two largest reservoirs, Lipno and Orlík on the Vltava cascade, helped to slightly decrease culmination flows, while surpassing maximum allowable water level in the Orlík reservoir. Using the Vltava cascade model and alternative simulations affecting flood wave at the lower Vltava River through various manipulations on the cascade reservoirs it was concluded that no manipulation could decrease culmination level of the second flood wave in Prague to harmless discharge.
- By statistical analysis of the relation between precipitation depths, runoff depths and physical-geographical characteristics of the basin it was demonstrated that with so extreme precipitation depths the effects of land use was nearly negligible.
- The development and magnitude of flows were significantly affected by large inundation areas. By filling up the inundation areas the flood wave became flatter and the magnitude of culmination discharges decreased downstream. This effect took place mainly along the Elbe River. While the return period of the discharge of 5,160 m^3.s^{-1} on the Vltava River in Prague was estimated at 500 years (according to an analysis of historic gauge marks the flood in 2002 was probably the biggest since the year 1432), the August flood wave on the Elbe River in Děčín (basin area of 51,104 km^2) with culmination discharge of 4770 m^3.s^{-1} was only third in rank within historic hydrological events. The floods from the years 1845 and 1862 were bigger.
- A comparison of boundaries of occurrence of fluvial soils showed that the boundaries of fluvial soils mostly corresponded to the boundaries of maximum inundation of the flood from August 2002. It can be concluded that although this flood was undoubtedly an extreme event, it was not uncommon within the context of historic floods, as in order for current boundaries of fluvial soils to develop, similar large inundations had to occur several times in past.
- In many flood prone sections of fluvial plains changes of river channels, new erosion zones, appearance of enclosed depressions and new sedimentation accumulations were found and recorded. Also hydrogeological conditions slightly changed, particularly concerning changes of the upper ground layers in relation to diffuse pollution of groundwater.
- During the transit of flood waves a range of watercourses experienced significant changes in longitudinal and cross-sectional segmentation. Some of the changes were positive, mainly in cases of watercourses close to natural status in view of their rehabilitation, and did not require heavy interventions.
- Impact of the August flood to surface water quality was not disastrous, although a number of parameters showed increased concentrations and in a few cases some of the permissible limits were surpassed. At the beginning of September 2002 the majority of parameters were already found close to their unaffected values.
- Contaminated water from 124 damaged wastewater treatment plants was the biggest source of pollution of surface water together with leaking of dangerous substances from inundated industrial sites with chemical production and historic ecological loads.
- Groundwater aquifers situated near to inundated areas experienced significant changes in parameters of organic pollution. Occurrence of organic polluting substances was also identified in a number of cases in fluvial soils. However, it concerned mainly simple surpassing of the background values of these substances.

- The August flood was a loading test for all of the water structures in affected areas. Out of 27 significant water structures of the I to III category, 15 of them were exposed to extreme dynamic load of the unbind water force and unusual operational requirements. Seven water structures passed flood without any substantial damage and eight experienced large damage without any loss of stability or operability.
- Due to flood more than 100 dams of fishponds bigger than 5 ha and 300 smaller fishponds with area below 5 ha were overflowed. Accidents due to rupture of the dam were experienced on the total of 23 fishpond dams. Other 84 fishponds were seriously damaged. About 75% of overflowed dams resisted rupture.
- At some sites stability and functionality of protective dams was also affected. It is also necessary to note in this regard that further failures of flood protection structures and propagation of inundation were prevented due to enormous efforts of intervention teams and a large number of volunteers. Based on surveys, a list of causes decreasing safety of these structures during the extreme flooding in August 2002 was completed.
- Inundation water penetrated into municipal residential areas, apart from surface overflowing of the river banks, often through sewerage systems lacking backflow valve and due to backwater when the level of the main watercourse was higher than the water level of a tributary of a water lead.
- Extreme flood situation tested also awareness of forecasting and warning meteorological and hydrological service. Among deficiencies low resistance of key water gauging stations against harmful effects of high water was identified including provision of power and communication links for automatic stations.
- It was demonstrated that the applied hydrological models better estimated development of flood for large river basins of the order of thousands km^2. Forecasts for smaller basins suffered largely from uncertainty of estimates of time and space distribution of precipitation by meteorological models, limiting a possibility for significant lead time forecasts of detailed development of flood waves.
- It was verified that flood management authorities were undoubtedly supported in their extremely demanding and difficult situation during the flood in 2002 by a range of organisational and legislation measures adopted after the flood events in 1997. The need of permanent development of flood protection activities was again confirmed together with the need for preparation for future flood events on a basis of experience acquired during past floods.
- For these reasons detailed analyses were carried out of shortcomings in activities of flood management authorities immediately after the flood in August 2002 with subsequent proposal of improvement measures.
- The damage caused by the August 2002 floods to properties has been estimated at CZK 73.14 milliard (USD 2.92 milliard); there were 19 causalities; and a total of 968 agglomerations and 3.2 million people were afflicted. In our modern times, this was overall the largest damage caused by a flood in the territory of the Czech Republic.
- A comparison of the disastrous flood situations in August 2002 and July 1997 has led to the conclusion that the August 2002 floods hit a larger area; featured a shorter time of run-off concentration; and affected a landscape with a relatively more complex economic infrastructure. This is the reason why the damage the floods caused was heavier.
- In addition to the final reports under the Government's project of the Evaluation of the August 2002 Disastrous Floods, an Atlas of Flood Maps has been produced. It contains for main streams in the afflicted areas the extent and depth of the inundation, the marks indicating the contaminated sites, and the bench marks of the maximum levels of the August 2002 flood. Furthermore, a digital relief model has been derived for a defined area, using both a geographic database and aerial photographs. Also, aerial video recordings of the post-flood condition of fluvial plains were taken. All of these and some other documents have been collected in the central flood data store developed at the T. G. Masaryk Water Research Institute, Podbabská 30, 160 62 Praha 6, e-mail: info@vuv.cz.

The Vltava River rushing through the Prague City

Mobile flood-protection walls in the city centre of Prague

The Troja Castle on the periphery of the Prague City

Czech Hydrometeorological Institute

Agency for Nature Conservation
and Landscape Protection
of the Czech Republic

Czech Geological Survey