The Analysis of the Danube Floods 2006

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An in depth analysis of the floods
on the Danube and its main tributaries in 2006

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This report has been prepared by Karl Wachter in cooperation with the ICPDR Flood Protection Expert Group (Chair person: Sándor Tóth) and the ICPDR Secretariat (Igor Liska). The report is based on national reports from the following Danube countries: Germany, Austria, Czech Republic, Slovakia, Hungary, Croatia, Serbia, Romania and Moldova. Specific information and maps were kindly provided by the Joint Research Centre of the European Commission.

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1 Executive Summary

In 2006, a serious spring flood occurred in the Danube River Basin, the result of specific meteorological weather conditions. Heavy floods inundated Central and Eastern Europe due to melting snow and heavy rainfall. Swollen rivers and rising groundwater levels caused widespread damage and forced thousands to leave their homes. For the first time in history, high water was recorded on the Danube, Sava, and Tisza at the same time – this rare coincidence caused an extreme flood event in the main Danube (primarily in the Central and Lower Danube reaching a 100-year return period).

The ICPDR decided to evaluate the flood event, not only to assess its specific hydrological characteristics, but also to analyse overall preparedness and assess the measures that were taken at the national level. The aim was to highlight lessons that could be learned in order to prevent or minimise damage in the future. This report provides an overview of the different aspects of the spring 2006 flood event including proposals for the way forward.

Table a shows hydrological data from selected representative gauges (as shown in **Figure a**).

Table a: Danube Spring Flood 2006: Data from selected representative gauges

No.	River	Gauge	Basin [km2]	Danube-km	Flood peak [date]	Duration of extreme flooding	Discharge [m³/s]	Return period [years]
1	Danube	Pfelling	38,000	2305	30.03.	30.03.-31.03	1,750	< 1
2	Danube	Passau	76,640	2225	30.03.	29.03.-31.03	5,060	< 1
3	Danube	Korneuburg	101,000	1942	30.03	27.03.-4.04.	6,700	~5
4	March/Morava	Angern	25,624	-	04-06.04	29.03.-9.04.	1,400	~100
5	Danube	Devín	131,000	1879	31. 03.	30.03.-3.04.	8,020	20
6	Váh	Hlohovec	9,600	-	30.03.	29.03.-2.04.	1,600	10÷20
7	Danube	Komárno	171,000	1766	03.04.	29.03.-9.04.	8,570	<50
8	Danube	Budapest	187,000	1647	04.04.	31.03.-10.04	8,570	80-100
9	Danube	Bogojevo	261,000	1368	10.04.	6.04.-17.04	8,620	~80
10	Tisza	Szeged	138,420	-	20.-22.04.	10.04.-10.05	3,790	< 80*
11	Sava	Sr.Mitrovica	88,000	-	27.03.	13.03.-8.05.	4,470	~5
12	V.Morava	Ljub.Most	37,000	-	28.03.	24.03.-28.03	1,740	~5
13	Danube	V. Gradiste	570,000	1059	15.-16.04	8.04.-13.05	15,800	~100
14	Danube	Gruia	618,000	851	15.-16.04	25.03.-16.05	15,800	~100
15	Jiu	Podari	10,000	-	15.03.	13.03-15.03	1,020	~20
16	Danube	Zimnicea	658,000	554	23.04.	16.03-21.05	16,000	~100
17	Siret	Lungoci	36,000	-	2.04.	30.03-4.04.	1,200	~2
18	Danube	Isaccea	805,000	102	24.-25.04.	19.04-3.05	14,400	~80

*Note: return period of flood discharge is given in the table. However, due to the flood volume transferred and the backwater effect of the Danube, record flood stages were observed on the River Tisza from Titel to Tiszaug (upstream of the Körös mouth).

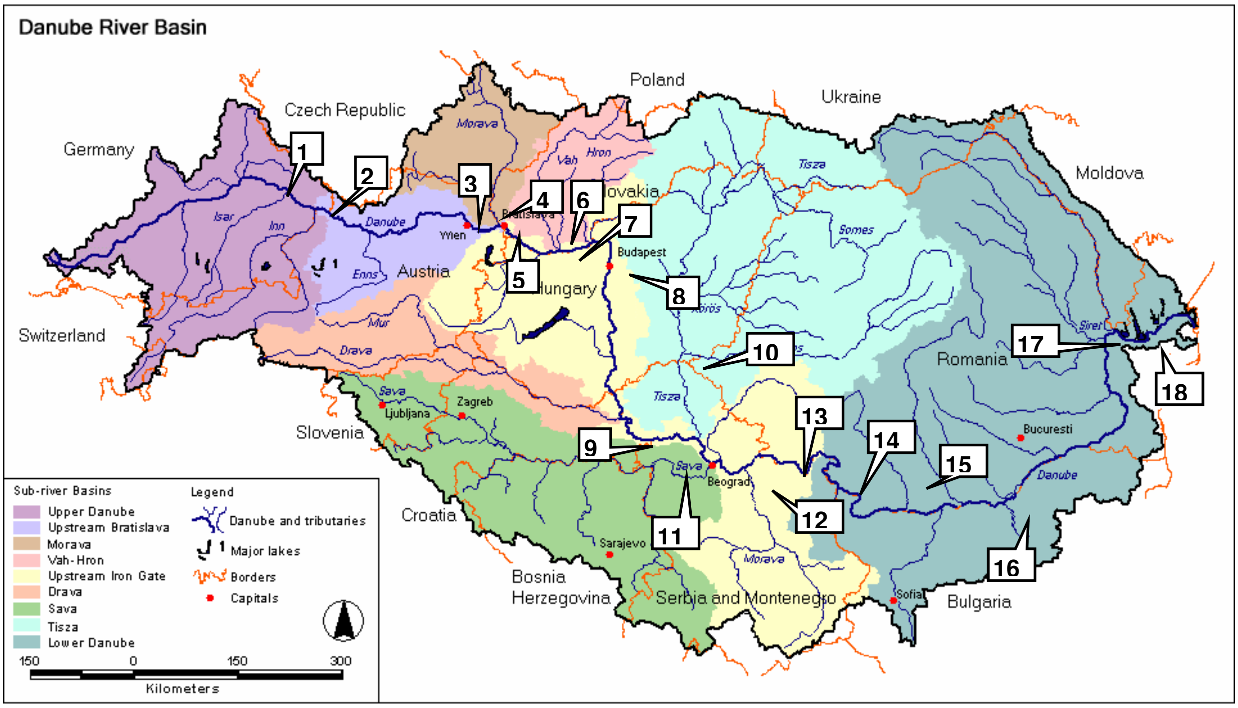


Figure a: Danube Spring Flood 2006: Map of selected representative gauges

1.1 The Upper Danube

The centre of the rainfall event at the end of March occurred in the region that includes the March/Morava and Thaya/Dyje Sub-basins. Spring floods occur frequently in these basins. In the central Alps, extreme flooding was not observed as melting at higher altitudes (above 2000 m) did not occur. During the last week of March, intensive, but not extreme, rainfall was registered in the whole area of the Upper Danube catchment. Additional extreme snow water storage occurred in the alpine region and the Morava Basin. A sudden temperature rise and heavy rainfall activity at the end of March resulted in fast snowmelt.

While only minor floods of a 2-5-year return period occurred on the main Upper Danube, floods up to a 100-year return period developed in some smaller tributaries in Germany, Austria, Czech Republic and Slovakia and increased the Danube flooding downstream.

Such runoff events represent a typical spring flood. However, this flood event was significant with regard to its discharge hydrograph and volume. While in the German and Austrian stretches of the Danube River the flood hydrograph had two well-marked peaks, this was not so evident on the Slovak stretch. This was the result of the influence of the Danube's left side tributary, the Morava River, in the Devín profile at the Austrian-Slovak border (river kilometre 1879). The critical flood flow proceeded slowly downstream the Danube with specific time delays from Passau (km 2225) to Sturovo/Estergom (km 1719) on a stretch of approximately 500 km.

Simultaneously, flood waves passed along the Morava, Váh and Hron rivers. On 3 April, a 1500 m³/s peak discharge on the Morava flood coincided with a 5-6000 m³/s flood peak on the Danube at Devín. A 1200-1400 m³/s flood peak on the Váh entered the Danube one day before the peak of the recipient arrived.

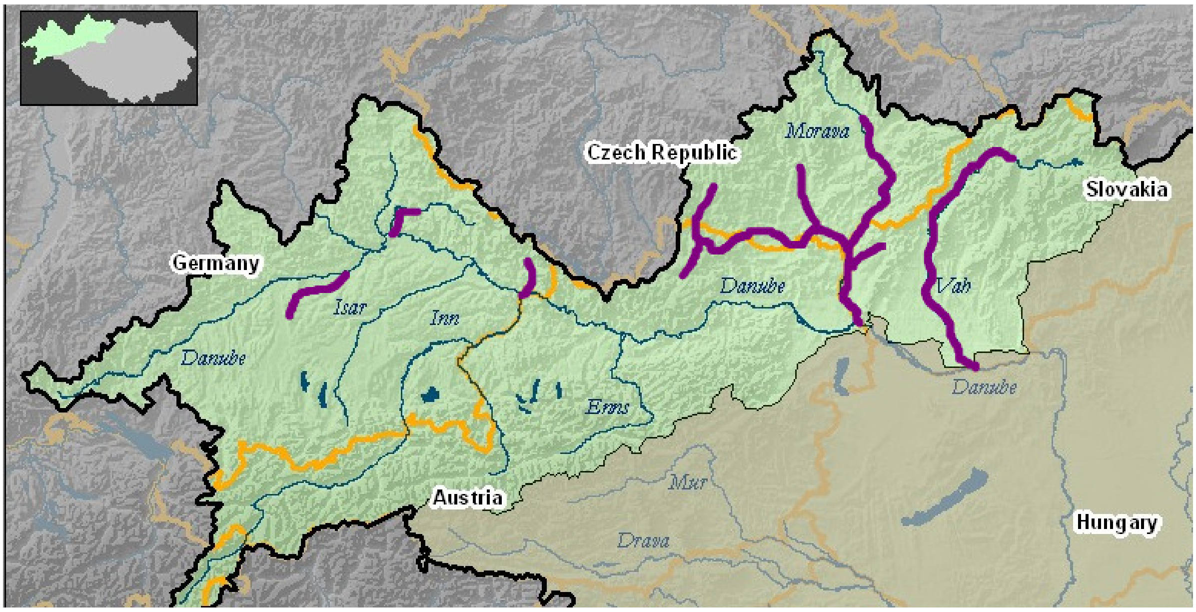


Figure b: Rivers affected by significant flooding in the Upper Danube Basin (violet)

Table b: Average precipitation in sub-basins of the Upper Danube

Catchments	25-31 March	1-6 April	9-13 April	Σ (mm)
Danube at the mouth of the Inn	39.2	23.2	35.2	97.6
Inn	33.3	26.3	28.4	88.0
Traun and Enns	45.0	18.0	18.8	81.8
Vienna Basin	37.9	6.4	12.2	56.5
Morava	42.1	9.3	9.8	61.2
Váh, Nitra, Hron	28.2	9.9	5.5	43.6

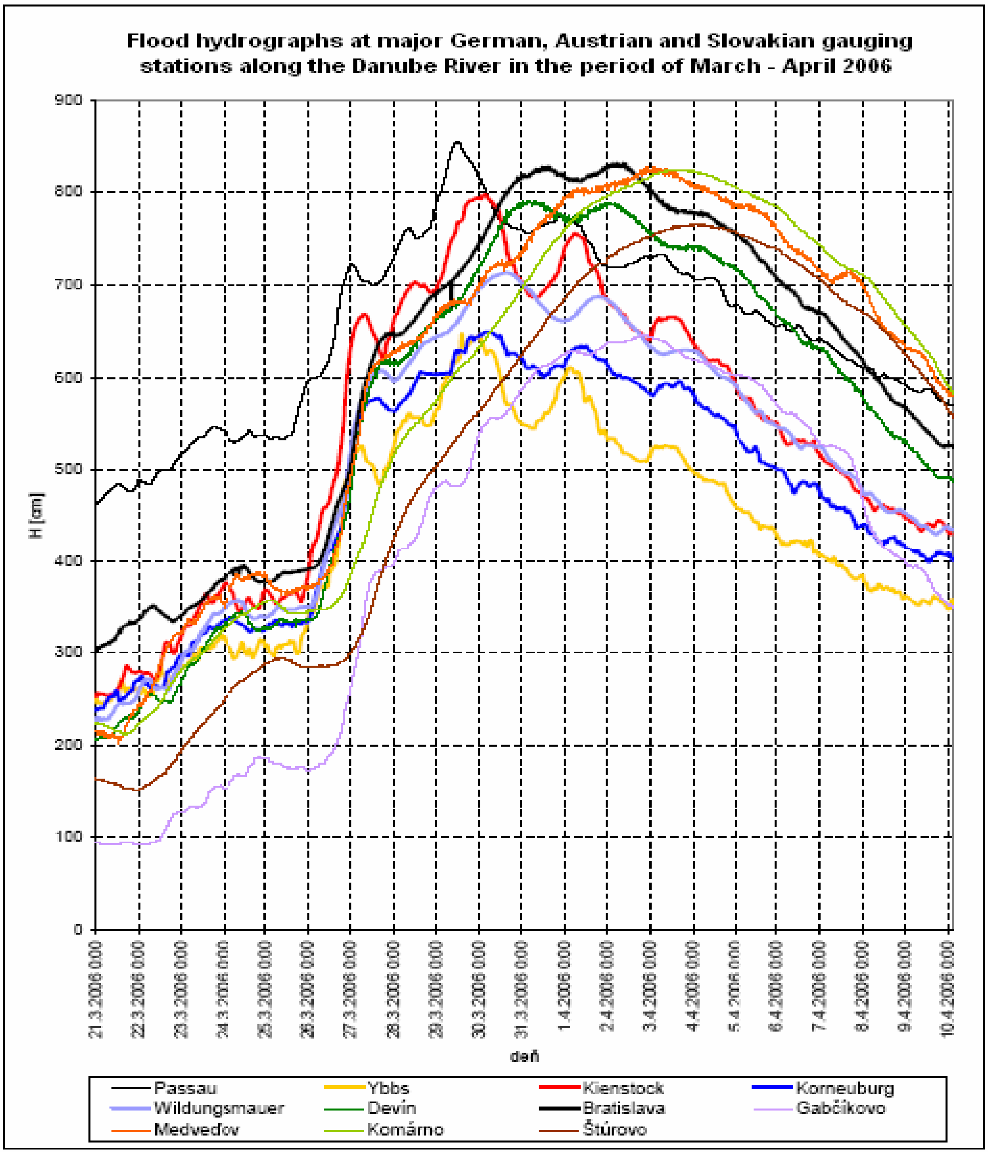


Figure c: The progression of changing water levels in the Upper Danube

1.2 The Central Danube

The Central Danube Basin is the catchment area between the Slovak Danube and the Iron Gate, having an area of approximately 430,000 km². The major tributaries are the Tisza, Sava, Drava and Velika Morava.

Meteorological conditions in the Upper Danube area had an important impact on the development of the extreme flood event on the Central Danube, especially in the Budapest region. The meteorological conditions in the Carpathian region of the tributaries were of prime importance for the Tisza River Basin upstream of Szeged. The 2005/2006 winter was exceptional in terms of its low temperatures and intensive snowfall from November to March. Relatively high daily air temperatures and a long, intensive period of rainfall from the end of March until the end of April caused melting and runoff (see **Table c**).

By mid February, water reserves accumulated in snow cover had reached approximately 150% of the multi-annual average for the given period. A significant amount of snow accumulated not only in the Upper-Tisza region but also in the Maros/Mures valley (where the water reserves recorded exceeded the multi-annual average by 70 %) and in the Körös/Crisul river system (where levels were exceeded by 30 %).

The combination if heavy precipitation and the snow melt resulted in an exceptional runoff.

Figure d: Rivers affected by significant flooding in the Central Danube Basin (violet)

Table c: Average precipitation in various sub-basins of the Tisza River Basin

Catchments	25-31 March	1-7 April	8-14 April	15-21 April	Σ (mm)
Upper-Tisza	30.4	21.6	37.5	16.3	105.8
Bodrog	24.3	20.7	35.1	10.9	91.0
Sajó-Hernád	18.2	16.8	26.8	9.8	71.6
Túr-Szamos-Kraszna	16.3	18.5	80.9	19.8	135.5
Körösök	22.3	28.0	73.8	31.1	155.2
Maros	8.9	26.2	64.1	14.1	113.3

The flooding on the Sava River lasted an unusually long period, beginning in mid March and lasting until mid May. During this time the river flow was always between 3000 m^3/s and 4000 m^3/s (a return period of 1-5 years). In this way, the rare coincidence of relatively large and prolonged floods on all the main tributaries of the Central Danube Basin resulted in one of the largest floods recorded in the lower Danube stretch.

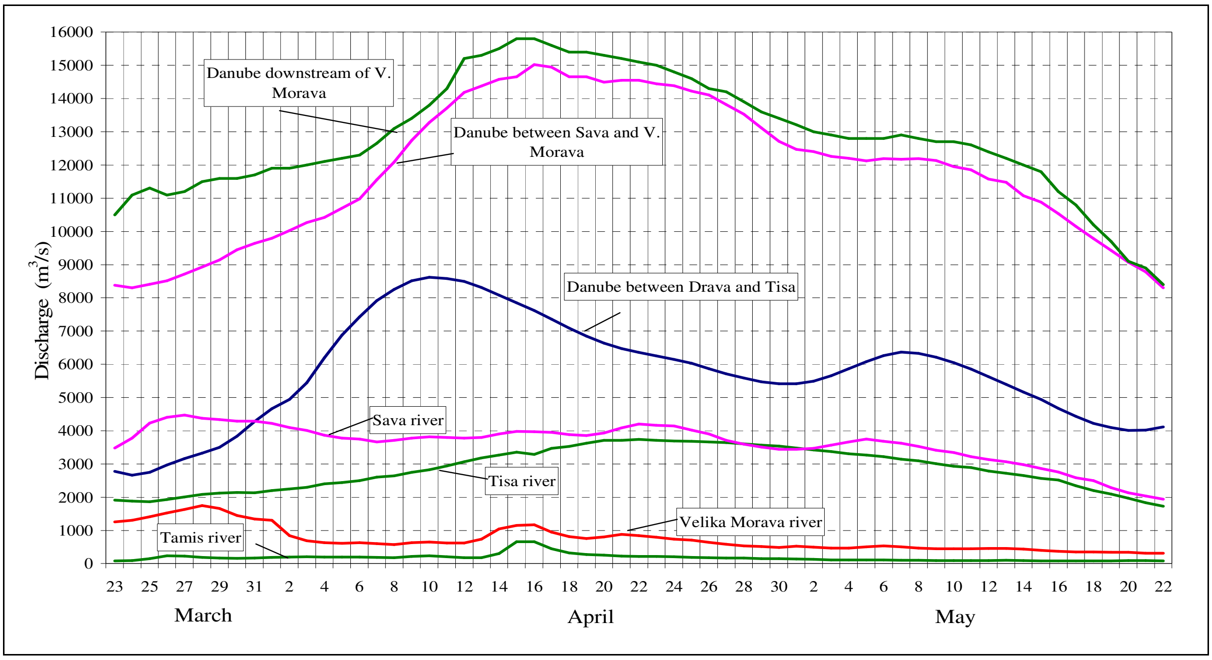
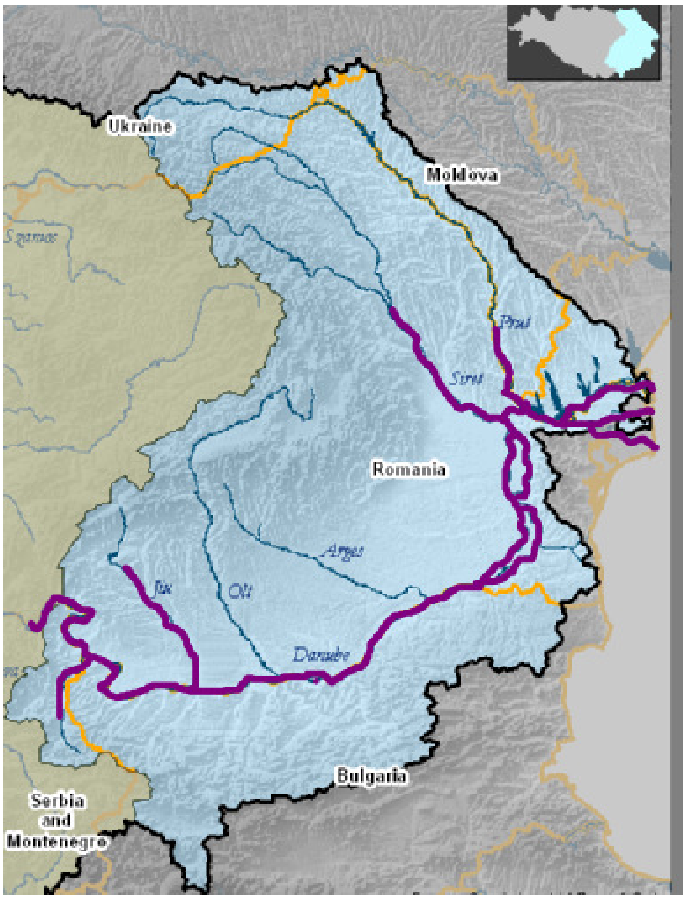


Figure e: Hydrographs of the Danube, Tisa, Sava, Velika Morava and Tamis (23.03. – 22.05.06)

1.3 The Lower Danube



A relatively long period of precipitation was recorded between mid March and the end of April in the Carpathian mountain area. As a result, a high discharge from all the major tributaries in the region (such as the Timis, Jiu, Arges, Ialomitsa, Siret and Prut) was recorded over several weeks.

As already mentioned for the Central Danube region, the extremely rare coincidence of relatively large floods occurring simultaneously in the Upper Danube, Tisza, Sava and Velika Morava rivers resulted in a very serious 100-year flood event downstream of Serbia. Throughout the entire Lower Danube, historically significant flows and water levels were registered, being the largest recorded during the last hundred years. The registered flows had maximum values of 15,600 -15,800 m³/s, similar to those in 1895. Unusually, there was also a long period of high flood alert on the Danube downstream of the Iron Gate, lasting more than 6 weeks (see the hydrographs in **Figure e**). Several dike breaks, especially on the Romanian side, took place.

Figure f: Rivers affected by significant flooding in the Lower Danube Basin (violet)

1.4 Summary

Exceptional weather conditions caused the 2006 springtime floods in parts of the Upper Danube (e.g. the Morava River Basin) and, primarily, in the Central Danube (the Tisza and Sava) and Lower Danube. An extremely rare coincidence of relatively large floods in the sub-basins of the Upper Danube, Tisza, Sava and Velika Morava rivers resulted in a very serious 100-year flood event along the Danube (from the mouth of the Morava to the southern tip of the Csepel Island in Hungary; downstream of the Tisza mouth in Serbia and on the entire Romanian section of the Danube). Historically significant flows and water levels were registered in many stretches. The extent of flooding in Romania was the largest in the last hundred years. During the period 12-25 April, the registered flows in Romania recorded maximum values of 15,600-15,800 m^3/s, similar to those of 1895. Particularly unusual was the long period of high flood alert on the Danube downstream of the Iron Gate, lasting more than 6 weeks.

The spring floods of 2006 caused minimal casualties, thanks mainly to efficient flood protection, preparedness and mitigation. Thousands of people were involved in the emergency operations. Flood warning and forecasting proved to be one of the key factors of an integral flood protection and provided valuable information, both on the national level as well as on the basin-wide scale (Danube EFAS). The estimated total costs of damages and related emergency operations exceeded €600 million.

The 2006 flood defence actions revealed a number of general and operational deficiencies and also served as a good test of warning, protection, preparedness and mitigation actions. The lessons learned from the 2006 floods will help to accelerate the implementation of the ICDPR Flood Action Programme as well as EU flood policy.

2 Introduction

Figure 1: The Danube Basin

In 2006, serious spring flooding occurred in the Danube River Basin, the result of specific meteorological weather conditions. As a result, an extreme flood event occurred throughout the Danube Basin, particularly in the central and lower sections where the flood had a 100-year recurrence interval. To provide an overview of the flood event in the light of the "Action Programme for the Sustainable Flood Protection in the Danube River Basin", the International Commission for the Protection of the Danube River (ICPDR) initiated preparation of this report.

An overall goal of the Action Programme is to achieve a long-term and sustainable approach for managing the risks of floods to protect human life and property. The major goals of this report are to review the events and respective actions that occurred at the national level and to highlight the lessons learned and way forward for flood prevention, protection and mitigation in the Danube River Basin, respecting the principles of the new European Flood Directive.

3 General meteorological boundary conditions

A shallow low-pressure area occurred over the Alps and the western part of the Carpathian Mountains from 20-21 March. A high-pressure area grew bigger over Germany and the Czech Republic on the 22 March and the cool air temporarily flew along its border into Central Europe on the 23 March. The high-pressure area moved away from Central Europe towards the southeast during the following days. Simultaneously, a low-pressure area moved from the Atlantic to Western Europe and warm, humid air began to flow along its boundary to Central Europe.

The wavy cold front associated with the low-pressure area over Scandinavia passed through Central Europe on the 2 April. The ridge of high pressure temporarily expanded behind the front over the Alpine region on the 4 April. As a result, cold and humid air began to flow over Central Europe from the northwest. A low-pressure area began to deepen over southern France on the 5 April and moved eastwards. The wavy cold front associated with the low-pressure area gradually influenced the weather over the whole of the Danube River Basin.

The ridge of high pressure began to extend from the west to Central Europe on the 6 April, which in the following days expanded as far as Belarus. On the 8 April, warm air from the southwest began to flow over Central Europe on the front side of the low-pressure area over the North Sea. The wavy cold front began to move to the east at the same time. The meteorological situation is shown in **Figures 2** and **3**.

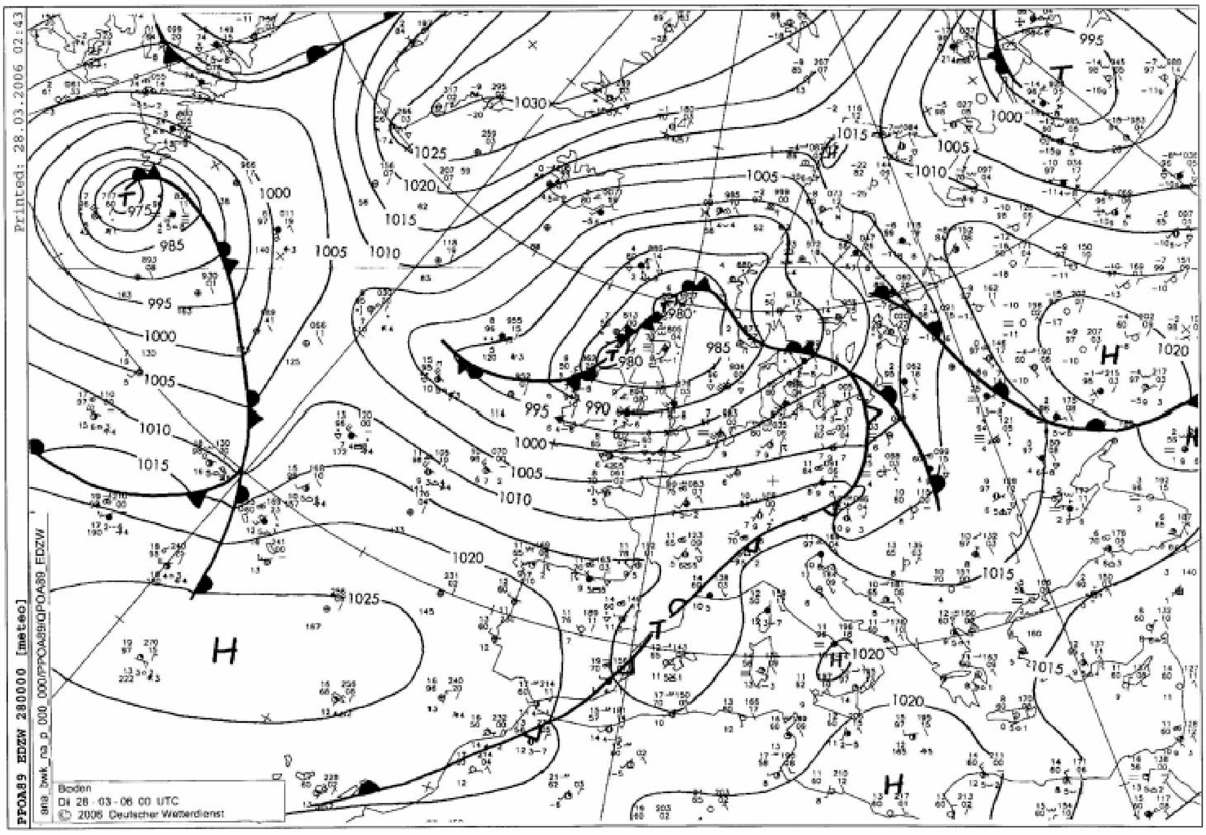


Figure 2: The synoptic analysis (28.03.06; 00:00 UTC)

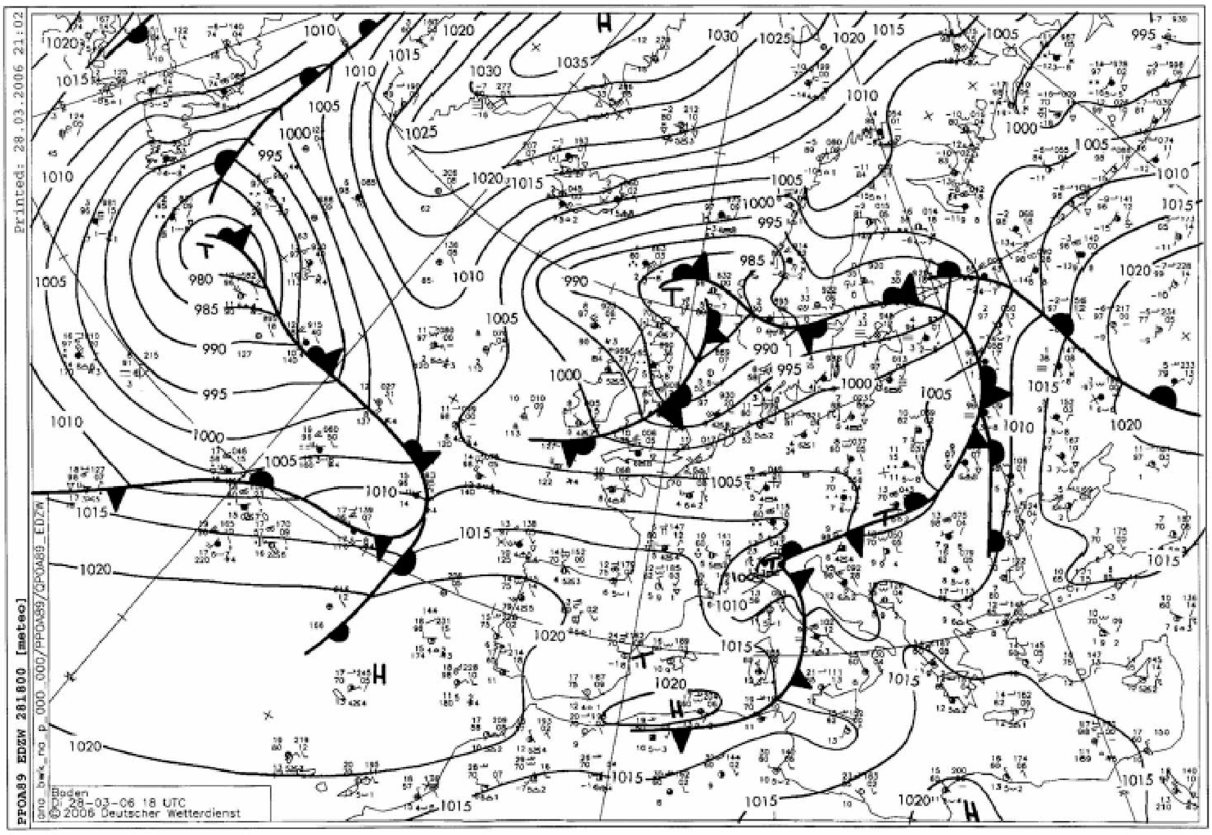


Figure 3: The synoptic analysis (28.03.06; 18:00 UTC)

The general meteorological situation during the period of warming from 27–29 March 2006 is shown in **Figure 4** below using a geopotential height at 500 hPa and temperature at 850 hPa.

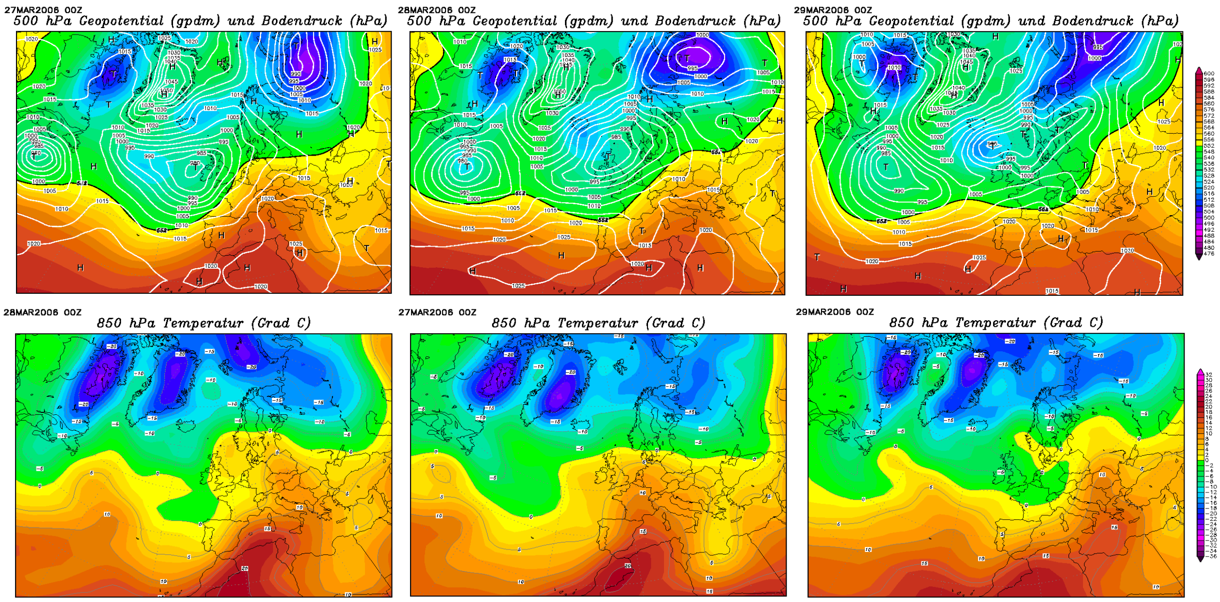


Figure 4: Geopotential [gpdm] height at 500 hPa (upper row) and temperature at 850 hPa (lower row) on 27, 28 and 29 March 2006 (from left to right) (Source: www.wetterzentrale.de)

Heavy snowfall at the beginning of March (60 cm in 24 hours occurred locally in the alpine area) turned into intensive rainfall in mid March. The coincidence of the melting snow and heavy rainfall became almost completely effective as surface run-off.

At the beginning of March, water reserves in the snow cover were significantly higher than multi-annual average levels. A fresh covering of snow formed in the lowlands of Central Europe, the Balkan Peninsula and the Carpathian region in mid March, and the snow cover in mountainous areas grew. Water reserves in the snow cover increased along the Danube and the Tisza. At the end of March, high air temperatures resulted in a rapid snowmelt in the higher alpine regions, on the Balkan Peninsula and in the Carpathians. Rainfall in April led to melting of the remaining snow cover at higher elevations within the Danube Basin and the Tisza Sub-basin.

Maps of snow depth and total water input in mid March 2006 have been provided by Vituki/Hungary. The total water input in the Upper Danube and Tisza catchments was predicted by the HOLV snowmelt model and estimated liquid precipitation added (see **Figures 5 and 6**).

The Joint Research Centre (JRC) of the European Commission provided maps showing the calculated (simulated) water equivalent of snow in March and April 2006 (see **Figures 7 and 8**). The “degree-day method” is used, which is a temperature index equation with an extension that accounts for accelerated snowmelt during rainfall (rain on snow). This method requires only precipitation and temperature data. All simulations are obtained with a 5x5 km2 spatial resolution using meteorological input of circa 980 synoptic stations within the Danube River Basin.

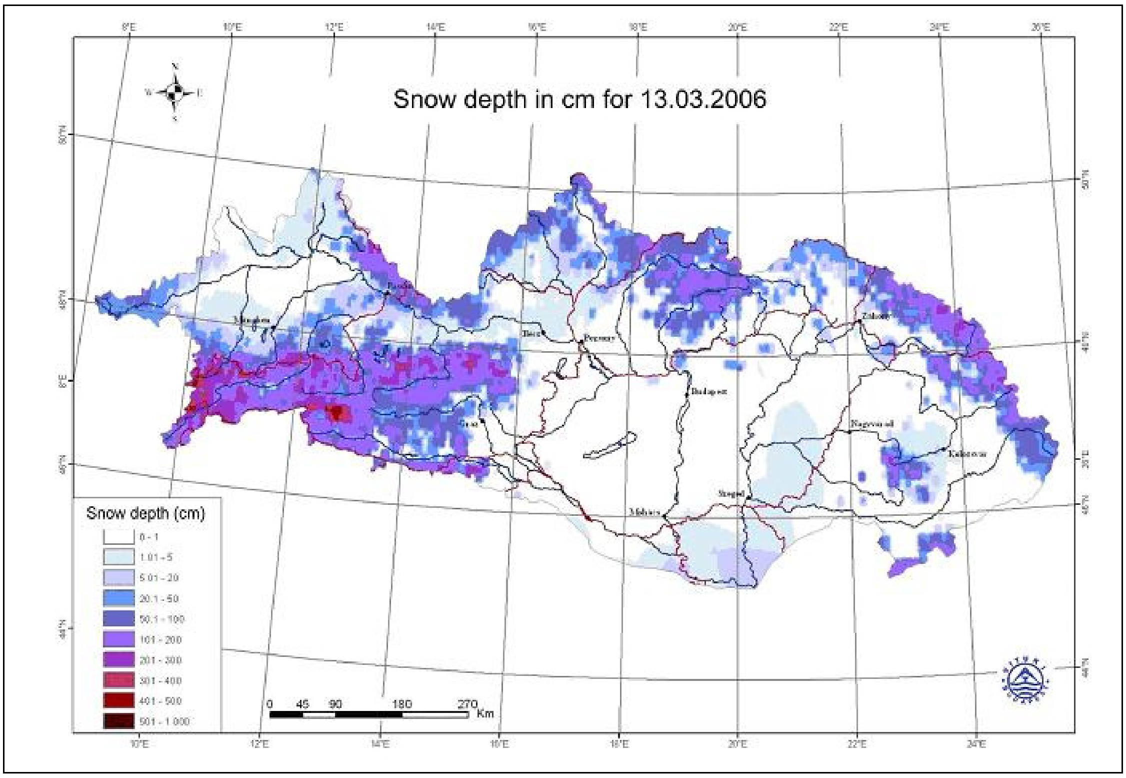


Figure 5: Snow depth in the Upper Danube and Tisza catchments

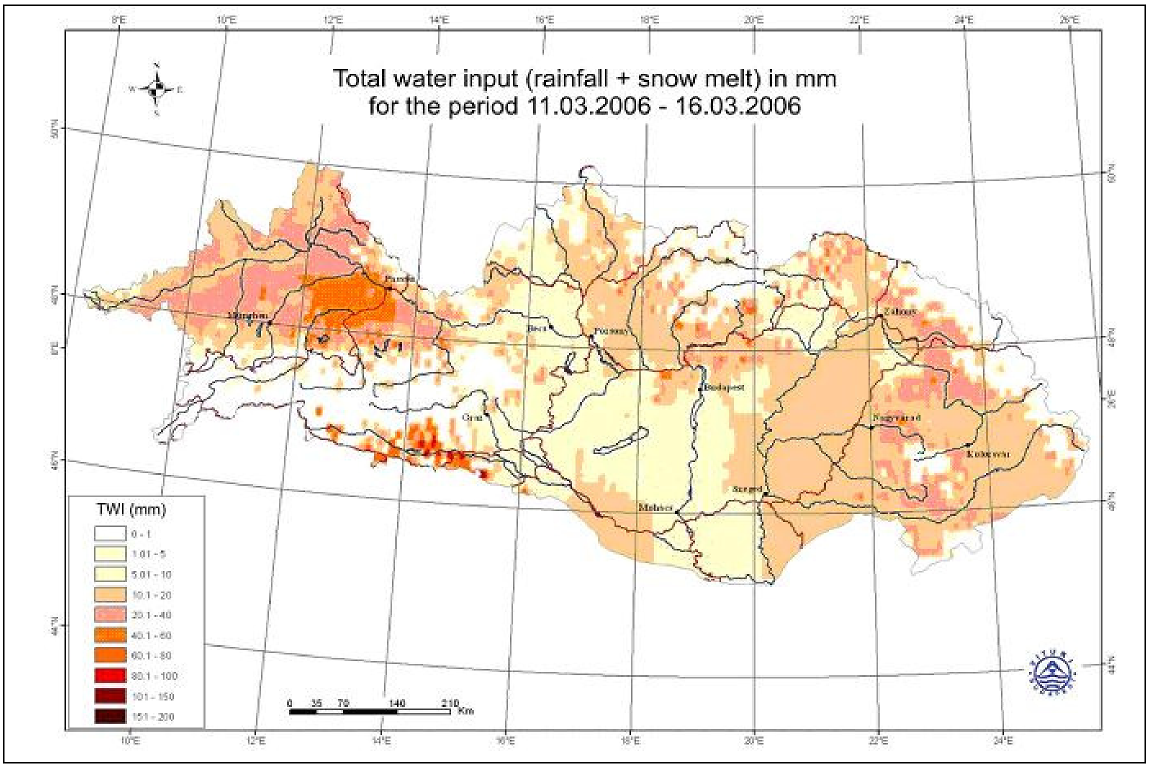


Figure 6: Total water input in the Upper Danube and Tisza catchments (predicted by the HOLV snowmelt module and estimated liquid precipitation added)

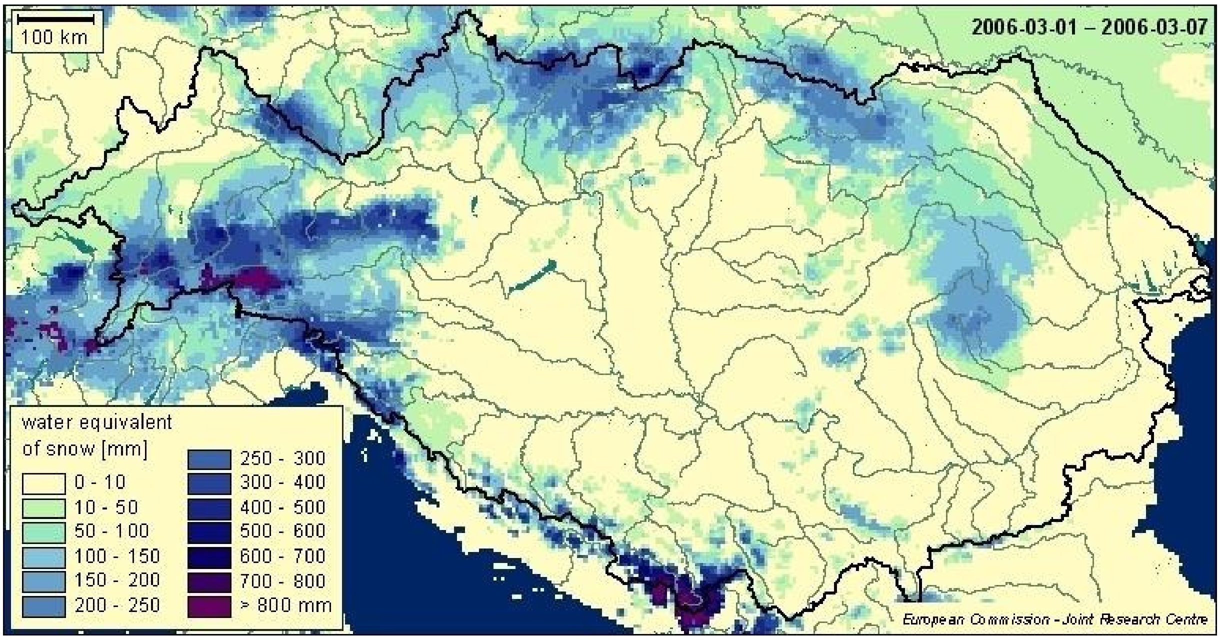


Figure 7: Water equivalent of snow at the beginning of March 2006

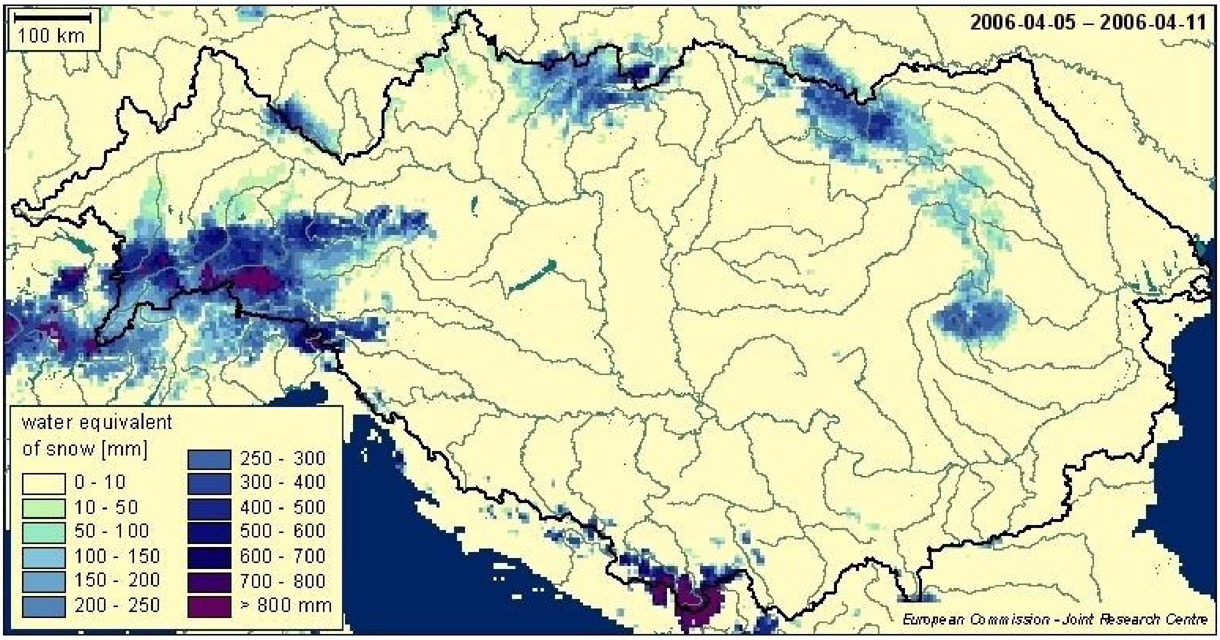


Figure 8: Water equivalent of snow at the beginning of April 2006

3.1 Precipitation

During the last week of March and beginning of April, intensive but not extreme rainfall was recorded in the entire Upper Danube catchment area.

In the Central and Lower Danube catchment areas, a relatively long period of precipitation occurred from mid March to the end of April, mainly in the Carpathian Mountains. A similar situation was observed in the mountainous regions of the Balkan Peninsula around the middle of April. Summarised precipitation in these time periods is shown in **Figures 9** and **10**. The combination of the precipitation with simultaneous rapid snowmelt led to a typical springtime flood.

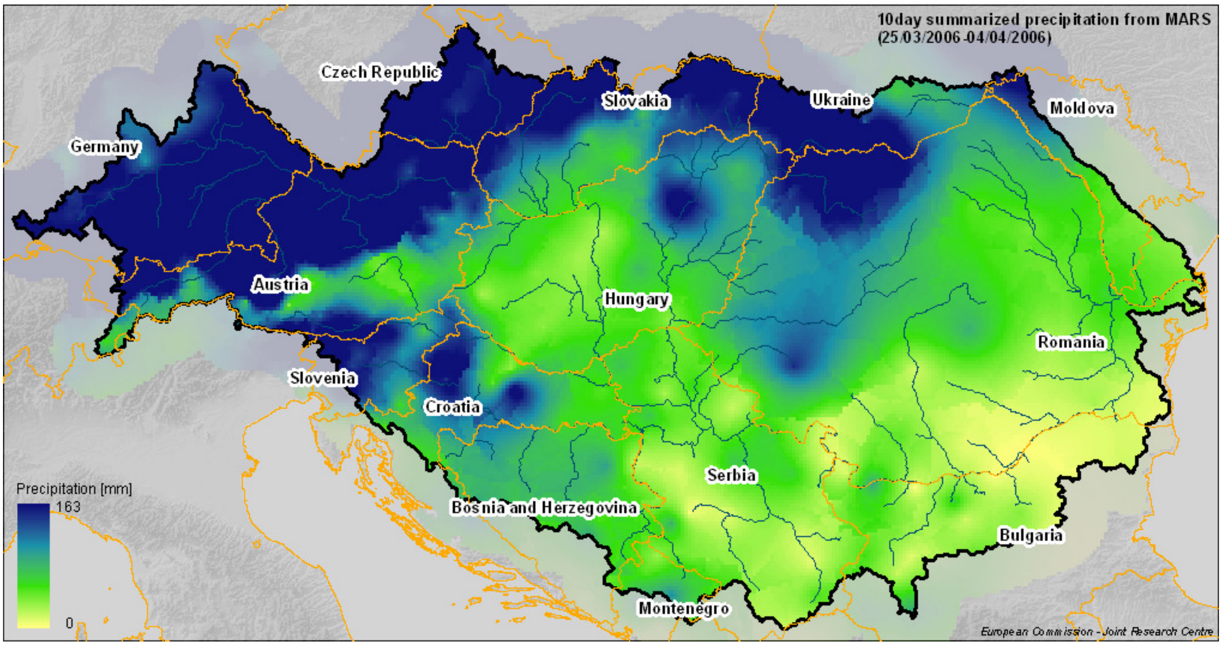


Figure 9: 10-day accumulated precipitation in the period 25March – 4 April 2006

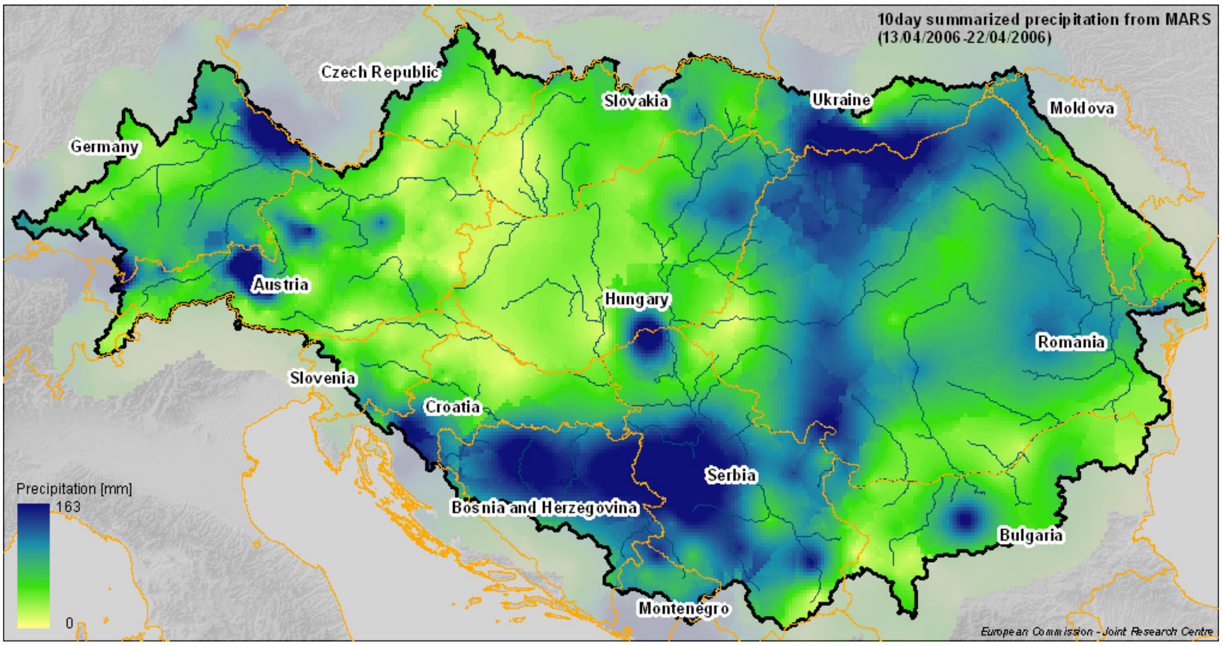


Figure 10: 10-day accumulated precipitation in the period 13-22 April 2006

The Joint Research Centre (JRC) of the European Commission provided the above maps, which represent two typical periods of precipitation in the Danube Basin in March/April 2006. The maps of 10-day summarised precipitation are based on 980 synoptic stations. All data are pre-processed data from the MARS (Monitoring Agriculture with Remote Sensing) project database of the JRC.

4 Country Reports

4.1 Germany

The brief description of the flood situation along the Danube and in the relevant sub-basins in Bavaria indicates two flood waves were registered in the Danube River. Reporting thresholds were repeatedly exceeded by 2 to 5 year water levels between Ulm and Passau. The following discharge hydrographs at the gauges at Pfelling/Danube (river kilometre 2,305) and Passau-Ilzstadt (river kilometre 2,225) exemplifies the progression of the floods in the German Danube (lasting from mid February to the beginning of April 2006).

Forecasts and warnings

The German Weather Service (DWD) and the Flood Information Service of Bavaria (HND) regularly reported on the flood situation and expected water levels during the periods from 7 to 14 March 2006 and from 24 March to 3 April 2006. Reports and flood forecasts were available to the public via the internet (www.hnd.bayern.de).

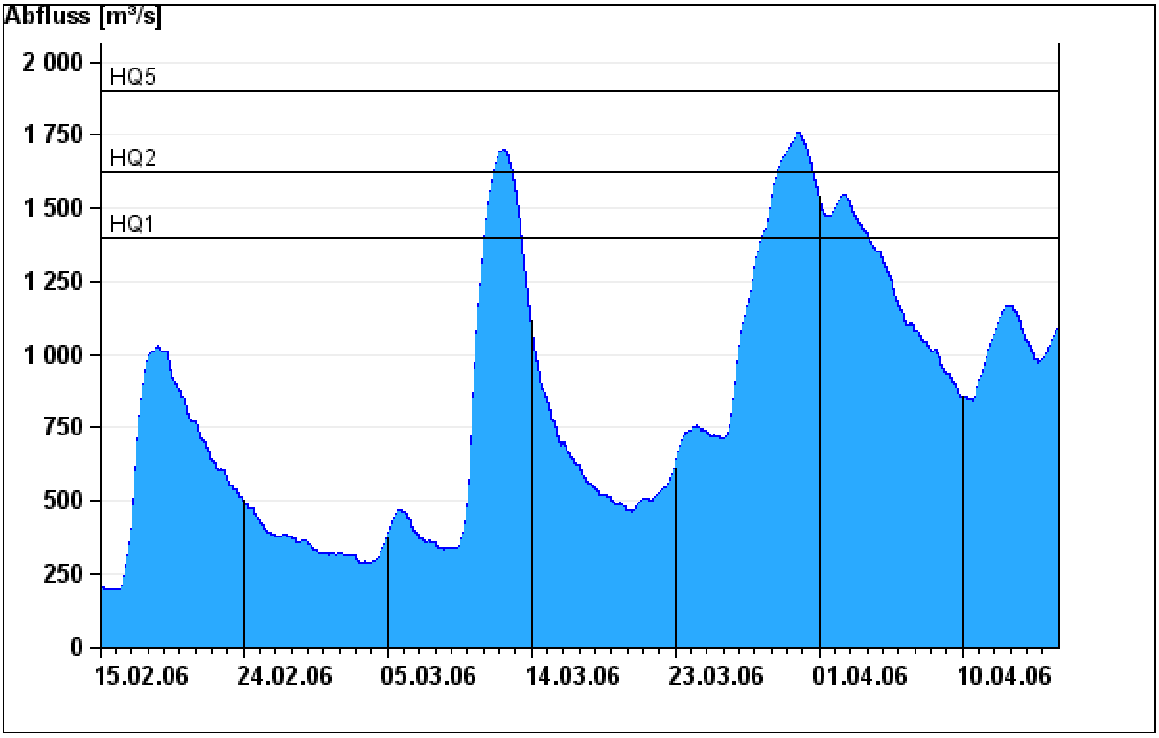


Figure 11: Hydrograph of the Danube River at Pfelling

Table 1: Observed flood peaks of the two flood events in Bavaria (at selected gauges)

	Gauge	River	Date	Discharge (m³/s)	Annuality
First flood	Achsheim	Schmutter	10.03.06	50	10-20
	Mühlried	Paar	10.03.06	60	50
	Manching	Paar	11.03.06	80	50-100
	Thann	Altmühl	10.03.06	70	5-10
	Inkofen	Amper	11.03.06	190	10
Second flood	Unterköblitz	Naab	01.04.06	225	5
	Grafenmühle	Vils	29.03.06	175	5
	Schrottenbaummühle	Ilz	31.03.06	115	5-10
	Kalteneck	Ilz	31.03.06	250	20

Flood interventions and affected area

The affected area included the Danube tributaries in northeastern Bavaria (such as the Altmühl, Regen, Naab and Ilz) and also some small rivers in the southern Bavarian Danube catchments (such as the Zusam, Paar, Abens, Amper and Rott). The Danube River spilled over its banks, particularly in the Kelheim and Regensburg areas. The flood return period was less than 5 years.

Flood levels requiring significant flood defence measures only occurred locally, particularly at the lower section of the River Paar (right tributary of the Danube, joining the Danube at kilometre 2,444) in the Pfaffenhofen district. Emergency dikes for the protection of settlement areas were erected in the municipalities of Manching, Baar-Ebenhausen, Schrobenhausen and Vohburg an der Donau. The existing flood protection facilities and measures fulfilled their tasks trouble-free and evacuations were not necessary. Approximately 2,000 external workers were engaged for flood defence in the Pfaffenhofen district.

Victims, damage and losses

There were no victims and large-scale damage to settlement areas and infrastructure was prevented by flood control measures.

4.2 Austria

Thawing and precipitation caused an extreme flood event in the northeast of Austria. Between November 2005 and March 2006, 550-1100 cm depth of fresh snow was recorded in the northern Alps. The snow depth at the beginning of the melting period was 150–250 cm in the northern Alps and 50-100 cm in the area near the Czech border. Melting and consequent fast runoff were caused by relatively high daily air temperatures, intensive rainfall and the fact that the soil was still frozen at the end of March 2006.

The spring flood occurred mainly in northeast Austria. On the Thaya/Dyje and March/Morava Rivers, the return periods were approximately 100 years. The spring flood event in Austria is shown in **Figure 12**.

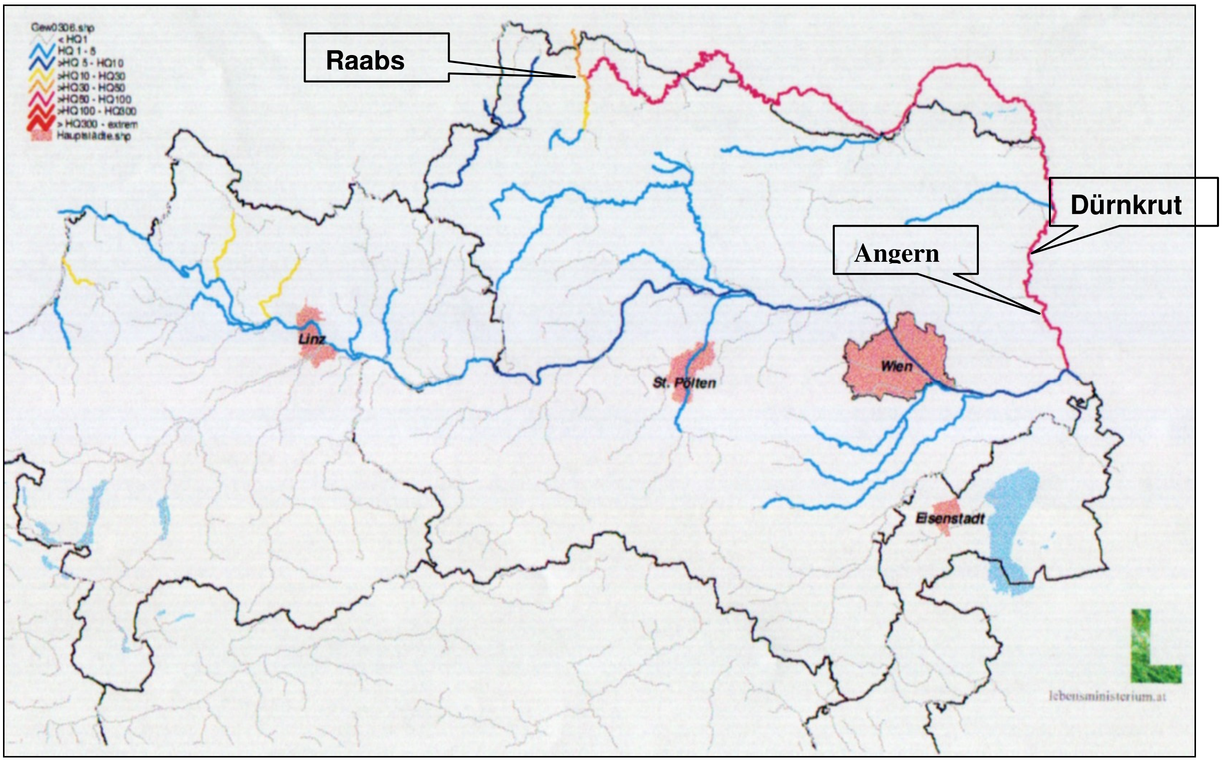


Figure 12: Flooding on Austrian rivers in March-April 2006 (with estimated return period)

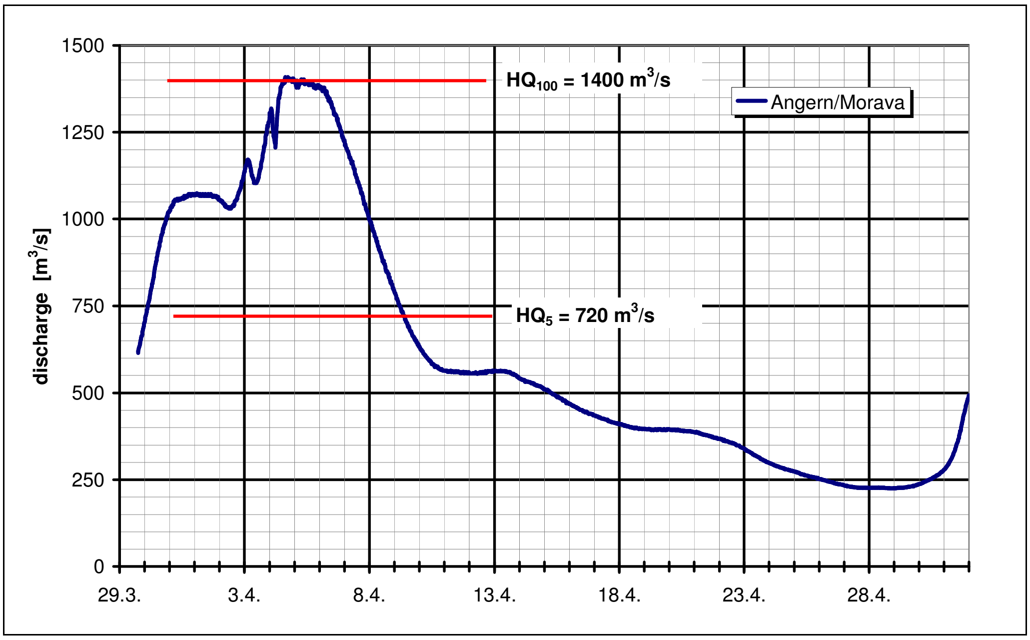


Figure 13: Hydrograph of the March River at Angern (basin area 25,624 km2)

In the catchments of the March/Morava River and its tributary, the Thaya/Dyje, an extraordinary flood event occurred with a return period of approximately 100 years. An extreme flood level was recorded on 30 April at the Raabs/Thaya gauge at the confluence of the Mährischen Thaya (Moravská Dyje) and the Deutschen Thaya. The hydrograph for the March/Morava River at the gauge downstream of Angern/March (at the Austrian-Slovak border) illustrates this situation (**Figure 13**). The hydrograph is influenced by the Nove Mlyny reservoir as well as by three dike breaks that happened on the Austrian side.

Forecasts and warnings

Weather forecasts for the critical period are available on the website of the ZAMG (Zentralanstalt für Meteorologie und Geodynamik): www.zamg.ac.at.

Due to the federal structure of Austria, the regional states (Bundesländer) are responsible for flood forecasts and warnings. The respective warnings were given via media (TV, radio-broadcasting) and through local administrations.

The Lower Austria hydrology unit is formally responsible for the Austrian stretch of the Danube. All relevant data and warnings were available to the public during the floods of 2006. Federal coordination is undertaken by the "Wasserhaushalt/HZB" unit of the Federal Ministry of Agriculture, Forestry, Water and Environment. General disaster coordination is under the responsibility of the Ministry of the Interior.

Flood interventions and affected area

Severe flooding was recorded along the Thaya and March Rivers. A dam on the March River burst on 3 April and flooded the village of Dürnkrut at the Austrian-Slovak border. Another dam was broken on 4 April about 8 km downstream of Dürnkrut, followed by a breach of a protective barrier on a dam in Stillfried the following day. About 500 people were evacuated in the Dürnkrut region. Approximately 460 homes were heavily affected or destroyed.

Flood defence interventions were managed by the coordination centre of the civil protection unit and the fire brigade. Relief units comprised 1,500 units (770 army, 603 fire brigade, 150 Red Cross, 260 volunteers, 6 helicopters). About 500,000 sandbags were used.

Victims, damage and losses

There were no victims of the flooding in Austria. Three dikes broke on the March/Morava flood protection dam. The main line from Vienna to Prague and some roads were damaged/destroyed. As mentioned above, about 460 homes were heavy affected or destroyed. Private losses are estimated to be €28 million; while infrastructure losses total approximately €40 million (rail line and road damage). The cost of dike reconstruction is estimated to be €3.5 million.

4.3 Czech Republic

In March 2006, the meteorological situation in Central Europe resulted in heavy rainfall in the Morava River Basin. The sum of the average precipitation depth in the Morava Basin was approximately 40-50 mm in the period 25 March – 10 April 2006. Additional extreme snow water storages occurred in the Morava and Dyje rivers catchments. As a result of a sudden temperature rise and heavy rainfall activity at the end of March, rapid snowmelt occurred. Due to a rapid temperature rise during the last week of March 2006, accompanied by strong precipitation, snowmelt was massively accelerated.

On Monday 27 March, a third degree of flood alarm (flooding) was announced in the upper part of the Dyje River Basin. In the following days, such alarms were declared in 32 monitoring sites. Peak discharges were reached during the period from 29 March to 1 April 2006 and in some profiles the discharges reached values associated with a return period of 100-200 years. For the first time in the 80-year history of discharge monitoring in the Morava Basin, the Dyje and the Morava catchment areas were struck by simultaneous flooding. The peak discharges and water stages are given in **Table 2**.

Table 2: Peak discharges in the Morava Basin

Gauge station	River	Catchment area	Qa	Peak discharges			
				Date	Water stage	Discharge	Return period
		[km²]	[m³/s]		[cm]	[m³/s]	years
Spytihněv	Morava	7891,1	55,40	31.3.	683	731	50
Strážnice	Morava	9145,8	59,60	29.3.	703	733	100
Lanžhot	Morava	9721,8	65,00	30.3.	572	553	20-50
Janov	Moravská Dyje	517,0	2,63	29.3.	339	89,4	100-200
Podhradí	Dyje	1756,0	8,50	30.3.	472	395	100-200
Vysočany	Želetavka	367,7	1,08	29.3.	300	83,0	100
Vranov	Dyje	2228,0	9,74	30.3.	346	313	200
Znojmo	Dyje	2499,2	10,30	31.3.	412	324	200
Trávní Dvůr	Dyje	3531,4	12,30	30.3.	558	222	20-50
Brno-Poříčí	Svratka	1637,7	7,68	1.4.	282	186	20
Bílovice	Svitava	1120,3	5,22	30.3.	432	112	20-50
Židlochovice	Svratka	3940,16	15,40	30.3.	515	230	20
Mor. Krumlov	Rokytná	563,3	1,28	30.3.	443	82,4	50-100
Ivančice	Jihlava	2682,2	11,50	1.4.	507	248	10
Nové Mlýny	Dyje	11878,0	41,10	1.4	712	657	50
Ladná	Dyje	12280,0	41,70	2.4	457	432	10

The water levels on the Morava River and its tributaries began to increase gradually from the 21 March. A relatively high daily air temperature resulted in increasing water levels. The system of water management reservoirs such as the Nové Mlýny hydraulic structure on the Dyje (right tributary of Morava River, Czech Republic) was already full to the brim by the 27 March. As a result, the outflow from the system of reservoirs enlarged from Q = 66 m³/s (27 of March) to Q = 640 m³/s (by the 2 April). An outflow of more than 640 m³/s from the Nové Mlýny reservoir system continued until the 4 April. The 'state of emergency' (III) was exceeded between the 1 and 4 April and the 'state of danger' (II) was continuously exceeded between the 29 March and 16 April.

Flood interventions and affected area

The state emergency system, through its fire and rescue services, was involved in all flood interventions. About 16,000 hectares of agricultural land were under water in the Dyje River and the Morava River catchments. A special emergency reservoir management was in operation.

Forecasts and warnings

The Czech Republic has a highly developed early warning system that is connected to the state and regional emergency (crisis management) systems, in accordance with crisis management legislation and specific laws such as the "Water Act" (for flood warning). Flood warning responsibility lies with the national Hydro-meteorological Service (Czech Hydro-meteorological Institute - CHMI) together with the River Basin Authority. Moreover, a system of flood commissions (and in more serious cases, crisis management staff) has been established on state, regional and community levels. All warnings issued by the above-mentioned institutions and services are disseminated by means of the Fire and Rescue Services.

During the 2006 flood, responsible experts from the CHMI (Regional Forecasting Office) routinely issued summary reports on water levels, flood warnings and alerts, along with respective meteorological information. Reports were broadcast via the state emergency system through the Fire & Rescue Services and also through public media (TV, radio). The Central Forecasting Office also issued several special reports for the country's Central Crisis Management Staff (CCMS) and the Regional Forecasting offices cooperated similarly with regional staff. The Director of the CHMI regional office in Brno worked in the Flood Commission. Special "flood pages" on the internet were also regularly issued.

Hydrological forecasting during the March/April flood period was computed twice a day for selected forecasting profiles (discharges). The lead-time was on a 48-hour basis and, on the request of the Morava River Authority, inflows to the reservoirs were calculated with a lead time of ten days in some cases. Forecasts were sent to the Morava River Authority control centre and were also available on the CHMI web sites.

Forecasts were dependent on snow cover information from the Austrian part of the Dyje catchments. On 27 March, Austrian stations reported a 26-50 mm snow water value (5-15 cm snow cover depth). Based on back simulation, the snow water content should have been higher, probably mainly in forest areas.

Victims, damage and losses

Three people lost their lives during the flood in the Morava Basin. The flood damage was estimated to be € 70 million. A large amount of damage occurred on agricultural land (16,000 hectares of agricultural land were inundated).

4.4 Slovakia

The highest precipitation occurred in the western and eastern parts of Slovakia on the 29 March. In the west of Slovakia, the precipitation was located in the Morava Basin. While in the East, monthly precipitation totals were 109-211% above the long-term average for March.

The largest water accumulation occurred in the snow-covered area of the northwest, where the accumulation period was not interrupted by any episodes of melting. Since the end of December 2005 until spring 2006, water supplies into the snow-layer had accumulated almost continuously.

a) Morava River

Water levels in the Morava River exceeded the state of emergency limit (III) between 29 March and 8 April. They did not fall below the state of alert limit (I) until 22 April. The maximum discharge reached a value of Q = 1547m³/s (representing an occurrence probability of less than once in a 100-year period). A similar situation also occurred at the next water gauge station (downstream at Záhorská Ves). Critical water levels occurred between 7.00 p.m. on the 4 April and 0.30 a.m. the following day. The state of emergency (III) took place from 29 March until 9 April and the water level was higher than the limit of the state of alert (I) until the 21 April. The maximum discharge was measured at Q = 1402 m³/s with a return period of approximately 100 years.

Table 3: Morava River profiles, peak discharges, stages and return intervals

Rivers	Profile	Date	Peak discharge [m³/s]	Peak stage [cm]	Return period [years]
Morava (tributary to Danube)	Moravský Svätý Ján	03.04.	1547	618	>100
	Záhorská Ves	04.04.	1402	720	100
Myjava (tributary to Morava)	Myjava	29.03.	16.1	168	10 - 20
	Jablonica	30.03.	41.5	286	10 - 20
	Šaštín – Stráže	30.03.	55.0	391	5 - 10
Teplica (tributary to Morava)	Sobotište	29.03.	37.2	309	20

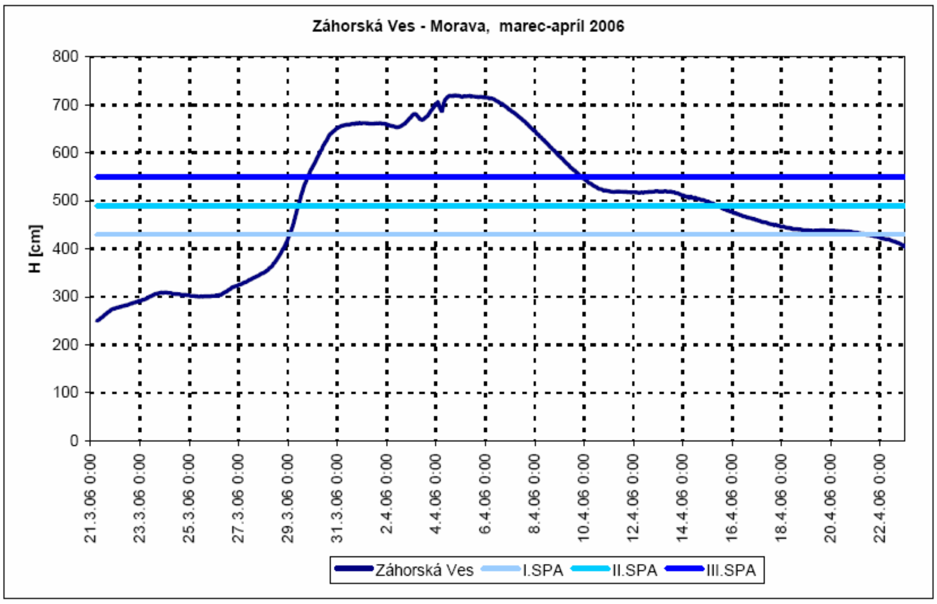


Figure 14: Water levels at Záhorská Ves gauging station (close to the river mouth)

b) Danube River

In the Slovak stretch of the Danube River, the flood situation was significant from the hydrological point of view, including the volume of the flood event. The water level achieved state of danger (II) in the profiles of the Devín-Bratislava water gauge station (**Figure 15**) and a state of emergency (III) further downstream at the Komárno and Štúrovo water gauge stations (**Figure 16**). Results of the statistical evaluation of flood discharges at the major reporting stations (undertaken by the Slovak Hydro-meteorological Institute's Hydrological Service) are summarised below.

Table 4: Danube profiles, peak discharges, stages and return intervals

River	Profile	River km	Date	Peak discharge [m³/s¹]	Peak stage [cm]	Return period [years]
Danube	Devín	1879	31.03.	8020	792	20
	Komárno	1767	03.04.	8648	825	~ 50
	Štúrovo	1718	03. – 04.04.	8288	766	~ 50

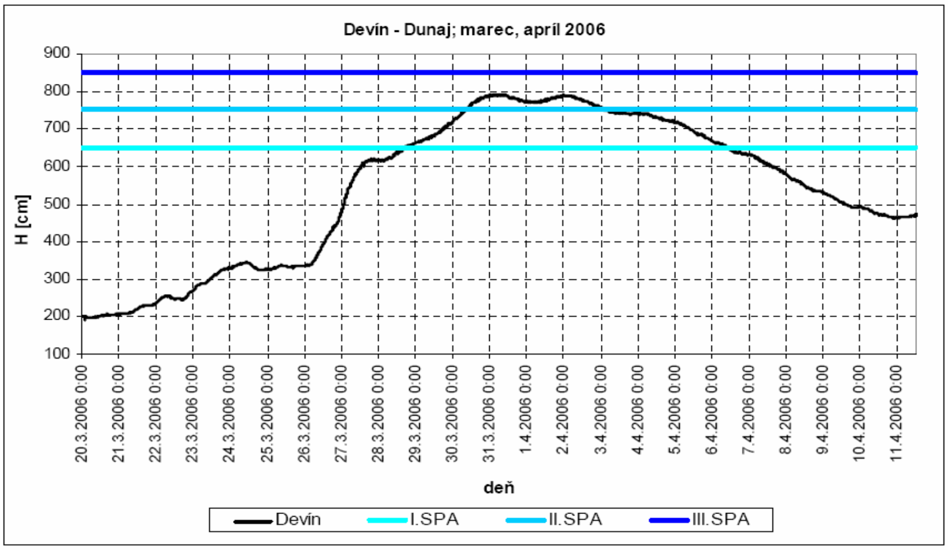


Figure 15: Water levels at the Devín gauging station

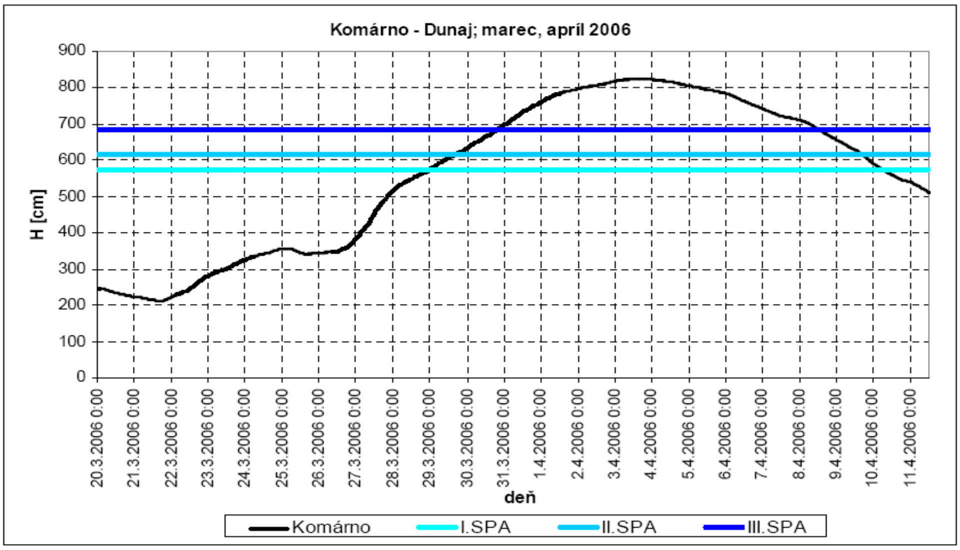


Figure 16: Water levels at the Komárno gauging station

Considerably higher water stages/discharges on the lower part of the Slovak stretch of the Danube were caused by high-ranking water stages/discharges in the Váh and also the Hron (river mouth into the Danube) at Komárno and downstream at Štúrovo. As a result, the water stages/discharges in that part of the Danube were much higher than during floods occurring only on the Danube itself.

c) Nitra River

The flooding situation first occurred in the upper part of the Nitra Basin. At the Nedožery gauge, levels exceeded the limit of the state of emergency (III) and peaked at 227 cm. The flood hydrograph had two peaks, the first on 28 March (at 9.15 p.m.) and the second on the 29 March (between 6.30-7.30 p.m.) The maximum discharge had a return period of c. 10 years.

At the Nové Zámky gauge (near the Nitra-Váh confluence), the water level also exceeded the limit of the state of emergency (III). The maximum level reached 634 cm on the 31 March between 0.45 - 2.00 a.m. The reason for such high levels was the meeting of floodwater from the Nitra and Žitava rivers and the backwater effect from the Váh and Danube.

Table 5: Nitra River Basin profiles, peak water stages/discharges and return periods

River	Profile	Date	Peak discharge	Peak stage	Return period
			[m³/s]	[cm]	[years]
Nitra (tributary to Váh)	Nitrianske Pravno	29.03.	17.5	140	>5
	Nedožery	28. – 29.03.	57.5	227	10
	Chalmová	29.03.	79.2	266	<2
	Nitrianska Streda	30.03.	258.3	425	5 - 10
	Nové Zámky	31.03.	321.2	634	10 -20

d) Váh River

Serious flooding occurred in the lower part of the river basin. Backwater from the rivers Danube, Nitra and Žitava influenced water levels in the Váh River. The water levels at the Kolárovo gauge peaked at 893 cm on 3 April between 5.45 and 9.30 a.m. The backwater from the Váh River seriously endangered settlements adjacent to the watercourses and melioration canals across the whole area. The most dangerous situation appeared along the lower part of the Čierna voda creek between 2-4 April.

Table 6: Vah River profiles, peak water stage/discharge and return periods

River	Profile	Date	Peak discharge	Peak stage	Return period
			[m³/s]	[cm]	[years]
Váh (tributary to Danube)	Hlohovec	30.03.	1600	523	10 - 20
	Šaľa	31.03.	1440	750	10
	Kolárovo	03.04.	-	893	-

e) East Slovakian rivers

Hydrologically significant spring floods occurred at river basins in Eastern Slovakia with return periods of approximately 1-10 years.

Table 7: East Slovakian rivers: profiles, peak water stages/discharges and return periods

River	Profile	Date	Peak discharge [m³/s]	Peak stage [cm]	Return period [years]
Hornád [tributary to Slaná (Sajó)]	Kysak	30.03.	180	331	1 - 2
	Ždaňa	31.03.	310	370	2

Uh (tributary to Laborec)	Lekárovce	30.03.	585	874	1 - 2
Laborec (tributary to Latorica)	Krásny Brod	29.03.	130	193	10
	Humenné	30.03.	315	383	2 -5
	Michalovce	08.04.	120	429	> 2
	Ižkovce	31.03.	550	807	2
Latorica (tributary to Bodrog)	Veľké Kapušany	01.04.	360	862	2 - 5
Bodrog (tributary to Tisa)	Streda nad Bodrogom	02.04.	850	939	5

Forecasts and warnings

General forecasts are generated by the Slovak Hydro-meteorological Institute (SHMI) and flood warnings are issued together with the river basin authorities. During the 2006 flood, SHMI routinely issued summary reports about water levels with flood warnings and alerts distributed together with the state emergency system and rescue services, as well as through the public media (TV, radio).

Flood interventions and affected area

Individual measures were performed in accordance with the progress of the flood situation, hydrological forecasts and level of flood hazard.

Flood protection work was organised, and in the majority of the localities performed, by the regional plants of the Slovak Water Management Enterprise (SWME) with their technicians and general workers. In numerous localities they closely co-operated with the units of the fire and safeguarding brigades and with the local population.

The most dangerous situation was on the Čierna Voda creek, where backwater from the Danube and Váh almost overtopped the protection dike and inundated the village of Trstice. Here the staff of the Slovak Water Management Enterprise and fire and safeguarding brigades co-operated with 700 citizens and 337 soldiers to raise the dike crests, placing about 175,000 sand bags in four days. In addition, three helicopters (military and police), heavy military machines and motorboats were used in flood protection works in this area.

Table 8: Human effort during the springs flood in Slovakia

Rank	Staff of the SWME	Others	Total
Engineers and technicians	326	-	326
Workers	1451	1153	2604
Machinists and drivers	329	112	441
Total	2106	1265	3371

Table 9 shows information about the use of machinery during the 2006 spring floods. In additional, mobile cranes, feeders, bulldozers, road rollers, motor saws, pumps and other specific machinery were used.

Table 9: Machine use during spring floods in Slovakia

Sort	SWME	Others	Total
Lorries	130	35	165
Auto dredgers	29	9	38
Walking dredgers	18	6	24
Tractors	69	21	90

In the Slovak Republic, the management of flood risk and flood hazards is the task of the flood commissions authorised by Slovak law. The flood commissions manage and inspect the activities of all organisations functioning in the flood protection system before, during and immediately after floods. Each flood commission has a technical staff composed of expert, consultative and executive teams.

Victims, damage and losses

There was one victim of the spring floods in Slovakia. The flood, which occurred up to the end of June in Slovakia, caused property damage with a total cost of 1.7 billion SKK (approximately €44.4 million). The estimation of costs of safeguarding flood operations from 20 February to 20 April 2006 was approximately €3 million (119 million SKK).

The estimation of direct damage to property and renewals of water bodies and technical structures owned by the Slovak Water Management Enterprise was about €18 million (700 million SKK).

4.5 Hungary

For Hungary, the meteorological conditions in the Danube catchment upstream of Nagymaros were critical in the development of an extreme flood situation on the Danube in the Budapest region. While, in the Tisza River Basin upstream of Szeged, it was the meteorological conditions in the Carpathian region of the tributaries which was of prime importance.

a) Danube River

The Danube spring flood of 2006 proved to be a major flood - upstream of Komárom and downstream of the southern tip of Csepel Island, Alert Level III was registered. Along the intermediate section – from Esztergom to Tass – flood crests exceeded the highest ever-recorded highest high water (HHW) values. Flood discharges (9,000 m³/s recorded at Nagymaros; 8,800 m³/s at Budapest) indicate that this flood had a recurrence interval of 80-100 years.

The flood discharge of the Danube increased to over 8,500 m³/s at the confluence with the Váh River. Flood crests exceeded the previously recorded maximum downstream of Esztergom to the southern edge of the Csepel Island (Tass gauging station).

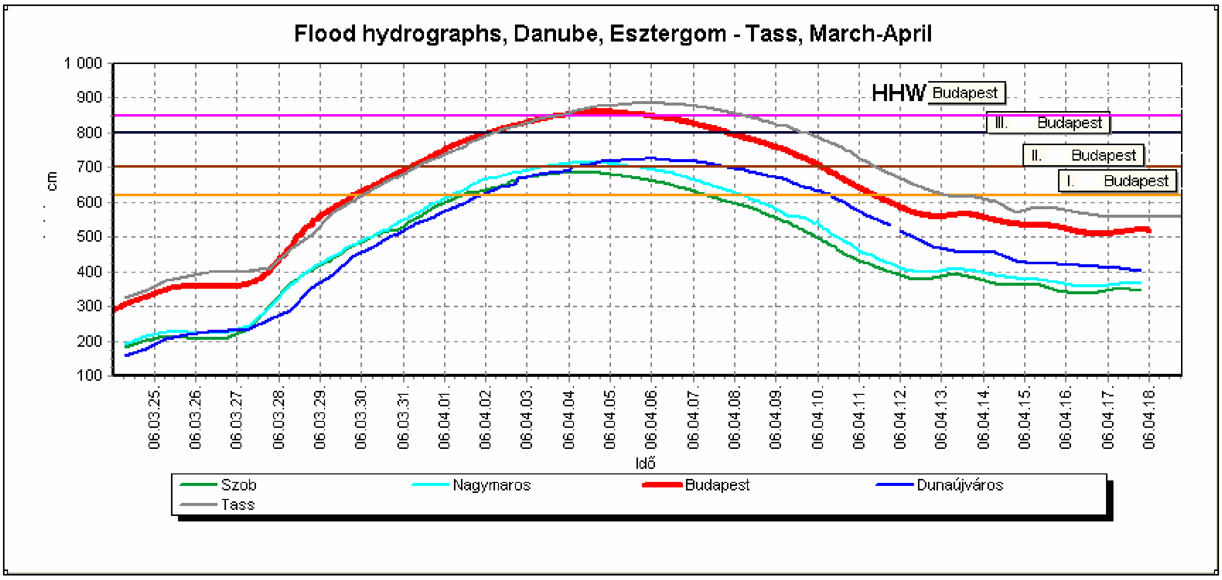


Figure 17: Flood hydrographs of the Danube from Esztergom to Tass

Table 10: Flood crests at characteristic sections along the Danube

River	Station	Danube km	Flood crests in cm	Date, time	Flood crest in 2002
Danube	Szob	1707.2	**686**	April 4, 03.00	684
Danube	Nagymaros	1694.6	**714**	April 4, 10.00	707
Danube	Vác	1679.5	**767**	April 4, 14.00	757
Szentendre-Danube	Szentendre	10.8	**758**	April 4, 10.00	746
Danube	Budapest	1646.5	**860**	April 4, 16.00	848
Danube	Érd	1626.8	**795**	April 4, 20.00	781
Danube	Dunafüred	1621.0	**658**	April 4, 20.00	644
Danube	Szigetújfalu f	1611.7	**756**	April 5, 10.00	744
Danube	Tass	1586.2	**885**	April 5, 16.00	872

Note: figures in **bold** represent new maximum-recorded levels for ice-free high-water (HHW) values

b) Tisza River

The series of floods in February and March had already filled the Tisza riverbed and its tributaries prior to the period of intensive warming and raining at the beginning of April. Due to flooding on the Hármas-Körös River, the Hortobágy-Berettyó floodgate at Mezőtúr had to be closed on 2 April. In order to control the Hortobágy-Berettyó, water arriving from the Hortobágy River was diverted firstly, closing the Ágota gate to the Nagyiván detention basin (64 million m³ capacity) and secondly, evacuating water into the Hármas-Körös using mobile pumps at the Mezőtúr flood gate.

The Tisza flood culminated at Tokaj at 892 cm on 8-10 April, almost reaching the recorded historic maximum of 1999. Flooding on the downstream part of the Tisza was heavily influenced by backwater from the Danube, having also reached a new historical record on the Serbian stretch thus blocking the conveyance of the Tisza flood. At Titel the Tisza flood culminated at 818 cm, exceeding the historical record by 27 cm. Although the Danube water levels started falling in the middle of April, a series of heavy rainfall episodes triggered repeated floods on the Körös/Crisul and Maros/Mures rivers, which led to new flood records along the Lower Tisza.

Table 11: Flood crests at characteristic sections on the Tisza and its main tributaries

Gauging station	River km	Prevailing HHW		Flood crest 2006	Culmination date and hour
		cm	date		
TISZA					
Tiszabecs	744,3	736	2001.03.06	414	31 03. 2006. 0:00 - 2:00
Vásárosnamény	684,45	943	2001.03.07	834	02.04. 2006. 19:00 - 03.04. 05:00
Záhony	627,8	758	2001.03.09	662	04 04. 2006. 17:00
Tokaj	543,08	928	2000.04.12	893	08 04. 2006. 10:00
Tiszafüred	430,5	881	2000.04.12	835	09 04. 2006. 14:00-16:0
Kisköre-alsó	403,1	1030	2000.04.17	981	15 04. 2006. 10:00 - 16. 04. 13:00
Szolnok	334,6	1041	2000.04.19	1013	15 04. 2006. 21:00 - 17. 04. 02:00
Tiszaug	267,6	932	2000.04.20	946	21 04. 2006. 11:00 - 23. 04. 03:00
Csongrád	246,2	994	2000.04.20	**1033**	22 04. 2006. 08:00 - 23. 04. 00:00
Mindszent	217,7	1000	2000.04.21	**1062**	21 04. 2006. 14:00 - 22. 04. 22:00
Szeged	173,6	960	2000.04.21	**1009**	20 04. 2006. 22:00 - 22. 04. 12:00
Titel	9,5	791	1965	**818**	16 04. 2006. 19:00 - 17. 04. 07:00
HÁRMAS-KÖRÖS					
Szarvas	53,8	954	1970.06.15	**986**	20 04. 2006. 22:00-21 04. 02:00
Kunszentmárton	19,8	987	2000.04.21	**1041**	21 04. 2006. 0:00-2204. 06:00
MAROS					
Makó	24,3	625	1975.07.10	533	19.04.2006.

Note: figures in **bold** represent new HHW values

There is no doubt that the coincidence of relatively major floods occurring on all four rivers simultaneously (Danube, Tisza, Maros/Mures and the Körösök/Crisul system) is rare. However, neither the adverse reciprocal effects of these floods, nor the hydro-meteorological factors in 2006 explain why the HHW values recorded exceeded previous records to such an extent.

Table 12: Recorded peak flood discharges in the Tisza Basin

Gauging station	fkm	HQ_{max}		HQ 2006	Return period
		m³/s	year	m³/s	year
TISZA					
Vásárosnamény	684,45	3,930	1970	2,150	< 20
Szolnok	334,6	3,150	1932	2,400	< 50
Csongrád	246,2	2,800	2000	2,320	< 50
Szeged	173,6	4,100	1932	3,730	< 50
HÁRMAS-KÖRÖS					
Kunszentmárton	19,8	1,900	1970	640	< 50
MAROS					
Makó	24,3	2,460	1975	1,000	< 50

Forecasts and warnings

For flood forecasting purposes, the Hungarian Meteorological Service processes medium time forecasting (up to 10 days ahead) from the European Medium Range Weather Forecasting Service (ECMWS). The sub-catchment aggregated air temperature and precipitation values (using a 12–hour time step for the time span of 48 hours) are usually replaced by results from the ALADIN-HU model. Based on a subjective judgement by a synoptic meteorologist, the German Meteorological Service (DWD) and other services are also used. The first 6 days of these forecasts are visualised in the form of a quantitative precipitation forecast map for the Upper and Central Danube region, including the Tisza Basin (a VITUKI product). This serves for general orientation purposes for central and regional water agencies, as well as an input value for the VITUKI National Hydrological Forecasting and modelling system.

Hydrological monitoring, forecasting and warnings are common tasks of the twelve REWD (local river administrations) and VITUKI in Hungary. Due to the cumulative impact of a tributary inflow and backwater effect, the spring water levels in Hungary surpassed historical maxima on many stretches, which made flood forecasting a particularly difficult task during the 2006 events. Flood forecasting for the Danube downstream of Esztergom (Hron mouth) was extremely efficient during the flood period for lead times shorter than 3-4 days. Complexity created by multiple backwater effects on the middle/lower Tisza added to forecasting difficulties. Although the range of the peak was fairly well predicted on a 6-day lead time, the extent to which historical maxima were surpassed meant estimates could only be made 3-4 days before actual peaks occurred on the middle Tisza and Hármas/Körös tributary.

Within the framework of the European Flood Alert System (EFAS), 14 warning messages were received in March and April 2006 from Joint Research Centre Institute for Environment and Sustainability. The complex information bulletin (based on ECMWF and DWD 10-day and 7-day deterministic meteorological forecast ensemble prediction systems (EPS) and LISFLOOD simulation runs) served as a good pre-warning tool.

Although the underestimation of snowmelt-induced runoff resulted in lower predicted ranges for the Danube flood, the consistent indication of very high tributary inflow (on the Morava, Váh and Hron) meant a valuable contribution was made to forecasting the flood wave in, and downstream of, the Danube Bend and Budapest. This underestimation and ongoing deficiencies in the calibration of the hydrodynamic part of the LISFLOOD model (resulting in underestimating the impact of the backwater effect), in turn resulted in an underestimation of, and an earlier prediction of the timing of, peaks within the Tisza system.

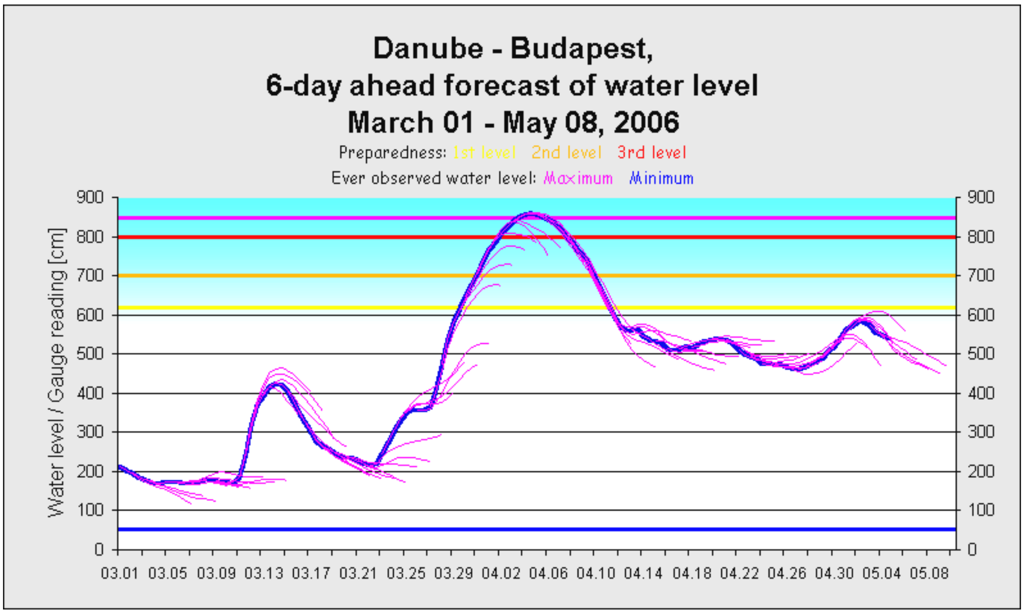


Figure 18: Danube – Budapest 6-day forecast

Flood interventions and affected area

During the extraordinary alerts on the Danube and Tisza Valley, 267 communities, 70,180 buildings and 200,890 inhabitants were threatened. The spring flood affected the major part of the Hungarian river network. Figures 19 and 20 below show the development of the flood situation in Hungary in April 2006.

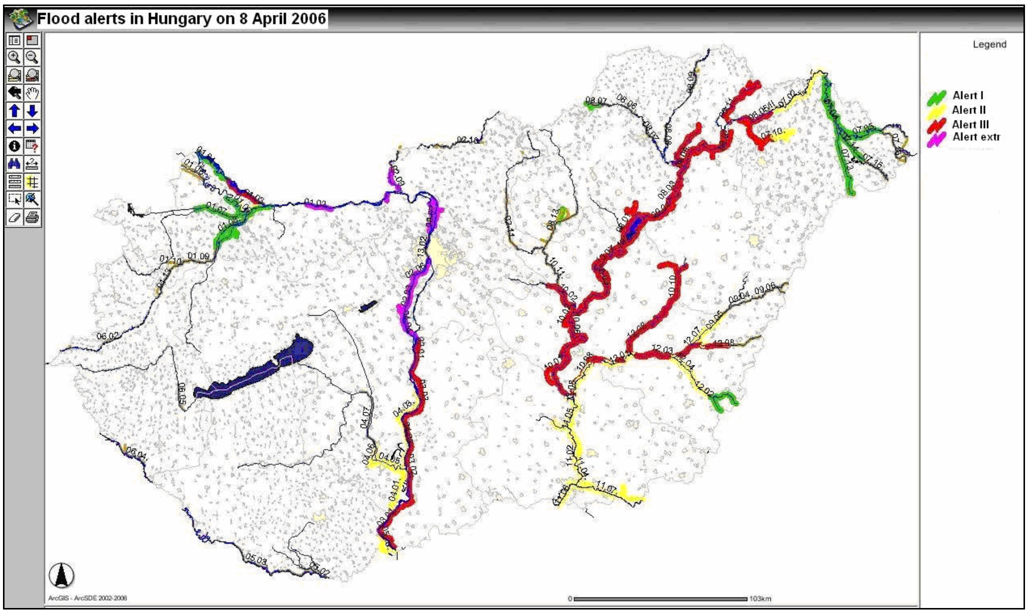


Figure 19: Status of the Hungarian flood alerts on 8 April 2006

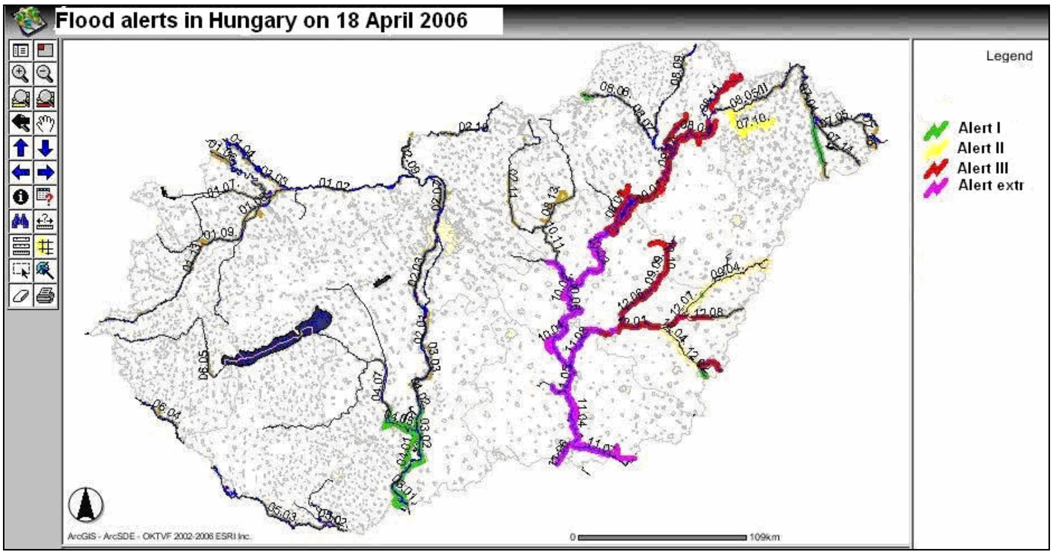


Figure 20: Status of the Hungarian flood alerts on 18 April 2006

The Danube flooding necessitated evacuation of inhabitants from low-lying, unprotected areas along the Danube River. 268 people in Pest County and another 67 in the capital were obliged to leave their homes.

The National Directorate for Disaster Management (NDDM) reinforced the work of local civil defence agencies and mayoral offices by commanding officers from counties not threatened by floods.

Due to the Danube flood, limits were imposed on piped-water supplies and road and railway traffic (mainly in the Budapest-Szentendre-Esztergom region).

Table 13: Emergency interventions along the Danube River

Emergency interventions		
Type	units	volume
Supporting ribs	m	75,115
Drainage berms	m	1,850
Drainage trenches	m	7,130
Sand boil control	piece	21
Drainage of counter pressure cassettes	piece	16
Counter pressure of saturated landside toe	m	6,986
Protection of cracked wet slope by laying plastic foil	m	500
Closing of channel due to piping	piece / m^3	3 / 520
Sandbags	piece	2.880 259
Stearine torches	piece	22,125
Plastic foil	m^2	55, 728
Geotextile	m^2	680
Machines and vehicles	piece	490
Employed staff (maximum)	persons	2,510
Flood fighters (maximum)	persons	1,5058
Evacuated people	persons	335
Total manpower	man-days	129,376

On the Tisza and its tributaries (flooding April – May), the defences focused mainly on the crests and quality of the dikes. As the floodplains of the Tisza, Körös and Maros rivers are 100% protected by flood dikes, there is no open floodplain available. The effectiveness of these defences varies. Focusing on the conditions of defences on the Middle and Lower Tisza, height deficiencies occur mostly along the Kisköre-Csongrád section (especially on the right bank) and on both banks downstream of Szeged. Deficiencies in both height and profile are a feature of the flood embankments in the Körös-corner and along the Hármas-Körös River at Kunszentmárton. The Maros dikes meet existing standards.

Table 14: Emergency interventions along the Tisza River

Emergency interventions along the defences		
Type	unit	volume
Temporary heightening (sandbagging)	m	171 934
Protection of eroded wet slopes	m	64 958
Temporary defences on high banks	m	8 100
Supporting ribs	m	74 895
Drainage berms	m	1 850
Drainage trenches	m	7 130
Counter pressure of saturated landside toe	m	6 986
Total manpower	persons	14,350

The most critical situation developed in the Körös-corner where, at flood stages equal to the dike crest, the land-side slope of the dike suffered landslides at 12 different places (between 18 April and 1 May) directly threatening a dike breach. Thanks to early observation and fast intervention, stabilisation of the sliding earth mass was achieved within one day. Defence actions were based on counter pressure of the toe and support of the sliding earth mass with large gravel bags and containers as well as 1m³ plastic tanks filled with water, carried and placed by helicopters.

Table 15: Main materials used for flood defence in the Danube and Tisza Valleys

Nomination	Dimension	Danube Valley	Tisza Valley	Total
Sandbags	piece	2 880 259	8 868 372	11 748 631
Container-bags (big-bags)	piece	0	17 318	17 318
Stearine torch	piece	22 125	114 757	136 882
Plastic foil	m^2	55 728	391 216	446 944
Geotextile	m^2	680	125 420	126 100

2,365 people were evacuated in the Tisza Valley including 244 due to standing water inundation. During the most intensive period of flood fighting, more than 2,500 people worked along the flood embankments under their legal obligation to civil defence. Charity organisations also provided aid and support.

Disaster management staff continuously informed partner organisations in neighbouring countries about the flood situation in Hungary and asked for support via the EU MIC (Monitoring and Information Centre). Offers of assistance arrived from Sweden, Austria, Slovenia and Romania (sandbags, raincoats, rubber boots and shovels).

Victims, damage and losses

There were no flood victims in Hungary. According to the post flood assessment, damage and losses on the Danube occurred in the floodway and open floodplain in 385 properties, practically all upstream of Budapest. Nearly 30% of the damage was registered in Szentendre, Nagymaros and

Visegrád. Damage to private property totalled up to HUF 192 million. While damage to municipal properties (including public roads damaged by heavy traffic during emergency operations as well as damage to facilities such as ports and ferries) totals HUF 595 million. Restoration costs are of course higher, totalling HUF 861 million. In the capital Budapest, 39 public properties (buildings, roads and defence structures) and 51 private properties were damaged, assessed at near HUF 100 million. The cost of emergency operations in the Danube and Tisza Valleys are listed below.

Table 16: Cost of the emergency operations in the Danube Valley

	1 Jan – 3 Apr 2006 (prior to extraordinary alert)	4 – 10 Apr 2006 (during extraordinary alert)	11 Apr – 30 June 2006 (after extraordinary alert)	Total [million HUF]
Flood emergency				
Danube Valley	389.0	1 011.0	629.0	2 029.0
Recovery of the capacity of the defences during flood fighting				
Danube Valley			569.2	569.2
Total:				2 598.2 (€10.6 million)

Table 17: Cost of the emergency operations in the Tisza Valley

	1 Jan – 14 Apr 2006 (prior to extraordinary alert)	15 Apr – 9 May 2006 (during extraordinary alert)	10 May – 15 July 2006 (after extraordinary alert)	Total [million HUF]
Flood emergency				
Tisza Valley	3 263	10 279	4 427	17 969 (€73.1 million)

The cost of the emergency operation along the Tisza and tributaries includes immediate recovery interventions ordered to secure the stability of the flood defences. The cost of the prioritised recovery works along the Tisza is estimated at an additional HUF 11,236 billion (€45,675 million). The Government allocated financial resources for immediate restoration by utilising a general reserve of the 2006 central budget.

4.6 Croatia

During the first half of 2006 (up until August), precipitation levels in the Croatian Danube Basin were higher than the long-term average by some 15%. However, this did not significantly influence the flood wave, which was formed upstream.

The floods of spring/summer 2006 in Croatia were mainly induced by the Danube flood wave. It was the second largest flood observed since 1900 (after that of 1965). The flood wave peak occurred 2.5 months earlier than had done in 1965, and it was the highest ever-recorded water level in April. However, the flood volume and duration were considerably lower than the volume and duration of the 1965 flood (see **Figure 21**).

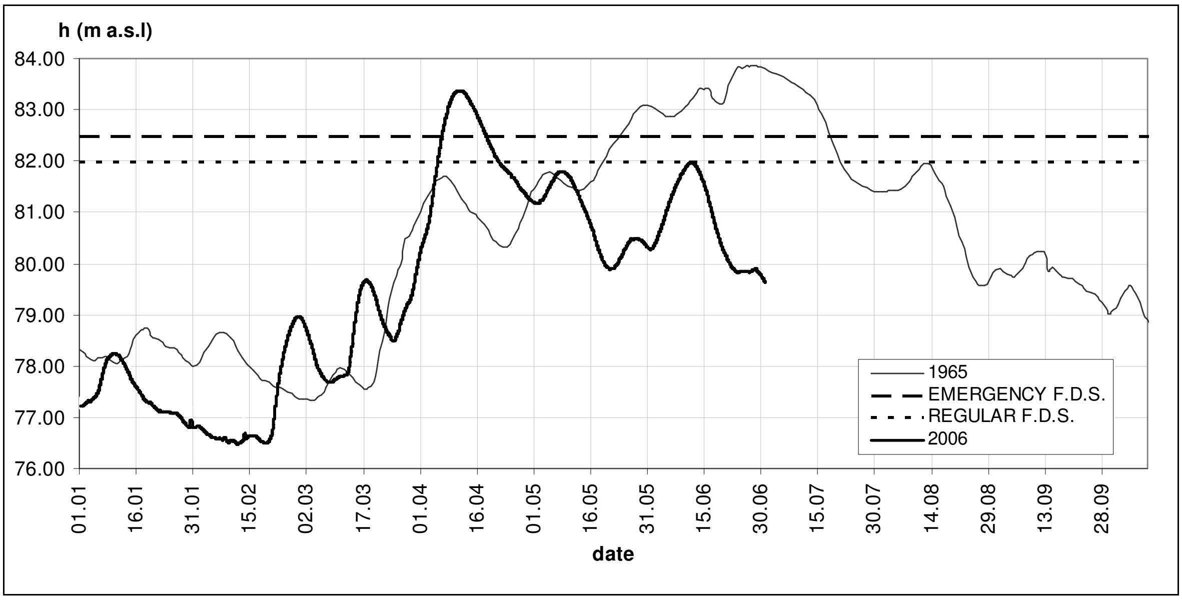


Figure 21: Flood levels on the Danube at Vukovar: 1965 and 2006

High water levels on the Drava and Vuka resulted from Danube flood backwater. The maximum water level on the Drava at Osijek was the third highest observed (after the floods of the 1965 and 1975). The peak of the 2006 flood is the highest recorded water level in April (see **Table 18**).

Upstream of the Danube backwater influence on the Drava, no exceptionally high water levels were recorded and discharges were generally lower than the 10-year return period. On other watercourses of the Croatian Danube Basin (Mura, Sava, Kupa), there were no significant flood events in the summer of 2006.

Table 18: Return periods: comparison of selected representative gauges in Croatia

River	Gauge	Flood peak [date]	Stage [m a.s.l.]	Return period [years]
Danube	Vukovar	10.04.2006	83.39	73 (2006)
		26.06.1965	83.87	170 (1965)
Danube	Ilok	11.04.2006	81.48	113 (2006)
		26.06.1965	81.77	160 (1965)
Drava	Osijek	10.04.2006	86.51	47 (2006)
		13.07.1975	86.69	62 (1975)
		14.06.& 25.06. 1965	86.93	190 (1965)

Forecasts and warnings

As the flood formed in the upper part of the Danube Basin, the data used for flood forecasting were acquired from upstream countries, mostly via the internet. They were used for level and tendency calculations using empirical mathematical models commonly used in water management. The flood wave was monitored by the Croatian state hydrological network and the Hrvatske Vode hydrological flood monitoring network. During the flood, there were no major problems with the functioning of the flood monitoring network. However, a need for additional flood monitoring stations and the upgrading of existing ones was noted.

Flood interventions and affected area

In the Republic of Croatia, 31 March marked the start of regular flood defence actions on the Danube stretch from the Hungarian border to the confluence with the Drava, and on the Drava stretch from the confluence with the Danube to the Vučica River. On 7 April, emergency flood defence began and on 11 April, a state of emergency at the protection waterworks was declared. At 07:00 on the 16 April, the state of emergency at the protection waterworks ended, followed by the end of emergency flood defence actions at 12:00 on the same day.

On the Danube stretch from the Drava mouth down to the town of Borovo, the state of alert that precedes the declaration of regular flood defence measures was declared on 30 March.

Regular flood defence actions on the Danube stretch from Borovo to the town of Ilok started on 5 April and was promoted to emergency flood defence level and then to a state of emergency at the protection waterworks in the following two days. At 07:00 on 16 April, the state of emergency at the protection waterworks was ended, followed by the end of emergency flood defence measures at 10:00 on the 18 April.

At the Tri kućice pumping station (part of the Vukovar wastewater system), high water levels on the Danube resulted in enormous quantities of groundwater in the sewerage system, requiring the use of an additional 300 l/s pump. The Danube backwater also caused flooding at the shafts of gravitational outlets of buildings not connected to the Vukovar sewage system, necessitating sandbag dikes be built around them.

The greatest possibility of major flooding was at the village of Bilje and in parts of Vukovar, where, because of the seepage, the stability of embankments was uncertain.

During a night of heavy rain on the 11 to12 April, more than 500 people (utilising 25,000 sandbags) repaired a seepage problem along 15 km of the Drava–Danube embankment. Other smaller settlements along the Danube were also defended by sandbag-dikes, PVC-foils and/or pumping because of seepage and overtopping.

Victims, damage and losses

There were no flood fatalities. Flood damage occurred mostly at hydro-technical structures, as there was no significant flooding. A small number of structures, which had been illegally built on floodplains, were also affected. A list of the indicative costs of emergency operations is shown in **Table 19**.

Table 19: Costs of the emergency operations in Croatia

INDICATIVE COSTS OF EMERGENCY OPERATIONS								
CURRENCY	HRK				EUROS			
FLOOD MANAGEMENT UNITS	WORKS	EQUIPMENT AND MATERIALS	PEOPLE	TOTAL	WORKS	EQUIPMENT AND MATERIALS	PEOPLE	TOTAL
VGO OSIJEK	5 063 000	257 000	325 000	5 645 000	684 000	35 000	44 000	763 000
VGI BARANJA - DARDA	311 000		30 000	341 000	42 000		4 000	46 000
VGI VUKA	3 016 000		71 000	3 087 000	408 000		10 000	418 000
VGI KARAŠICA VUČICA	69 000		27 000	96 000	9 000		4 000	13 000
TOTAL	8 459 000	257 000	452 000	9 169 000	1 143 000	35 000	62 000	1240000
Numbers are indicative only. Final numbers are expected to be significantly higher.								

4.7 Serbia

A rapid snowmelt in the beginning of April resulted in the concentration of a large amount of water in the Danube along its Serbian sector, as well as in its major tributaries (the Sava, Tisza and Velika Morava).

The highest water levels in the history of monitoring were recorded along the Danube downstream of the Tisza mouth; along the Serbian sector of the Tisza; on the Sava near Belgrade; and on the Velika Morava near Bagrdan. Flood waves on the Danube, Tisza and Sava lasted for a significant time and water levels declined very slowly.

The Danube's peak water level upstream of the Tisza was recorded on 10 April 2006 (Bogojevo HMS station, H_{max} = 792 cm) at a discharge of Q = 8620 m³/s. Downstream from the Sava, peak water level was recorded on 15 and 16 April when its discharge was approximately Q = 15800 m³/s. The return period of these peak discharges is approximately 100 years. Figure 20 shows that the highest water level recorded at Golubac (rkm 1042 of the Danube) was 59 cm higher than the previous 1981 record level.

Peak water levels on the Tisa river were recorded on 21 April 2006 at a discharge of Q = 3740 m³/s. The return period of this 2006 peak discharge is approximately 100 years. 1970 peak levels were exceeded by 19-37 cm.

The spring flood wave on the Sava preceded the one on the Danube. The peak level was recorded on 27 March 2006 (Sremska Mitrovica HMS station, H_{max} = 668 cm) at a discharge of Q = 4470 m³/s (5-year return period). The Sava flood wave had an unusually long duration at a discharge of some 4000 m³/s, which coincided with flood waves on the Danube and the Tisa River.

Table 20: Water levels and discharges on the Danube, Tisa, Sava, Velika Morava and Tamis rivers in the spring of 2006

River	HMS station	Level of flood defence		Data recorded in 2006			Previous abs. max.		
		Regular (cm)	Emergency (cm)	Date	Max. water level (cm)	Water discharge (m³/s)	Water level (cm)	Year	ΔHmax (cm)
DANUBE	Bezdan	500	700	09-Apr	736	7620	776	1965	
	Apatin	600	750	10-Apr	808		825	1965	
	Bogojevo	600	700	10-Apr	792	8620	817	1965	
	Backa Palanka	530	650	11-Apr	738		790	1965	
	Novi Sad	450	700	12-Apr	745	8610	778	1965	
	Slankamen			15-Apr	**794**		773	1965	21
	Zemun	550	650	16-Apr	**783**		757	1981	26
	Pancevo	530	650	16-Apr	**777**		756	1981	21
	Smederevo	600	700	16-Apr	**845**	**14800**	804	1981	41
	Ban. Palanka	765	865	16-Apr	**954**		908	1981	46
	V. Gradiste	600	800	15-Apr	**960**	**15800**	915	1981	45
	Golubac			15-Apr	**826**		767	1981	59
TISA	N. Knezevac	550	750	21-Apr	**949**		912	1970	37
	Senta	600	800	21-Apr	**926**	**3740**	907	1970	19
	N. Becej	500	700	21-Apr	**819**		785	1970	34
	Titel	500	650	16-Apr	**818**		791	1965	27
SAVA	S. Mitrovica	550	750	27-Mar	668	4470	800	1974	
	Sabac	400	500	27-Mar	514		590	1981	
	Beograd	500	600	16-Apr	**738**		718	1981	20
VELIKA MORAVA	Cuprija	400	470	26-Mar	477		700	1963	
	Bagrdan	500	600	27-Mar	**603**	1640	552	1986	51
	Ljubic. Most	450	600	28-Mar	242	1740	706	1958	
TAMIS	Jasa Tomic	340	600	15-Apr	762	733	844	2005	
	Secanj	400	650	16-Apr	710		746	2005	

Note: numbers in **bold** represent new HHW values

The most adverse conditions occurred near the mouths of the Tisa and the Sava, due to the Danube's backwater. High water levels were also recorded upstream from the Iron Gate Gorge as a result of its specific morphological features.

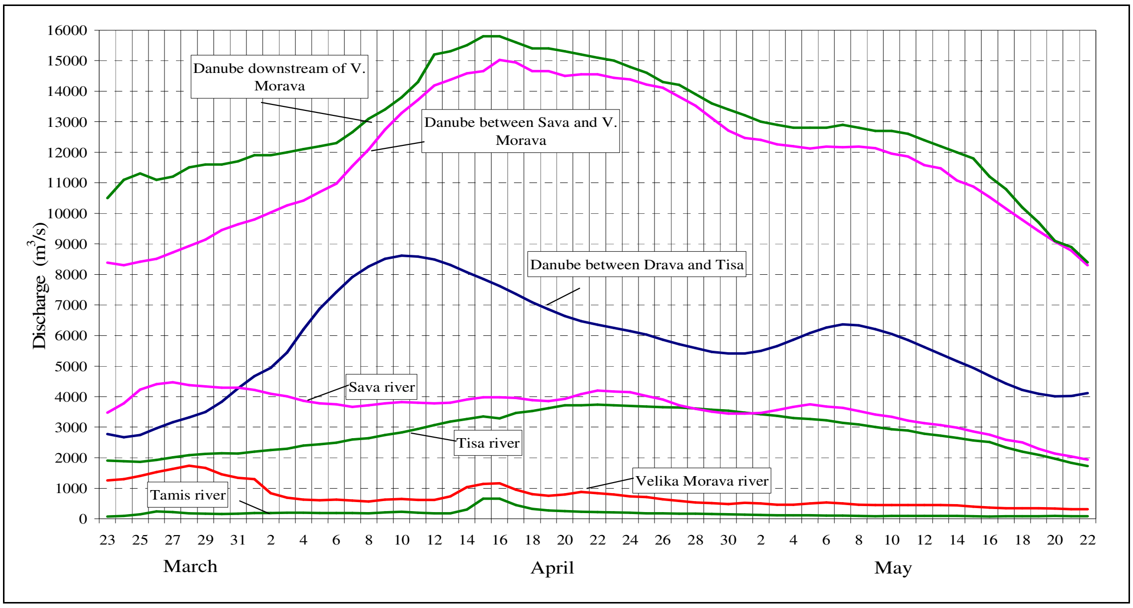


Figure 22: Hydrographs of the Danube and its tributaries in Serbia (23 March – 22 May 2006)

Forecasts and warnings

During the spring of 2006, the Hydro-meteorological Service of Serbia (HMS) monitored data on sudden temperature increases and rainfall within the Danube River Basin (DRB). Warnings about expected water level increases due to rapid snowmelt were issued in March for the Sava and Morava, and in the beginning of April for the Danube, Tisza and Banat rivers.

The HMS issued a warning on 15 March 2006 that flood waves were likely to occur in the Sava and Morava rivers by the end of March, and on the Danube and Tisza rivers in the beginning of April. During the period from 22 March to 19 May, all flood defence actors (as identified in the national 2006 Flood Action Plan) received updated information, warnings and forecasts. The information included current and expected water levels, dates of forecasted flood-wave peaks and emergency monitoring data (emergency water level monitoring was performed every 6 hours from 1 April to 14 May on the Danube, Tisza and Sava rivers; and every 3 hours during the period of flood-wave culmination). Water level forecasts were prepared for the next 1-4 day periods for the Danube and the Sava and for the next 1-2 day periods for the Tisa, and have been assessed as quite good.

During the period of extremely high flows on the Danube and Tisza (3 to 25 April), hydrometric measurements were made (12 measurements on the Danube upstream from the Tisza and 6 downstream from the Sava, as well as 4 measurements on the Tisza), in order to update discharge rating curves.

During the 2006 flood, cooperation between HMS Serbia and other Danube countries was good. Data on snow cover and precipitation were obtained from Austria, Czech Republic, Slovakia, Hungary, Romania, Slovenia and Croatia, and on snow cover water reserves from Hungary. Hydrological data (stages, discharges and water temperatures) were received from Austria, Slovakia, Hungary, Romania and Croatia; and forecasts from Austria, Slovakia, Hungary, and Romania.

HMS Serbia sent out details of water levels, discharges and temperatures as part of its morning bulletin, along with 4-day forecasts. Exchange of information and forecasts with the Romanian Institute of Hydrology started in mid-April. The exchange of data, bulletins and warnings was conducted through the GTS network, via electronic mail and fax.

Flood interventions and affected area

In 2006 about 240,000 ha of agricultural land within Serbia was flooded, approximately one half by rivers and the other half by groundwater. During April and May, 2000 houses in 30 communities within unprotected areas were flooded. Civil Defence evacuated about 1000 residents.

Flood defense measures in Serbia, which lasted for almost two months, were generally successful. Floods threatened the entire region along the Danube and the Tisza but, as a result of the emergency flood defence measures; there was no levee overtopping or breach. Extremely high groundwater levels throughout the spring period occurred in protected areas.

The most challenging situations existed in towns along the Danube River (Novi Sad, Belgrade, Smederevo, Veliko Gradište and Golubac) where flood protection structures have insufficient freeboard above the flood level, due to urban planning criteria. With major efforts made by organisations responsible for flood defence, citizens and the Army, temporary sandbag dikes were erected in these cities and towns on the top of existing structures. Additionally, great efforts were made to increase the height of non-reconstructed levees along the lower course of the Tisza, where water levels were under the influence of the Danube backwater. Secondary levee lines were built along the Tisza, to protect populated areas in the event of main levee overtopping or breach.

In mid-April, emergency flood defence was in force along the entire Serbian sector of the Danube, the Tisza, the Tamis, the Sava and the lower Drina. On 14 April the Serbian Government declared a state of emergency in 10 municipalities: on the right bank of the Danube (Smederevo, Pozarevac, Veliko Gradiste, Golubac and Negotin), along the Tisza (Zabalj, Titel and Zrenjanin) and along the Tamis (Secanj), since those responsible for flood defence assessed that the levees had reached their safety limits.

During the 2006 flood, flood protection structures were reinforced and heightened, new (secondary and confinement) protection lines were built and mobile pumps evacuated seeping water from protected areas.

In mid-April, within the territory which is managed by PWC Vode Vojvodine (levees along the left bank of the Danube, as well as along the Tisza and Banat rivers), regular flood defence was in force along 998 km, and emergency flood defence along 826 km. Temporary dikes were built on top of existing levees and confinement dikes were built within protected areas. The total length of new structures was 65 km. Some 7,000 jumbo sandbags, 600,000 small sandbags and 350,000 m3 of earth were built-in, and plastic sheeting was placed along 40 km of the dikes. Up to 50 bulldozers, 20 dredgers, 30 trucks, 10 tugboats and ferries, dozens of boats, more than 100 water management engineers and technicians, 400 military servicemen and 120 civilians were involved on a daily basis.

Within the territory of PWC Srbijavode (levees along the right bank of the Danube, the Sava and Velika Morava rivers), flood defence was organised along almost 800 km of levees, and the main task was to protect the towns (Belgrade, Smederevo etc.). About 14.9 km of temporary dikes were built, made of 340,000 small sandbags, 8,600 large sandbags, 8,000 kg of plastic sheeting, 17,000 m3 of sand and 40,000 m3 of earth. 15 water management companies, 20 other companies (along with their machinery and manpower), citizens and military servicemen were involved.

No overtopping of main levees or temporary flood protection structures was registered. Protection of towns along the Danube and the Sava was successful, although water levels were much higher than in 1981, when the flood caused significant damage. Construction of temporary defence lines was based on timely forecasts provided by HMS Serbia and good estimates from the engineers in charge, and was therefore very cost-effective. The Iron Gate Hydropower and Navigation System (HPNS) successfully evacuated the largest flood wave in its history, while its operation complied with the 1998 Convention that defines the responsibilities of Serbia and Romania under all conditions, including flood control.

During the flood, water management companies established cooperation with Civil Defence departments of the Serbian Defence Administration, the Army, the Iron Gate HPNS administration and municipal flood defence staff. In addition to water management personnel identified in the 2006 Action Plan, 9000 military servicemen with 290 field vehicles and 149 vessels, were involved in flood defence. Civil Defence departments provided 1700 people and 570 vehicles. Citizen participation was extensive, but no specific figures are available.

The Ministry of Health and public health institutes were responsible for epidemic control in the flooded areas. The population received guidelines and recommendations on measures to be undertaken during the flooding and afterwards. No increase in the number or change in disease types in the flooded areas was reported.

Victims, damage and losses

In 2006, 240,000 ha of agricultural land within Serbia was flooded, approximately one half by rivers and the other half by groundwater. During April and May of 2006, 2000 houses in 30 communities within unprotected areas were flooded. Civil Defence evacuated about 1000 residents. There were no flood victims. Water management companies reported flood defence costs of approximately €10 million. Damage was initially estimated at roughly €40 million.

4.8 Romania

In Romania, a relatively long period of precipitation was registered between 15 March and 30 April resulting in a relatively high discharge in all major tributaries of the Tisza (Somes, Mures, Crisuri) and the Lower Danube (Timis, Jiu, Arges, Ialomitsa, Siret, Prut) was drained during several weeks. These rivers originate mainly in the Carpathian region. The Danube levels in Romania exceeded average monthly multi-annual values for April and May, inducing massive flooding in the 12 counties along the Danube River. During the period of 12-25 April, historical flows and water levels were registered on the whole Romanian part of the Danube, the largest in the last 100 years. The registered flows had maximum values of 15,600-15,800 m³/s.

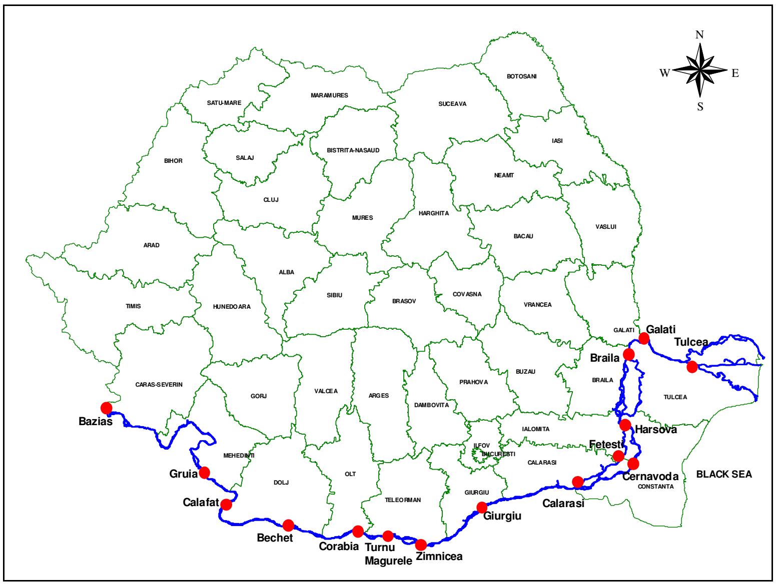


Figure 23: Location of Danube gauges on the Romanian stretch

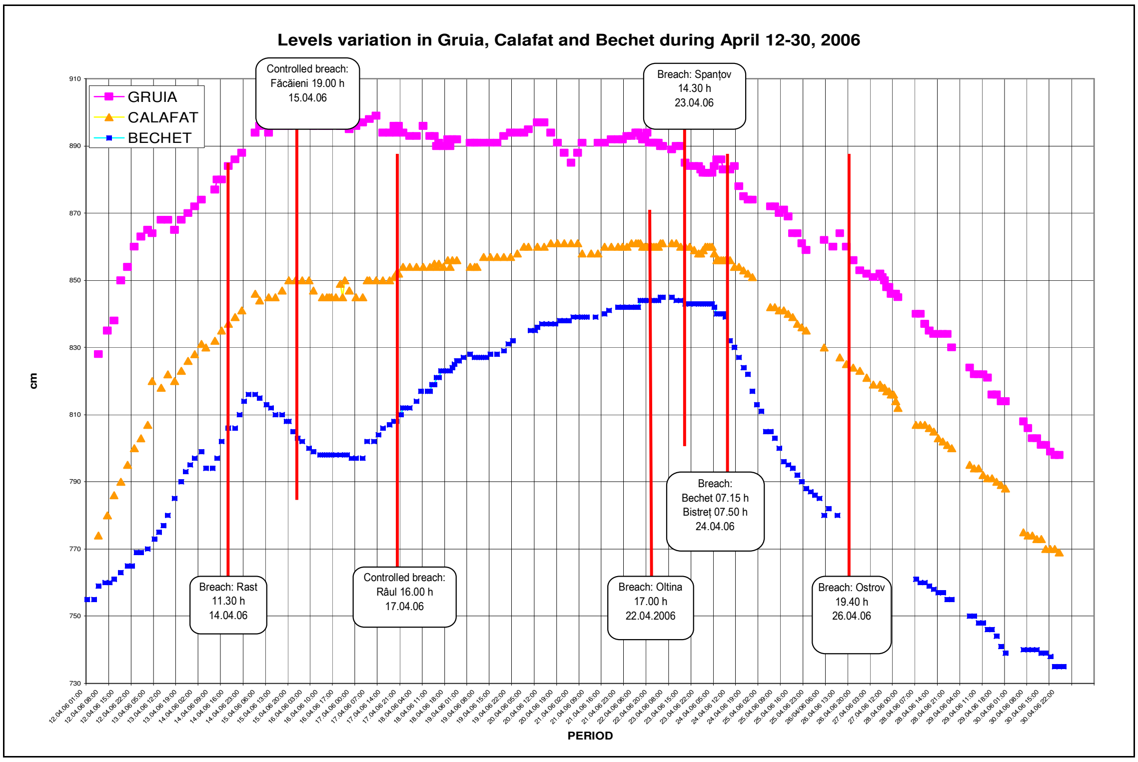


Figure 24: Hydrographs on the Romanian upper Danube stretch

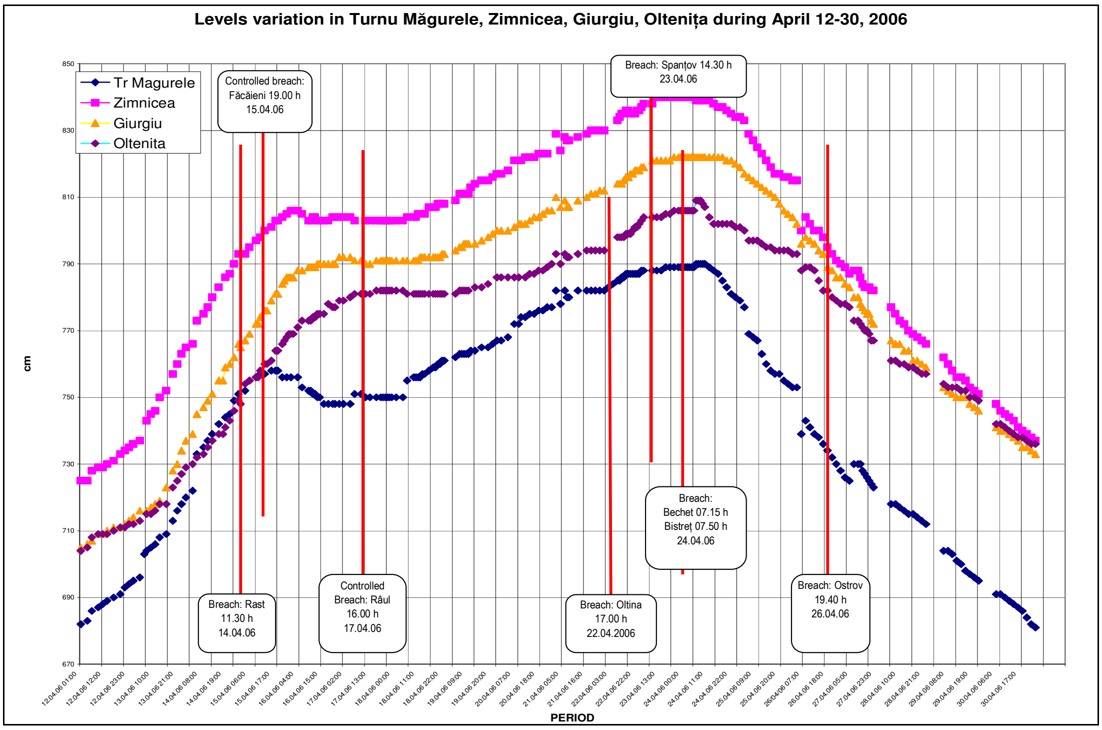


Figure 25: Hydrographs on the Romanian central Danube stretch

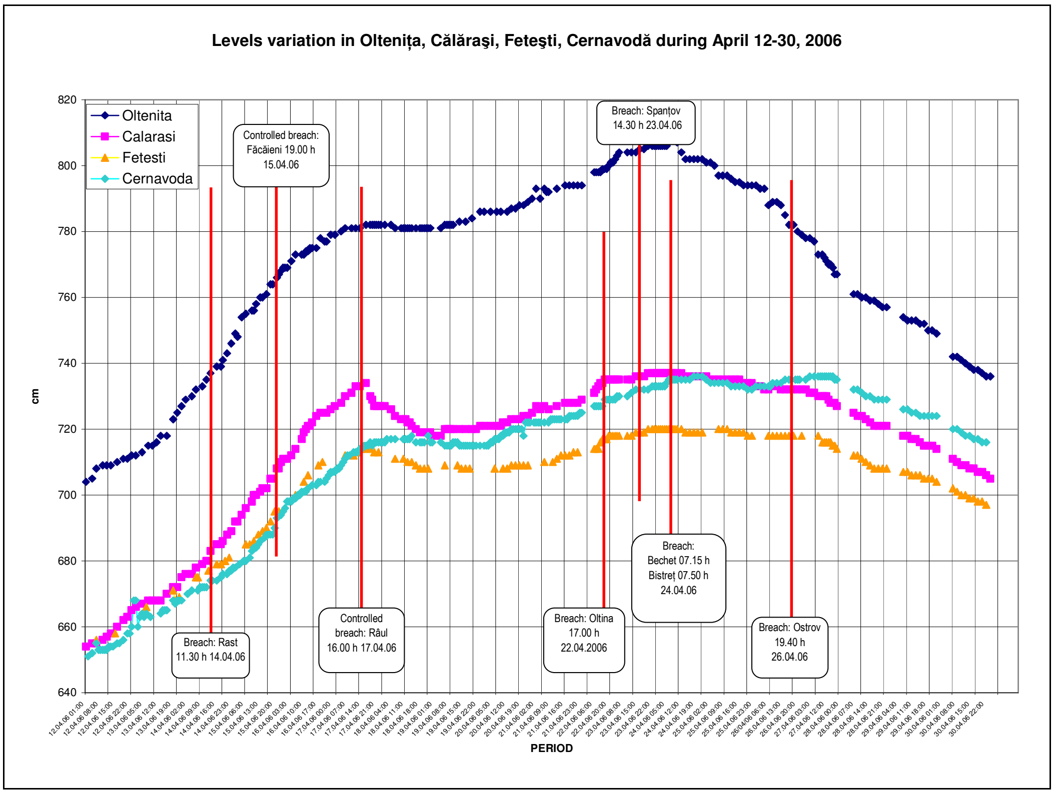


Figure 26: Hydrographs on the Romanian lower Danube stretch

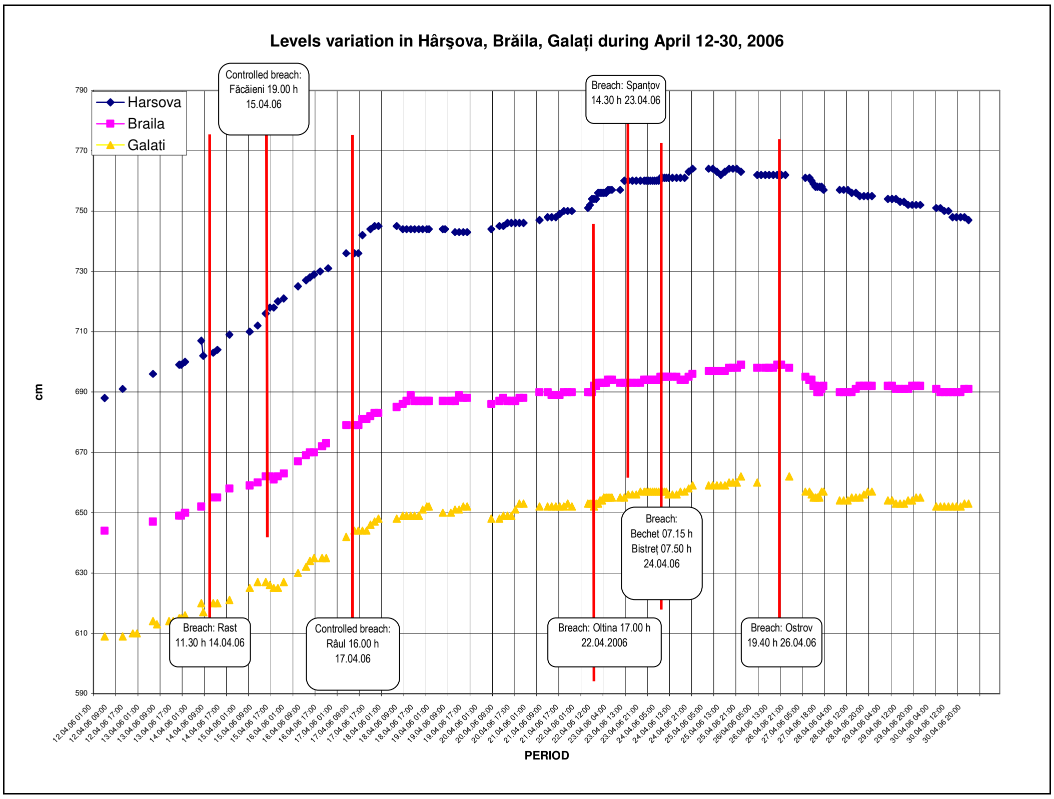


Figure 27: Hydrographs close to the Romanian Danube Delta

The maximum registered flow of the Danube was 15,800 m³/s, the same as in 1895. The extreme 2006 flood levels are shown in **Table 21**:

Table 21: Comparison of extreme flood levels (Iron Gate to the Danube Delta)

Cross-section	Designed level		Registered level before 2006 (cm/year)	Level in 2006 (cm)			Difference 1970/1981 (cm)	Difference 2006-design level	
	1%	5%		Registered	Reconstituted	Difference		1%	5%
Gruia			862/1981	899	899	0	+37		
Calafat	782	734	802/1981	861	865	+4	+59	+79	+127
Bechet			787/1981	845	857	+12	+58		
Corabia	773	711	756/1970	801	812	+11	+45	+28	+90
Giurgiu	804	750	795/1970	822	830	+8	+27	+18	+72
Oltenița	794	741	772/1970	809	815	+6	+37	+15	+68
Călăraşi			703/1970	737	765	+28	+34		
Cernavodă	690	644	708/1970	736	760	+24	+28	+46	+92
Hârşova	678	641	727/1970	764	792	+28	+37	+86	+123
Brăila	678	619	639/1970	699	724	+25	+60	+21	+80
Tulcea	458	411	435/1970	438	450	+12	+3	-20	+27

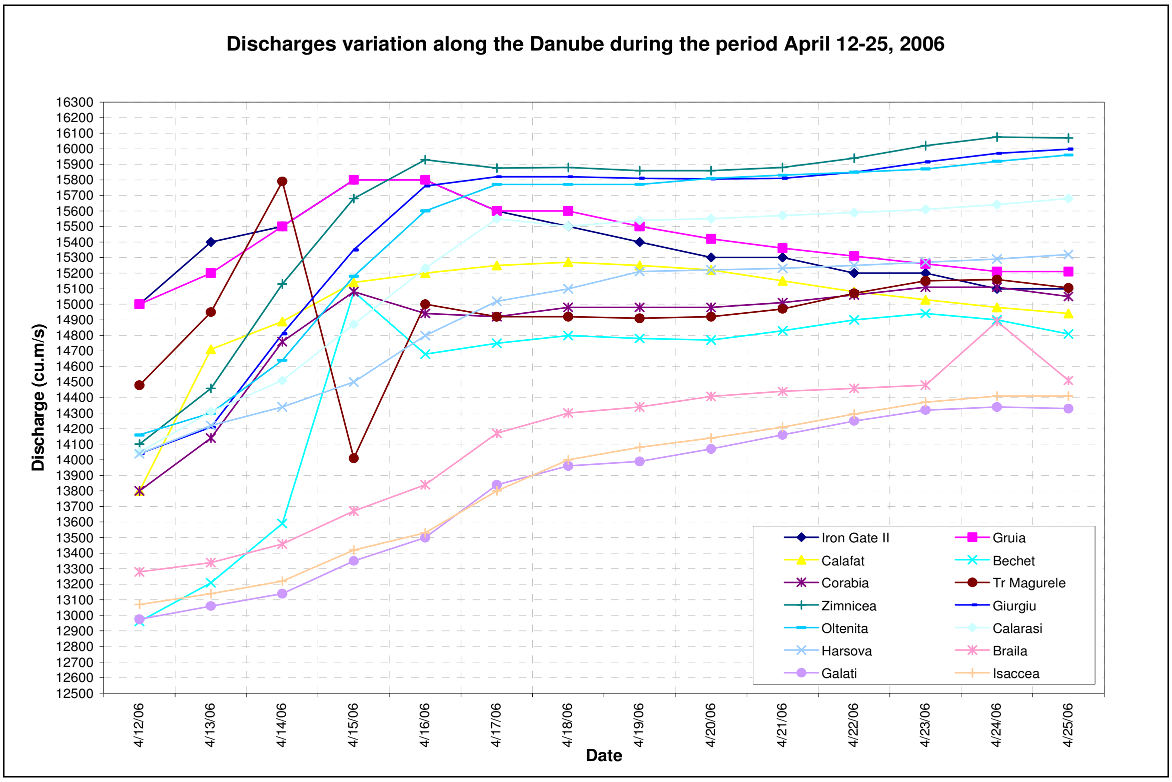


Figure 28: Discharge hydrographs in the Iron Gate II to Danube Delta stretch

All of the major Romanian Danube tributaries arise from the Carpathian Mountains. The Jiu River (peaks of about 1000 m³/s on 15 March and again on 14 April) and Siret River (peak of about 1200 m³/s on 2 April) had flood discharges < Q20. On the other larger tributaries, such as the Olt, Argeş and Ialomitsa, no flood discharges were recorded. The downstream part of the Prut River was influenced by Danube flooding.

The Romanian Tisza tributaries (Crisul, Mures and Somes) had repeated flood discharges in the range of < Q20 (see also section 3.5).

Forecasts and warnings

The National Institute of Hydrology and Water Management (NIHWM) issued seven warnings in March and April regarding the significantly increasing rivers discharges and water levels.

The flood forecasting procedure in Romania consists of the following steps:

- *Should the meteorological forecast provide warnings concerning precipitation quantity or increasing temperatures (that could produce intensive snow melt in the next 1-2 days) and hydrological conditions at the basin level could potentially lead to exceeding of river warning levels, the NIHWM hydrological forecasting service issues the first forecasts and provides a first hydrological warning. The decision is made as to whether to initiate a "hydrological alert".*
- *When levels at gauging stations exceed warning levels or precipitation measured at rain gauges exceeds critical thresholds, these stations are obliged to intensify measurement readings and transmission. Based on this hydro-meteorological information, the NIHWM elaborates and provides forecasts to all hydrological users at the national level. At the basin level (11 major river basins) forecasting is downscaled by the Apele Romane (Romanian Waters) water directorates' hydrological services.*
- *The end of a hydrological alert (returning back to a standard measurement and transmission programme) is decided by NIHWM, with consultation with specialists working at the sub-basin level and based on meteorological forecasting (provided by the NIHWM Meteorological Forecasting Centre).*

Flood interventions and affected area

The registered levels induced longitudinal dike failures at Ghidici-Rast-Bistret, Bechet-Dabuleni, Oltenita-Surlari-Dorobantu, Oltina, Ostrov-Pecineaga and Ciulinet-Isaccea flood area.

The large volume of water stored at Ghidici-Rast-Bistret flood area caused partition dike failure in the Bistret-Nedeia-Jiu flood area. The volume stored in the Bechet-Dabuleni flood area led to partition dike failure in the Potelu-Corabia flood area. At Oltenita-Surlari-Dorobantu, two existing partition dikes were damaged.

The Danube levels greatly exceeded the attention, inundation and danger values, resulting in severe flooding of some localities, affecting farm animals, isolated buildings and large agricultural fields. Problems also arose from the huge number of buildings constructed in flood plain areas, the majority of them being unauthorized.

Considering that for almost two months huge pressures had been exerted on the dikes, the use of controlled breaches were very successful in protecting cities close to the Danube River. In general, seven out of nine floodplain basins were flooded due to dike failure, inundating an area of approximately 88,000 ha. Two floodplain basins were flooded in a controlled manner (through dike destruction). This was undertaken in the counties of Calarasi- at Calarasi-Raul (10,748 ha) - and Ialomitsa -at Facaieni-Vladeni (4859 ha).

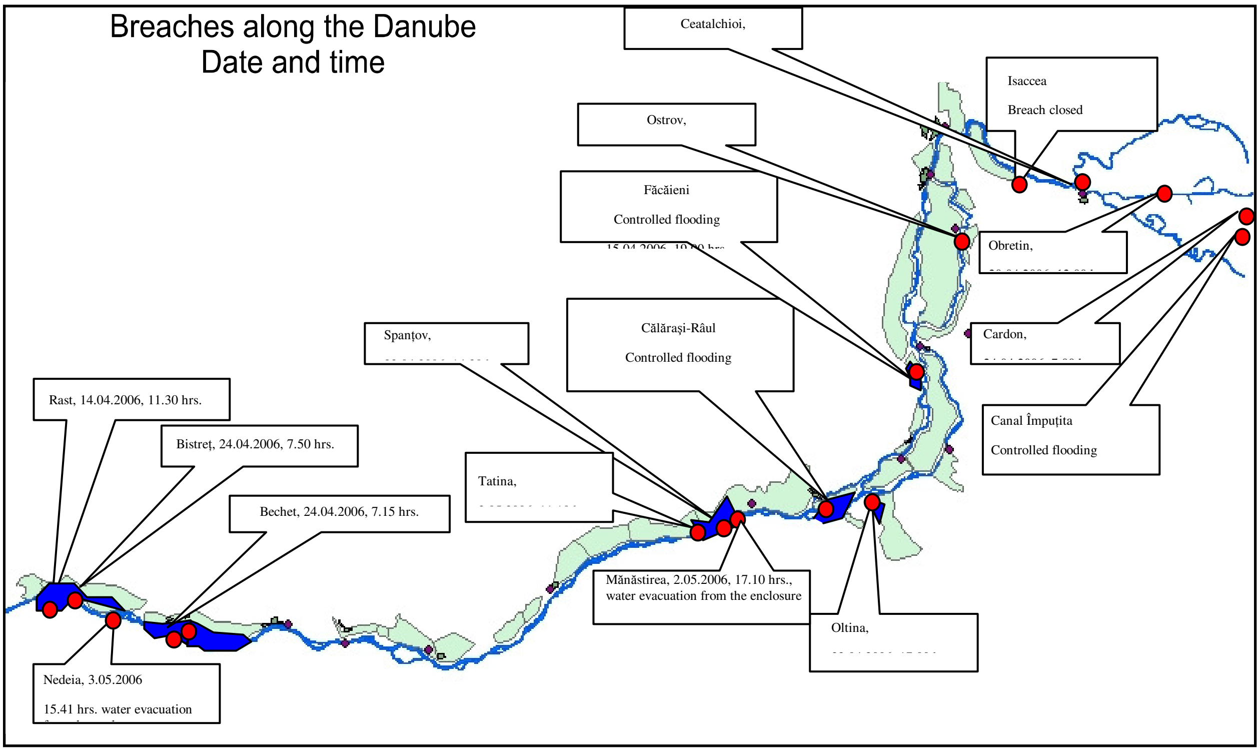


Figure 29: Dike breaches along the Romanian Danube

The Ministry of Environment and Water Management elaborated scenarios regarding potentially affected objects for 13,600, 14,800, 15,500 and 16,000 m³/s, proposing various measures in order to protect localities and important features along the Danube and Delta. All scenarios have been presented to the National Committee for Emergency Situations and sent to each prefect's office for preparation of public warning systems and other planning with regard to staff, tools, equipment and intervention teams. This is based on a forecasted discharge of 15,800 m³/s, above the historical value dating from 1970 (14,600 m³/s).

The Ministry of Environment and Water Management received 391 pumps and distributed them as follows: 70 in Dolj county, 45 in Olt, 70 in Calarasi, 32 in Ialomitsa, 31 in Braila, 11 in Galati, 32 in Constanza, 30 in Teleorman and 70 in Tulcea. The complexity and magnitude of these floods, which affected 12 counties, required a concentrated effort in all areas identified with maximum risk.

During this period an average of 6,104 persons/day intervened. Around 500 tools and other equipment were utilized every day (including 3 helicopters, 125 cars and trucks, 109 heavy trucks, 10 boats, 45 pumps and 79 non-specified tools).

Specialised intervention services participated in 358 actions to address flooding impacts. 80% of total intervention actions concerned the general public and 20% local public institutions or public administration land.

During the floods, 325 persons were rescued and goods with an estimated value of over 2 million RON were protected. Over 1000 persons took part in actions to limit the damage.

Internal and international aid:

Coordination with local authorities and Romanian Red Cross county branches assured an enhanced response to the emergency. Aid was distributed in many of the affected counties: Caras-Severin, Mehedinti, Dolj, Calarasi, Constanza, Tulcea, Braila and Gorj (the latter due to landslides).

By May 16, 9 countries had sent humanitarian aid through the European Commission's Monitoring and Information Centre - MIC (Moldova, Austria, Germany, Sweden, Slovenia, Slovakia, Hungary, Norway, Malta and Belgium). This consisted of: 6 pumps, 3 electric generators, waterproof suits, 900,000 sandbags, 12 tonnes of food, 99 tents, 250 blankets, thermal isolating containers for blood and disinfectants.

Technical conditions for adopting emergency procedures were assured with regard to acquisition through the State Reserve of 1000 temporary modular dwellings; the stating of an alert situation in all 12 counties contiguous to the Danube; raising to the second degree the intervention capacity of professional units for emergency situations (including police and border police in affected counties); actions for damage mitigation; actions for receiving and distributing internal humanitarian aid and financial evaluation of the damage. 1,755,750 million RON was released in order to provide immediate help to 11,705 people as well as humanitarian aid with a value of 3 million RON (covering food, clean products, fuel etc) from the State Reserve. Other actions concerned the maintenance of public health and farm animal welfare, prophylactic measures (disinfectant etc); and a State Inspectorate of Construction's inventory of dwellings and bridges affected or destroyed by the floods.

Victims, damage and losses

As a result of the flooding, 681 dwellings were destroyed, 2,598 affected and a further 487 bridges and footbridges destroyed or damaged. Good cooperation took place between the General Inspectorate for Emergency Situations (and its subordinated institutions) and the Ministries of Administration and Interior structures; Environment and Water Management; Health; Agriculture, Forests and Rural Development; and also with local administrations and local people.

Fortunately, the human loss in Romania was zero. Damage was also lower than during the 2005 floods in the Siret and Banat catchments areas. The estimated total damage in Romania amounted to approximately €200 million.

Table 22: Affected and destroyed infrastructure in Romania

County	Affected constructions				Railroads and roads		Bridges and footbridges (no.)	Other constructions (no.)
	Destroyed dwellings (no.)	Affected dwellings (no.)	Depen-dencies (no.)	Wells (no.)	Railroads (km.)	Local, county and national roads (km.)		
Teleorman	9	28	-	27	-	-	1	5
Olt	3	5	87	-	-	4	11	4
Călăraşi	312	792	934	866	-	1	4	4
Giurgiu	-	8	3	-	-	0,2	-	2
Galați	-	-	-	-	-	-	-	1
Constanța	7	141	145	3	0,5	3	4	1
Brăila	-	11	-	-	-	-	-	-
Ialomița	2	2	8	-	-	2	1	-
Tulcea	144	101	-	-	-	-	-	-
Dolj	372	919	596	2133	21,0	3	169	48
Mehedinți	29	79	-	70	-	2	134	-
Caraş Severin	3	442	990	782	2,4	6	163	3
Total	681	2598	2763	3881	23,9	22	487	67

4.9 Bulgaria

The Danube floodwater also resulted in bank overflow on the Bulgarian side and seriously affected an area of several hundred kilometres along the Danube River. Due to the relatively steep bank profile the flooded area was limited.

Many residential areas, especially in the cities of Vidin, Nikopol, Ruse and Silistra, were affected. It was necessary to evacuate over 2000 people.

Bulgaria requested assistance through the EU MIC on 25 April 2006, in particular requesting high capacity pumps and hoses; draining equipment for flooded dwellings; disinfectants, anti-mould latex and sandbags. Sandbags were received from Austria, Denmark, Poland and Slovenia. Belgium provided a pumping unit that included two special pump devices and a 10-person team.

4.10 Moldova

Spring flooding occurred in two waves following heavy precipitation. Maximum flood levels were recorded on the Prut River on 31 March, in the region above the Costesti-Stînca reservoir. A rise of 3 metres flooded the water meadow without severe consequences. However, further downstream, below the Costesti-Stînca reservoir, an unfavourable situation did develop. From 31 March until 10 April, the Costesti Hydro Power Station was discharging 400 m³/s daily. The rise in water levels at the mouth began in the middle of March, rising to approximately 2 metres. Following that, levels at the mouth rose to nearly 4 metres, connected with the growth in the reservoir's discharge. On the Danube River at the Reni gauge-station (in Ukraine), the maximum level reached 562 cm which exceeded the historical maximum of 560 cm from 25 March 1942.

A flooding situation developed on the lower course of the River Prut: high water levels coincided with backwaters from the Danube River resulting in the wash-out of dike banks and flooding of several agricultural areas and houses. Flooding of riverside houses was successfully prevented through the building of additional dams and barrages.

4.11 Additional local flooding in 2006

a) Extreme flooding of the Hernád River (Tisza tributary)

Slovakia and Hungary were hit by an additional flood on 2-6 June 2006. Heavy rain in the Carpathian Mountains and unseasonable snow resulted in flood warnings for 40 villages in Eastern Slovakia and triggered an extreme flooding on the Hernad River downstream in Hungary.

During the period of 2-5 June, when 1800 km still remained under primary defence alert and 75,000 ha was still under water due to the previous floods, 40-80 mm of precipitation fell in several parts of Hungary (the Northern Hills was particularly affected). This resulted in flash flooding of creeks and rivers, threatening several settlements and inhabitants living there. This precipitation also contributed to an increase in the area inundated by water to 111,000 ha by 9 June.

Evacuation of inhabitants became necessary at Gesztely, Hernádkak and Onga. Traffic on public roads crossing floodways or open floodplain was temporary obstructed but all settlements remained accessible.

b) Additional floods in Romania

Romania was hit by two additional heavy floods in 2006.

- *In the period 20 June – 6 July, northwestern Romania was affected (mainly in the Somes River Basin, a Tisza tributary) due to extreme rainfall in the Carpathian Mountains. There were 10 victims in the Bistret-Nasaud County (Somes) and 2 in Maramures County. About 80 villages were affected, 620 peoples evacuated, 75 bridges and hundreds of houses destroyed.*
- *In the period 30 June – 26 June, again in northwestern Romania (in Bistrita, Maramures, Arad and Suceava/Siret) extreme rainfall in the Carpathian Mountains caused more flooding. 25 people were killed and thousands of houses were affected or destroyed.*

5 Forecast and Warning Models

5.1 General

Depending on differing experiences, different forecast models are used in the Danube Basin. In general the following models are used, sometimes adapted to local circumstances: ALADIN; HYDROG; GAPI/TAPI; DANUBIUS; HEC-RAS, VIDRA and HOLV.

Since 2003, the Joint Research Centre of the European Commission has been developing and testing the European Flood Alert System (EFAS) for pan-European early flood warning. This system will be described briefly below.

5.2 Danube Flood Alert System (Danube EFAS)

Following the disastrous floods in the Elbe and Danube in August 2002, the European Commission launched the development of a European Flood Alert System (EFAS). The system is being developed at the EC Joint Research Centre with the support of the meteorological services and water authorities in Member States. To date, around 25 operational authorities across Europe, together responsible for more than 85% of the major trans-national river basins, are receiving EFAS information as early flood warning reports. EFAS monitors and forecasts the hydrological conditions across Europe. The system provides a number of novel features, such as flood forecasts based on a number of different weather forecasts including full sets of Ensemble Prediction Systems (EPS) as well as forecasts providing information for the entire river basin.

EFAS has been adopted within the Action Programme for Sustainable Flood Protection in the Danube River Basin of the ICPDR (ICPDR Document IC/082, 14 December 2004). The Danube part of EFAS – in the Action Programme referred to as the "Danube Flood Alert System" - is foreseen as a basin-wide measure to develop and improve Flood Forecasting and Early Warning, aiming to provide additional information to national and regional flood forecasting authorities.

The hydrological model for EFAS is the spatially distributed rainfall-runoff model, LISFLOOD, coupled with a kinematic wave routing routine for the river channels. It is set-up for the whole of Europe on a 5-km grid. Pre-operationally, EFAS produces early flood warnings twice a day up to 10 days ahead by making use of deterministic meteorological forecasts from:

- ***The Deutsche Wetterdienst (DWD):*** *forecast range of 7 days, twice a day (00:00 and 12:00);*
- ***ECMWF:*** *deterministic meteorological forecasts from the European Centre for Medium-range Weather Forecasts; forecast range of 10 days, twice a day at 00:00 and 12:00);*
- ***ECMWF EPS:*** *51 probabilistic meteorological forecasts from the Ensemble Prediction System of ECMWF; forecast range of 10 days, twice a day at 00:00 and 12:00*

EFAS forecasts are based on threshold exceedances. From long-term simulations based on observed meteorological data, four thresholds have been defined: Severe, High, Medium and Low. They correspond to levels for which flooding ranges from "not expected" to "potentially severe".

During the Danube floods in March and April 2006, the EFAS team sent EFAS Information Reports (EIR) with lead times in the order of 4-6 days for the severe flooding events. For the Tisza, 12 External EFAS Information Reports were sent out between 27 March and 7 April. For the main Danube, 10 External EFAS IR were sent out from 31 March to 9 April.

Figure 30 illustrates the flood alert map forecasted by EFAS, based on DWD deterministic weather forecasts from 28 March 2006, 00:00, showing high flood predictions (in red) for the Tisza and smaller Austrian tributaries to the Danube, as well as for the Vltava/Elbe and Morava rivers.

It also gives an example of the spatial extent of high flood alert levels indicated by EFAS simulations. From 22 March, floods were forecasted for 30 March onwards but initially not in a consistent way. The first report to Hungary was sent on 27 March.

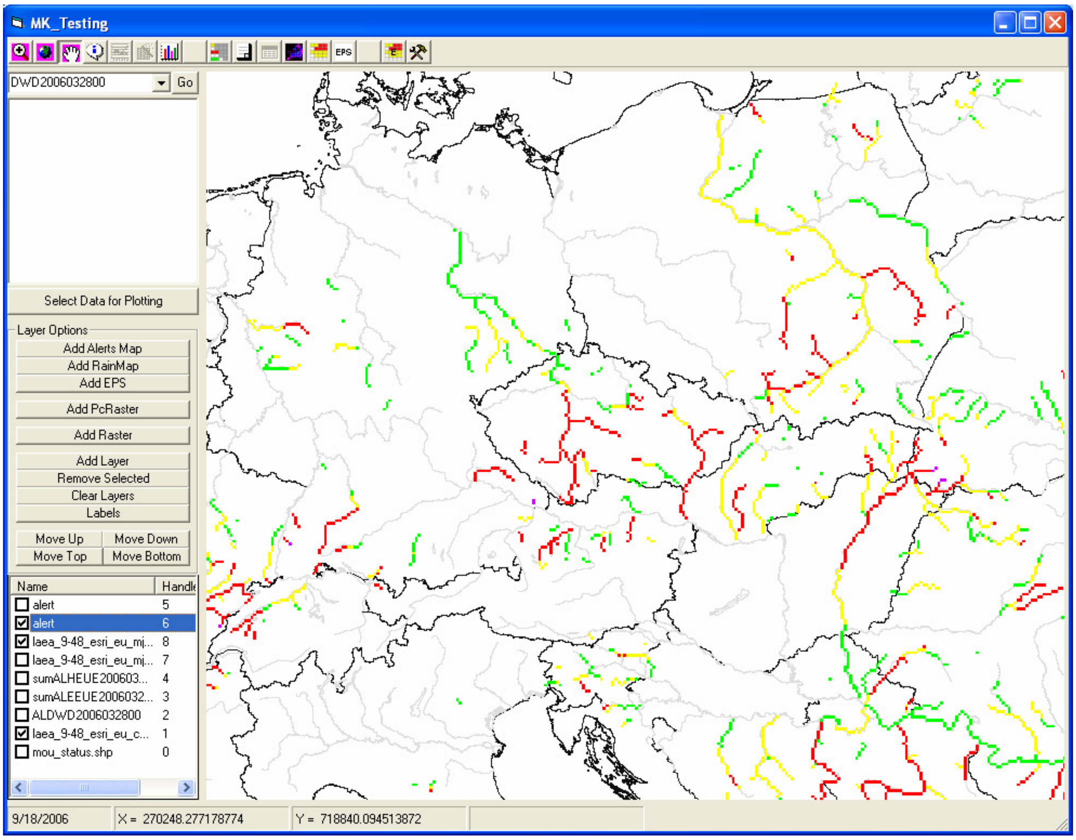


Figure 30: EFAS forecast of 28 March 2006 00:00 showing high flood predictions (in red)

5.2.1 Conclusions on EFAS performance during spring 2006

Despite some drawbacks of the current system (coarse calibration and resolution input data), EFAS work on the snowmelt floods in 2006 was a great success. From the operational point of view, more than 50 reports were sent to partner organisations, and the start of the floods (particularly those on the Elbe and Danube floods in the Czech Republic) were correctly predicted several days in advance. Considering the impact of EFAS information reports, in Slovakia the EFAS reports were used operationally and brought added value to the flood forecasts. The same happened in Germany, where the EFAS reports were used in Sachsen in discussions with politicians.

- *EFAS correctly forecast the onset of flooding in the upstream areas of the Danube (Morava, Tisza) with lead-times of up to 6 days in advance.*
- *Generally forecasted discharges were underestimated, particularly further downstream (Budapest, Iron Gate and beyond). Given the fact that simulations using observed synoptic weather station data also showed this underestimation, there is reason to believe that the rainfall/snowfall information obtained by the synoptic station network underestimates the real extent of rainfall/snowfall.*
- *Flood forecasts further downstream (Budapest, Iron Gate and beyond) showed a problem of river routing: the discharge is propagating too fast. The cause for this is two-fold:*

- *It should be noted that the results shown here are achieved using the coarsely calibrated 5-km model, and not yet with the 1-km thoroughly calibrated version under development for the Danube;*
- *Current gradients and roughness are estimates and in the base maps deficiencies were identified. The underlying maps for river gradients and surface roughness will be improved on the basis of the high-resolution data collected for the pilot catchments from the Danube countries.*

5.2.2 Encountered problems

The snowmelt floods also highlighted a number of short-comings of the EFAS pre-operational system that are now being addressed. The following lessons were learnt during the Danube floods of 2006:

- *The large number of alert reports brought the EFAS team to the limit of its operational capacity. As a result of so many reports needing to be sent out, the Morava River (a tributary to the Danube and a border river between the Czech Republic, Slovakia and Austria) was overlooked until the flood warning time was within 48 hours. Therefore, the Slovakian authorities were only alerted at a very late stage about the potential flooding of the Morava River; although EFAS had predicted the floods correctly more than 6 days in advance. In order to avoid similar problems in the future, the EFAS interface will be developed further and reporting procedures further automated. In addition, the dissemination strategy of EFAS information reports will be changed. From now on, the reports will be sent immediately to all partner authorities in the catchments, even if problems for downstream authorities are not yet predicted.*
- *EFAS underestimated snowmelt, probably due to a lack of sufficient precipitation data since EFAS only has access to synoptic stations at present. The use of other data and satellite information to update the snow cover data will be investigated. Introduction of temperature zoning to improve snowmelt modelling is already under investigation and studies have shown good initial results.*
- *The routing of the downstream part of the Danube will be improved by changing from the current 5-km set-up to a 1-km set-up, including updated channel related maps (gradient, cross section geometry, roughness) and a more in depth calibration.*
- *The introduction of major lakes and reservoirs needs considering.*

6 Conclusion

The 2005/2006 winter was exceptional, with temperatures from November to March falling below the multi-annual average. In addition, large amounts of water had accumulated in the snow cover across the Danube region, the result of several cycles of intense snowfall. By the end of March, daily air temperatures rose rapidly, causing significant snowmelt, which, along with intensive rainfall and a still frozen soil cover, caused a fast surface runoff. In consequence, massive springtime floods occurred across a large area of the Danube River Basin, including certain parts of the Upper Danube (e.g. Morava Basin) and, primarily, the Central (Tisza, Sava) and Lower Danube. An extremely rare coincidence of relatively large floods occurring in the sub-basins of the Upper Danube at the same time as flooding on the Tisza, Sava and Velika Morava led to a very serious 100-year flood event along more than 1000 kilometres of the Danube River. The flooding stretched from the Morava mouth to the southern tip of the Csepel Island in Hungary, downstream of the Tisza mouth in Serbia and along the whole Romanian section of the Danube (where historical flows and water levels were recorded). The extent of flooding in Romania was the largest in the last hundred years. During the period of 12-25 April, the registered flows in Romania recorded maximum values of 15,600-15,800 m^3/s, similar to those of 1895. Particularly unusual was the long duration of the high flood alert on the Danube downstream of the Iron Gate, which lasted more than 6 weeks.

The Danube in Hungary, Croatia, Serbia, Romania and Bulgaria was very seriously affected by the floods as well as the following sub-basins: Paar (Bavaria), Morava (Austria, Czech Republic), Vah (Slovakia), Velika Morava (Serbia), Tisza (Hungary, Romania, Serbia), Jiu (Romania).

The 2006 floods caused minimum casualties, mostly thanks to efficient flood protection, overall preparedness and the mitigation measures implemented. Thousands of people were involved in the emergency operations. Flood warning and forecasting proved to be one of the key factors of the integral flood protection process and provided valuable information both at the national level and at the basin-wide scale (Danube EFAS). The estimated total cost of damage and related emergency operations exceeded €600 million.

However, the flood defence actions also revealed a number of general and operational deficiencies and served as a good test of the effectiveness of warning, protection, preparedness and mitigation actions. The ICPDR agreed to evaluate the flood event, not only to assess its specific hydrological characteristics, but also to analyse the level of preparedness and effectiveness of measures taken at the national level. The aim has been to highlight the lessons that could be learned from the event in order to prevent or minimise the damage in the future. This report provides an overview of the various aspects of the 2006 events and the lessons learned provide a good and useful source of recommendations for improving flood protection throughout the Danube Basin.

7 Lessons Learned

The success of the emergency operations and level of international cooperation enabled the extreme 2006 spring flooding on the Danube and Tisza rivers to be coped with, whilst avoiding catastrophic consequences in many cases. A significant element of the success was the fact that the organisations involved, and their staff, had gained vital experience during the previous floods of recent years. However, without doubt, the flood events revealed existing gaps in flood prevention, protection and mitigation in the Danube River Basin. The experience highlighted the necessary steps that now need to be taken to ensure overall readiness and reduce risks of the future.

The following ‘lessons learned’ are based on the experiences of the 2006 spring floods. They are an important feedback for informing the details of the successful implementation of the ICPDR Flood Action Programme, as well as of the EU Flood Directive in the Danube countries:

7.1 Forecast and warnings

- *A timely forecast based on accurate information and a proper evaluation of the situation is an indispensable prerequisite of successful flood protection and mitigation.*
- *The application of the EFAS flood alert system extended the lead time of warnings on tributaries, thus improving the chances of an early response However due to the specific characteristics of the 2006 spring floods, no significant additional benefit was gained from the use of EFAS on the Danube and Tisza. The feedback obtained from the floods enabled further technical improvements of EFAS-Danube, ensuring an enhanced performance for the future.*

- *Close international cooperation and quick information-exchange, both before and during a flood event, are essential for ensuring effective disaster management. It is important for forecast preparation that hydrographical data from neighbouring countries are available and easily accessible on the Internet. Direct and easy access to continuously updated forecasting services is essential, especially during the period of 'peak interest'. A list of relevant websites should be continuously updated by ICPDR flood experts.*
- *Hydrodynamic modelling is an important tool; a better utilization of its possibilities in the disseminated flood forecasts should include consideration of the results of different modelling methods.*

7.2 Flood conveyance circumstances

- *The travel time of the Danube flood peak from the Austrian-Slovak border to the Iron Gate was about 3-4 weeks. It took an additional 3-4 weeks to reach the Danube Delta.*
- *An extremely rare coincidence of simultaneous, large floods in the catchments of the Upper Danube, Tisza and Sava caused a very serious 100-year springtime flood.*
- *The backwater effect caused unexpected historically high flood levels on many rivers at their confluence with the Danube - in Hungary, Croatia, Serbia and Romania.*
- *The Iron Gate hydropower plant successfully evacuated the largest flood wave in its history, whilst complying with the 1998 Convention (which defines Serbia and Romania's responsibilities under all operating conditions, including flood control).*
- *Characteristics of the 2006 flood indicated that the flood conveyance capacity of the river flood beds has been significantly decreased. This is an important factor in the rise in recorded "highest high water" (HHW) values. This decrease in capacity is a result of river alteration practises, primarily due to the loss of floodplains and increased sedimentation in the reservoirs.*
- *Besides the increased HHW values, a serious concern was the expanded duration of high flood stages. In the coming decades there is an increased probability of flood stages of 30-40 days duration over a design flood level.*

7.3 Flood risk assessment and mapping

- *Development of GIS-based flood hazard and flood risk maps should be undertaken quickly. They will need to be disseminated in appropriate formats. .*
- *Such maps should be made available to all flood-related actors and stakeholders in the River Basin; primarily to:*
    - *Authorities responsible for spatial planning and land-use (providing sufficient information on areas at risk)*
    - *Authorities responsible for emergency operations*
    - *The general public (with the aim of increasing awareness, enhancing personal decision-making and readiness.*

7.4 Land use

- *The general principle of 'hazard reduction' is a key factor in future land use planning i.e. preventing building development in the immediate areas of flood risk. Land use will need to be adapted to the hazards in the potential floodplains in order to minimise the potential for damage.*
- *The building permission process must take more account of the advice of water directorates on reducing the damage potential in flood-prone areas.*

- *A more efficient system of preventing the building of illegal constructions in inundation areas needs to be ensured.*
- *The introduction of a system of land classification according to risk of inundation (and connecting limitations) for use in detailed physical plans and land registries is a necessary prerequisite for effective development control.*
- *Existing constructions at risk of flooding should be made flood-compatible. In many cases, a technically sound and economically justified construction can contribute more to damage reduction than all the natural water retention measures and technical flood protection put together.*

7.5 Development of an integral flood protection system

- *It is imperative to make every effort to develop defence structures to meet current standards (while respecting, to the largest extent possible, the non-deterioration principle of the EU Water Framework Directive). Once again, experience has demonstrated that the probability of a critical situation developing (as well as the cost of emergency operations) is substantially lower along sections that meet such standards.*
- *Based on the recent experience, the necessary revisions and updates of the long-term development plan for flood defence must be accomplished. Special regard should be given to setting priorities and recommending solutions. Special attention must also be paid to the development of the municipalities' flood defences.*
- *The application of new principles and solutions already proved to be efficient (even if different from the traditional approach) should be considered during the planning and development of flood defences. For example, the relocation of existing facilities away from floodways and open floodplains, or encouraging owners to provide individual protection.*
- *An efficient flood protection system must be based on an integral approach combining structural measures with the need to provide more 'space' for rivers (by reclaiming floodplains), respecting all principles of ecologically sustainable development. Major principles of the ICPDR Flood Action Programme as well as EU Flood policy need to be followed in this respect.*
- *Strict adherence to the principle of 'solidarity' is of supreme importance for successful flood risk management in the Danube River Basin. The Contracting Parties should not pass on water management problems to each other. Every effort should be made to retain rainfall in-situ and store excess water locally and only then allow water to be discharged to downstream neighbours.*
- *Given increasing opportunities for accelerating flood protection developments utilising EU funds, it is advisable to use these funds for supporting integral flood protection.*
- *Opportunities for the combined, cost effective implementation of flood defence in combination with other infrastructure investments should be pursued.*
- *Annual inspection of the quality of dike banks by responsible national institutions (river basin authorities) is highly recommended.*
- *Harmonisation of solutions and strengthening activities in the framework of bi- and multi-lateral cooperation on trans-boundary water management is important. This process should be supported by the ICPDR through its Flood Protection Expert Group.*
    - *It is essential to enable efficient emergency interventions along the defences, in addition to filling gaps in development and raising maintenance standards.*
    - *Special attention must be paid to removing professional deficiencies with regard to defence activities in the municipalities, with special regard given to the continuous upgrade of their defence plans.*

7.6 Preparedness

- *The successful handling of an extreme flood event requires all necessary emergency operation plans to be in place and contain realistic measures and procedures. They must be based on close and smooth cooperation between all relevant actors (such as water management companies, civil defence, army, fire brigades, police, reservoir administrations, hydrological and hydro-meteorological services and municipal flood defence staff).*
- *The Public must be informed sufficiently on adequate self-prevention measures and on the flood risk and hazards. Public access to the key flood information sources must be ensured.*

8 The Way Forward

The 2006 floods underlined the need for the coordinated implementation of the ICPDR Action Programme for Sustainable Flood Protection in the Danube River Basin and the EU Flood Directive. The following targets of the ICPDR Action Programme should be given high priority by, and the full commitment of, all ICPDR Contracting Parties:

- *To reduce the adverse impact and likelihood of floods in each sub-basin through the development and implementation of a long-term flood protection and retention strategy (based on enhancement of natural retention as far as possible). This also refers to the other objectives in the Basin.*
  - *Restoration of the natural courses of tributaries and their overflow area.*
  - *Involvement of existing wetlands and extension of these where appropriate.*
  - *Detention along tributaries and rivers, creation of polders, dry flood reservoirs or multipurpose reservoirs with flood retention capacity.*
  - *Relocation of flood embankments (dikes) on smaller or larger scales.*
  - *Partial reactivation of protected floodplains applying controlled inundation.*
  - *Land use and spatial planning is a key issue to, on the one hand, slow run-off across the river basin and, on the other, reduce the damage potential on flood prone areas.*
- *To improve flood forecasting and warning suited to local and regional needs as necessary.*
- *To provide technical flood protection (structural defences)*
  - *Maintenance, restoration and, if necessary, improvement of the capacities of the structural flood defences or if appropriate, the construction of new ones, to protect human health as well as properties and valuable goods.*
- *To increase capacity building and raise the level of preparedness of organisations responsible for flood mitigation (advancing contingency plans, organisations, mutual assistance, etc.).*
- *To raise awareness and preparedness among the general public on sub-basin and local scale by:*
  - *Disseminating leaflets on flood hazards;*
  - *Utilising advanced information technological solutions such as a web-based information portal on flood management;*
  - *Flood marking (rehabilitation of existing ones);*

- *Developing programmes on capacity building, extended to education and stimulation and also addressing the utilisation of benefits of floods (thus raising public awareness about the need to adequately alter land use and functions subject to the flood risk;*
- *Enabling access to, and provision of, flood information and warning to the public;*
- *Encouraging public participation in the preparation of flood risk management plans and decision-making*