Flood Protection Expert Group

Assessment of Flood Monitoring And Forecasting in the Danube river basin

1. In General about the Danube River Basin

International cooperation of Danube countries has a long tradition especially as far as the utilization of the Danube River as a natural water-way for navigation and transport is concerned. An intensive economic and social development of Danube countries necessitates optimum water utilization not only in the Danube itself but also in its tributaries – i.e. within the whole drainage basin – for drinking and process water supply, hydropower and navigation purposes. The need to protect population and property from disastrous floods led to an effective cooperation of Danube countries.

The Danube with a total length of 2 857 km and a longterm daily mean discharge of 6 500 $m^3.s^{-1}$ is listed immediately after the River Volga (length 3 740 km, daily mean discharge 8 500 $m^3.s^{-1}$) as the second largest river in Europe. In terms of length it is listed as 21st biggest river in the world, in terms of drainage area it ranks as 25th with the drainage area of **817 000 km^2**.

The Danube River Basin (DRB) extends in a westerly direction from the Black Sea into central and southern Europe. The limits of the basin are outlined by line of longitude 8° 09´ at the source of the Breg and Brigach streams in Schwarzwald Masiff to the 29°45´ line of longitude in the Danube delta at the Black Sea.

The extreme southern point of the Danube basin is located on the 42° 05´ line of latitude within the source of the Iskar in the Rila Mountains, the extreme northern point being the source of the River Morava on the 50° 15´ line of latitude. Eighteen countries shared the Danube catchment: significant countries - Germany, Austria, Czech Republic, Slovakia, Hungary, Slovenia, Croatia, Serbia, Bosnia and Hercegovina, Romania, Bulgaria, Moldova, Ukraine – the smallest, almost insignificant parts of the catchement area are in Switzerland, Albania, Italy, Poland, and Montenegro. The source of the Danube tributaries adjoin the source of the Rhine tributaries in the west and northwest; The Weser, Labe, Odra and Visla river basin in the north, the Dnester river basin in the northeast and basins of the rivers flowing into the Adriatic and Aegean Sea in the south.

The River Danube drainage basin includes glacier-covered mountains, mid-mountain chainsclad with forests, karst formations devoid of growth, highlands and uplands, table lands plateaus with deeply cavered river valleys, and wide plains and depression parts.

About one-third of Danube River basin is mountainous, while the remaining two thirds consist of hill and plains. The mean altitude of the river basin is only 475 m, but the maximum difference in height between the lowland and alpine Peaks is over 3,000 m.

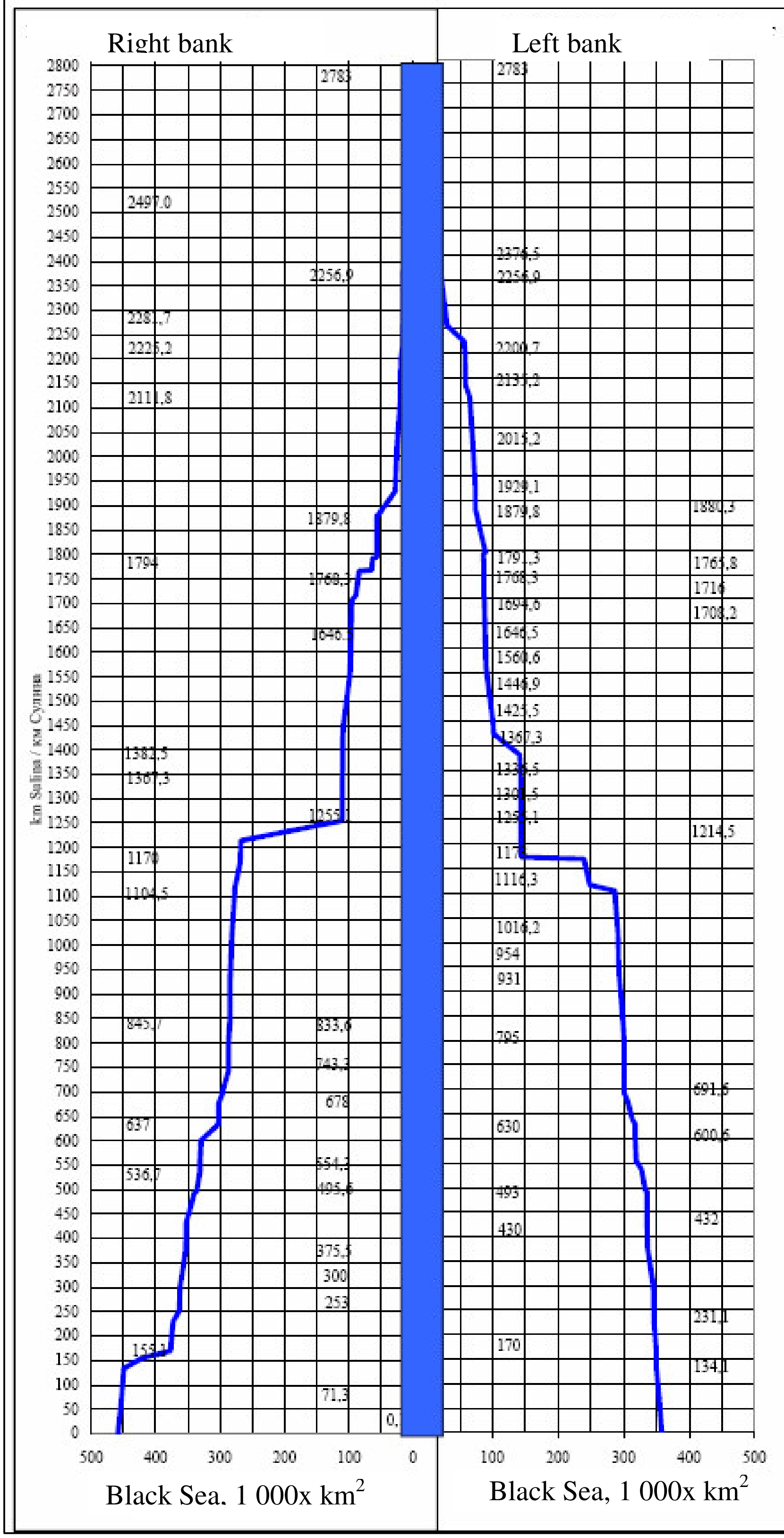
The Danube River basin is devided into four parts: the Upper region, the Middle region the Lower region and the Danube delta.

The Upper Region extends from the source tributaries to the Gate of Devin at the confluence with Morava. After the confluence of the river Brigach and Breg, the river is called the Danube (*Donau* in German). Downstream from this point the river follows the fault gap through the german Alp and its well-shaped valley. Major tributaries from the south, including the river Iller, Lech, Isar, Inn, Salzach, Traun, Enns and Ybbs drain the alpine sub-basins and augment the discharge in the Danube substantially. For example, the river Inn has a larger mean annual discharge then the Danube itself at the confluence. Orginally, these mountain tributaries transported large amounts of sediments, but sediment load is now greatly reduced because of the construction of hydraulic works. Major tributaries from the north are the rivers Naab, Kamp and Morava/March. The Morava is the most important and drains the Czech part of the Danube river basin and smaller areas of Slovakia and Austria.

The Middle Region is the largest of three regions, extending from confluence with the River Morava at Bratislava to the gorge of the Danube at the Iron Gate dam. Here the Danube enters a flatland region. The sediment-carrying capacity of the river is reduced and gravel and coarse material have been deposited. At times the river separates into branches forming several islands. The major tributaries in the region are from the left; the rivers Váh, Hron, Ipeľ and Tisza and from the right, the river Leitha, Raab, Drava, Sava and Velika Morava. Down to the confluence with the river Drava the mean runoff rate has increased to about 5,700 m3/s. At Velika Morava, the 117 km long gorge section begins between the Carpatian and Stara Planina (the Balkan Mountains). This gorge has been filled by large reservoirs for hydropower and navigation.

The Lower Region is formed by Romanian – Bulgarian lowland and its surrouding upland plateaus and mountains. From the mouth of River Timok to Silistra, the Danube forms the Romanian-Bulgarian border, flowing mostly east. The Danube flows as a wide (800 m), slow-moving River, with extensive, well developed alluvial plains especially on the left bank. The inundated area during floods can reach a width up to 10 km. The right bank is a narrow riverine plain flanked by steep bank. Much of the sediment load of the Danube is deposited behind the Iron Gate Dams, resulting in active riverbank erosion in this floodplain.

The Danube Delta covers an area of about 600,000 ha. It was created by the division of the river into tree main branches, forming a triangle with about 70 km long sides. Almost two-thirds of the delta area is seasonally submerged due to the low absolute altitude. The whole of Romanian part of the delta was declared a Biosphere Reserve in 1990 and registred under the Ramsar Convention. Over half of its areas is listed under the World Heritage Convention. Some 15,000 ha of the Ukrainian part of the Deltais protected the rest being used for agriculture. The population in the Romanian part of the delta is only 15 000, while the Ukrainian part has about 68 000 inhabitants.



1	2497,0	Lech
2	2376,5	Regensburg-Schwabelweis
3	2281,7	Isar
4	2256,9	Hofkirchen
5	2225,2	Inn
6	2200,7	Engelhartszell Wehrstelle-Aschach
7	2135,2	Linz
8	2111,8	Enns
9	2015,2	Kienstock Stein-Krems
10	1929,1	Korneuburg-Wien
11	1880,3	Morava
12	1879,8	Bratislava-Devín
13	1794,0	Rába
14	1791,3	Gönyű
15	1768,3	Komárom
16	1765,8	Vah
17	1716,0	Hron
18	1708,2	Ipoly
19	1694,6	Nagymaros
20	1646,5	Budapest
21	1560,6	Dunaföldvár
22	1446,9	Mohács
23	1425,5	Bezdan
24	1382,5	Drava
25	1367,3	Bogojevo
26	1336,5	Vukovar
27	1301,5	Ilok
28	1255,1	Novi Sad
29	1214,5	Tisza
30	1174,0	Zemun
31	1170,0	Sava
32	1116,3	Smederevo
33	1104,5	V. Morava
34	1016,2	Drencova
35	954,0	Orşova
36	931,0	Drobeta Turnu Severin
37	845,7	Timok
38	833,6	Novo Selo
39	795,0	Calafat
40	743,3	Lom
41	691,6	Jiu
42	678,0	Oriahovo
43	637,0	Isker
44	630,0	Corabia
45	600,6	Olt
46	554,3	Svistov
47	536,7	Jantra
48	495,6	Roussé
49	493,0	Giurgiu
50	432,0	Argeş
51	430,0	Olteniţa
52	375,5	Silistra
53	300,0	Cernavodă
54	253,0	Hârşova
55	231,1	Ialomiţa
56	170,0	Brăila
57	155,1	Siret
58	134,1	Prut
59	71,3	Tulcea
60	0,1	Sulina

Increase area of the Danube River basin

2. Climate and Hydrological Conditions of the Danube River Basin

Climatic conditions of the DRB are influenced by its position in the moderate climatic zone of the Northern Hemisphere, with regular alternating of the seasons of the year. Due to the elongated shape of the DRB in the west–east direction the climatic conditions are variable. In the main contributing areas the complicated orographic structure of the Alpine and Carpathian regions has the most significant impact on climatic variables. Differences extend from the Upper Danube with high Atlantic influence to the eastern territories affected by continental climate. South of the Alps and in the middle Danube Basin, especially in the Drava and Sava basins, the climate is influenced by the Mediterranean. Interaction of the mentioned three main effects can trigger floods in the Carpathian basin in any period of the year.

The range of fluctuation of mean monthly air temperatures between the warmest and coldest months increases from the upper Danube basin with 20-21 ^{o}C to the confined Carpathian basin with 22-24 ^{o}C and to the lower Danube reaches with 26 ^{o}C. Average annual air temperature within the basin ranges from -6.2 to 12 ^{o}C. The lowest value originates from the Alpine summits, the highest mean annual temperature was observed at the Black Sea coast. In the entire DRB July is the warmest month, January being the coldest one. Winter usually lasts from December to February. The summer is usually hot and lasts from about June to August. The absolute range of recorded temperatures is from -41 ^{o}C to 45 ^{o}C.

The hydrological regime, especially the runoff conditions of the Danube, is substantially influenced by precipitation. Average annual precipitation fluctuates within the range of above 3000 mm in high mountains to 400 mm in the delta region. In upper Danube regions precipitation fluctuates between more than 2000 mm in the upland areas of the Alps and up to 600 – 700 mm in mid-altitude. However, the actual figures can deviate drastically from the long-term mean values. There has been recorded daily precipitation of more than 260 mm at the upper Danube.

The catchments of central Danube regions are characterised by similar range. Annual precipitation varies from just above 500 mm in the middle Tisza region to above 2000 mm in the high mountains. Contributing areas of the Upper Drava and Sava in the Julien Alps and in the Kupa spring region have the highest value up to 3800 mm.

In the plains of the lower Danube the precipitation is only 500-600 mm, though the lowest annual values are below 400 mm.

The number of days with snow cover, the duration and depth of snow increase with the altitude. The Alpine regions have an average such days less than 60 while at elevations above 3000 m more than 190.

The shortest duration of snow cover (~10 days) is at the Black sea coast. The snow cover last for only 20-30 days in the Hungarian Plains, 40-60 days in the upper Danube basin, the mean proportion in the total annual precipitation being 10% - 15%. In the Alpine foothills and in high regions of mid-mountains the snow cover lasts more than 100 days (20% to 30 % of precipitation falls in the form of snow). The snow cover remains more than four months in the highest regions of the Alps (above 1500 m a.m.sl.). The snow cover survives relatively longer also in the Carpathians, more than year just above 2000 m.

The upper Danube has a regime characterized by two distinct seasons: high-water season, and low-water season. All the way to mouth of the Morava/March the Danube River belongs to the glacial type, with maximum monthly discharge in July and minimum in winter months (January-February). Discharges down to the Tisza mouth are still under dominant influence of the glacial regime. However, further downstream the River Danube discharge regime is changing, especially downstream from larger tributaries, such as Tisa and Sava Rivers. Thus, the histogram of monthly discharges on the lower Danube is similar to ones on lower Sava and Drina Rivers, with two maximums during the year. Low discharges on the Danube River appear during early autumn (September-October).

Flood protection activities are mostly related to plain floods; however flash floods and torrential floods of small streams have even higher damage potential. Valleys of the Central Alps, the peripheral mountains, Carpathians and Dinarians belong to regions with such type of risks, combined even with debris and mud flows. Due to climatic and morphologic conditions ice jam floods may also occur along the Danube and her tributaries in the Carpathian basin.

In general, the floods which occur in the Danube river basin, can be divided into several main types as follows:

- *Winter and spring floods* caused by snow melting which can be combined with rain. This type of flood is most frequent in under-mountain areas but these floods can also affect lower reaches of the rivers.
- *Summer floods* caused by long-lasting regional precipitation. These floods usually occur on all watercourses in the area exposed to the precipitation with highest impacts along middle or large-size rivers.
- Summer floods caused by short high-intensity storms (frequently over 100 mm during several hours) affecting relatively small areas. These floods can occur anywhere on small rivers with catastrophic consequences mainly in those basins that are highly declined and fan-shaped.
- Winter floods caused by ice phenomena, which can occur also during the periods when the flows are relatively low. These floods occur in those river reaches which are exposed to formation of ice jams, etc.

Hydrological conditions on the territory of the country are predominantly the causing factors of the floods.

3. Flood monitoring system

3.1. Description of the meterological network

The meteorological monitoring network consists of synoptic and additional synoptic stations, where the automatic meteorological station are established; network of climatological stations and network of rain gauge stations (modus WMO). Generally, the observation system in the Danube river basin consists of station measurement and remote sensing tools, such as radar, satellites and lightning detection systems. For hydrological purposes, the raingauge stations and weather radars play an important role. The number of raingauge stations in the Danube river basin is about 3 500. Most of them are manually operated and have a status of so-called cooperative stations, i. e. the observers are not professional meteorologists.

Fig. 1 Countries and main tributaries in the Danube River Basin

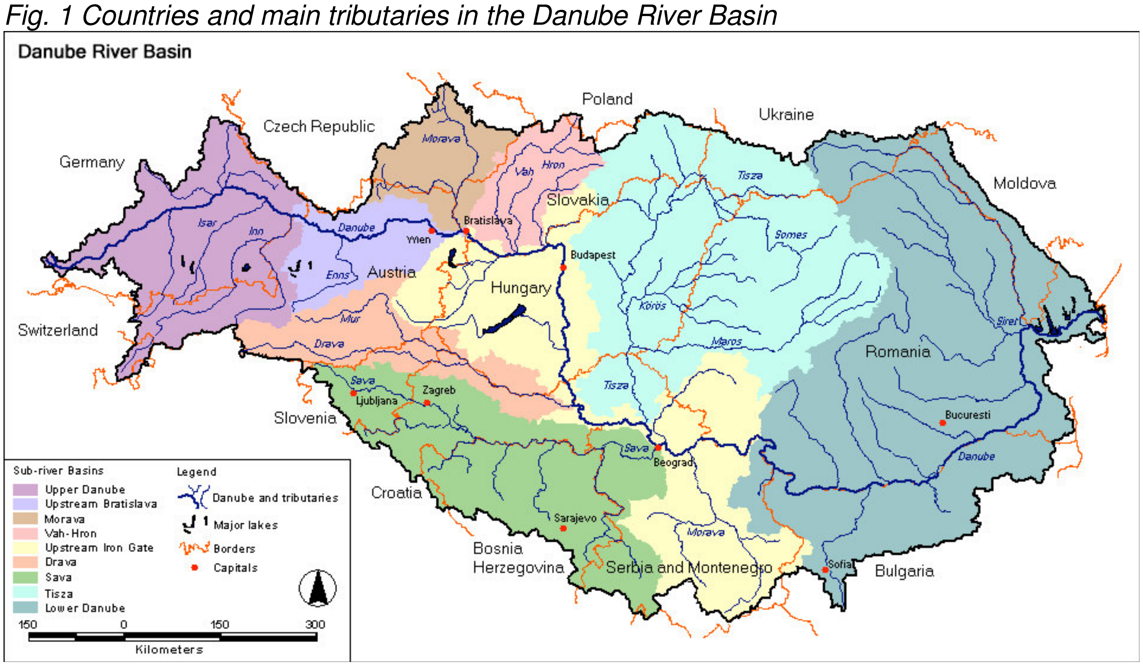


Table 1 Meterological observation

State	Radar network	Raingauge stations	Raingauge telemetric stations	Climatological stations	Precipitation forecast
Austria	4	259	61		INCA ALADIN-Vienna, ECMWF
Bosna and Herzegovina	-	15	16	15	HRM WRF-NMM WRF-ARW
Bulgaria	1	500	35		ALADIN
Croatia	8	337	61	154	ALADIN-HR, ALADIN-SLO, MRF
Czech Republic	2	240	60	60	ALADIN ECWMF
Germany	16	400			LME (Local Model Europe GME Global Model Europe ECWMF
Hungary	3	1200	173	148	ALADIN, ECMWF, QPF, DWD, COSMOLEPS
Moldova	2	25	-	7	ECMWF Offenbah Brackchell GFS Using Internet
Romania	9	281		160 (87 with automatic weather stations)	ALADIN LM MM5
Serbia and Montenegro	13	710		28	ECWMF ETA, GME
Slovak Republic	2	227	24	39	ALADIN, ECMWF, INCA
Slovenia	1	127		39 (24 automatic)	ALADIN/SI, ECMWF, INCA,DWD

Hydrometeorological Metadatabase of the Danubian Countries

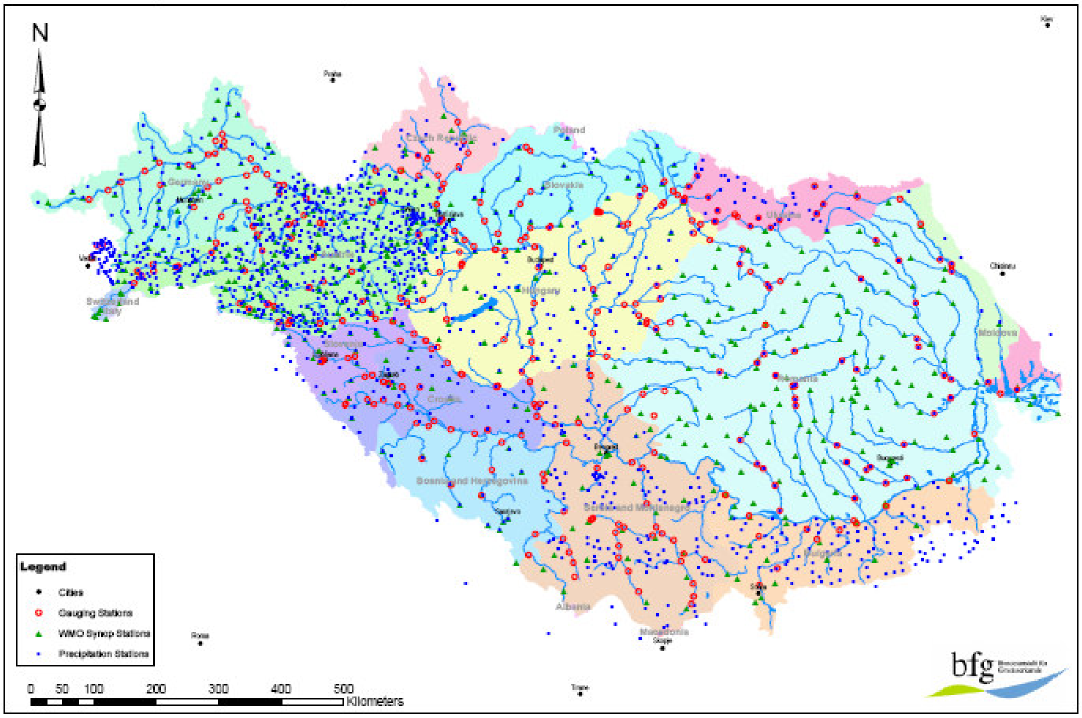


Fig. 2 Hydrometeorological metadabase of the Danube Countries

Precipitation gauge stations network and the meteorological stations are basic supply for the real-time hydrological forecasting. It is essential to have an instant precipitation estimate which is being achieved by the raingauge telemetric network of approximately 1 000 stations located in the Danube River Basin.

3.2. Desription of the hydrological monitoring network

The network of main watergauge stations in DRB countries is listed in the Table 3 More information on these stations is available on the national web-sites (see Table 2).

Table 2 Hydrological observation

State	Numer of gauge station	Data transmission	link
Austria	146	52	www.noel.gv.at www.ooe.gv.at
Bosna a Herzegovina	15	50	www.voda.ba
Bulgaria	215	6	www.meteo.bg
Croatia	331	113	www.voda.hr
Czech Republic	145	80	www.chmi.cz, www.pmo.cz
Germany	600	560	www.elwis.de www.hnd.bayern.de

Hungary	542	180	www.hydroinfo.hu www.vizugy.hu www.ovisz.hu
Moldova	16		www.meteo.md
Romania	903		www.hidro.ro
Serbia and Montenegro	195	15	www.hidmet.gov.rs
Slovak Republic	371	190	www.povodia.sk/dunaj/de/ www.shmu.sk
Slovenia	147	34	www.arso.gov.si

Table 3 Main water gauge stations on Danube

Station	River	Country Code	Distance from the mouth (river km)	Area (km^2)	Gauge zero point above sea level (m)	Start of Obs.	End of Obs.
Hundersingen	Danube	DE	2662,40	2629	542,84	1930	
Berg	Danube	DE	2613,00	4037	489,58	1930	
Neu-Ulm, Bad Held	Danube	DE	2586,70	7578	464,92	1931	
Dillingen	Danube	DE	2538,30	11315	415,00	1924	
Donauwörth	Danube	DE	2508,10	15037	394,78	1924	
Ingolstadt	Danube	DE	2458,30	20001	360,40	1924	
Kelheim	Danube	DE	2414,80	22950	337,10	1924	
Oberndorf	Danube	DE	2397,38	26446	331,15	1926	
Schwabelweis	Danube	DE	2376,49	35399	324,49	1924	
Pflelling	Danube	DE	2305,53	37687	308,16	1926	
Hofkirchen	Danube	DE	2256,86	47496	299,60	1901	
Achleiten	Danube	DE	2223,10	76653	287,70	1901	
Wehrstelle KW Aschach	Danube	AT	2162,67	78190	260,00	1976	
Kienstock	Danube	AT	2015,21	95970	194,00	1976	
Hainburg an der Donau	Danube	AT	1883,92	104178	135,25	1961	
Devín Bratislava	Danube	SK	1879,80	131244	132,87	1990	
Rajka	Danube	HU	1848,40	131475	122,58	1955	
Dunaremete	Danube	HU	1825,50	131543	113,24	1953	
Medvedov	Danube	SK	1806,30	132168	107,42	1979	
Komárno	Danube	SK	1767,10	171623	103,4	1931	1995
Dunaalmás	Danube	HU	1751,80	171721	103,12	1948	
Nagymaros	Danube	HU	1694,60	183534	99,43	1883	
Budapest	Danube	HU	1646,50	184893	94,97	1924	
Dunaújváros	Danube	HU	1580,60	188273	90,30	1945	
Dombori	Danube	HU	1506,80	189538	83,52	1936	
Baja	Danube	HU	1478,70	208282	80,99	1930	
Mohács	Danube	HU	1446,90	209064	79,20	1924	
BATINA	DANUBE	HR	1424,84	210250	80,45	2001	
ALJMAŠ	DANUBE	HR	1381,50	251573	78,08	1909	
VUKOVAR	DANUBE	HR	1336,50	253147	76,19	1856	
ILOK	DANUBE	HR	1301,50	253737	73,97	1856	

BAZIAS	Danube	RO	1072,50	570896	64,17	1878	
Novo Selo	Danube	BG	833,60	584900	27,00	1937	
Lom	Danube	BG	743,30	588860	22,89	1921	
Svishtov	Danube	BG	554,30	650340	15,10	1917	
ZIMNICEA	Danube	RO	553,50	658400	16,22	1879	
Rousse	Danube	BG	495,60	669900	11,99	1908	
Silistra	Danube	BG	375,50	689700	6,50	1941	
VADU OII	Danube	RO	237,80	709100	2,63	1954	
ISACCEA	Danube	RO	103,70	805700	0,63	1895	

3.3. Inventory of the international monitoring network as defined by bilateral and multilateral agreements

The bi-lateral agreements on co-operation on transboundary waters related to flood protection are shown in the Table 4

Table 4

	AL	AT	BA	BG	CH	CS	CZ	DE	HR	HU	IT	MD	MK	PL	RO	SI	SK	UA
AL						x												
AT					(x)		x	x		x	(x)					x	x	
BA									x									
BG						x							x		x			
CH		(x)																
CS	x			x						x					x			
CZ		x						x						x			x	
DE		x					x			x								
HR			x							x						x		
HU		x				x			x						x	x	x	x
IT		(x)																
MD															x			x
MK				x														
PL							x										x	x
RO				x		x				x		x						x
SI		x							x	x								
SK		x					x			x				x				x
UA										x		x		x	x		x	

X – formal agreement between states, (x) = bilateral cooperation without formal agreement

4. Development of the flood information service for the Danube river basin

4.1. The flood information service

Activities associated with protection against floods are governed by the respective legislation of each Danube state (the Water act, the Act on Crisis Management, the Act on Integrated Rescue System etc.). All basic and foreseeable measures for protection against floods should be specified in the flood protection (contingency) plans. All measures are governed by the Flood protection authorities and in case of large disastrous floods also by Crisis authorities. Flood protection authorities and Crisis authorities are bodies of the State and/or municipal administration fully responsible in pertinent areas for organisation of the flood protection services. These authorities' co-ordinate and control the activities of other participants involved in the flood protection.

The extent of the flood risk determines the order of the flood prevention activities (differ for selection countries):

I. *STATE OF ALERT*
II. *STATE OF DANGER*
III. *STATE OF EMERGENCY*
IV. *SEVERE SITUATION*

The individual states depend on the waterlevels or discharges, which are defined for every section of the river according to the flood plans. The state of alert generally occurs when the water level rises above the river channel. The states of danger, state of emergency and severe situation are proclaimed at the behest of the competent river basin authority with reference to the hydrological forecast.

The major tasks of the **meteorological services** of the Danube states in the area of flood forecasting include monitoring and forecasting of the weather situation, and advisory and warnings on dangerous weather events such as heavy precipitation, storms, hail etc. Quantitative precipitation forecast belongs to the most important activities of the meteorlogical services and it is provided through the use of numerical weather modelling by the top European Meteorological Services (France, Germany, UK). This information is supplemented by data from the meteorological satellites and maps of rain intensities provided by national meteorological radars.

The **hydrological services** monitor the current situation on the rivers in the Danube river basin by gauging stations which provide regular hydrological information that is supplemented with the data from the River Basin Authorities. Hydrological data include those on flow regulation in reservoirs which influence the flood transit.

Forecasting methodology was improved by developing and introducing **hydrological models** into the forecasting service. The hydrological forecasting system is connected to the meteorological forecasting system. Rainfall-runoff and routing models are calibrated for all main river basins and river reaches in the DRB. Data on observed precipitation and quantitative precipitation forecast (QPF) enter to the models and this allows to extent the lead time up to **48** hours. In winter period the snow melting model is used within the system.

The **flood forecasting service** regularly provides hydrological forecasts to the River Basin Authorities and other stakeholders and publishes them on a web-site. In case of flood it informs the flood protection authorities and other participants involved in the flood protection about flood danger and flood evolution. Warning messages are disseminated as soon as the extreme meteorological or hydrological conditions have been forecasted, and during floods they are accompanied by information on the flood evolution and its further prediction.

4.2. Input of precipitation forecast

Meteorological data and weather forecasts are the most important components of a flood forecasting and early warning system.

Data sources – domestic and those from international cooperation

• *Satellite*

Data from Meteosat Second Generation (MSG-1) is received by EUMETCAST DVB system.

• *Radar*

Automatic production of typical radar data (base reflectivity, rain intensity, VIL, CAPPI, PPI, etc.) Every Danube state can also use data from neighbouring countries through the CERAD network.

• *Terrestrial stations*

- Meteorological stations
- Automatic rainguage stations - Online data
- Climatological stations

Nowcasting and very short range forecasting system (0-6 h forecast)

Warnings of severe weather phenomena are provided at the forecasting offices through the use of information obtained from radar, satellites and numerical models that are interpreted subjectively. There are available tools for monitoring and tracking weather systems and diagnostic tools, which are part of the radar software.

Short-range forecasting system (6-72h forecasts)

Short-range forecast is based in most of the Danube countries on the high resolution LAM ALADIN model. It is a limited area numerical meteorological model (LAM) designed for operational use. The ALADIN model was developed in 1991 by cooperation of Meteo France with European countries. It is still being refined according to a scientific plan in order to improve quality of its forecasts. Two new version of model are issued twice a year (in average).

Mid-range forecasting system (72-240h forecasts)

The mid-range forecast covers ranges from 3 days (72 *h*) up to 10 days. There is great uncertainty in predictions for such long ranges, due to the chaotic nature of the atmosphere. Therefore, 18 ensemble forecast methods (EPS) are used to address the uncertainty of weather developments. In practice, the prediction of an event (a given amount of precipitation, for example) is associated with its probability of occurrence. These kinds of forecasts are usually generated with low resolutions and are therefore useful only for the prediction of the probability of regional floods or of the occurrence of early spring floods.

A recommendable solution for European flood forecasting services is membership in **ECMWF**, which provides the highest quality mid-range forecast from the most scientifically developed operational suite (deterministic and ensemble as well) in the world.

4.3. Hydrological Forecasting and Products

Forecasting Methods:

For the Danube – the basis of the forecasting methods is a **simple method** of corresponding water stages/discharges, which can be seen as more traditional but is very reliable.

Hydrodynamic models

For modelling of the flood wave run at the upper part of Danube (Germany, Austria) the hydrodynamic model is used. The discharge at the main tributaries of the Danube is calculated by separate rainfall runoff models based on computation of direct runoff and its transformation to river runoff. Also, the raifall-runoff relation to the API (antecedent precipitation index) with numerical and gaphic expression is used.

Rainfall-runoff model

Discharge forecasts for the tributaries on the basis of precipitation - discharge - models (N-A-models) are attached to the hydrodynamic models.

N-A models are deterministic models. They calculate discharges as a reaction of precipitation. In the simplest case a discharge-effective area of precipitation is accepted as a proportional part of the total precipitation in dependence of the wetness of the area and overlaid by superposition over a firm linear relationship (unit hydrograph curve) between precipitation and discharge reaction. In case of the river basin model, the hourly precipitation data, the discharge data, the precipitation forecasts, and snowmelt - computations and precipitation predictions are introduced into the model. QPF plays a dominant role among the forecast results for river basins of size up to 10 000 km^2. An improvement of the forecasting process and its outputs is a never-ending story, in which the uncertainty of a forecast, the interaction with end-users and new tools and techniques are the key areas of future development.

Uncertainty

- *Uncertainty in hydrological forecast due to QPF uncertainty*
  QPF uncertainty is the most important uncertainty source. Unfortunately it remains unexpressed. The use of EPS ensembles from ECMWF is not a proper approach for small streams and mountainous areas. Therefore either the use of meteorological ensembles based on fine resolution NWP or the statistical postprocessing of QPF have to be considered as an alternative. In both cases a close cooperation with meteorologists (developers and forecasters) is necessary.

- *Uncertainty due to other sources*
  The other types of uncertainty have to be taken into account as well: the uncertainty of model parameters calibration ot that of initial conditions etc. There are some tools currently available for decrease of those uncertainties (e.g., temporal parameters change, initial conditions optimalization)but statistically based expression seems to be a more promising tool for future.
- *Uncertainty combination to produce probabilistic hydrological forecast*
  After expressing of QPF and other sources uncertainty the total uncertainty has to be derived by combination of uncertainties.

Tools and techniques

- *More use of radar data*
  Very good experience with assimilation of radar data leads us to extend its use in flood forecasting. This version will be "more distributed" in the meaning of computing smaller internal catchments (with not observed closing water gauge) – for every catchment the MAP radar estimate will input.
- *Nowcasting & flash flood forecasting*
  Flash flood forecasting is a very problematic task as regards both warning and accurate localization of possibly endangered area. That is the field of important cooperation between meteorologists and hydrologists. The aim is to develop some reasonable and operationally usable tool for production of grid risk maps of dangerous precipitation amounts in the first step. This tool should be combined with radar data in the step two.
- *Distributed models*
  Some studies and projects prove the growing possibilities of operational use of distributed (grid based) hydrological models in near future. If a new operational system will be developed it should be the distributed one. With two or more operational systems ("old" lumped man operated, one automatic distributed) the multi-model approach appears to be very beneficial to "express" the uncertainty.
- *Data measuring and transmission*
  To ensure a proper function of automatic gauges a continuous improvement of measuring technology and "not limited" maintenance is necessary (resulting in great budget demands). The transferring technology has to follow the telecommunication development – it is necessary to find a cheap and robust transfer technology. Ideally two independent ways of data transfer from every measuring point should be available. (Next steps - data processing –have to be also concerned).

End-users feedback and training

- *Training of forecasters*
  The forecaster is the most important element in the forecasting process. A good forecaster needs to possess an excellent knowledge of both hydrology

and the river catchment achieved throough a long-term experience. Therefore the education and training of forecasters (but also the motivation) are crucial.

- *Training of end-users*
  There is often a gap between a forecaster and end-user in different way of thinking and different technical language used. We have to ask ourselves if our products are understood and interpreted correctly by our end-users.
- *Learn from end-users feedback*
  The feed back of end-users needs and demands must be taken into an account in developing of new tools and in the shape of forecast outputs.

  Unfortunately this feedback is often missing.

5. The European Flood Alert System (EFAS)

The first international system for forecasting Danube floods and providing an early flood warning was launched on 10th March 2008 by the International Commission for the Protection of the Danube River (ICPDR) and the Joint Research Centre (JRC) of the European Commission.

The new system provide the national authorities of countries in the Danube River Basin – the most international river basin in the world - with up to 10 days to prepare for large floods. Examples of national response measures include opening temporary flood retention areas, building temporary flood protection structures such as sandbag walls, and civil protection measures, such as closing down water supply systems (to ovoid contamination) and evacuating community residents.

Memoranda of Understanding for the development of the Danube-EFAS have been signed with, Austria, Bulgaria, Czech Republic, Germany, Hungary, Moldova, Serbia, Slovakia, Slovenia, and Romania. EFAS complements but does not replace existing national flood forecasting system. While the Danube-EFAS has already had some testing in the Danube, it will improve through user feedback, so JRC and the ICPDR Flood Protection Expert Group strongly encourage the new system to be used as much as possible.

Danube-EFAS information is available through a password-protected website, 24 hours a day, through an online service managed by the JRC. The system currently includes 700 rainfall stations in the Danube Basin, with plans for an increase to around 3,000 stations through an ongoing European-funded EU-FLOOD-GIS project carried out by JRC. Information includes rainfall and flood forecasts throughout the river basin, and maps showing revers potentially reaching critical alert levels for all Danube tributary revers with upstream areas larger than 4,000 km^2.

The benefit of EFAS is two-fold. First, EFAS should provide the European Commission with useful information for the preparation and management of aid during a flood crisis. Second, National Water Authorities should benefit from additional medium-range flood information that might contribute to increased preparedness in an upcoming flood event. EFAS is aimed at complementing national flood forecasting systems, not to replace them.

The advantages of EFAS for the European Commission are

- Overview of current flood situation in Europe for European Commission services
- Comparable results across Europe
- Fostering harmonised exchange of hydrological data and information in Europe

The advantages of EFAS for the National hydrological Institutes could be

- Additional information on possible flood situations more than 3 days in advance based on different weather forecasts
- Interpretation of flood ensemble prediction system forecasts based on full sets of EPS
- Increased exchange on flood forecasting issues and EPS research between the different institutes participating in EFAS.

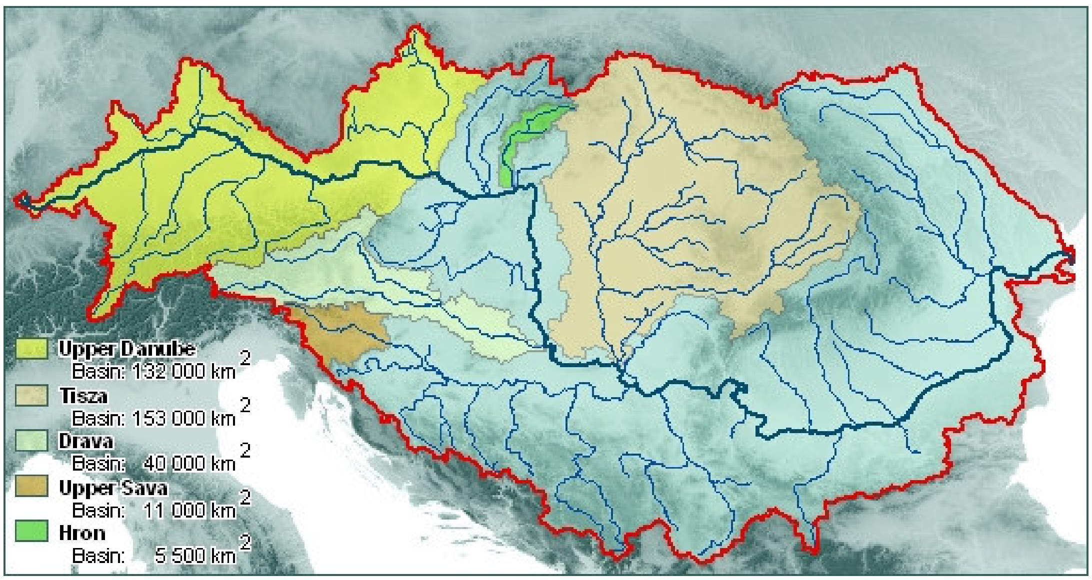


Fig 4: Selected subcatchments of Danube basin for test and evaluation the model

6. Navigation

The Danube countries cooperate on navigation under several agreements dating back 1856. The Danube, particularly the middle and lower reaches, has been an important natural waterway for centuries. There are close cooperation between ICPDR and Danubian Commision (centrum in Budapest). In the next table are list of principal watergauge stations which are permanent using for navigation needs.

NAVIGATION: **Main hydrological water gauge stations at the Danube River**

Name of water gauge station	Distance from the Sulina	Gauge "O" point above see level	1961 - 1990 Minimal operating water stages	Responde discharges	Maximal operating water stages	Responde discherges	1971 - 2000 Minimal operating water stages	Responde discharges	Maximal operating water stages	Responde discharges
	km	м	cm	m3/s .	cm	m3/s	cm	m3/s	cm	m3/s
Germany										
Regensburg - Schwabelweis	2 376,49	324.49 N	***292***	***205***	***497***	***1350***	***292***	***221***	***472***	***1332***
Pfelling	2 305,50	308.16 N	***290***	***211***	***643***	***1370***	***290***	***221***	***659***	***1378***
Hofkirchen	2 256,86	299.60 N	***207***	***324***	***505***	***1760***	***207***	***335***	***514***	***1763***
Austria										
Engelhartszell	2 200,70	276.99 A								
Linz	2 135,17	247.74 A	316	680	545	3691		***730***		***3342***
Kienstock (Stein-Krems)	2 015,21	194.00 A	177 (KWD	870	625	5002		***918***		***4621***
			1996)							
Wien (Korneuburg)	1941.5/	154.05 A	78	855	591	5121		***976***		***4707***
	1 929,09									
Orth	1 901,83	143,30 A	86 (KWD							
			1996)							
Hainburg	***1 883,92***	***135.25 A***						***975***		***4652***
Slovak Republic										
Devín	1 879,80	132.87B	134					***1030***		***4899***
Bratislava	1 868,75	128.43B	65	1010	682	6552				
Sap	***1 809,97***	***108.10B***					***115***	***1025***	***617***	***4778***
Medveďov most	***1 806,41***							***1025***		***4778***
Medved'ov	***1 806,40***	***107.42B***	85	1037			***132***	***1025***	***631***	***4778***
Vámosszabadi	***1 805,60***	***108.40B***					***23***	***1025***	***522***	***4778***
Nagybajcs	***1 801,00***	***107.40B***					***75***	***1025***	***532***	***4778***
Kližska Nema	***1 792,37***	***104.65B***					***168***	***1025***	***639***	***4778***
Gönyű	***1 790,61***	***106.04B***					***-8***	***1025***	***463***	***4778***
Zlatná na Ostrove	***1 779,10***	***103.92B***					***111***	***1025***	***575***	***4778***
Komárno ž. most	***1 770,40***							***1025***		***4778***
Komárom	***1 768,30***	***103.88B***					***79***	***1095***	***513***	***4695***
Komárno nové	***1 767,88***	***103.40B***					***124***	***1095***	***559***	***4695***
Komárno c. most	***1 767,80***							***1095***		***4695***
Komárno	1 766,20	103.69B	88	1140						
Hungary										
Medve	1 806,40	108.42 B					***35***	***1025***		
Vámosszabadi	***1 805,60***	***108.40 B***	36				***22***	***1025***		
Nagybajcs	1 801,00	107.62 B	35		570		***66***	***1025***		
Gönyű	1 790,61	106.20 B	-38		564		***-11***	***1095***		
Komárom	1 768,30	103.88 B	60		590	6412	***79***	***1095***		
Komárno	***1 767,88***	***104.12B***					***54***	***1095***		
Dunaalmás	1 751,80	103.12 B	67		546		***97***	***1170***		
Radvány	***1748,25***	***102.88B***					***106***	***1170***		
Dunamocs	***1745,10***	***102.64B***					***99***	***1170***		
Esztergom	1 718,52	100.92 B	38		536		***60***	***1170***		
Szob	1 706,60	99.85 B	69		549		***80***	***1180***		
Nagymaros	1 694,60	99.38 B	-10	1040	510	6344	***-10***	***1180***		
Vác	1 679,50	98.12 B	-5		557		***11***	***903***		
Felsőgöd	***1671,60***	***97.48B***					***25***	***903***		
Surány	***1670,50***	***97.51B***					***12***	***903***		
Obuda	1 654,50	95.38 B					***122***	***1180***		
Budapest (Vigadó tér)	1 646,50	94.98 B	80	1040	668	6170	***92***	***1180***		
Kvassay zsilip	***1642,17***	***94.82B***					***87***	***1180***		
Budafok	***1636,93***	***94.30B***					***42***	***1180***		
Ercsi	1 613,20	92.73 B	-28		556		***18***	***1180***		
Adony	1 597,70	91.68 B	1		539		***11***	***1180***		
Dunaújváros	1 580,60	90.28 B	-8	1040	551	5767	***-10***	***1180***		
Dunaföldvár	1 560,60	88.86 B	-58		546		***-116***	***1180***		
Paks	1 531,30	85.38 B	-6		720		***7***	***1180***		
Dombori	1 506,70	83.58 B	-4		755		***-6***	***1180***		
Baja	1 478,70	80.99 B	121		805		***108***	***1254***		
Dunaszekcső	1 459,90	79.92 B	134		814		***128***	***1254***		
Mohács	1 446,90	79.20 B	144	1080/1040	815	5103	***124***	***1206***		

Croatia										
Vukovar	1 336,50	76.188 A	73							
Ilok	1 301,50	73.96 A								
Serbia										
Bezdan	1 425,50	80.64 A	30	1150	596	5305	***10***	***1140***	***576***	***5048***
Bogojevo	1 367,40	77.46 A	80	1530	635	6106	***84***	***1480***	***593***	***5720***
Novi Sad	1 255,10	71.73 A	80							
Zemun	1 173,00	67.87 A								
Smederevo	1 116,30	65.36 A								
Bulgaria										
Novo Selo	833,60	27.00 MN	120	2710	784	12542				
Lom	743,30	22.89 MN	174	2826	795	13201				
Oriahovo	678,00	21.56 MN	46	2630	658	11633				
Svistov	554,30	15.10 MN	88	2848	782	13990				
Roussé	495,60	11.99 MN	107	2865	783	14751				
Silistra	375,50	6.50 MN	77	2928	717	12980				
Rumania										
Calafat	795,00	26.683 MN	60				***57***		***671***	
Corabia	630,00	20.123 MN	23				***44***	***2908***	***632***	***11839***
Giurgiu	493,00	13.06 MN					***6***	***3085***	***637***	***12015***
Oltenița	430,00	10.01MN	44		714	13593	***48***	***3104***	***631***	***12026***
Călărași	370,00	7.306MN					***1***	***3143***	***585***	***12151***
Cernavoda	300,00	4.866 MN	-39		604	6266	***-42***	***990***	***595***	***7822***
Hârșova	252,00	3.08 MN	19				***35***		***633***	
Brăila	170,00	1.08 MN					***101***	***3243***	***601***	***12213***
Galați	150,00	0.861MN	52				***102***		***569***	
Isaccea	103,80	0.688 MN	42				***77***		***462***	
Tulcea	72,00	0.559 MN	50		388	10895	***64***	***1721***	***389***	***11248***
Moldavia										
Ukraine										
Reni	127,23	0.36MN	61	3180			***60***	***3170***	***482***	***13100***
Ismaïl	***93.6*4)***	***-0.18MN***					***58***	***1990***	***317***	***7160***
Vilkovo	***18,0*4)***	***-0.75MN***					***65***	***1920***	***149***	***7360***

Values expressed in altitude system
A - Adriatic altitude systém
B - Batic altitude sys-tém
N - North altitude system
MN - Mediterrian altitude system

References:

National reports *Assessment of Flood monitoring and Forecasting* of the Danube River Countries**.** (2006, 2007, 2008, 2009)

IHP of the Danube countries: Project 10 *Common hydrological metadatabase of the countries sharing the Danube Catchment"*

Stančík A., Jovanovič S. and all.H: Hydrology of the river Danube.1988

Hydrologischers Nachschlagewerk Der Donau 1921 -2001, Donaukommission, Budapest 2006