REPORT ON THE ICE EVENT 2017 IN THE DANUBE RIVER BASIN

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EDITORS

Marina Babić Mladenović, Karoly Gombás, Igor Liška, László Balatonyi

Text and photo contributions:
Bosnia and Herzegovina: Almir Prljača
Bulgaria: Rumeliya Petrova
Croatia: Silvio Brezak
Hungary: László Balatonyi, Karoly Gombás, Pál Kötél
Romania: Razvan Bogzianu, Elena Anghel, Florinela Georgescu, Lucian Bucuroiu, Corneliu Carp
Serbia: Marina Babić-Mladenović
Slovakia: Monika Supeková
Ukraine: Svitlana Rebryk

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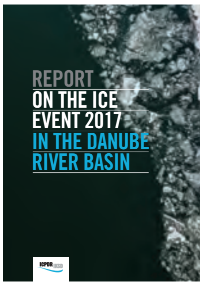
SZÉCHENYI



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2017

INTRODUCTION

In January-February 2017 many countries in the Danube Basin found themselves facing a similar situation. On the Danube River and even some of the main tributaries, ice drifts appeared and aggregated into ice jams. To avoid the potential flood hazard and its consequences a number of measures had to be carried out. Fortunately, no casualties were reported. This event highlighted the need for basin-wide development of technical and human resources for sustainable ice-management.

The problems that occur as a result of ice on the Danube and its tributaries have been known for centuries. There have been many critical situations occasioned by ice events along the river course. In severe winters, there were many instances of ice jams, as well as ice floods. As a result, ice management became an integral part of flood protection on the Danube a long time ago. The problems related to ice were previously described in the ICPDR Sub-Basin Level Flood Action Plans (2009), especially for the Pannonian Central and Southern Danube, but also in the Plan for the Lower Danube Corridor and others. These plans also review the existing and planned ice control measures (https://www.icpdr.org/main/activities-projects/flood-action-plans).

Figure 1: Hungarian icebreakers on duty near Apatin, Serbian-Croatian border (credits OVF)

After 50 years of mild winters with only occasional and local appearances of ice on the Danube, these problems were almost forgotten. The severe winter in 2017 proved to be a warning, that even in a time when global climate changes are proved, ice management on the Danube must remain an issue for the future. Due to the modest focus on this topic, the knowledge about handling such ice events is disappearing even on professional level.

This report aims at raising attention on ice management in the Danube River Basin and underlining its relevance for the future.


SZÉCHENYI

1 SOME BASIC FEATURES OF THE RIVER ICE

River ice is a complex issue. During the winter period, the thermal regime of the Danube is governed by the continental climate of the catchment area, or by sub-zero air temperatures, which cause the formation of ice on the river. There are several classifications (more or less complex) in the world to describe the types and characteristics of ice events. These classifications are based on: the structure of the ice, origin, zone and manner of transport, status of movement (or lack thereof), physical and mechanical properties of the ice, and the like.

1.1 Simplified classification of the ice phenomena

In view of the fact that there is a limited assortment of ice monitoring data on the Danube and its tributaries, a simplified streamlined classification is possible. This classification is based on presence and status of ice movement on the river surface and practically includes only two categories: ice drift and ice cover.

Ice drift: This expression is used for ice floating on the surface of a river in the form of ice sheets (floes), whose surface area and thickness vary, or big or small fields of slush-like ice (frazil), whose consistency, density and structure differ. The ice drift density (relative coverage of the river by drifting ice) also varies: from near zero (infrequent drifts, solitary floes or floating frazil) to close to one (dense drift ice, with frequent contacts between ice floes before it become static ice cover). The classification of the different stages is not uniform in the Danube basin and different national coding systems are in use.

Ice drift can be calm: slow movement downstream and gradual stop at a downstream obstacle or ice cover; but also turbulent: tumbling and colliding of ice floes, breakage and piling up of floes, accumulation at man-made or morphological obstructions, and underpinning of a static ice cover and formation of so-called ice jams in the riverbed. The way the ice drifts depends solely on the hydraulic and morphological characteristics of the river and the amount of ice *(see Fig. 15)*.

Ice cover: This expression is used for any fixed ice formation on the river surface. It may be autochthonous ice (compact ice of uniform thickness in relatively calm waters), stopped ice drift composed of uniformly distributed floes and frazil, or piled up ice and ice barriers of considerable thickness, depending on the hydraulic conditions at the time the ice cover was formed *(see Fig. 14)*.

Combined stages of ice features are possible and rather frequent, with static ice in one part of the river (attached to the riverbanks) and floating ice along the main stream.

1.2
Potential effects of the ice phenomena

Water levels along a river reach depend on boundary conditions (riverbed morphology and resistance to the flow), hydrological conditions of incoming flows (of the main river and tributaries) and on the downstream conditions (water levels downstream from the considered reach).

To some extent the ice on the river changes the water levels. Due to additional resistance of the ice formations, the river stages are higher than in normal conditions (for the same river discharge). River stages depend on the ice regime: amount of ice, type and condition of ice formations and the way they move (or stand still) in the considered reach (especially in the immediate downstream reach), as well as incoming ice from upstream reaches.

On the other hand and in addition to meteorological drivers, the ice regime (amount of ice and development of ice formations over space and time) primarily depends on the river regime – hydraulic, morphological and hydrologic conditions along the river over time. In view of this inter-dependence, the flow regime and the ice regime cannot be addressed separately, but rather as one comprehensive winter river regime.

Given that the occurrence of ice on rivers is a direct consequence of weather conditions (most of all sub-zero air temperatures), and in view of the fact that cold waves occur at different times from year to year and are of different duration and severity, with air temperatures at times falling below 0°C several times in a single winter, it is clear that ice events do not begin and end at the same times each year.

In late winter, as air temperatures rise above the freezing point, river ice begins to melt. It can deteriorate and rot in place with little jamming or significant rise in water level. More likely, however, the ice may be moved and form ice jams.

During the spring, but also during periods of mid-winter thaw, additional runoff from snowmelt and rain increases the flow in the river. The increased flow raises the water level and may break ice loose from the banks. The ice cover will move and break up and be transported downstream. At some places the quantity of ice will exceed the transport capacity of the river, and an ice jam will form. The jam may then build to thicknesses great enough to raise the water level and cause flooding.

Spring breakup jams are usually very destructive because of the large quantities of ice present. Besides causing sudden flooding, the ice itself may collide with structures and cause damage, even to the point of taking out bridges. Sometimes a jam forms, water builds up above it, and the jam breaks loose and moves downstream only to form again. This process may repeat itself several times.

In the case of the Danube the ice mass does not necessarily form directly in the main riverbed. It is common to receive a huge load via the tributaries (Morava, Váh etc.) and the conglomeration may happen in still zones or technically unfavourable sections in the main riverbed. The incoming ice floes could act like catalysts to initiate or speed up the development of larger ice floes in the Danube.

The ice drift and ice cover block navigation, damage water regulation structures and hamper their operation. In certain cases a whole structure could be covered with ice. The movement of the floating ice can impact the manmade structures and the natural habitats in the riverbed, along the banks and extensively in the floodplain. The driftwood and floating debris accelerate the cumulating process of ice jam. If the ice conveyance is obstructed, ice jams can occur e.g. at shallow sections, bridges or low radius bends which can lead to elevated flood water levels, peaking high above the normal conditions.

1.3
Mitigation measures in general [1]

The hard winter conditions are not easy to handle due to the freezing circumstances and low temperature, so special equipment is needed. Also human resources are usually limited and the performance capacity is far less than in the summer. The number and availability of the experienced crew is reduced, leading to a decrease of capacities that could be utilized in an emergency situation.

Some examples of measures to avoid ice jam on rivers in order to maintain the required flood protection level are listed below:

Thermal shield

It is utilized on structures to temper moveable parts like a sluice gate. The protected component has internal heating assemblies, which keep its temperature above the freezing point. It has only local effect and the aim is to secure the function/operability of the structure. The electric consumption and the cost of the solution depend on the size of the structure. In special cases, the warming could be carried out by manpower as well.

Oscillation of the water level

In case of having a water level influencing structure in the problematic area, it is possible to constantly lift-and-drop the water level in order to avoid the forming of the full surface ice coverage or shredding the plates. This solution eases the upstream conditions as far as the backwater effect still plays a role but the impact is limited and not controlled. The intensified ice plate conveyance can endanger the structure operation and the stability as well.

Intervention from the banks with machinery

It is possible to execute measures with excavators or long cranes but only on smaller streams from banks, bridge pavements or solid structures. As the ice core develops the effectiveness of such activities decreases. It is quite dangerous in general and the riverbanks are usually hard to be reached, particularly those sections, which are subject to protection measures.

Blasting with explosives

Formerly it was an applied routine to use explosives in order to fragment the large ice plates. The location of the detonation determines the effect of the method so the placement of the explosive shall be carried out by divers or by (precise) throwing or dropping. It is very dangerous not only because of the shrapnel dispersed by an explosion, but also due to the handling of the explosive materials. Special permissions and qualifications have to be obtained. The utilization

[1] *Due to the close cooperation with the EU Strategy for the Danube Region Priority Area 5 "Environmental risks", the report includes content from the article "Extremities in winter season – outlook for mitigation measures (Gombás – Balatonyi)", which was published in the Hungarian Journal of Hydrology special issue on 18 October 2017.*

has to take in account the seismic effect and the potential damage of the riverbed or structures around. Despite the complicated circumstances, this is a feasible solution at certain river segments. *(Fig. 7)*.

Gunfire, bombardment

This is a special treatment of river sections in case that no other tools could be utilized. It needs a military intervention.

Icebreaker ships

On larger rivers one of the most important tasks is to keep on the conveyance of the ice plates and at the same time provide a sufficient route for navigation. Both of these goals could be served with special icebreaker ships with reinforced hulls and other appropriate equipment. There are different types of boats and technics to slice the ice plates or the massive surface ice cover. The effectiveness of the measure is based on the ice thickness and the location of the boats, so pre-arrangements are necessary. From downstream to upstream the boats can operate the best. The fleet needs to be regularly maintained to avoid becoming obsolete while its deployment is quite random in time depending on the weather conditions.

An effective - but at the same time the least natural - way of avoiding such problems with ice is to artificially correct the centerline of the river and the floodplain. It means to excavate and rebuild the banks or deploy hard coverage (bank protection), clean and reshape the riverbed. Due to the current horizontal engineering perspective, which respects the environmental objectives of the EU Water Framework Directive, such measures are applied only exceptionally when alternative possibilities have no effect. A proper consideration of ice hazards is a very important aspect during the design phase of any water management structure.

The international aspects of the ice phenomenon are similar to other water related hazards and the effects can extend beyond national borders. The backwater effect influences the water levels in the upstream country and an intensive ice flow could create a devastating situation in any downstream country. The development of the ice-formations is key information and the ice input from the tributaries could play an important role for adequate precautionary actions. Performing an action in the national territory might be less effective than an internationally coordinated operation. The observation is a key issue to a frequent exchange of forecasting data.

2 PAST ICE EVENTS IN THE DANUBE RIVER BASIN

2.1 Danube ice floods in the XIX century

There are many historical examples of ice floods in the Danube Basin. For instance, there are records of the ice flood near **Bratislava in 1408,** and also on large damages caused by ice flood in **Hungary in 1768.** According to archives 557 houses were destroyed.

Bratislava and its surroundings suffered a lot from ice floods in the XIX century. There are still marks in the old city centre indicating the level of ice floods *(Fig. 2)*. From the mid-century the warning service drew attention to the danger of floods by cannon shots from the castle hill. The worst ice flood happened in January **1809,** when the city centre was completely and violently flooded. The Petržalka village on the right side of the Danube River (app. 500 inhabitants in that time) also suffered because almost all houses were destroyed. This is why this flood is considered as a milestone in further urbanization of Petržalka. The next ice flood happened in January **1813** and then again in February **1850**, when the city of Bratislava and the village of Petržalka were flooded and 6 persons died.

The area of present-day **Budapest** was hit by a number of ice floods during the XIX century. The flood of March **1838** was one of the greatest natural disasters in the history of Hungary. Dozens of people, several municipalities and thousands of houses fell victim to the icy deluge. Buda, Pest and Óbuda – the ancestors of the modern capital – suffered the greatest losses and casualties, as well as Csepel and Albertfalva, two settlements at the south of Budapest. The settlements affected by the flood were built within the floodplain area in the second half of the 1700's. The primary causes of the flood were obstructions in

1400 1500 1600 1700

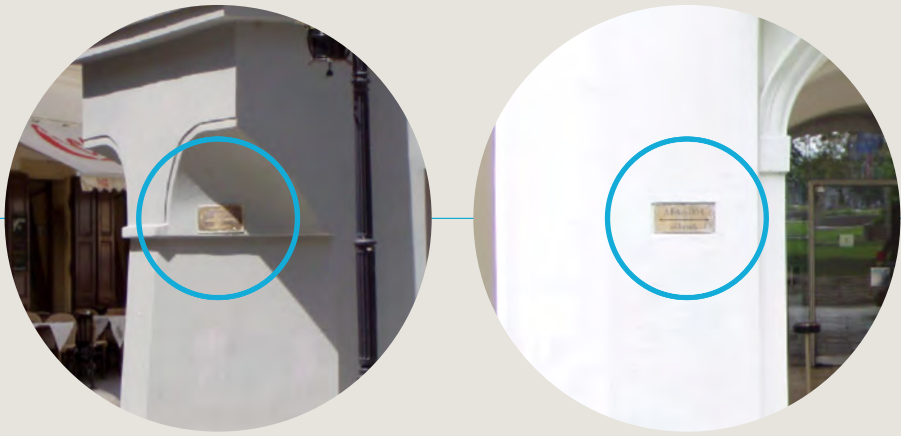
the river channel (two reefs and bifurcation around Csepel Island), which caused the formation of the large ice barrier. The barrier grew during a particularly cold February with temperatures below -18 ºC.

In late February/beginning of March 1838, the spring warming began firstly at the upper parts of the Danube. The ice carried by the thawing water was caught up on the ice barrier and jammed the river even further. At the same time, the discharge of the river constantly raised, due to snow and ice melting. The Danube first burst its banks on 6 March, when some inhabited areas on the right bank were flooded. The water level increased by 2.5 m in 6 days. The dikes built in 1775 could not withstand the water, and the large inhabited areas (including the entire inner city) were flooded by the peak wave. The extent of the flooded area between Pest and Buda was 2800-3200 m, while between Tétény and Soroksár, a 10,600 m wide area was under the icy water for two days[2]. 2281 houses collapsed in Pest, and 601 houses in Buda (including Óbuda). There were 150 casualties, and 50.000 - 60.000 persons became homeless and lost their jobs.

The next destructive ice flood in **Hungary was in 1862,** when many of flood protection dykes collapsed. Another serious ice flood occurred in **Budapest in 1876.** The ice jammed at Ercsi, the water level raised and Óbuda sustained serious damages after inundation. There was an attempt to reduce the water level by ice blasting.

The total duration of ice phenomena on the Lower Danube (Romania) was extreme in some winters of the XIX century. In winter **1841/42** the Danube in Romania was frozen for 95 days, in **1862/63** for 92 days (from early December till the end of February) and in **1880/81** for 101 days (until the end of March). **1863** was an especially difficult winter in the Danube Delta, when several tons of ice barriers formed near Tulcea. No damages were reported.

[2] *Woldemár Lászlóffy, Az 1838-i árvíz és a Duna szabályozása. Vízügyi Közlemények, 1938 (20. évfolyam)*



1860

Figure 2: Reminders on past ice floods in the center of Bratislava

2.2
Danube ice floods in the XX and the beginning of the XXI century

In the XX century, ice conditions on the Middle Danube have been recorded and monitored every year. These records prove that the ice was a standard feature of the Danube winter regime, almost every year. For example, on the Danube section Mohac – Turnu Severin only 6 winters between the period of 1900 and 1970 did not have significant ice formation. In other years, the ice regime was in strong correlation with meteorological conditions. There were only a few mild winters when a short ice drift appeared, while in many years the ice conditions lasted 1 to 3 months.

A slightly better situation was on the Lower Danube, where the Danube has frozen 28 times in the XX century. This picture showing a completely frozen Danube in Romania *(Fig. 3)*, taken in the early 1900s, shows a row of people crossing the river on foot. The first historical records about freezing of the Danube in Bulgaria date from the period 1902-1903. Such phenomena were also recorded in 1906-1907 and 1908-1909. The longest freeze was in 1954-1955, when the ice regime lasted for 89 days. The occurrence of ice events decreased in last 30 years. The last ice phenomena on the Danube in the XX century occurred in the winter of 1985-1986. The river was completely frozen in the region of Silistra and the ice regime lasted until mid-March.

Winter 1922/1923

On February 17, the Danube River in **Bratislava** overflowed its riverbed and caused considerable damage. The water level reached 886 cm *(Fig. 4)*. In the same winter, the ice on the Middle Danube lasted only ten days and caused no problems.

Winter 1928/1929

It was one of the coldest winters on record in the Danube River Basin. An extremely cold wave lasted from the beginning of January to the end of February 1929. Air temperatures were extremely low *(Fig. 5)*. These weather conditions resulted in icing along the entire

1900

Figure 3: Ice on the Danube River in Romania

Figure 4: Bratislava, February 1923

1925

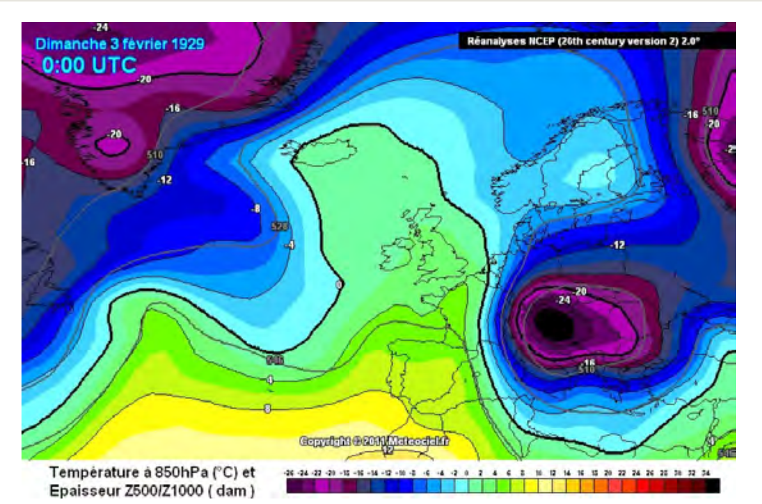


Figure 5: Reconstruction of air temperatures in Europe at the beginning of February 1929 (http://www.meteociel.fr)

course of the Danube from Linz to the Black Sea. Ice conditions lasted for more than three months, and ice cover for about two months. The thickness of the ice was 30 to 50 cm (excluding ice jams).

Ice induced considerable damages in **Bratislava,** where the ships along the banks were smashed.

Problems with ice on the **Yugoslav sector of the Danube (presently shared by Serbia and Croatia)** were significant. Ice jams began to occur as early as the beginning of February, during the first ice drift. At critical reaches (e.g. at Dalj, km 1355), the thickness of the accumulated ice was 3 to 5 m.

At nearly the same time an ice jam was formed in the narrowest part of the Iron Gates gorge, which stopped the flow of the Danube and raised the river stage by some 4 m. Along other reaches (e.g. at Belgrade), there was a 50 cm thick plate-like ice cover, which people and vehicles could easily cross.

The ice cover lasted until mid-March, at which time warming and increased water levels caused the ice to break up and drift. The sudden drift of ice destroyed a ship winter shelter in Belgrade, and many ships sunk *(Fig. 6)*.

The drifting ice created ice jams on many locations along the Danube, backing up the flow upstream and threatening ice floods. To prevent flooding, the military was deployed to break up the ice around bridge piers and blast ice jams at the Dalj bend and the Iron Gates gorge *(Fig. 7)*. The ice finally melted at the end of March.

Figure 6: Sunk ships at the confluence of the Sava and the Danube

Figure 7: Blasting of ice in the Djerdap gorge

1935

Winter 1939/1940

On the **Serbian** section of the Danube, this winter was similar to that of 1928/29 in meteorological terms and with regard to the duration of ice. However, the hydrologic conditions were much more hostile, especially during the spring ice drift. Since the discharge of the Danube downstream from the mouth of the Velika Morava was extremely high (Q_{max}=12000 m^3/s), very high river stages were recorded. The most threatened zone was near Smederevo, due to downstream ice jams.

Winter 1940/1941

The ice jammed and caused dike failure at many places in **Hungary,** between Dunaföldvár and Apostag. Huge areas were inundated, and two persons were reported dead. The ice barriers were bombed by aeroplanes for the first time.

Winter 1941/1942

The river was frozen and rescue operations were carried out along the **whole Bulgarian** riverbank. According to the available historical records, the ice floes blocked the river in the region of town Vidin and the water level increased rapidly. The water overflowed the protection facilities, land dikes and drainage channels and the city was quickly flooded. The water depth reached up to 5 meters. 345 residential buildings in the town were destroyed or heavily damaged and threatened by collapse *(Fig. 8)*. 665 buildings in the surrounding villages were destroyed or damaged. Almost the entire population of Vidin was evacuated. 13 people died in the flood. The rescue campaign lasted 7 days.

Winter 1946/1947

On 14 March the Danube River was frozen along a 12 km stretch of **Bratislava**. Although there was an attempt to destroy ice by airplane bombing, the water flew over river banks and flooded mainly the Petržalka village.

Winter 1953/1954

It was very cold and ice conditions on the Middle Danube lasted for a very long time (about 80 days).

1940

Figure 8: Vidin, Bulgaria March 1942 (https://www.24chasa.bg/Article/1227002)

Figure 9: Completely frozen Danube in Bratislava, 1956

There were several occurrences of ice jams, mostly in the **Iron Gates sector.** The spring ice drift in March 1954 coincided with elevated discharges of the Danube (9000 m^3/s downstream from the mouth of the Velika Morava) and the town of Donji Milanovac was flooded.

This was the worst winter in **Romania** during the period 1900-1982. Downstream of Călăraşi the total duration of ice phenomena exceeded 90 days (Sulina 97, Galaţi and Călăraşi 93, and in Tulcea 90 days), while ice cover was present 80-85 days (Hârşova 85, and in Cernavodă 84 days).

Winter 1955/1956

Major ice floods were recorded in Slovakia and Hungary. The Danube in Bratislava was completely frozen on February 20th *(Fig. 9)*, obstructing the water flow and inducing the increase of water levels. Ice coverage was 1.8 m thick *(Fig. 10)*. The water level reached 912 cm on 3rd March, when the attempt to destroy the ice cover by aerial bombing began.

A huge ice volume accumulated along the Danube River in Hungary. In mid-March, local ice thickness reached almost 8 m. The ice jams were blasted by the military and aeroplanes, while thousands of people worked on the flood protection dikes and used almost 1,5 million sandbags. These activities were concentrated near Mohács. None of the undertaken defence measures were effective, and ice flood caused by ice jams upstream from the mouth of the Drava River (Serbian/Croatian sector of the Danube) hit the area. The “Margitta Island” was fully inundated, and 5800 persons had to be evacuated. The 1956 ice flood caused 58 dike crashes and 740 square kilometers were flooded, from 39 settlements over 57.000 persons were evacuated. *(Fig. 11 a, b)*.

There were also ice jams along the Serbian reach of the Danube (near the mouth of the Velika Morava and the Iron Gates). However, the ice jams were blasted and ice floods prevented.

Figure 10: Standing ice in Bratislava, 1956

Figures 11a, 11b: Devastating effects of the 1955/56 ice flood in Hungary

Winter 1963/196

was very cold and ice coverage remained for a long time (from the **Hungarian border** down to Drava river mouth 71 days). Significant problems were not reported.

Winter 1984/1985

had two separate cold waves on the **former Yugoslavian section** (December – January and in February). Upstream from Novi Sad, ice lasted for 40-45 days and ice cover for 10-20 days. Within the zone of Iron Gate 1 HPP, ice conditions lasted for 30-40 days and ice cover for 15-20 days. In the first cold period, the ice cover formed quickly along the entire course of the Danube in Serbia, due to low temperatures and low river discharges. In the second instance, only ice drift occurred at much higher discharges of the Danube. Between the Hungarian border and Belgrade, active ice management involved four Hungarian icebreakers no. I, V, VII and XI *(Fig. 12)* and two Serbian icebreakers (Čakor and Vučevo). Another pair of Serbian icebreakers (Greben and Bor) operated downstream of Belgrade. Given that the river stages were low during the first cold wave and there were only ice drifts during the second, there was no danger of ice floods.

In the winter of 1984 - 1985 the ice floes in the region of the town of Tutrakan (Bulgaria) reached 11 m in thickness.

Winter 2011/2012

Due to the extremely cold weather, which started at the beginning of February, a critical situation appeared on the Danube River in **Slovakia**. The water table in the Hrušov storage basin *(Fig. 13)* and the Gabčíkovo canal *(Fig. 14)* were completely covered by ice. The ice coming from the Morava River significantly affected the situation in the Danube River.

Ice conditions on the Danube section in **Serbia** *(Fig. 15-18)* lasted for 20-26 days and the longest-lasting ice cover was at the Iron Gates reservoir (25 days). The discharges of the Danube were around average for that time of the year. Active ice management at

Figure 12: Hungarian icebreakers near Dalj, 1985

2000

Figure 13: Ice breaking at Hrušov storage basin

Figure 14: Frozen water-table of Gabčíkovo canal

the common HU-RS sector included four Hungarian icebreakers (VII, Széchenyi, VI. and XI.), which were deployed only to break an ice barrier in the Dalj bend, on 12 and 13 February *(Fig. 15)*. The Serbian ice-breaker Greben operated in the Iron Gates sector, for five days. There was no threat of ice floods, but the ice drifts damaged riverside structures.

In 2012, the Danube River was completely frozen from the 510 km to 496 km (Ruse) and from 485 km to 375 km (Silistra) on the **Bulgarian section.** Due to the potential flood danger, an emergency reserve of sandbags for the building of additional protective dikes was ensured.

Figure 15: Dalj, 12 February 2012

Figure 16: Novi Sad, 18 February 2012

Figure 17: Grocka, 25 February 2012

Figure 18: upstream Iron Gates dam, 25 February 2012.

2.3
Description of changes in the Danube ice regime

When ice regime changes of the Danube are considered, the complexity of ice formation and its dependence of several important factors need to be addressed. Apart from natural drivers related to climate conditions, it is important to note that anthropogenic factors, which affect hydraulic and morphological parameters and the river's thermal regime also play an important role in that process.

2.3.1
Meteorological conditions in the Danube River Basin

Meteorological parameters are fundamental drivers of a river's ice regime. The most significant among them is the air temperature along the river's course, but also in the entire river basin.

The analysis of meteorological conditions along the Danube in the XX century shows certain changes in the meteorological drivers of its winter regime. The mean annual air temperature in **Hungary** has increased between 1901 and 2009 *(Fig. 19)*, while the number of frosty days decreased *(Fig. 20)*[4]. The warming is more intensive after the 1970s, from which point the decreasing length of icy periods on the Danube can also be observed.

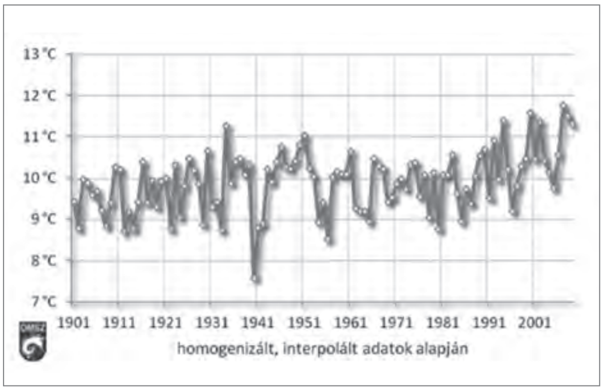


Figure 19: Annual mean air temperature in Hungary from 1901 to 2009.(Source:http://www.met.hu/eghajlat/magyarorszag_eghajlata/altalanos_eghajlati_jellemzes/homerseklet/)

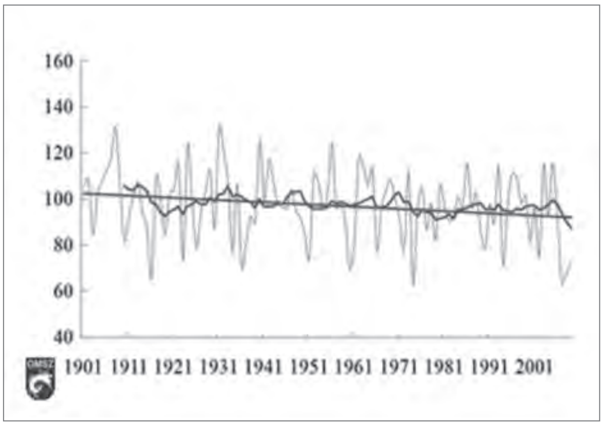


Figure 20: The annual number of frosty days (grey curve) with 10-year moving average (black curve) and the estimated linear trend between 1901 and 2009. (Source: http://www.met.hu/eghajlat/eghajlatvaltozas/megfigyelt_valtozasok/Magyarorszag/)

[4] *Szalai S., Szentimrey T., 2000: Has the climate of Hungary warmed in the 20th century? - in Hungarian*

Similar tendency in the period from 1900 to 2014 is observed in **Serbia.** *Fig. 21* shows the variation of a specific indicator of winter meteorological regime – a numerical sum of negative mean daily air temperatures during a winter period. Sum of negative mean daily air temperatures is between 0°C and -50°C in mild winters, between -50°C and -180°C in cold winters, while long and exceptionally cold winters are characterized by values between -180°C and -450°C (as in the coldest winter 1928/29). Comparing the periods of 1900-1970 (P1) and 1971-2014 (P2), from a qualitative perspective, both periods exhibit similar characteristics with regard to variation and alternating average and severe winters. From a quantitative perspective, however, there are differences between these two periods as exceptionally cold winters were more frequent during 1900-1970.

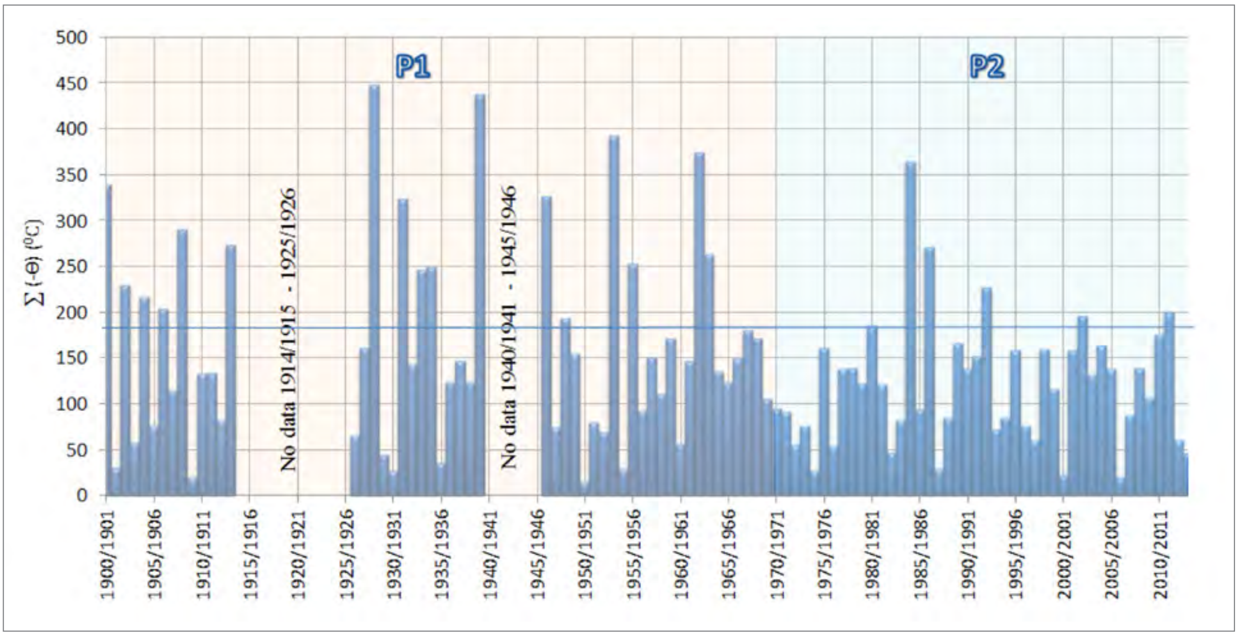


Figure 21: Histogram presenting the sum of negative mean daily air temperatures during winter period, at the meteorological station Veliko Gradiste (km 1059), 1901-2014

2.3.2
Changes of the Danube water temperature

In response to the provisions of the ICPDR Climate Change Adaptation Strategy the ICPDR Monitoring and Assessment Expert Group has been analysing the data on Danube water temperature. Trend analyses have shown that water temperatures have increased since the mid-1970s *(Fig. 22)*.

Water temperature during winter is an extremely important hydrodynamic parameter, which strongly depends on the formation of ice. It is important to note that this process does not depend solely on air temperature, but also on other drivers of the river cooling process. It is influenced by the inflow of the

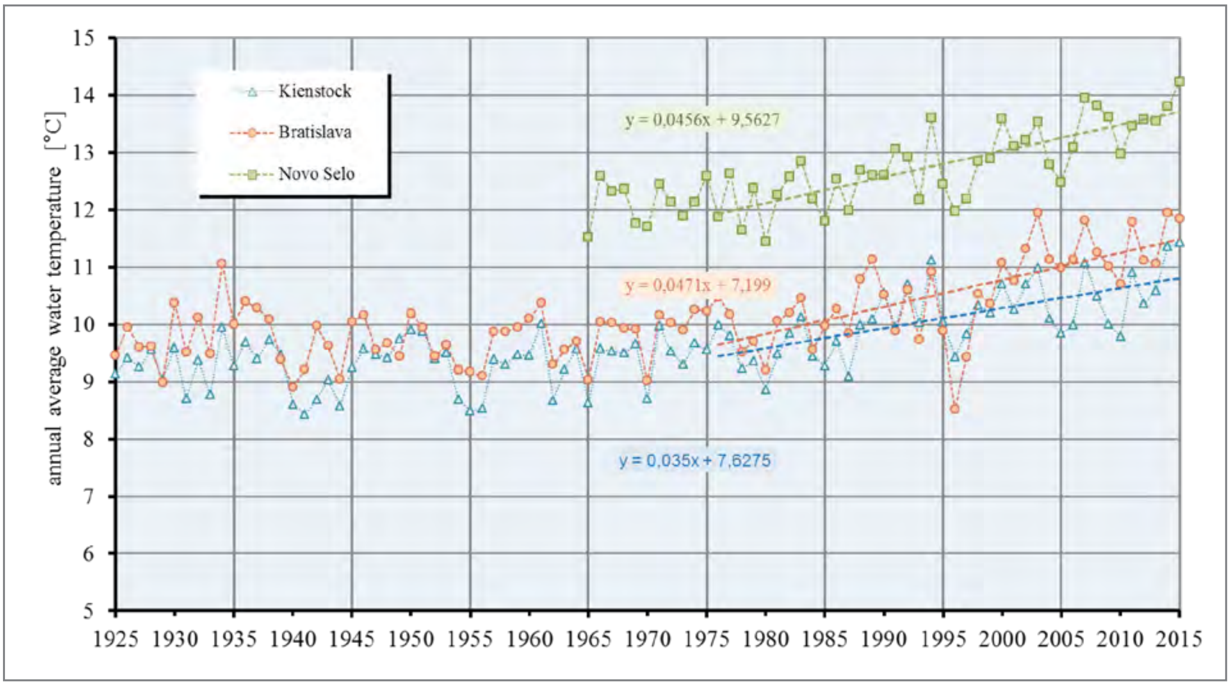


Figure 22: Annual average water temperature 1925 - 2015 at the measuring points in AT (Kienstock), SK (Bratislava) and BG (Novo Selo)

groundwater and the purified sewage for instance, and also by the diffuse load of agricultural substances. The ice regime has changed a lot because of the regulatory activities as well, that have been carried out in the last 200 years. The generally decreased water levels and increased local streams also effect ice development.

The river cooling process begins in autumn and is accelerated with the onset of sub-zero air temperatures. The rate of river cooling down to 0°C, or to the time the water begins to change its physical state, depends on weather conditions and the downward mean daily air temperature gradient. In the case of a sudden cold wave and several days of low average temperatures, the time interval of water temperature decline from 3-5°C (most frequent before the onset of sub-zero mean daily air temperatures) to 0°C takes 5-15 days.

The formation of ice on the Danube River occurs when the average daily temperatures drop below -4 or -5°C for 5 or 6 days in a row. However, in some cases this process of ice formation may be extremely quick. As an example, in winter 1933/1934, at particularly low waters and a 10 Beaufort wind blowing against the water flow, St. George's arm in the Danube Delta was frozen in one night over its entire length.

2.3.3
Changes of the Danube ice regime

Analysis of the long-term changes of the ice regime in **Bratislava and Mohacs** shows a clearly decreasing tendency between 1880 and 1980[7] *(Fig. 23)*. Length in days of the ice period diminished significantly at the end of the period in comparison to the end of the XIX century when the ice lasted 50 to 70 days in average.

Fig. 24 presents results of a similar analysis for the Danube at **Rajka and Mohács,** between 1953 and 2011. It shows that in the last 30-40 years the average length of the icy period remained below 20 days, which is a significant decrease compared to the previous decades.

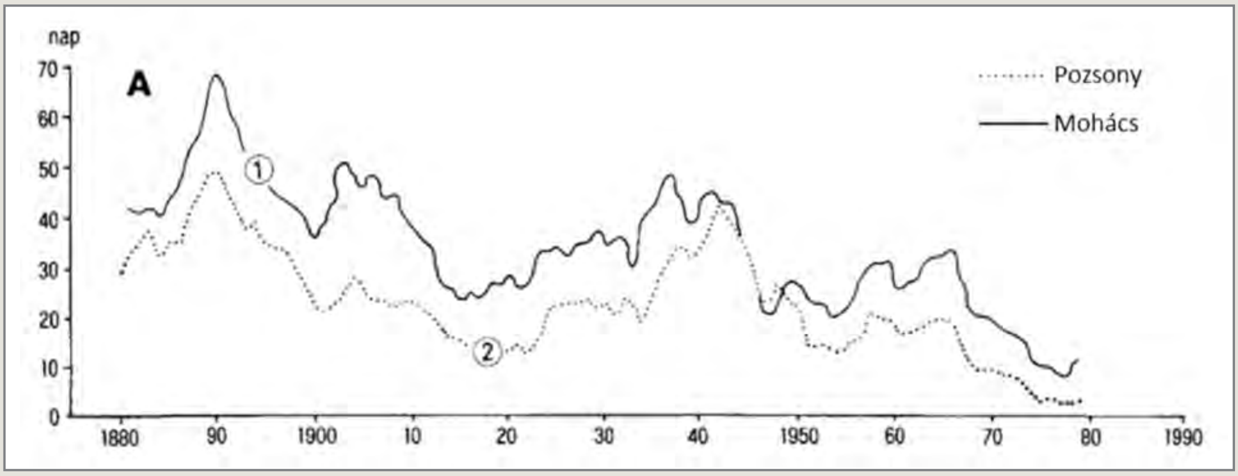


Figure 23: Changes of the average length of the Danube icy period at Bratislava (Pozsony) and Mohács. (Note: the diagram shows 10-years moving average to highlight long-term trends)

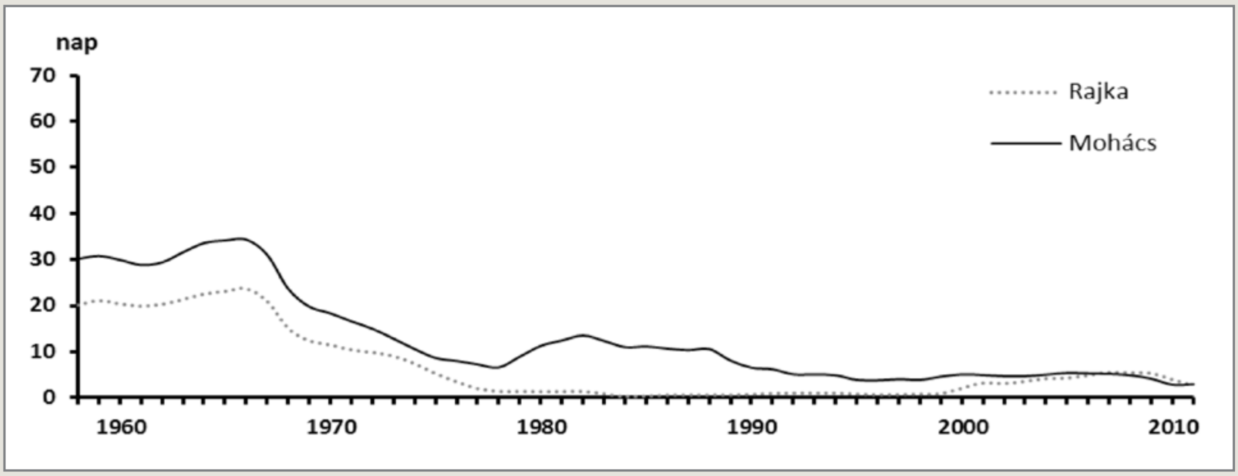


Figure 24: Changes of the average length of the Danube icy period at Rajka and Mohács. (Note: the diagram shows 10-years moving average to highlight longer-term trends)

[7] *Lovász Gy: A jégviszonyok évszázados változásai a Kárpát-medence folyóin (Földrajzi Értesítő XL. Évf. 1991.3-4. Füzet, pp. 347-353.*

An analogous comparative analysis was done for the **Serbian river section**[8], using data on ice observed in between 1900-1970 and 1971-2014. The year 1971 was selected as the cut-off year between the two periods, because it marked the completion of the Iron Gate 1 HPP dam and the formation of the reservoir, which altered the ice regime to a considerable extent. Additionally, a significant increase in thermal and chemical pollution of the Danube was recorded after the 1970's. *Figures 25 and 26* reveal a large difference between the two periods: in 1900-1970 the ice appeared on the Danube in 70 to 90% of winter periods, and in 1971-2014 in 30 to 60%. The frequency of ice cover forming in 1900-1970 varied from 30 to 60%, and in 1971-2014 from 3 to 18%.

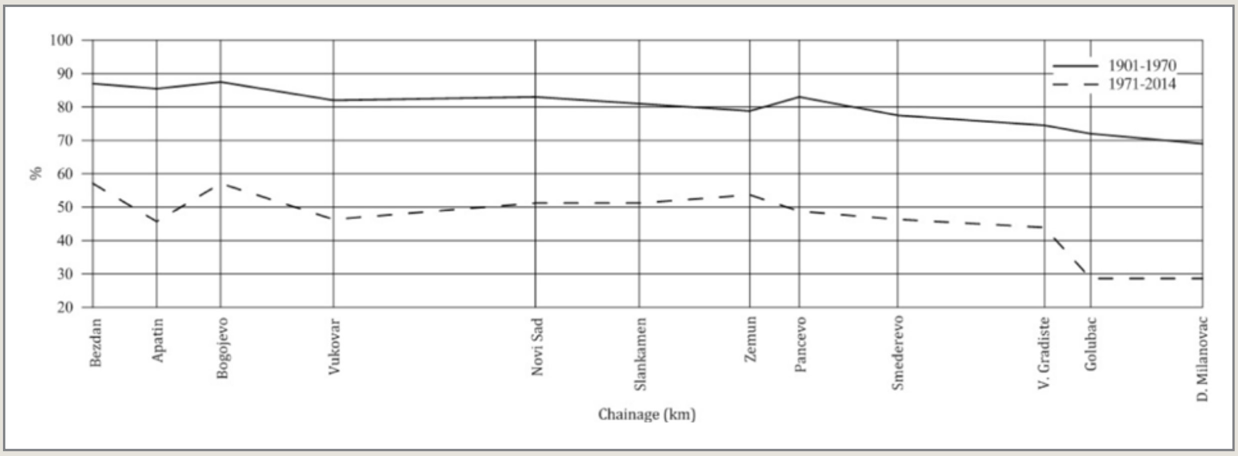


Figure 25: Ice frequency on the Serbian section, 1900-1970 and 1971-2014

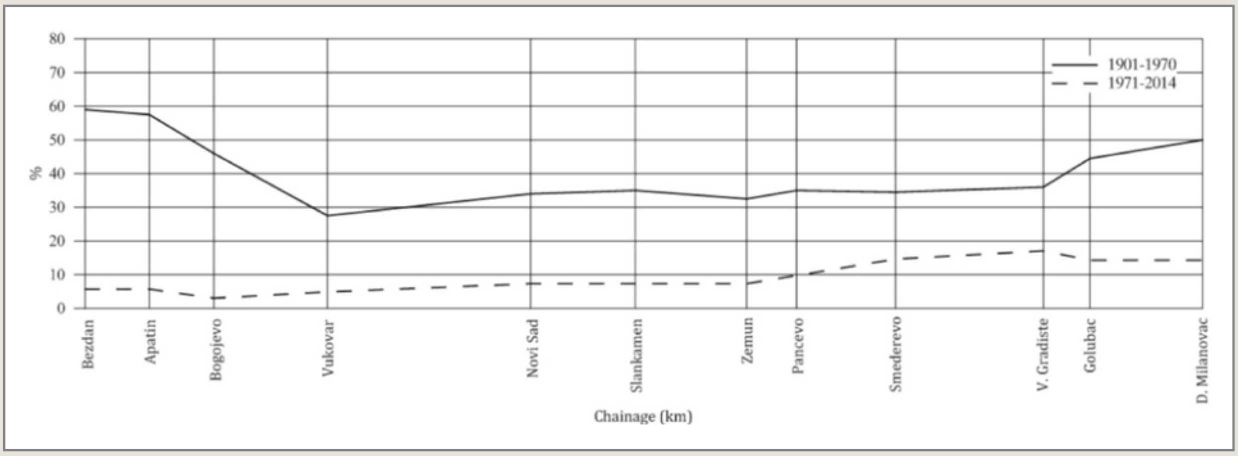


Figure 26: Ice cover frequency on the Serbian section, 1900-1970 and 1971-2014

[8] *Petković S., Babić-Mladenović M., Batroš Divac V. (2015): Ice Regime Variation in the 20th Century Along the Serbian Sector of the Danube and Assessment of Global Climate Change Impact, Journal of Serbian Water Pollution Control Society „Water Research and Management“ (http://www.wrmjournal.com)*

Another important indicator is the duration of ice phenomena and ice cover. *Figures 27 and 28* show the variations in maximum durations of ice phenomena and ice cover along the Serbian sector of the Danube, for considered periods. The figures attest to large differences between the two periods. The maximum duration of ice phenomena in 1900-1970 was 69–94 days, while in 1971-2014 it was 31–54 days. The duration of static ice cover in 1900-1970 was 56–85 days, and in 1971-2014 10–31 days.

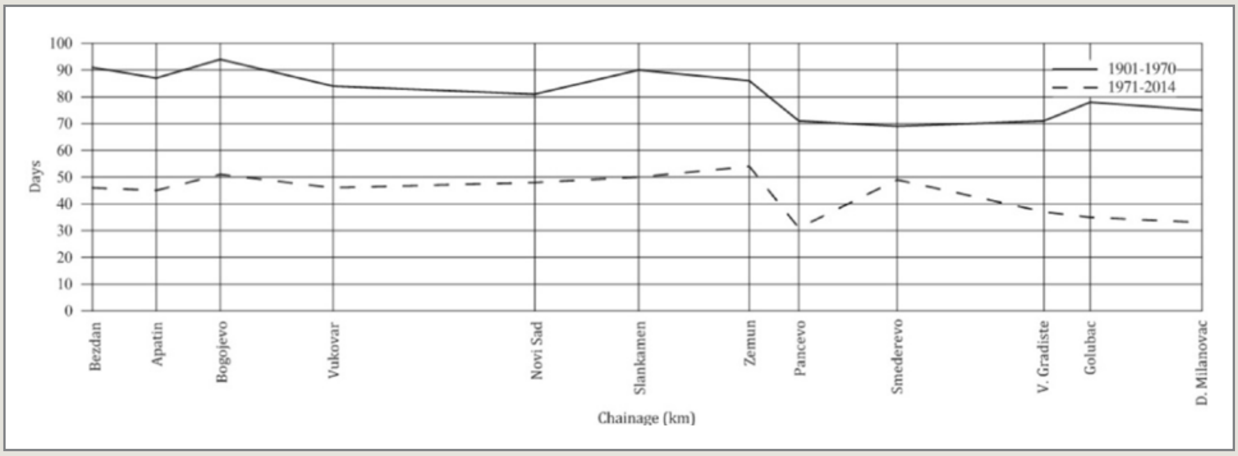


Figure 27: Maximum ice duration on the Serbian section, 1900-1970 and 1971-2014

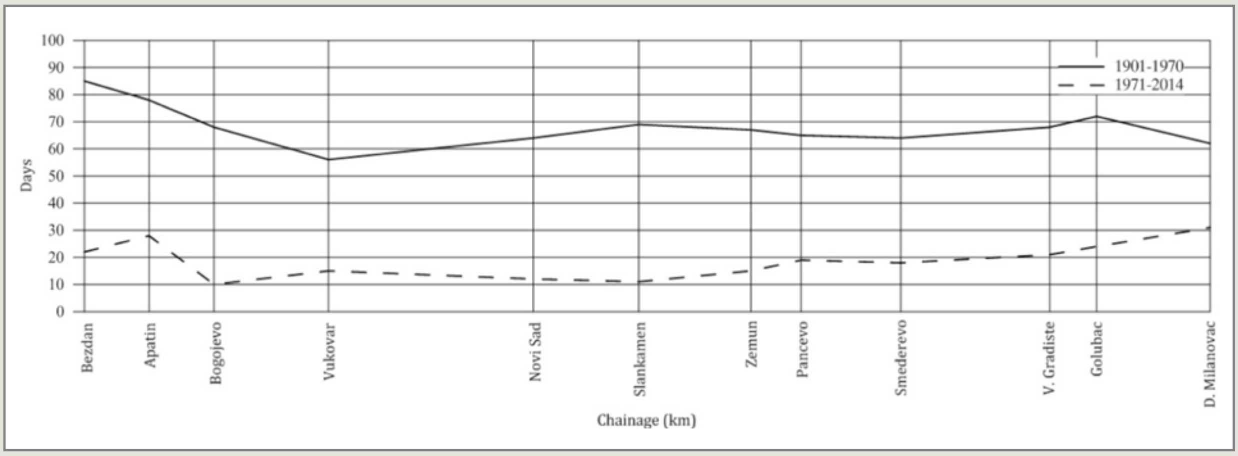


Figure 28: Maximum ice cover duration on the Serbian section, 1900-1970 and 1971-2014

In the first decade of the XXI century, the ice appearance on the Danube River stretch in Croatia was observed less frequently than in the past. After the winter 1986/87, ice was recorded only in the years between 2001 and 2012. All these ice events were characterized by a significantly lower intensity and shorter duration than the events in the previous century, mainly because extremely cold and long lasting winters did not appear. Moreover, nowadays the processes of the water-cooling are slower due to the thermal and chemical pollution of the river.

According to information from EAEMDR in **Bulgaria** (the Executive Agency for Exploration and Maintenance of the Danube River), ice phenomena on the Danube are usually observed from December to March, most often in January. The occurrence of these phenomena is very unstable with regards to either time period they occur or their duration. The ice conditions on the Danube usually appear when three major factors are in place: a prolonged period of at least 10 days, in which the air temperature is below -10°C; low water level and a water temperature of 0°C.

The ice regime has decreased over the past 30 winters. According to the observation of EAEMDR, the appearance of ice events on the Bulgarian Danube section as well as their duration reduced significantly after the Iron Gate 1 dam was put into operation in 1972. The Iron Gate 1 and Iron Gate 2 dams have an influence on the ice-regime on the Bulgarian Danube stretch because they retain the ice formed in the upper part of the Danube and release water from a greater depth. The temperature of the released water is higher than the freezing point, which affects the water-temperature on the upper part of the Bulgarian Danube section. *(Fig. 29.)*

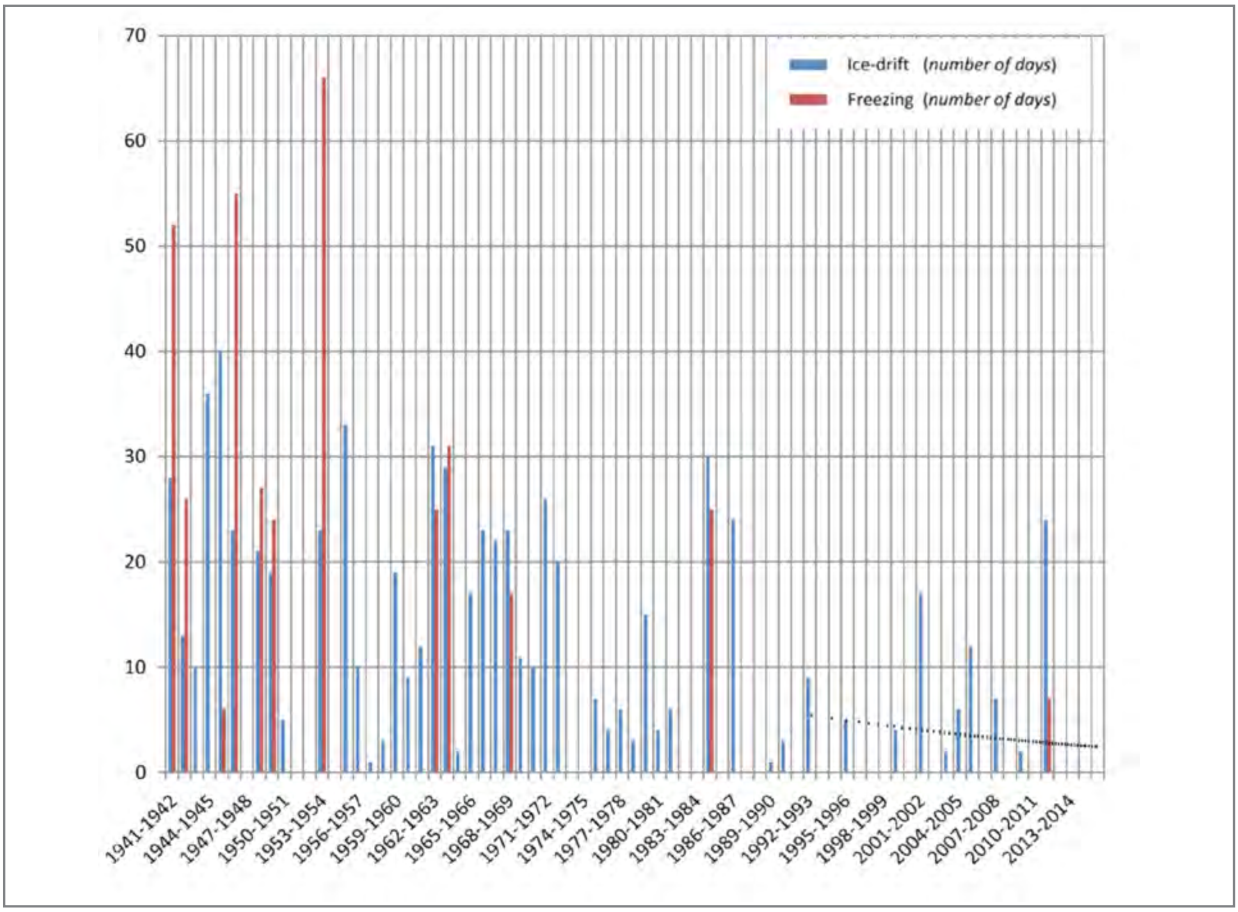


Figure 29: Statistical overview of the ice-events on the Danube at Ruse (km 496) between 1941 and 2016

2.3.4
Building of dams and HPPs

In the XX century dams and hydropower plants (HPPs) were built on the Danube in **Austria and Slovakia.** These installations have different impacts on the downstream and upstream ice regime. The hydraulic conditions in the reach upstream of the dam (decreased slope and water velocity, decreased water depth due to sediment deposition, etc.) favour ice formation. By contrast, the hydraulic conditions downstream decrease the probability of ice formation (high water velocity, fluctuating water depth, etc.). Nevertheless the dam operation could enhance the ice flow with fragmenting the plates by oscillating the upstream water level.

Due to the effect of upstream dams and HPPs, the probability of ice along the Danube in **Hungary** is higher at Mohács than at the Danube section above Budapest. It is also important to note that the ice drifts released from backwater pools of hydropower plants can have a significant impact on the Hungarian section of the Danube. If the stored ice at the Austrian and Slovak hydropower plants is let through at the same time, then the risk of ice jam formation will increase significantly on the Hungarian Danube section.

Similarly, the Iron Gate 1 HPP had a tremendous effect on the ice regime in the **Serbian sector** of the Danube. Above all, the dam totally changed the ice flow boundary conditions in two ways: first it acts as a physical barrier to the incoming ice (evacuation of ice over the dam spillway is found to be impossible), and second as a hydraulic barrier as well (due to low flow velocity and ice discharge capacity immediately upstream from the dam). The hydraulic and morphological conditions of the ice regime along the lengthy reservoir (more than 300 km from the dam) were also altered to a large extent. The lowered ice conveyance capacity of the river channel (compared to the Danube's natural regime) tends to hinder the ice drift from the upstream sector of the Danube. In current conditions, there is no transit of ice through the Serbian territory, i.e. all ice that comes from Hungary or is formed at the Serbian section of the Danube, remains within the Iron Gate 1 reservoir until it melts.

The section of the Danube from the Iron Gate 1 HPP to the **Bulgarian border** may be considered as the easiest. Unsteady operations of Iron Gate 1 and Iron Gate 2 HPPs govern the ice regime in this sector, and the occurrence of ice is significantly less frequent than in the upstream reservoir.

2.3.5
River training works

Until the large river training works started in the middle of the XIX century, ice jamming caused exceptionally devastating floods on the Pannonian Central Danube[9]. The river training works executed under uniform principles improved the situation, but still further measures had to be taken.

River training works on downstream sections of the Danube were beneficial for the ice control as they decrease the seriousness of the ice threat, enabling better ice drift and thus prevent ice jamming. However, there are many remaining critical locations **between the Hungarian border and the upstream end of the Iron Gate gorge,** where the ice drift may stop and the ice jam develop. These are sharp river bends and other unfavourable locations *(Fig. 30),* where ice transport capacity is low (as constrictions, bifurcations around river islands, confluences of large tributaries etc.).

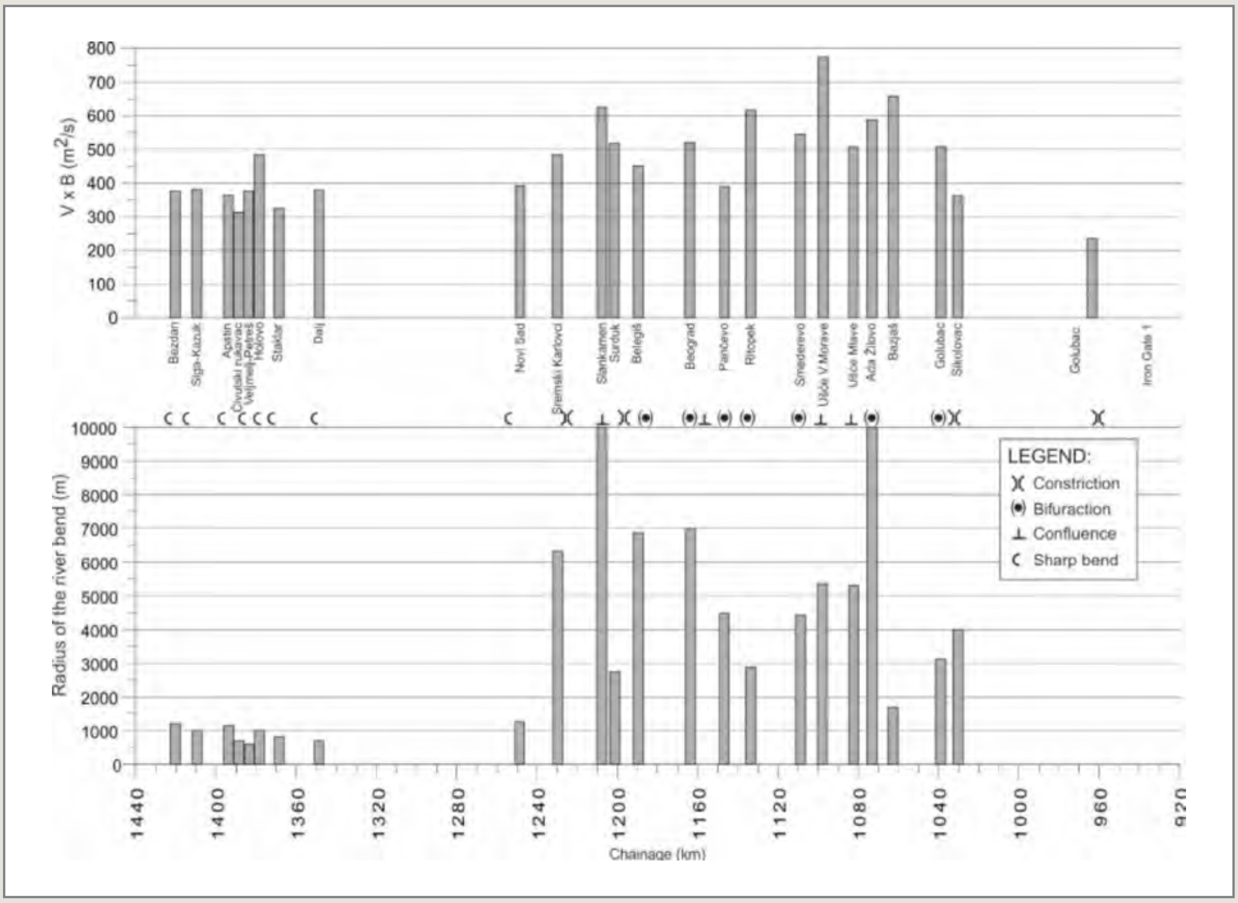


Figure 30: Critical locations for ice conveying along the Danube in Serbia

[9] *Flood Action Plan for the Pannonian Central Danube, ICPDR (2009) (https://www.icpdr.org/main/activities-projects/flood-action-plans).*


SZÉCHENY
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3 CURRENT POLICY FOR ICE CONTROL IN THE DANUBE RIVER BASIN

3.1 International agreements

The **Danube River Protection Convention (DRPC),** based on which the ICPDR has been established, asks for activities and measures in the field of flood control and ice-hazards abatement. DRPC Art 16(4) stipulates that in order to control and reduce the risks originated from floods including ice-hazards, the competent authorities shall immediately inform the downstream Danubian States likely to be affected and the ICPDR on the occurrence and run-off of floods as well as on forecasts of ice-hazards (https://www.icpdr.org/main/icpdr/danube-river-protection-convention). The international cooperation on floods and ice hazards in the Danube River Basin has been established within the framework of the ICPDR and is technically carried out by the ICPDR Flood Protection Expert Group.

The **Belgrade Convention** (Convention regarding the regime of navigation on the Danube signed in Belgrade on 18 August 1948) is a multilateral agreement regarding navigation issues on the Danube, and the Danube Commission (http://www.danubecommission.org/dc/en/) was established as a joint body under the Belgrade Convention. One of its duties is to inform the Danube countries downstream about the upcoming flood risk and ice drifts and about ice forecasts. Numerous river training measures derived from this Convention were also favourable for the ice drift conditions along the Danube.

3.2 Bilateral agreements

The bilateral cooperation of the **Slovak Republic** on the border sections of the rivers is based on valid intergovernmental treaties and agreements with Austria, Hungary, Ukraine, Poland and the Czech Republic. Border commissions have specific responsibilities in the field of flood protection and ice drifts and for warning systems as well.

Specific plans are in force to rule the operation during winter regime and ice drifts on the Danube River at the **Gabčíkovo Waterwork** with respect to possible downstream impacts on Hungary. A special body has been established – the Operative Group, where each of the members represent relevant Slovak and Hungarian water management authorities. During the so called "winter regime" one of the regular activities of Slovak Water Management Enterprise is to compile by 30 November each year "Reports on preparedness for the winter regime," which present the measures proposed. After the winter ends the "Reports on behavior during the winter regime" (assessments, requirements and proposals for improvements for the next season) are being produced each year by 15 May. During the ice jam in 2006, the Hungarian colleagues provided solidarity help and at the frozen Danube the Hungarian icebreaker supported the Slovak icebreakers with 24/7 service.

In general, **Hungary** does have an ice protection regulation with all neighbouring countries regarding the major border intersecting water courses. The ice protection regulations are always based on the intergovernmental bilateral water management cooperation agreements or the cross border treaties. In most cases these regulations have – as part of the water damage protection regulation – various levels of detail and different technical content adjusted to the local conditions concerning the management of the ice situations and the necessary measures. For river sections of a high importance, more detailed ice protection plans are available (e.g. Dunakiliti SK-HU, Dunaföldvár-Vukovár HU-HR-SRB). The joint ice protection plans contain all necessary details and in addition to the general regulations they also include the intervention plans and the detailed description of joint measures.

Compared to its neighbouring countries, the ice protection tasks done by icebreakers is a special case as Hungary has a significant Hungarian icebreaker fleet of 19 ships *(Fig. 31)*. The operation of this fleet beyond the borders is also necessary for the protection of Hungarian territories. Separate regulations administer icebreaker deployment in Serbia and Croatia. These regulations determine three ice protection alarm levels: from icebreakers in standby mode to execution of icebreaking tasks and an extraordinary alert. The regulations also administer the bearing of costs and the extent of the area of an icebreaker operation.

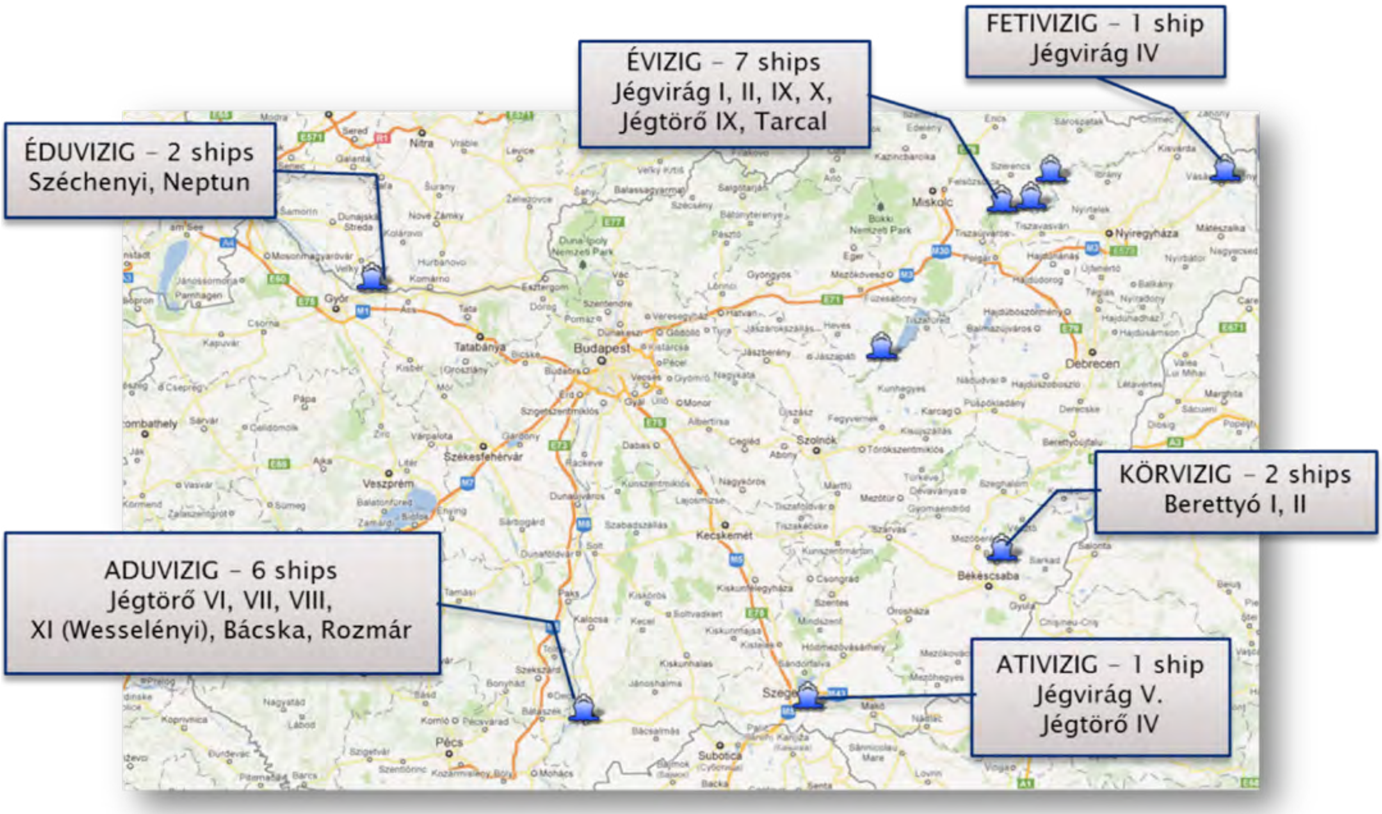


Figure 31: Present homeports of the Hungarian icebreaker fleet

Ice control on the common **Hungarian-Croatian-Serbian** section of the Danube (Dunaföldvár-Vukovar, km 1560 – km 1333) is based on bilateral agreements between Serbia (Yugoslavia) and Hungary and includes permanent exchange of information and icebreaking operations. Since Hungary and Croatia have a similar agreement, a trilateral communication has been established. Those agreements define all necessary aspects of the cooperation between the three countries on this particular stretch of the Danube River and reflect their common interests, including the engagement of the Hungarian icebreakers in order to prevent ice flooding. The experts meet regularly once a year on trilateral HU-HR-RS meetings, where they exchange data on long-term weather forecasts for upcoming winters and other information including the preparedness for implementation of ice control measures.

The **Serbian-Romanian Convention** for exploitation and maintenance of the Iron Gate systems from 1998 is a basis for ice control measures between Belgrade (km 1170) and the mouth of the Timok River (km 845). A fleet of four icebreakers for the ice control within the reservoirs is planned in this Convention. Each party has to provide two icebreakers, capable of working in 0.5 m thick ice. The Romanian icebreakers should work between the Iron Gate 2 dam and the upstream border between countries, while the Serbian fleet should be used in the ice control up to Belgrade. This plan has not been fully implemented, because the modern icebreakers have not been built. The Serbian party employs two vessels during winter (tug Bor and icebreaker Greben), or lends Bor to the Romanian party. It should be noted that this fleet can be used only for maintaining of ice drift or breaking some ice cover, but in critical situations cannot perform the planned role (as was the case during the winter of 1984/85). Additional measure may be variation of water levels at the Iron Gate 1 HPP, although it was never used so far for the ice control within this reservoir.

Bilateral agreements of Romania with the neighbouring countries provide for specific actions necessary to be taken in the event of the occurrence of ice on the inland rivers and on the Danube. In the **Romanian-Hungarian** agreement of 2003 it is specified that each country will take measures to ensure the flow of water and ice on the watercourses that form or cross the border. During the periods of flood danger and during the defence activity, countries shall ensure the exchange of data and hydrological, meteorological and other information necessary to carry out this activity in accordance with the provisions of the specific regulations.

The agreement between **Romania and Serbia** contains measures and actions to mitigate floods, high waters and ice. According to this agreement the defence against floods on the Romanian - Serbian Danube section starts when the ice covers 40% of the Danube at the confluence of the Sava River.

The Agreement between **Romania and Ukraine** from 1997 includes protection and the respective measures against floods caused by high water, internal waters, as well as harmful ice drift. According to this agreement both countries shall work on the border waters and in their basins' actions designed to prevent and reduce the danger of floods, ice and droughts and shall also provide mutual assistance.

Romania has also signed an agreement **with Moldova** on cooperation for the protection and sustainable use of the Prut River and the Danube that includes prevention, mitigation and surveillance of impacts with unfavourable cross-border effects possibly caused by ice phenomena.

The maintenance of the common **Bulgarian-Romanian** waterway is carried out in accordance with the Agreement from 1955. According to the bilateral agreement, in case of occurrence of dangerous ice-events in the common Danube section experts are to prepare an action-plan jointly.


-23°C

4
DESCRIPTION OF THE ICE EVENT IN JANUARY/FEBRUARY 2017

4.1
Meteorological and hydrological situations

An extremely cold, dry air mass of Siberian origin arrived in the Danube River Basin on 6 January 2017, bringing sunny weather and record breaking low temperatures. The cold weather remained until 12 January, when a cyclone brought warmer and wetter air to the region. From 15 January until the very end of the month an anticyclone affected the weather by blocking the cyclones from the west and the colder weather became dominant again.

The mean daily air temperature in January 2017 in Bratislava *(Fig. 32)*, compared to the long-term average, clearly illustrates this meteorological situation. The minimum temperatures in Hungary were below the freezing all month, and dropped to below -20°C to -23°C on the coldest mornings over snow covered territories. In the Tisza basin in Ukraine very cold weather was observed too: from -20°C to -27°C in mountains and from -13°C to -18°C in lowlands. Other countries in the Danube River Basin saw a similar situation in January.

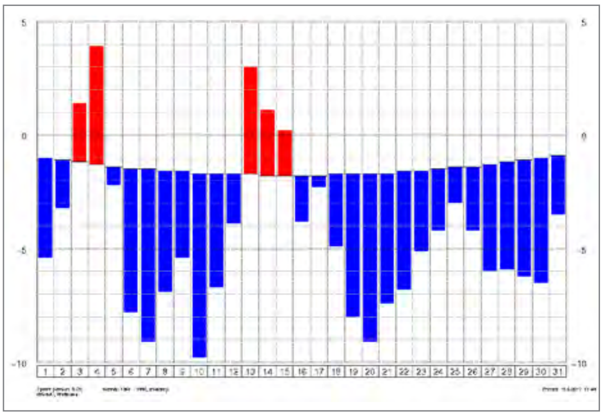


Figure 32: Mean daily air temperature, Bratislava/Airport, January 2017

In Hungary it was the 10th coldest January since 1901 and the coldest one since 1985. In the eastern parts of Croatia the mean monthly air temperature was 3.9°C below the average in the period 1961-1990. The average in Romania was -6.0°C, far below the long-term average and 5th lowest in the period of 1961-2017.

In the first days of February the weather became volatile. Between the 3rd and the 7th of February several fronts passed through Central Europe, causing precipitation and snowmelt.

The sum of negative mean daily air temperatures in January and February 2017 was in Serbia between -15.3°C and -23°C in the riparian belt of the Danube and its tributaries. This was not as large as previously observed in other severe winters in the past and indicates that low water flows also contributed to formation of the abundant ice along the Danube and its tributaries. For example, the Danube flow on the Iron Gate section was 2500 m^3/s *(Fig. 33),* which was half of the monthly multiannual average (4950 m^3/s). A similar hydrological situation was recorded in the whole DRB. Romania reported that the January average in all of Romania's hydrographic basins was between 50-80% of the monthly multiannual averages.

On the Bulgarian section, the combination of low air-temperature; low water temperature; north-eastern wind, snowfall and low water level led to a rapid ice formation and a surprisingly sudden overnight 40% ice drift on 8 January.

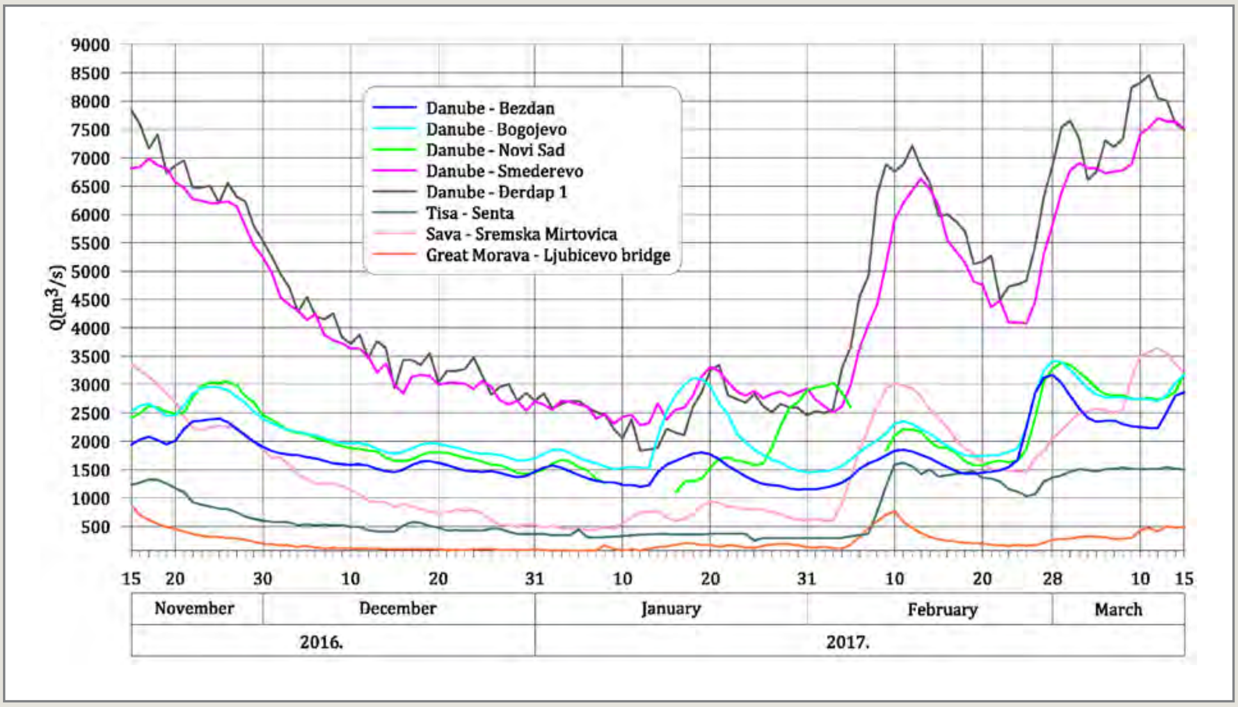


Figure 33: Hydrographs of the Danube River and its tributaries during winter of 2016/17

4.2
Ice phenomena observed along the Danube and on its tributaries

4.2.1
The Danube River

Figure 34: Icebreaking along the Slovak section of the Danube River

In January 2017, the ice appeared on the Danube and caused substantial problems due to its large reach from Slovakia to the Danube delta.

Problems in **Slovakia** were related to navigation and the operation of the Gabčíkovo Waterwork. Three icebreakers were used in the ice control operations, in order to ensure safe navigation *(Fig. 34)*.

The ice conditions at the **Hungarian section** of the Danube River, between 15 November 2016 and 15 March 2017 are presented on *Fig. 35*. The ice drift began on 7 January (upstream part) and 9 January (downstream part), and reached its maximum coverage between 8 and 12 January. After a temporary decrease, the ice drift increased again between 20 and 23 January and then once more between 27 and 31 January. Ice jams were not reported. The section became free of ice on 7 February.

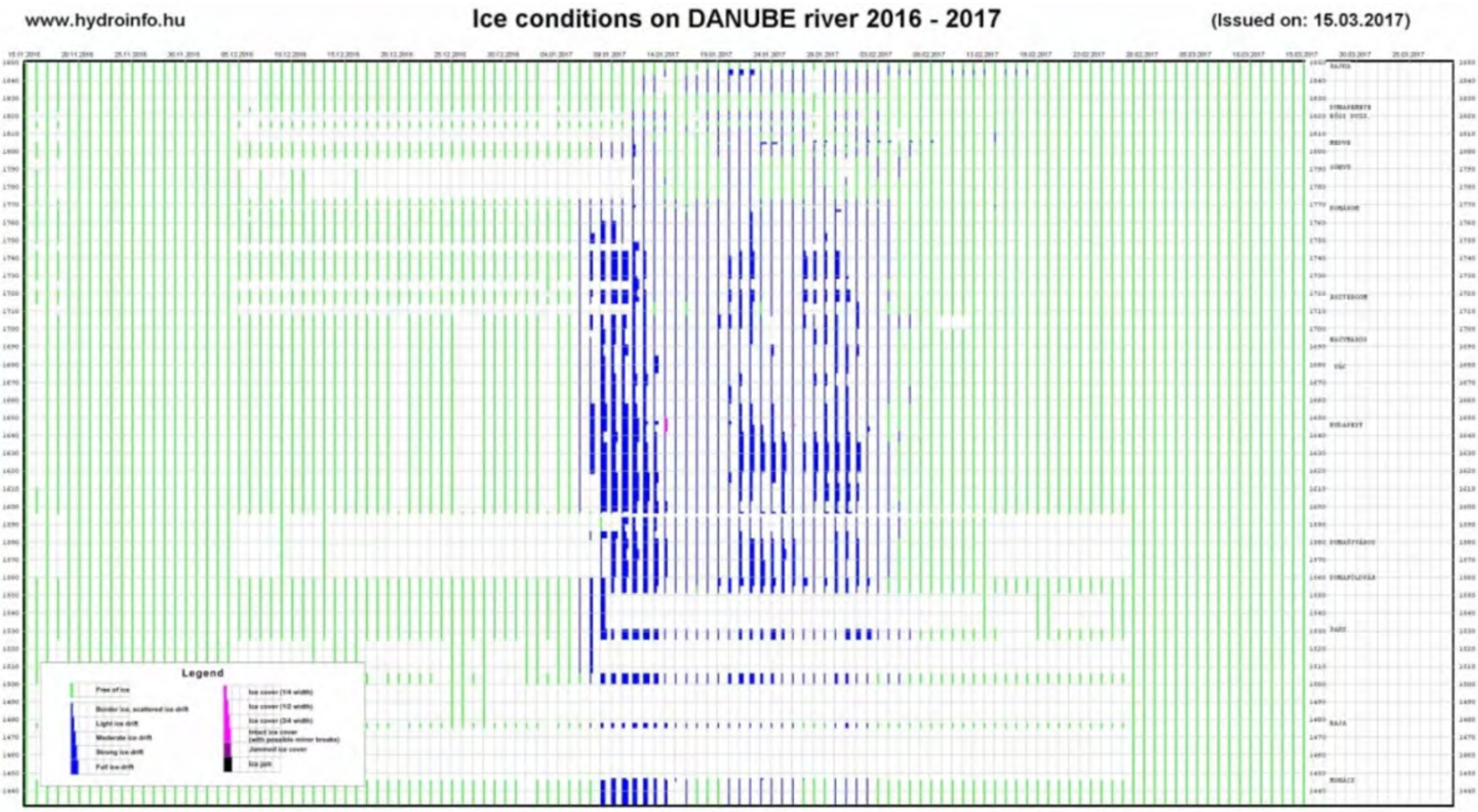
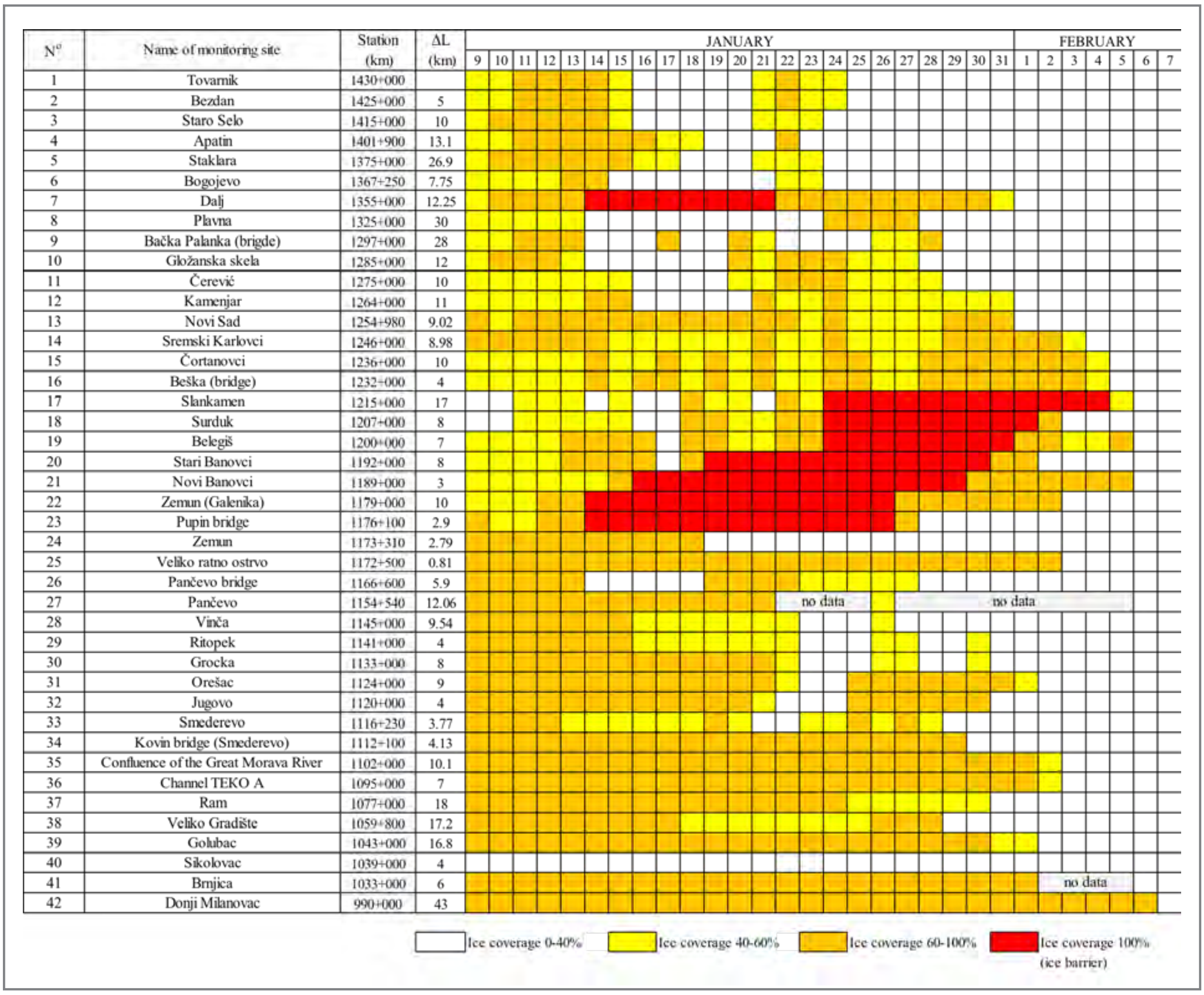


Figure 35: Ice conditions on the Hungarian Danube stretch between 15 November 2016 and 15 March 2017

The chronological presentation of ice events on the Serbian Danube is provided on *Fig. 36.* In yellow we see that the Danube reaches 40-60% ice coverage on the water surface, the orange represents the reaches where ice covered more than 60%, but less than 100% and in the portions in red show a 100% ice cover or with ice barriers.



N°	Name of monitoring site	Station (km)	ΔL (km)
1	Tovarnik	1430+000	
2	Bezdan	1425+000	5
3	Staro Selo	1415+000	10
4	Apatin	1401+900	13.1
5	Staklara	1375+000	26.9
6	Bogojevo	1367+250	7.75
7	Dalj	1355+000	12.25
8	Plavna	1325+000	30
9	Bačka Palanka (brigde)	1297+000	28
10	Gložanska skela	1285+000	12
11	Čerević	1275+000	10
12	Kamenjar	1264+000	11
13	Novi Sad	1254+980	9.02
14	Sremski Karlovci	1246+000	8.98
15	Čortanovci	1236+000	10
16	Beška (bridge)	1232+000	4
17	Slankamen	1215+000	17
18	Surduk	1207+000	8
19	Belegiš	1200+000	7
20	Stari Banovci	1192+000	8
21	Novi Banovci	1189+000	3
22	Zemun (Galenika)	1179+000	10
23	Pupin bridge	1176+100	2.9
24	Zemun	1173+310	2.79
25	Veliko ratno ostrvo	1172+500	0.81
26	Pančevo bridge	1166+600	5.9
27	Pančevo	1154+540	12.06
28	Vinča	1145+000	9.54
29	Ritopek	1141+000	4
30	Grocka	1133+000	8
31	Orešac	1124+000	9
32	Jugovo	1120+000	4
33	Smederevo	1116+230	3.77
34	Kovin bridge (Smederevo)	1112+100	4.13
35	Confluence of the Great Morava River	1102+000	10.1
36	Channel TEKO A	1095+000	7
37	Ram	1077+000	18
38	Veliko Gradište	1059+800	17.2
39	Golubac	1043+000	16.8
40	Sikolovac	1039+000	4
41	Brnjica	1033+000	6
42	Donji Milanovac	990+000	43

Figure 36: Summary of ice events on the Danube River in Serbia

In the common **HU-HR-RS sector,** the most critical situation occurred in the Dalj river bend, where by 14 January, there was 100% ice cover. In some places, the thickness of the ice exceeded 3m and the water level at the upstream gauge station Bogojevo rose to 2.5 m *(Fig. 37)*. Hungarian icebreakers *(Fig. 38)* made a corridor through the ice jam on 22 January. The ice remained in place until 31 January.

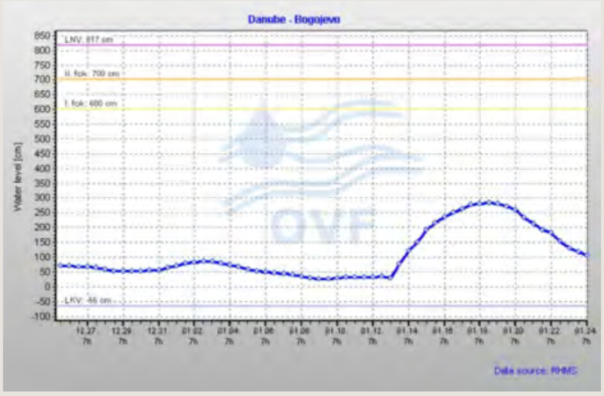


Figure 37: Danube water levels at Bogojevo between 26 December 2016 and 24 January 2017

Figure 38: Dalj (km 1355), 22 January 2017

The ice in the **Novi Sad sharp bend** was long lasting *(Fig. 39),* but slowly drifted downstream. On 14 January, the ice drift stopped at Zemun (a few kilometres upstream of the Sava river mouth) and located upstream of the recently built Pupin Bridge. The 100% ice cover spread upstream for 40 km *(Fig. 40),* and its thickness grew. Hungarian icebreakers were deployed from 24 January to 5 February and they cut a channel through the ice. The last ice drift (10%) was reported on 9 February.

Figure 39: Novi Sad (km 1255), 09 January 2017

Figure 40: Novi Banovci (km 1189), 28 January 2017

On 9 January along the entire **section from Belgrade to the Iron Gate 1 Dam,** ice was formed and covered up to 100% of water table *(Figs. 41 and 42).* The ice thickness was 10-30 cm. No ice jams were reported. The Serbian icebreaker Greben operated in this area. The ice cover slowly disappeared until 8 February.

Figure 41: Kovin-Smederevo bridge (km 1112), 25 January 2017

Figure 42: Mouth of the Velika Morava River (km 1105), 27 January 2017

In the **Bulgarian section of the Danube** at Silistra the river was frozen from 16 January to 12 February and for a couple of days Ruse was fully blocked as well. From Novo Selo to Silistra 10-80% of ice conveyance was recorded between 8 January and 16 February. *(Figs. 43a and 43b).*

Figure 43a, 43b: Danube – January-February 2017, Bulgaria (source EAEMDR)

The first ice formations appeared on the **Romanian Danube sector** on 7 January (ice covered 10% of the surface water at the Calafat and Olteniţa hydrometric stations and 60% on the Borcea branch). On 8 and 9 January the ice was observed at gauge stations Turnu Măgurele, Zimnicea, Giurgiu and Călărași. Until 20 January, the ice phaenomena was present all along the Romanian Danube and the Delta: at sectors Gruia-Olteniţa, Cernavodă- Hârșova and Brăila-Galați shore ice and ice drift (on 3-50% of the surface) prevailed, while at Călărași, Fetești, Vadu Oii and Isaccea-Tulcea ice jams were present. In the Danube Delta ice drift and ice jams occurred.

Between 21 and 31 January ice formations remained unchanged, but they later expanded and intensified until the end of the month. On the Danube sectors Gruia-Giurgiu, Hârșova and the Isaccea - Tulcea shore ice and ice drifts (in 10-50% of the water) were present, while in the sectors Olteniţa-Cernavodă and Brăila-Galați the ice cover prevailed.

The **navigation channels Danube - Black Sea** and Poarta Albă-Midia Năvodari have a special flow regime. The flow rate should be 4 m/s. In January and February 2017, due to the lack of water consumption in the canal (at sluices, irrigations etc.) and the extreme decrease in traffic, the flow rate was almost zero, the water was standing and ice formed very quickly *(Fig. 44)*.

Figure 44: Ice cover in the Danube – Black Sea Canal

4.2.2
The Danube tributaries

In winter 2017, the ice was present on all Danube tributaries as well.

The ice phenomena on the tributaries of the Danube in Slovakia **(Morava River and Nitra River)** were more intense than on the Danube. Continuous ice coverage was formed due to the lower water levels, discharges and flow velocity *(Fig. 45)*. Frozen water-tables were observed also on some other major rivers/tributaries in Slovakia such as Hron, Slaná, Laborec or Uh River. Water tables of reservoirs were frozen continuously for the whole period.

Ice cover formed on all Hungarian tributaries of the Danube **(Rába/Raab, Marcal, Lajta/Lejtha, Ipoly/ Ipel, Kapos and Sió rivers),** due to very low water levels. *(Fig. 46)*.

Figure 45: The ferry between Slovakia and Austria on the Morava River at Záhorská Ves affected by the ice on 12 January 2017

Figure 46: Frozen dam, Rába River, Nick, Hungary

The ice was reported on the **Tisza River** in Ukraine, Hungary and Serbia.

During January very cold weather was observed in the Tisza basin in Ukraine: from -20°C to -27°C in mountains and from -13°C to -18°C in lowlands. The thickness of ice on the rivers was up to 35-40 cm. As a result of a rapid temperature increase and heavy rainfall, snow melts occurred causing strong ice-breaking and ice-drifting. On the Tisza section in Ukraine the ice drift started on 2 - 3 February, with water level increasing up to 4.7 m in lowlands. Ice jams formed at more than 50 locations. On 9 February the maximum ice flood level formed, reaching 10 m in Chop (only 30 cm below the water level of the 2001 catastrophic flood).

Due to the relatively low discharges and velocities at certain sections of the Upper Tisza and its tributaries in **Hungary**, strong ice drift or ice cover appeared already by the end of December. On 9 January the entire Hungarian section of the Tisza River and most sections of its tributaries were covered by ice *(Fig. 47)*. The ice coverage started to break up in the first week of February and the Hungarian section of Tisza became free of ice on 19 February. The icy period in 2017 was much longer than the multi-annual average.

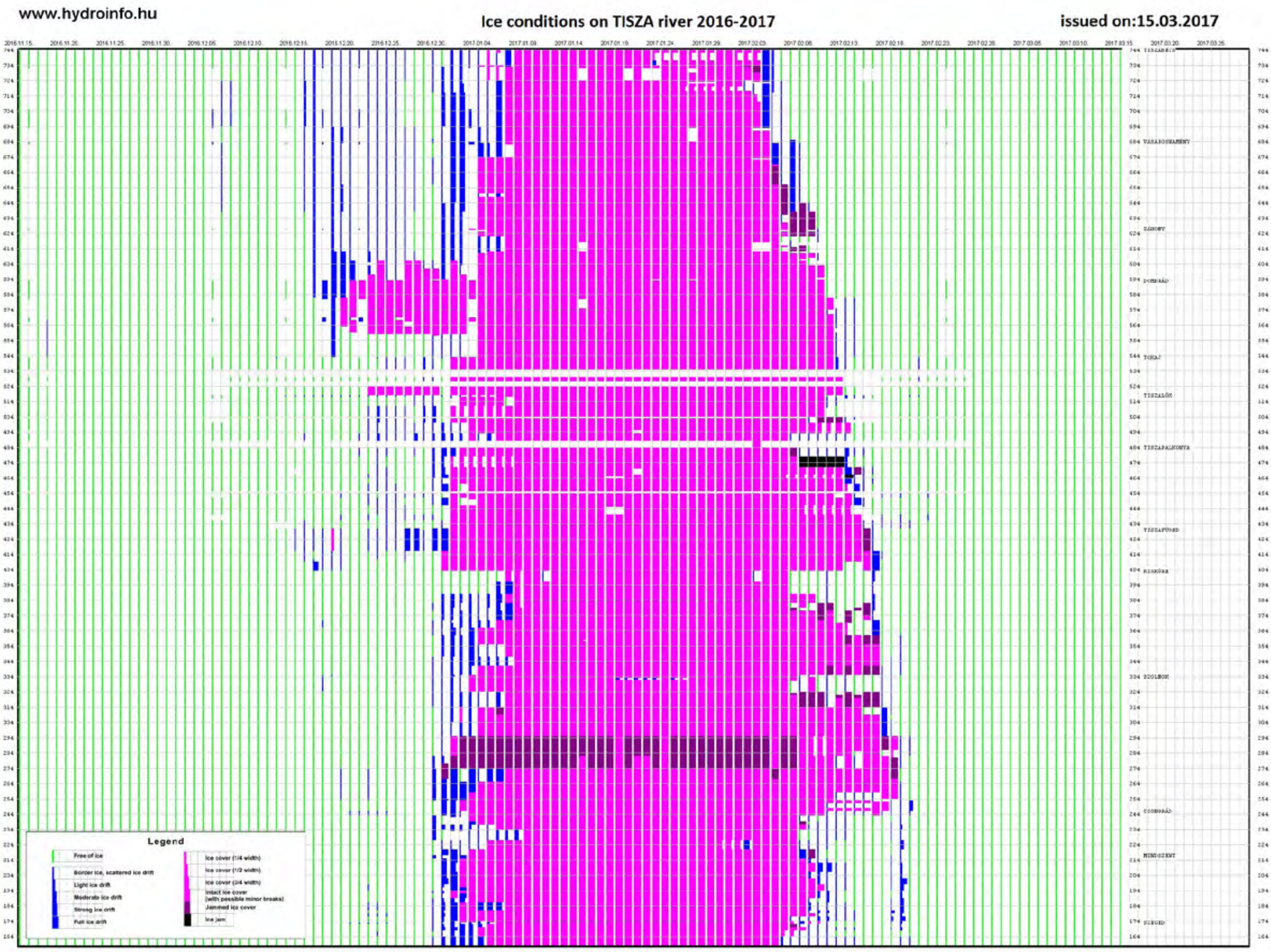


Figure 47: Ice conditions on the Hungarian section of river Tisza between 15.11.2016 and 15.03.2017

Ice on the Serbian section of the Tisza lasted for a long time, from the beginning of January to the beginning of February (and for a somewhat shorter time near the Tisza mouth to the Danube). A long-lasting ice cover and ice drifts of short duration were also typical, as shown in *Fig. 48*.

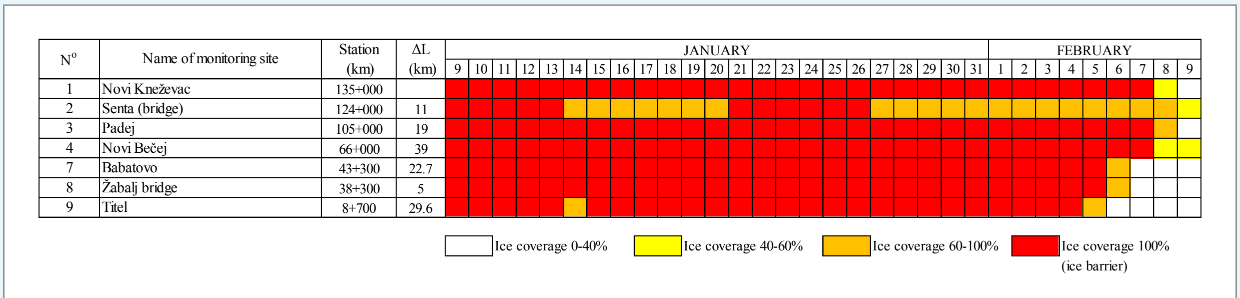


Figure 48: Summary of ice events on the Tisza River in Serbia

In the winter of 2016/17, as well as in the past, the ice events on the Sava River were not as pronounced as they were on the Danube or the Tisza. In the Bosnia and Herzegovina the **Sava River** did not show any significant ice accumulation. The chronology of ice events on the Serbian section of the Sava is shown on *Fig. 49*.

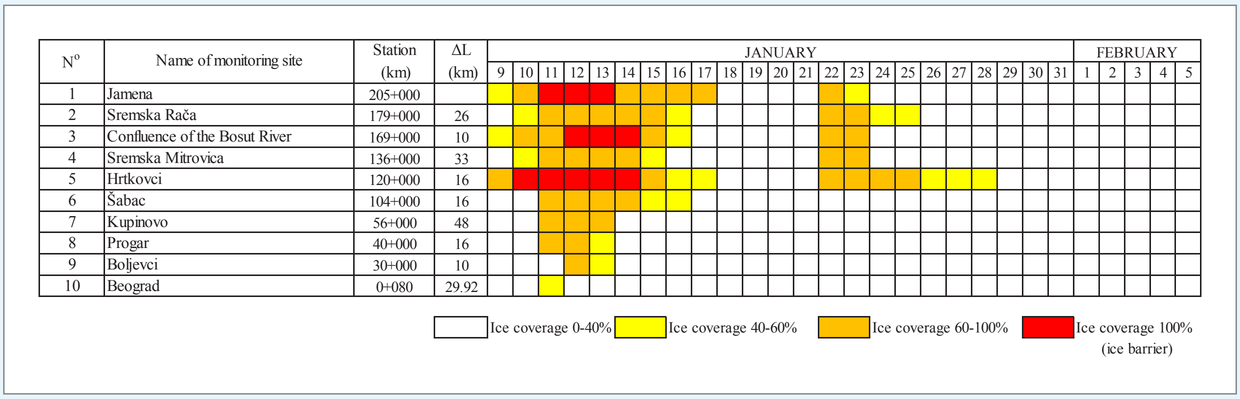


Figure 49: Summary of ice events on the Sava River in Serbia

Due to the extremely low temperatures in Bosnia and Herzegovina and low water levels, the ice on the **Bosna River** (right tributary of the Sava) occurred *(Fig. 50)*.

Figure 50: Ice jam and ice cover on the Bosna River in January 2017

On the **Velika Morava** River in Serbia, ice events were present from 9 January to the beginning of February *(Fig. 51)*. Along its entire course, the ice covered 60 - 100% of the water table, while the 20 km long section at the mouth to the Danube was fully covered by ice until the melting of the Danube ice.

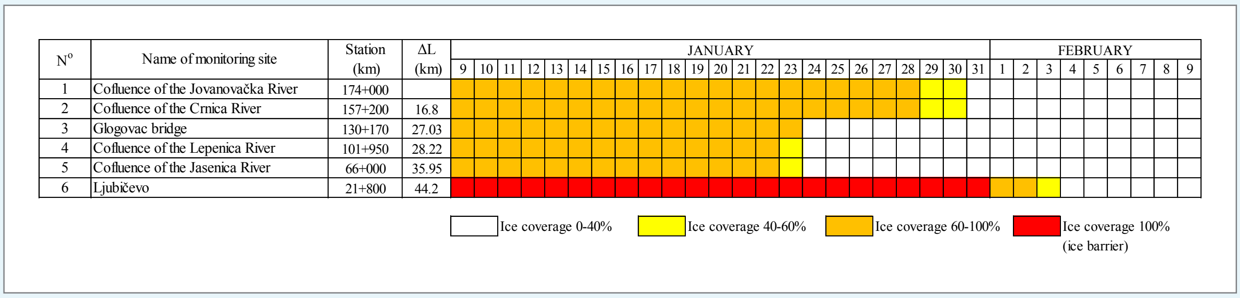


Figure 51: Summary of ice events on the Velika Morava River

4.3
Description of applied emergency measures

4.3.1
Weather forecast and warning services

The **Slovak** Hydrometeorological Institute warned against the low temperatures from the beginning of January. The first arctic day was forecasted on the 6 January, with the air temperature around -12°C/-18°C at night and -15°C/-9°C during the day, with lower temperatures in the north of the territory, and temperatures at the south of the western and middle Slovakia around -8°C/-4°C *(Fig. 52).*

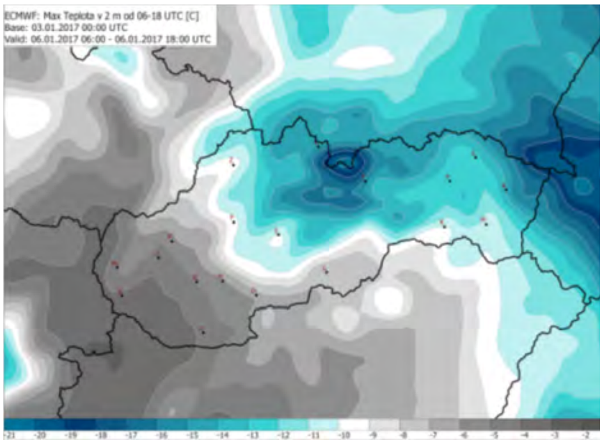


Figure 52: Forecast of the maximum daily temperature by the ECMWF meteorological model for 6th January, 2017 (Used as an example)

The **Hungarian** Hydrological Forecasting Service (HHFS) produces 6-day lead time water-level forecasts for the Danube every morning, Tisza and Drava rivers and for their tributaries. During flood events, forecasts are issued several times a day, including the most up-to-date measurements and meteorological forecasts. The forecasting procedure considers meteorological and hydrological conditions of the past period, as well as the expected values of precipitation and temperature for the lead-time interval. After all meteorological and hydrological data are processed; forecasts are calculated using HHFSs proprietary forecasting system, which consist of several functional modules running one after another. The first module models snow ablation and melting processes on the Danube catchment. The next module is the rainfall-runoff module, followed by the flow routing module, which calculates the movement of water in the channel. The next module is the backwater effect module, which takes into account the effect of dams and of other rivers. Error correction modules assist in the required accuracy of the forecasting model. All products of HHFS are presented on its homepage (www.hydroinfo.hu).

The **Croatian** Hydrometeorological Institute delivered a short term (3-5 days ahead) and long term (14 days ahead) weather forecasts on a daily basis to Croatian Waters, which is the agency responsible for carrying out the ice control measures and activities in Croatia.

The National Hydrometeorological Service of **Serbia** (RHMZ) provided regular forecasts of meteorological and hydrological developments in the Danube River Basin, including ice forecasts.

Through its regular weather reports, the Federal Hydro-Meteorological Institute in **Bosnia and Herzegovina** informed the public and relevant institutions about the necessary weather forecasts. For the days with exceptionally low temperatures, alarms were also raised for this type of weather conditions.

In **Bulgaria** the National Institute for meteorology and Hydrology (NIMH) is responsible for providing meteorological information and forecasting at national level. On the web site of NIMH up-to-date forecasts, latest satellite and radar images and measurements related to the weather conditions and precipitation are being published. The results of numeric model ALADIN and the Global Forecast System (GFS model) are used for short–term weather forecasts and for hydrological and environmental early warnings.

The meteorological information provided by NIMH is used for analysis and forecasting of the navigation conditions on the Danube, including for forecasting related to potential ice-conditions. The EAEMDR performs hydrometeorological observations in the Bulgarian section of the Danube through observation stations situated in the cities of Novo Selo, Lom, Oryahovo, Svishtov, Rousse and Silistra. The Agency regularly issues and disseminates a "Bulletin on hydrometeorological and navigational situation in the Danube River", addressed to all interested parties, incl. vessel crews and ship-owners. The bulletin is published on the web site of EAEMDR. Up-to-date meteorological information is also published on the web-portal of the National River Information Services System in the Bulgarian part of the Danube – BULRIS.

In **Romania** the National Meteorological Administration produced the regular forecasts and warnings and transmitted daily the meteorological situation and forecast for 24 hours and for the next 3 days. In January and February 2017, the National Meteorological Administration issued 500 meteorological now casting warnings (3 hours anticipation) on the immediate meteorological phenomena through the Regional Weather Centers (RMC).

4.3.2
Ice monitoring and forecasting

The increased and continuous monitoring of the conditions is very important, but difficult. Airborne survey or satellite images provide the best perspectives, however they cannot replace the manmade visual observations. Moreover, the icy conditions could hinder the water level remote sensing.

In **Slovakia**, the relevant messages on navigation measures and particular recommendations were available on the webpage of the Transport Authority (http://plavba.nsat.sk/plavebna-bezpecnost/plavebne-opatrenia/)

During winter periods, the **Hungarian** Hydrological Forecasting Service (HHFS) receives daily data on river ice conditions from Hungarian and other European hydrological services. River ice reports for the Danube, Tisza and Drava rivers and their tributaries are summarized every morning. HHFS produces the Daily Ice Regime Map (DIRM) based on the observations of ice phenomena each day between 15 November and 15 March each year since 2011. The Ice Regime Map summarizes the current ice conditions on the river network in Hungary, similarly to the Daily Water Regime Map (DIRM), which presents the current hydrological situation (http://www.hydroinfo.hu/en/hidinfo/vt.html). *Fig. 53* shows DIRM for 31 January 2017. There are three basic categories of river ice conditions: free of ice, ice drift and ice cover. Within these three categories, the intensity of the ice pheno-

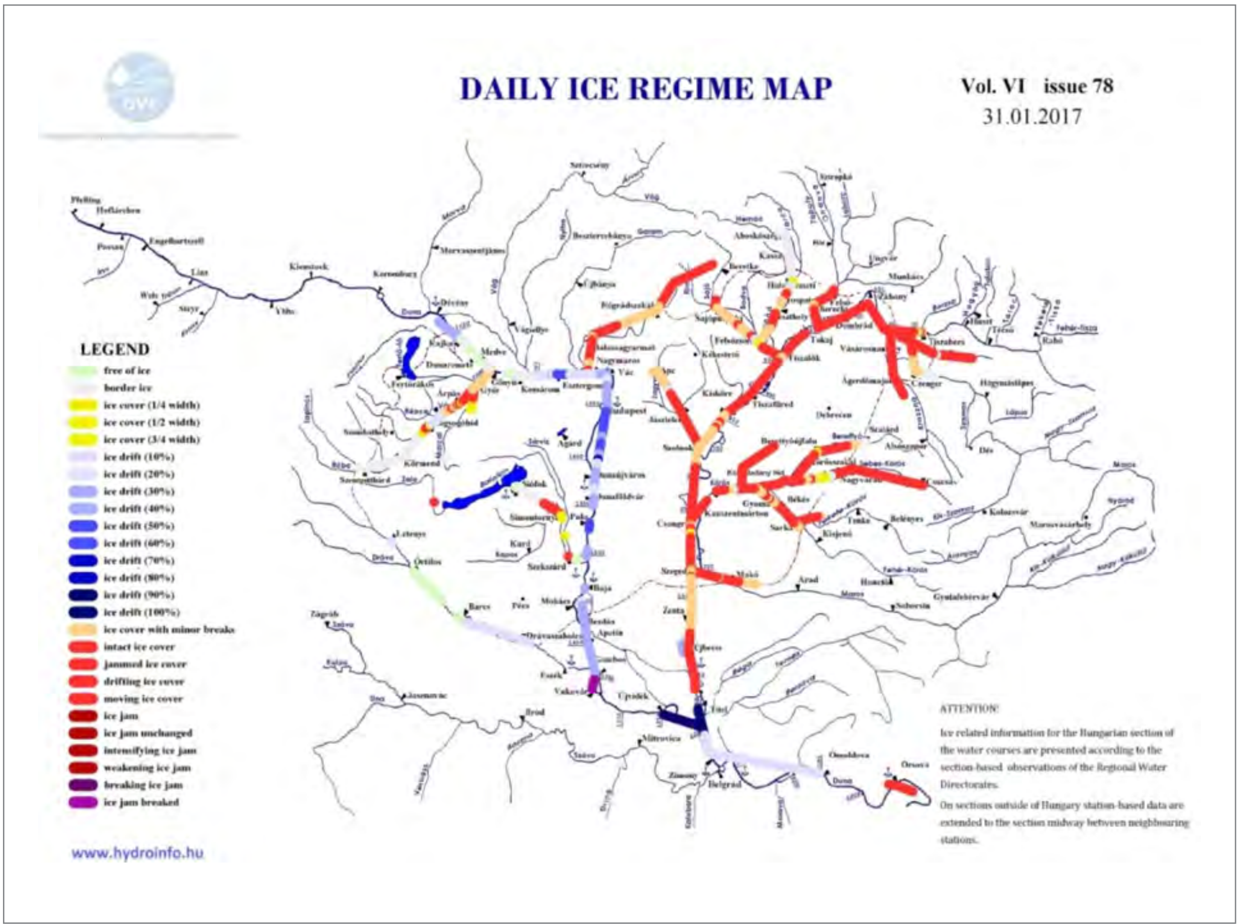


Figure 53: Daily ice regime map for 31 January 2017

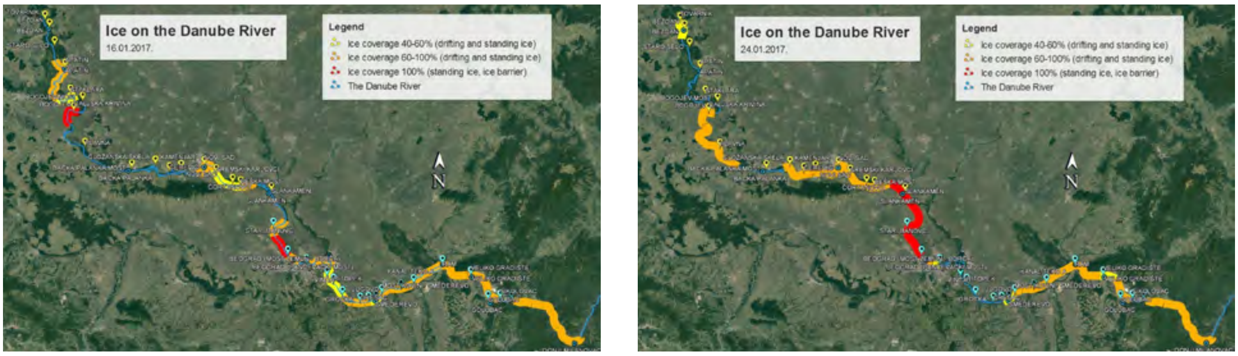


Figure 54: Ice on the Danube River in Serbia on 16 January 2017 and 24 January 2017.

menon is also indicated. Lead-time of the forecast is 6 days, but this may change in justified cases. Observations and forecasts always refer to mornings. It should be noted that this method is not suitable for forecasting the appearance and the break-up of ice jams.

The ice cover on the Danube and its tributaries in **Serbia** was monitored on a daily basis by expert teams from Vode Vojvodine, Srbijavode, Beogradvode, RHMZ and Jaroslav Černi Institute. All the collected data was compiled in daily reports, which described the iced river reaches. To provide a better insight, the river reaches were classified based on the ice conditions, endangered reaches were identified, and icebreaker deployment was planned accordingly. Examples of the ice status of the Danube are shown on *Fig. 54*.

There was an intense exchange of information concerning the ice situation at the common interest section of the Danube River (but also on the upstream and downstream sections) between the Hungarian, Serbian and Croatian water management units. The exchange of relevant data (weather forecasts, water levels, ice cover and information on the undertaken ice control measures) was done on a daily basis, through phone communication and written reports.

The Sava River Watershed Agency in Sarajevo, **Bosnia and Herzegovina** regularly monitored the state of the ice on the Sava River.

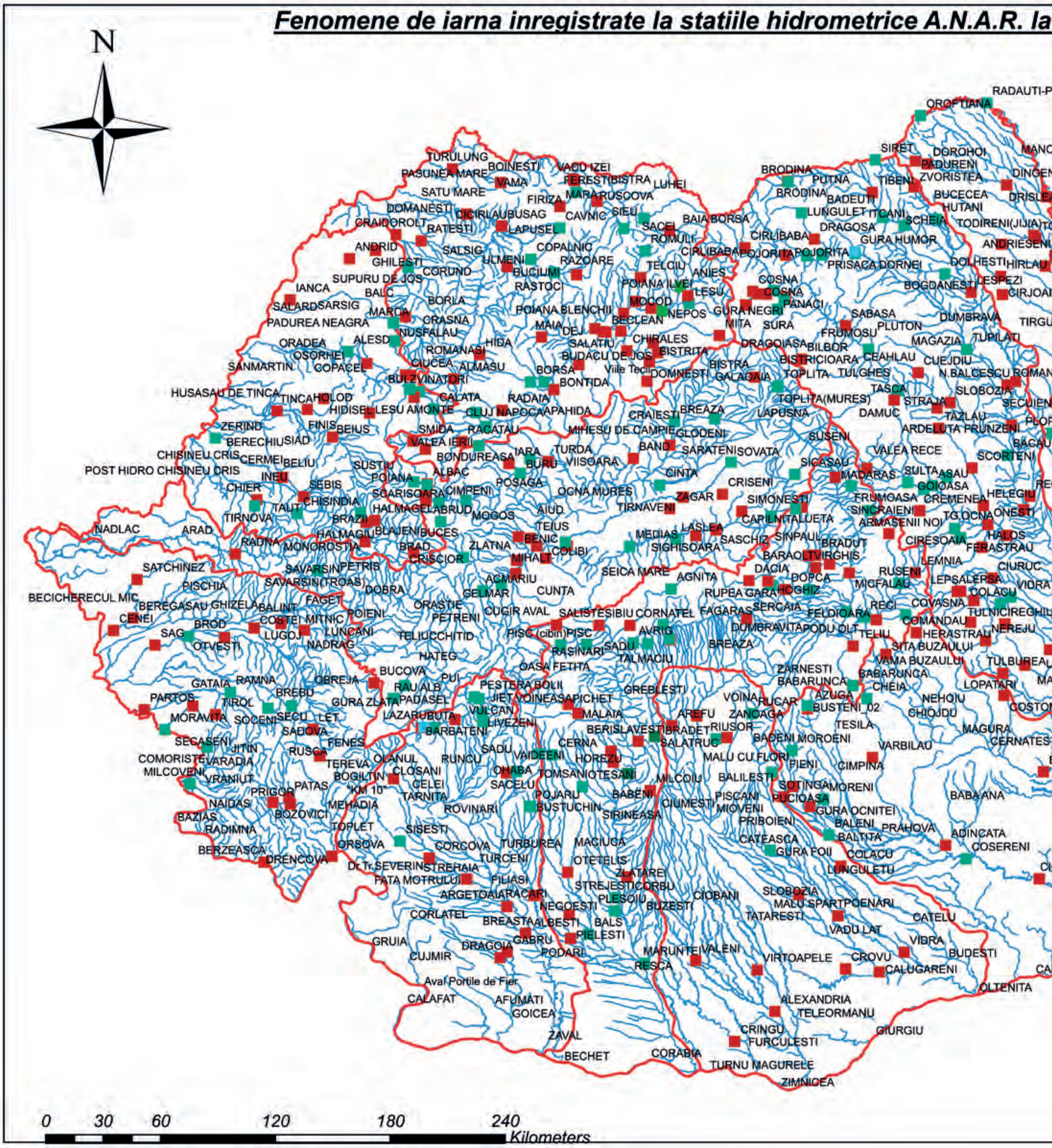
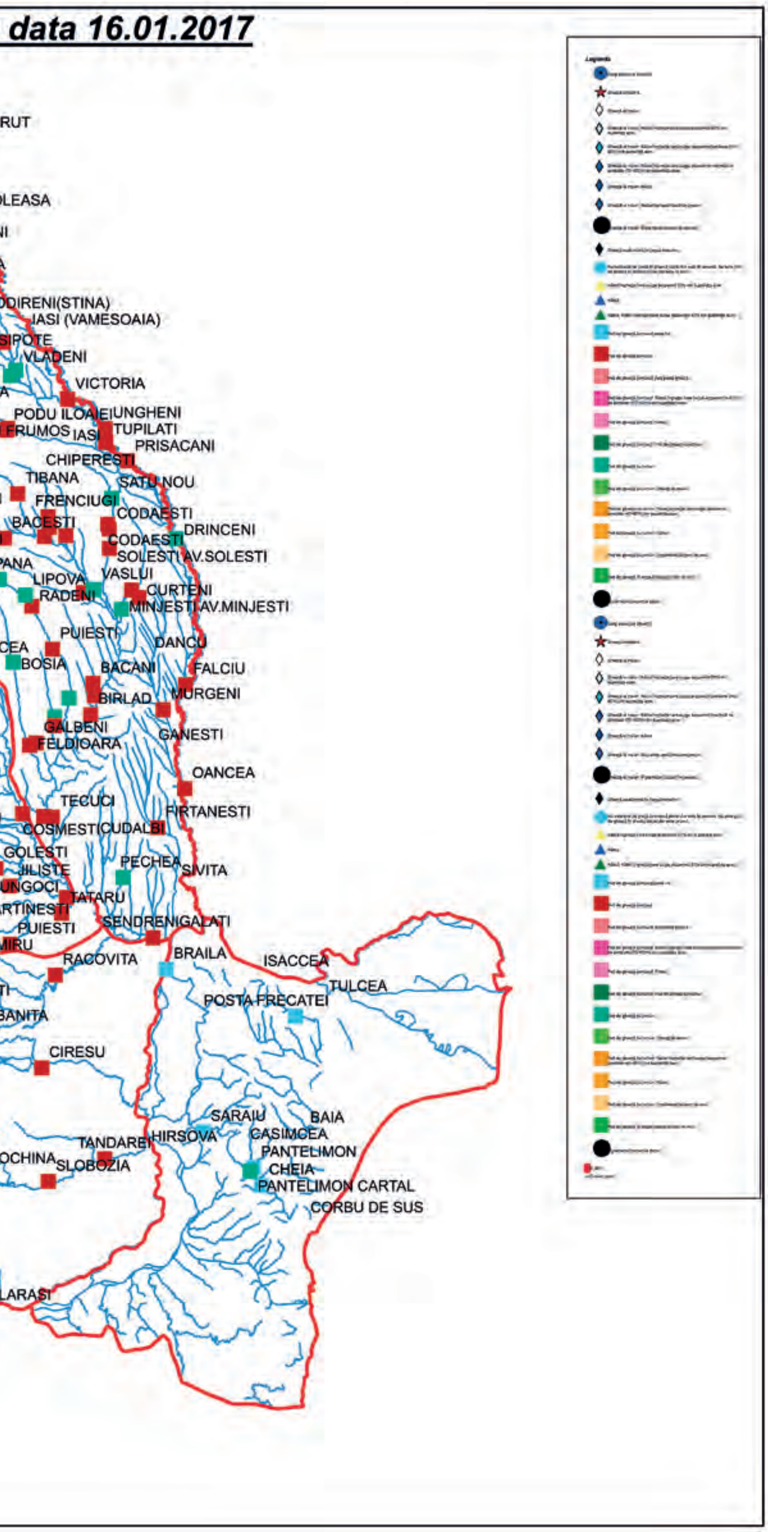


Figure 55: Ice situation on the Romanian Rivers on 16.01.2017

In **Bulgaria** the information on the navigation conditions including the ice regime and flood hazard has been published daily on the web site of the EAEMDR. The Agency maintains a database with all hydrological and meteorological parameters related to the Danube River and provides this information to skippers and all other stakeholders via the web site. In case of potential icing danger, the EAEMDR sends e-mails and warning messages about the expected and potentially negative consequences of ice phenomena to the Governors of the districts along the Danube river, to the responsible officers in the Ministry of Transport, information technology and communications (MTITC), to the Regional offices of the Ministry of the Interior, to the ship-companies and other relevant institutions. EAEMDR disseminates this information via the Danube FIIS-portal and the RIS-portal (BULRIS). The "Notices to skippers" (NTS) subsystem of the BULRIS system is used for providing messages related to water levels and ice formation. The NTS publishes announcements related to the navigations and in particular – related to the ice regime. All available reports can be viewed in different formats and their attachments can be downloaded. The issued reports are available on the web site of the subsystem Notices to skippers (http://nts.bulris.bg).



In **Romania** the National Institute of Hydrology and Water Management (NIHWM) produces information, forecasts and warnings on floods and ice phenomena and their transmission to the Operational Center for Emergency Situations within the Ministry of Waters and Forests, to the Operational Center of the National Administration Romanian Waters (NARW) as well as to other stakeholders. In January 2017, NIHWM did not issue any hydrological warning, but in February six warnings were issued, mainly on the rapid melting of the snow, the predicted rainfall as well as the evolution of ice formations that can lead to increase of water levels and possible local floods on some river sectors, along with the associated map.

On the basis of the information provided by NIHWM and the water basin administrations, NARW compiled daily a national map describing the ice phenomena on the Romanian rivers *(Fig. 55)*, which was published also on the NARW website (http://www.rowater.ro/Fenomene%20de%20iarn/Forms/AllItems.aspx).

4.3.3
Ice control measures in the Danube River

In **Slovakia** three icebreakers were operating during January 2017: the icebreaker "Brezno" *(Fig. 56)* in the Bratislava port, the icebreaker "Krupina" *(Fig. 57)* at Čunovo Danube profile and the icebreaker "BD Dunaj" in the port of Komárno.

Figure 56: Icebreaker operation in the Bratislava port

Figure 57: Icebreaker operation at Čunovo

The active ice management in the **HU-HR-RS sector** of the Danube included icebreaker deployment based on bilateral agreements. Hungarian Icebreakers VI and XI entered the sector on 16 January, after an agreement at a trilateral meeting held in Sombor. The icebreakers were needed to cut through the ice barrier in the Dalj river-bend *(Fig. 58)*. The operation was successful and the problematic sections could have been broken through. However, the work was exceptional, because both ships had to cut themselves through the icefield from upstream. Cutting from upstream of the congested ice involves considerable risks, as the ice has no place to cling to behind the ship. It can slip back to the ship's aft and close it in the ice (as in the case of the Icebreakers VI and VII). For successful crossing, it is necessary for the ships to keep moving in the ice and this requires „scrolling" ships. Without scrolling equipment it is impossible to cut through an ice-wall from upstream. It also became apparent that without the high-performance two-engine vessels the crossing would not have been possible.

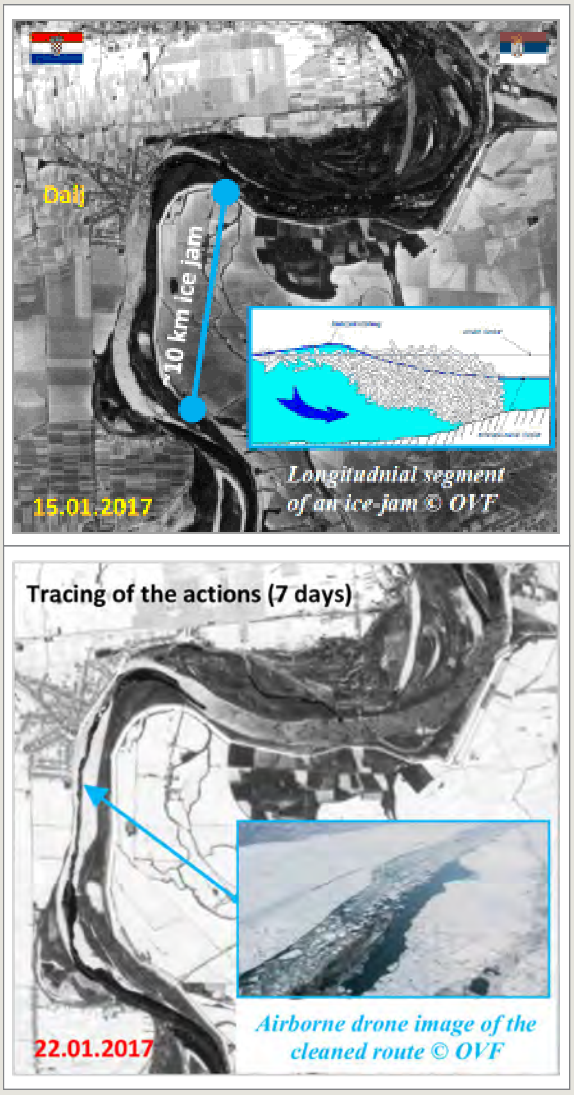


Figure 58: Satellite images of the Danube band at Dalj, 1358-1348 rkm
© U.S.G.S., 2017, Landsat

Figure 59: Icebreaker VI

Figure 60: Icebreaker XI working near Dalj

The icebreakers reached the ice barrier on 17 January *(Figs. 59 and 60)*. At rkm 1357 they found very thick (up to 3 m) layers of ice, where the Icebreaker VI got trapped. After two and a half days, the Icebreaker XI managed to pass through the entire ice barrier. Following a short stay in Vukovar, the Icebreaker XI started cutting through the Dalj ice jam from the downstream end and on 21 January managed to reach its upstream end and release the Icebreaker VI. As a result of this operation, the water levels upstream from Dalj rapidly decreased (as presented on *Fig. 37*). The Icebreaker XI continued to maintain a 100 m wide channel through the Dalj bend from 22 to 30 January, when representatives from HU, RS and HR concluded that the Hungarian icebreakers could be called off.

Hungary received on 16 January 2017 an official request from the Republic of Serbia for an urgent help in solving the ice-related problems on the Danube between Vukovar and Belgrade. An additional pair of icebreakers (Széchenyi and Icebreaker VII) started from Apatin on 22 January, and permanently working on ice breaking they arrived at Belgrade port on 26 January. At that moment, the ice jam upstream of Belgrade was 40 km long, with ice cover to further extend upstream over 30 km in next days. As water table was fully covered by ice, its level at Novi Sad gauge station was 1.5 m higher than usual. The intensive icebreaking activities through thick ice between Belgrade and Novi Sad were necessary until 6 February *(Figs. 61 and 62)*.

Figure 61: Icebreaker Széchenyi near Slankamen (km 1215), 02 February 2017

Figure 62: Icebreaker VII near Surduk (km 1208), 04 February 2017

Figure 63: Icebreaker Greben

Figure 64: Icebreaker Bor

Serbian icebreakers Greben and Bor were deployed in the Iron Gate 1 HPP reservoir, on behalf of the Serbian and Romanian Iron Gate authorities. Following hydro-meteorological reports on the status of ice on the Danube, Greben *(Fig. 63)* left the downstream dock of Iron Gates 1 Dam on 10 January, and continuously worked on icebreaking between the upstream end of the Iron Gate gorge (km 1039) and Belgrade (km 1170) until 9 February. Bor, a vessel equipped with icebreaking tool *(Fig. 64)*, deployed on behalf of Romania, was active from 31 January to 7 February 2017, breaking the ice between the dam and the mouth of the Nera.

In **Bulgaria**, the ice-conditions in the first days of January 2017 changed rapidly and the ice drift at the lower part reached 90%. The measures were taken between 8 January and 27 February 2017. An extraordinary meeting of the staff under the "Disaster Protection Plan", part "Ice formation on the Danube River" was held on 9 January in Ruse. At the meeting, the appropriate measures for avoiding adverse consequences were discussed and the responsibilities of each institution in that respect were clarified. The navigation on the entire Bulgarian section of Danube was temporarily suspended on 10 January. Actions were undertaken to break the ice around the ships in the frozen part of the Danube, in order to avoid blockage and damage due to ice pressure. Although Bulgaria does not have an icebreaker, it deployed a special ship, which can be used for ice breaking in case of emergency. After normalizing of the navigation conditions, shipping along the Bulgarian Danube section was restored on 17 February.

In **Romania** the Lower Danube River Administration mobilized four ships for ice management issues: R/M Perseus, R/M Galaţi 3, R/M Gheorghieni 2 and the Mamaia signaling ship 2. R/M Perseus was deployed for an ice-breaking mission to Tulcea and R/M Galaţi 3 was deployed to the Galaţi harbour and later to Braila for ice breaking. R/M Gheorghieni 2 has been ordered to patrol the Sulina Canal since 9 January, by breaking the ice and providing assistance to all seagoing vessels that have crossed the Sulina Canal and have been trapped in ice. The Mamaia 2 signalling ship has made humanitarian missions between 10 and 15 January transporting 437 people and food from Sulina to Tulcea.

R/M Perseus ensured the breaking of the ice drifts *(Figs. 65a, 65b)* between rkm 34 and rkm 60 and participated together with R/M Galaţi 3 and R/M Gheorghieni in the transfer of 59 merchant ships from Sulina to rkm 175 and of 57 merchant ships downstream the Danube from rkm 175 to Sulina, between 8 January and 21 February.

From 7 February the meteorological phenomena developed in a negative direction. This led to the formation of the ice cover over the entire section between rkm 400 and rkm 495 and the ships and convoys located in that area were not able to shelter in the nearest harbours. Therefore, the Romanian Anti-ice Command asked the external companies for a lease of tug boats capable of breaking the ice in order to release the ice blocked areas and ensure their downstream flow, but no positive response was received.

The NARW intervened with terrestrial equipment and high-capacity transport means. In order to ensure the access of the machines to the intervention area, specialized intervention teams carried out grubbing works and earthworks. In the first stage removing the ice from the downstream to the upstream created a drainage channel. The long-range excavators took the action simultaneously on both sides. In the second stage, bulldozers, excavators and dumpers ensured the relocation of the ice into appropriate areas. Simultaneously, the Romanian General Inspectorate for Emergency Situations carried out controlled explosions to ensure water flowing through the ice.

Figure 65a, 65b: Ice control measures by the icebreaker Perseus on the Romanian Danube

4.3.4
Ice control measures in the Danube tributaries

In the Upper-Tisza River section in Ukraine, the ice jams broke naturally or were removed by blasting. The pyrotechnical teams performed 58 explosions at 9 ice jams. 17 pumping stations pumped 28 000 m^3 of water during the flood period, draining it out of irrigation systems. The volume of water accumulated in reservoirs was 19.3 million m^3. In total, 770 persons and 151 machines participated in the prevention of ice flood, steaming from the ice jamming. 3 500 sandbags were used for flood prevention purposes.

Figure 66: Location of measures in the Upper-Tisza, Ukraine

In the **Hungarian section** of the Tisza River there were many sections where remarkable measures had to take place in order to avoid serious damage. They were required due to the ice cover of the Tisza and the approaching flood from upstream.

From Tiszabecs to Vásárosnamény the ice plates were able to convey with 100% ice drift, however downstream to the Szamos confluence the load from the two rivers created several ice jams. Between Zsurk and Györöcske a 22 km long section was stuck with 100-120 cm ice thickness that in some areas reached even 250 cm. It caused sudden and remarkable water level elevations at Vásárosnamény (+8.5 meters) and Záhony (+10 m). At Zámoly the water level exceeded the third highest water level ever recorded (the highest two happened in 1998 and 2001).

The surrounding river stretches of the Tiszalök powerplant were covered with permanent ice cover. The drift from upstream needed to hold back until the downstream stretch (Tiszadob-Tiszalök) was cleaned by the icebreakers. The segment gates were operated with lower outflow. Explosives were deployed if the prudent operation failed and a successful test blasting took place. Finally, the icebreaker executed the task. *(Fig. 67)*.

Figure 67: Icebreaker at Tiszalök

At the Tisza Lake the controllers operated the Kisköre dam in a way to slow down and stop the ice accumulation. The accumulative effect was amplified by the mass of driftwood, wreckage and other rubbish. Despite these efforts, the operators could not halt the conglomerate and they needed to pass it through the gates *(Fig. 68)*. Icebreakers assisted with the jams at the structure.

Upstream Szolnok the construction of the new M4 highway bridge was in place. The vessels in the riverbed and the floating crane needed to be secured. At Csongrád, a pontoon bridge had to be protected.

Figure 68: Kisköre dam ice passthrough

4.3.5
Damages and losses, costs of icebreaker operation

In **Slovakia** the personal costs of Slovak Water Management Enterprise staff amounted to 119 038 € and the ice-breaking costs (January – February 2017) reached 31 939.70 €.

As a result of the ice event in **Ukraine**, 161 houses, 525 yards, 512 ha of arable land and 9 roads were flooded, four houses destroyed, and the respective losses were 123 000 €. One person died and 56 persons were evacuated during the event.

The expense for materials for ice blasting amounted to 730 €. The ice drift produced damages on bank strengthening structures and flood protection dikes. Construction of automated measuring stations of AIMS Tysa in five regions of Zakarpattya took place. The total cost of rehabilitation works was about 775 000 €.

In **Hungary** on 11 February 2017 the ice jam from the Tisza River drifted up to the Bodrog River. This resulted in damages generated to ships and port structures. Fortunately, no personal injury occurred. Due to the flowing ice flood, the affected Water Directorates warned the floating structure owners to provide the necessary activities in order to avoid serious damages. *(Fig. 69)*.

The total costs of the **Croatian waters** icebreaker operations carried out in Croatia on the Danube River in January 2017 amounted to an estimated 60 381 €. The people who live in these areas did not express great concern regarding the ice flood threat when the formation of the ice barriers started, because they were taking into account very low water level of the Danube River. Some of them were forced to rescue their own vessels from being damaged by ice.

Although the ice events along the **Serbian section** of the Danube were significant, there was no danger of ice floods (due to low river discharges at the time). As such, there was no flood damage in Serbia.

However, there have been specific problems with ice over the last several cold winters, primarily damages to structures along the riverbanks caused by ice drifts. These are new problems, because in the past there was no infrastructure along the shore belt of the Danube. A large number of river marinas and floats are modern developments and a positive aspect of overall urban growth. Unfortunately, the ice events in the winters of 2012 and 2017 showed that the riverside infrastructure is vulnerable during periods of ice conditions. On 14 January 2017, drifting ice damaged the new port at Apatin and the Marina

Figure 69: Damaged port in Tokaj

Figure 70: Damaged dock in Apatin

Figure 71: Damaged boats at Marina in Belgrade

in Belgrade, where several floats were demolished *(Figs. 70 and 71)*. A large number of vessels (mainly boats) became detached or were damaged at the marinas in Zemun and Belgrade, by large incoming blocks of ice. Several floats that operated as restaurants were destroyed.

The total cost of deployment of Hungarian Icebreakers VI and XI, working at the common HU-HR-RS section of the Danube was 243 323.22 €. Based on the cost-sharing agreement, Serbia's portion was 60 831 €. The operation of Hungarian icebreakers invited to work at the Serbian territory was 311 269 €. Total cost of the ice monitoring and icebreaking activities in Serbia (both for Hungarian and Serbian vessels) was nearly 800 000 €.

All in all, the Hungarian icebreaker fleet operation – with domestic transport and ice breaking – reached almost 400 million HUF (app. 1,2 M€) (Fig. 72).

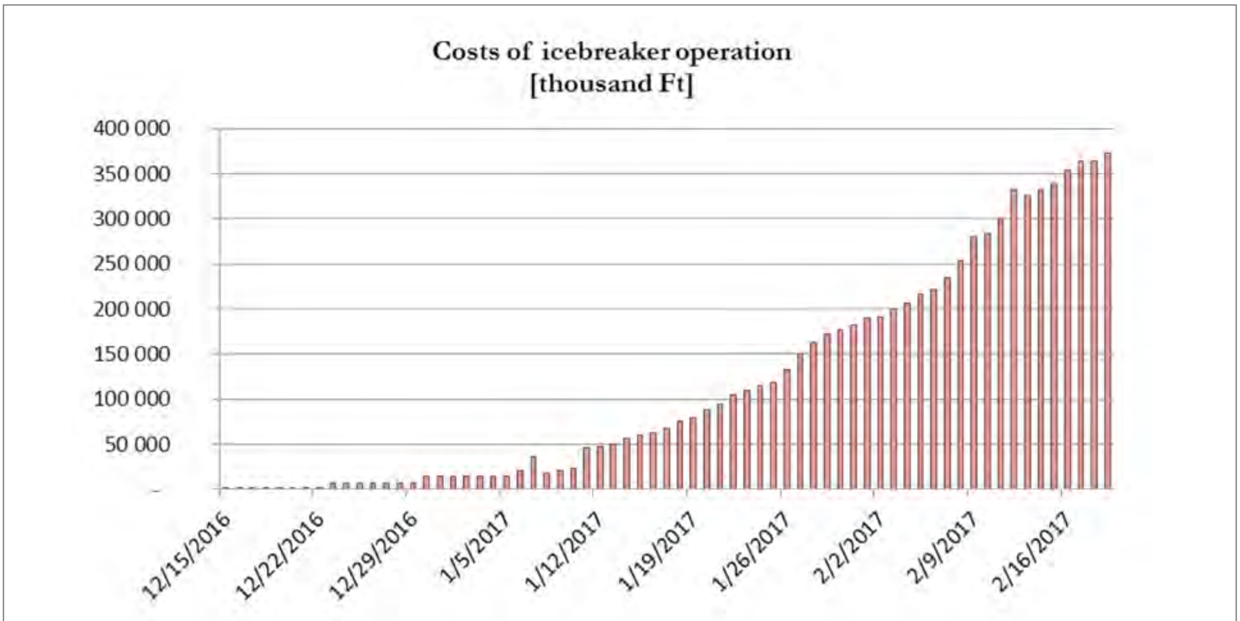


Figure 72: Cost of operation of Hungarian icebreakers (1 EUR = 310 HUF)

The complicated navigation situation due to ice-conditions along the **Bulgarian section** of the Danube has led to significant direct and indirect losses. The indirect losses are mainly related to the economic damages and profit losses as a result of the obstructed and suspended shipping. The direct losses included the damaged equipment and the extraordinary expenses, including fuel consumption, for the emergency activities related to minimizing the damages and the recovery of the normal navigation conditions. The EAEMDR reported a total of 42 048 € direct losses, including 35 038 € for the damaged floating navigation signs and 7 010 € for fuel expenses. No floods occurred on the Bulgarian territory as a result of the ice-events in 2017 and no additional damages and losses were registered except those related to navigation.

The cost of fuel for ships removing the ice jam on the **Romanian Danube** between 8 January 2017 and 21 February 2017 was 244 800 €. The damage caused by ice on the ships amounted to 45 250 €. The Romanian National Administration Company of Navigable Canals had losses due to reduced navigation on the Danube. In January and February 2017 total damages caused by the dangerous meteorological phenomena on the national rivers in Romania (mainly due to ice jamming and sudden melting of the snow simultaneously with the rainfall) reached about 1.57 mil €.

During the occurrence of ice on the watercourses in the Sava River area in the **Bosnian Federation** no significant material damage or danger to human life was noted. Minor damage to equipment (sensors and watertight lathes) was recorded at some automatic hydrological stations.

4.4
Impacts on navigation and hydropower generation

In **Slovakia** navigation on the Gabčíkovo canal was interrupted on 11 January 2017. Later on navigation on the Danube River stretch from Bratislava to Gabčíkovo Waterwork stopped for 17 days, from 20 January to 4 February 2017. Small hydropower plants Dobrohošť and Mošoň were either out of operation or in limited operation during the ice event.

On 7 January 2017, the Water Directorates in **Hungary** started to collect the navigation marks due the expected intensive ice drift on the Danube. On 10 January 2017, a complete navigation stop was ordered between km 1811 and km 1433 of the Danube. Later on, due to the intensifying ice drift and the colder weather, a complete interruption of navigation was ordered on the Hungarian Danube section.

In **Croatia** the Vukovar Port Authority declared suspension of navigation along the Danube River from 6 January to 1 February 2017.

In **Serbia** navigation on the Danube and the Sava was suspended from 8 January to 10 February 2017. It was resumed on 10 February 2017, at which time it was deemed that there was no longer an ice hazard. The loss sustained has been estimated at 50 000 € per day.

The extreme cold led to a decrease in the flow on the Danube and the Iron Gate 1 and 2 HPPs had turbines reduced to a minimum and produced a very small amount of energy.

In the **Bulgarian section** shipping was suspended for more than a month – from 10 January to 17 February. Some ships were blocked at the lower part of the Bulgarian section of the Danube.

Pontoons, auxiliary craft and river navigation equipment were swept away by the ice-drift along the Danube near the town of Silistra. Some vessels, blocked in the ice were damaged after the ice broke up, but the damages were not crucial and the ships were able to continue their journey.

The Lower Danube River Administration in **Romania** issued four notices on the Danube navigation: the vessels were shifted due to the presence of ice between rkm 175 and Sulina (10 January); the ban on navigation between rkm1075 and rkm 75 (10 January); resuming navigation between rkm 1075 and rkm 175 (21 February) and resuming navigation between rkm 175 and Sulina (27 February). Moreover, the navigation was stopped at the Poarta Albă-Midia Năvodari Canal and there was reduction of the length of the convoys allowed to transit through the Danube-Black Sea Canal.

5 LESSONS LEARNED IN WINTER 2017, GAPS OBSERVED AND RECOMMENDATIONS FOR THE FUTURE

5.1 Slovakia

The ice event on the rivers has been well managed. It is of a great importance that all components in the system continue to perform their professional tasks. It is necessary to intensify the effectiveness of the devices, which serve to push the ice away from the ship locked gates on Gabčíkovo Waterwork.

5.2 Hungary

There is uncertainty in development of the ice situation. The ice jams cause rapid and sudden rising of the water level. Defining of actual river discharge is difficult, because the ice affects water levels.

For better water level monitoring and ice forecasting it is recommended to review the method of ice detection/observation and include satellite and aerial ice monitoring, ground camera system, ice thickness measurement, water temperature observation as well as the calculation of ice mass. It is advised to organize closer cooperation with the Hungarian Space Research Office to ensure efficient protection operations.

For better ice protection it is recommended to:

- Review the winter operation rules of the Tiszalök and Kisköre barrages and propose measures, which should be considered in the Tisza operation control;
- Propose river sections where it is advisable to use preventive icebreaking;
- Determine the flood levels with 1% probability for winter months (December, January, February, and March) and include these in the ice protection plans;
- Examine the use of the ice blasting jointly with the responsible body (Police) and develop a protocol of ice blasting;
- Review the ice protection plans including the hydraulic structures' operation of the regulatory facilities and also potential loading of the bridges;
- Review the ordering rules of the point defence alert and set up a clear rule system for the ice protection;
- Integrate public communication into the ice protection plans, with particular attention to the vulnerability of floating structures and coastal facilities.

To improve the operation of icebreaker ship fleet it is recommended to:

- Recruit new crews for the icebreaker ships;
- Develop a method of winter marking (navigation signs) and ordering of navigation break due the ice events;
- Revise the allocation of the icebreaker ships and the suitability of winter homeports;
- Investigate the reconstruction needs of the available icebreaker fleet.

It is also necessary to review the applicability of the existing drones and propose drone technical parameters for use in case of ice flood. The used batteries seemed to be at insufficient capacity in tolerating the freezing conditions. The legal background of the immediate deployment of drones must be drawn up, and if necessary, amendments of legislation must be made. The applicability of aerial reconnaissance (planes, helicopters) should be pre-investigated and the expectations should be drawn up.

Hungary also recommends reviewing the Serbian-Croatian-Hungarian conventions based on the 2017 ice protection experiences, including faster deployment of icebreakers, approaching the ice jams from downstream, and the proper cost sharing. The international conventions should be reviewed for better information flow (ice blasting on the common interest of river section).

Based on the experiences from 2017, the professional visual reporting of such unconventional events brings wider attention from the media and society as well. This serves the aim of awareness raising.

5.3 Croatia

The ice flood defence event in January 2017, once again confirmed the importance and necessity of good trans boundary cooperation between Hungary, Croatia and Serbia in order to avoid ice floods. Croatian Waters are considering buying their own icebreakers in the future and establishing their own fleet, which can be useful not only for ice breaking on the Danube, but also on the Drava River.

5.4 Serbia

Principles and strategies of ice defence in Serbia were defined on the basis of the study, which was completed in 2010. The basic conclusion is that the control of ice in the Serbian section of the Danube is done only for the purpose of protection from ice floods. According to the adopted strategy, permanent ice monitoring is the first precondition for ice control. Preparatory activities for flood defence on the levees and flood defence in general should be commenced only if they are due to ice jamming water levels that rise above defined thresholds. Operational measures for ice control include preparations for the blasting of ice jams and engagement of the existing icebreakers. The construction of new, multi-functional icebreakers is planned (outside of the ice period they may be used in various emergency situations on the waterway, such as fire fighting, rescue, etc.).

It is necessary to conduct hydrologic-hydraulic analyses and develop a strategy for ice control in extremely cold and long-lasting winter (for example of the reoccurrence of a winter similar to 1928/1929) in cooperation with Hungary and Croatia (for the sector of common interest) and with Romania (for the section within the HPP Iron Gate 1 reservoir). As it was already pointed out above, there is no transit of ice through the Serbian territory, i.e. all ice that comes from Hungary or is formed at the Serbian section of the Danube, remains within the Iron Gate 1 reservoir until it melts. At the Serbian section of the Danube, there are many critical sites where ice can accumulate enough to jeopardize the existing flood defence system. Therefore, the conditions for the engagement of Hungarian icebreakers in the sector of the common HU-HR-RS interest should be defined in the ice control strategy, depending on the state of ice in the Serbian section of the Danube. Also, a program for blasting of ice jams, especially those, which may be formed at critical locations such as Dalj (RS-HR border) or entrance to the Iron Gate gorge near Golubac (at the RS-RO border) in case that the activities of icebreakers are not timely or sufficient to prevent accumulation of ice, should be defined.

5.5 Bulgaria

The forecasting of the ice phenomena, the good preparation and coordination of the competent institutions are important conditions for a successful management of the difficulties in case of ice events along the Danube. The availability and exchange of up-to-date information on the meteorological and hydrological conditions, including ice conditions, is an important basis for creating a strategy for actions in case of occurrence of ice phenomena. In 2017, the availability of Disaster action plans and the use of the specialized information system BULRIS with its capabilities for automatic exchange and dissemination of information and notifications to skippers, played an important role for the successful management of the ice disaster in Bulgaria. The future work should be aimed at improving the technical basis, expanding of the scientific support for the ice-events forecasting, including the use of modelling tools, and further strengthening of the capacity and the coordination of the involved administrations.

5.6 Romania

The Romanian experience in annual actions to reduce the damage caused by ice on the inland rivers, especially on the Danube, shows that the following actions are necessary:

- Improvement of basin, county and local flood defence plans with adequate provisions for anti-ice actions;
- Better material endowment of the institutions responsible for counteracting the harmful effects of ice (especially icebreakers) as well as Danube harbours with adequate housing and repairs structures;
- More in-depth study of the river ice phenomenon, especially given its uncertainty in the context of climate change;
- Better inter-institutional cooperation (including the Romanian Space Agency) and inter-state cooperation because the Danube is a border between Romania and Serbia, Bulgaria, Moldova and Ukraine (updating of water management conventions).

5.7 Ukraine

It is necessary to:

- Improve ice forecast and monitoring;
- Implement measures foreseen by Complex Plans of action for safe floods and ice drift passing;
- Build the capacities at all levels of government to improve information dissemination, communication and notification before, during and after the emergency situations;
- Enhance the experience on the use of explosives in ice jams blasting.

The technical status of defence dikes and structures on the Ukrainian part of Danube River does not meet the required standards and does not guarantee the necessary protection for settlements and arable lands. Most of the dikes require reconstruction and repair, while 31 km of dikes are in emergency conditions and the technical state of sluices is critical.

5.8 Bosnia and Herzegovina

Due to the possibility of more frequent occurrences, it is necessary to pay closer attention to ice events in the forthcoming period and be prepared to prevent the occurrence of ice flooding. There is a need to equip the civil protection units and the competent institutions with the relevant equipment in order to have the ability to respond to this challenge.

6
OVERALL SUMMARY AND OUTLOOK FOR THE FUTURE

This report provides a brief overview of the ice events in the Danube River Basin in 2017 and of the respective measures taken during this time and aims at raising awareness about the need for ice management in the Danube River Basin. For a better understanding of the problem the historical ice events in the Danube River Basin including the changes of the Danube ice regime are reviewed and the current policy for ice control in the Danube River Basin is taken into account. The lessons learned in the affected countries and the recommendations for the future are highlighted. A common summary map has been prepared to provide a better understanding of the whole event, *see Fig. 73.*

Ice reporting along the Danube is even more diverse than flood glossaries. In this field of expertise, the lack of common terms and coding makes basin wide summaries difficult create. Uniform solutions would certainly bring a better approach in the future.

Ice management in the Danube River Basin is an important issue, despite the varying threats to ice transport faced by countries. However, the solidarity principle applies in the whole catchment as it is stipulated in the first Flood Risk Management Plan in the Danube Basin District (DFRMP) prepared by the ICPDR and endorsed by the Danube Ministers in 2016. The DFRMP Annex 2 is listing the agreed project proposals in support of the flood risk management measures outlined in the DFRMP. Among them there is a project proposal DANICE - DANube river basin ICE conveyance investigation and icy flood management. This initiative aims at creating the Danube Basin Ice Management Plan and the long-term ice-management initiative of the Danube Basin. It would reveal the actual ice situation of the basin and the probable effects of ice conveyance. The project shall deliver national and basin-wide operative resource management plan for icy floods or other situations together with mitigation measures. Harmonization of ice management planning methods and recommendations for common standards are part of the proposal, too. Another project proposal “DAREFFORT - Danube River Basin Enhanced Flood Forecasting Cooperation” has received funding from the Danube Transnational Programme and it will deliver an overview about the present status of the national water

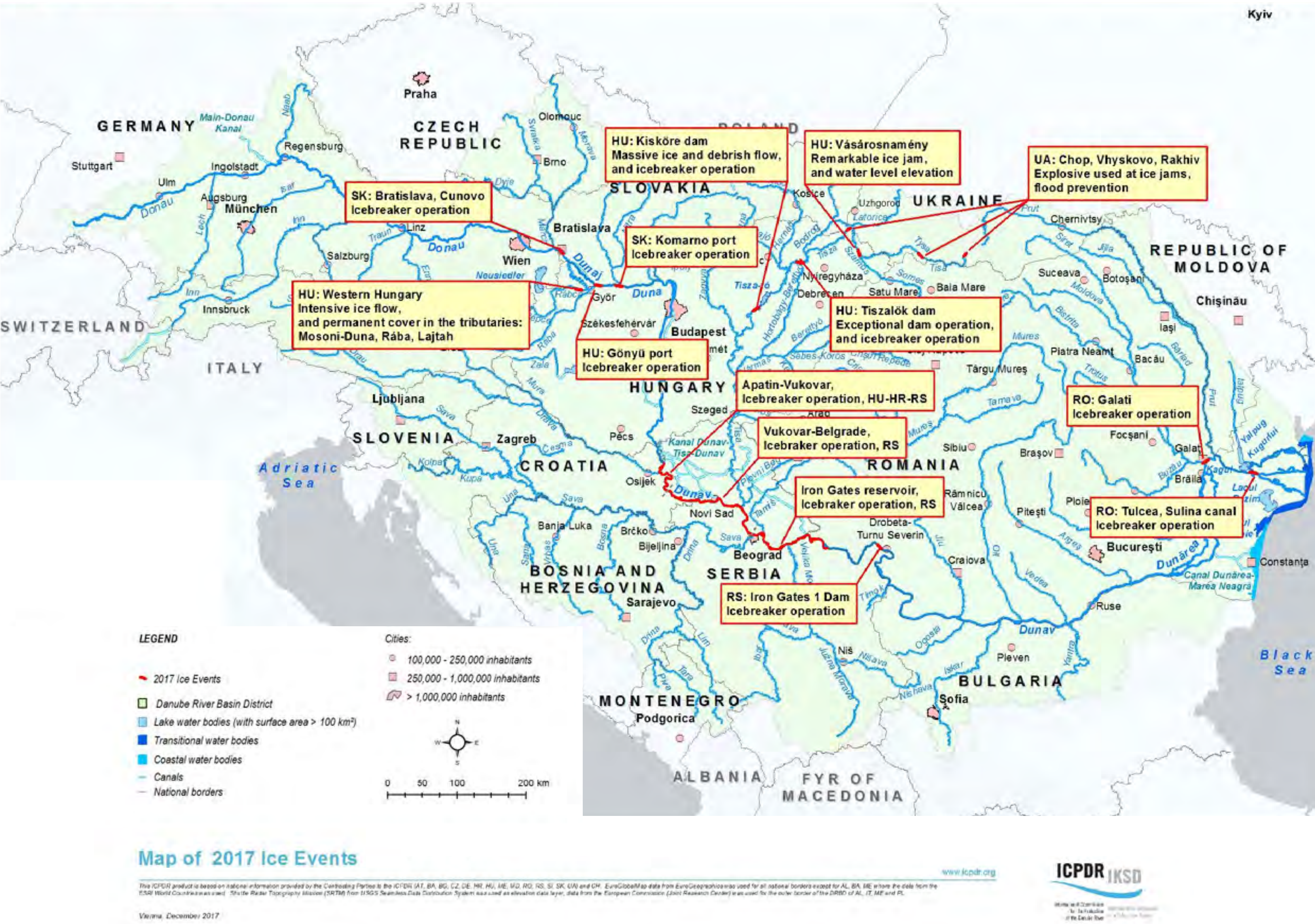


Figure 73: Summary of the reported measures and events

level/discharge and ice forecasting capabilities with the ambition to develop the existing systems in a comprehensive and compatible way. The project partners will jointly work out the policy recommendations to be submitted to the ICPDR in support of the development of the Danube Hydrological Information System (DanubeHIS), which will be a fundamental step towards a flexible and sustainable data exchange. Running these two projects will support the enhancement of ice management in the Danube River Basin.

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Contact:
ICPDR Secretariat
Vienna International Centre / D0412
P.O. Box 500 / 1400 Vienna / Austria
T: +43 (1) 26060-5738 / F: +43 (1) 26060-5895
secretariat@icpdr.org
www.icpdr.org

ICPDR IKSD