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CONSIDERATIONS ON RECENT FREEZING PHENOMENA ON BISTRIȚA AND BISTRICIOARA RIVERS

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Key words: freezing phenomena, frazil slush, ice jam, ice cover.

Abstract. It is highly important to have a better knowledge of river systems during the seasons when air temperature drops below freezing point if we consider the difficulties posed to hydrotechnical exploitations and the destruction caused by floods (as a result of ice jam development). The article presents briefly some opinions and hypotheses various researchers have formulated over time on the genesis of ice formations on rivers. Moreover, the article includes several analyses of ice formations developed on the Bistrița and Bistricioara rivers as wells as hazardous winter phenomena that may cause such ice formations, e.g., ice jams (ice dams). The development of winter-specific phenomena on the two rivers during the winter of 2011 - 2012 is illustrated in pictures, graphs, and maps taken or developed on the basis on data collected *in situ* during research.

Introduction

Starting from studies and research made by some hydrologists, hydro-technicians, climatologists, and geomorphologists (e.g., Ciaglic, 1965; Ciaglic *et al.*, 1975; Ciaglic, 1984; Ștefăniache D., 2002, 2003; Păvăleanu 2003; Ștefăniache D., 2007; Ciaglic, 2008, 2009; Rădoane M. *et al.*, 2008, 2009; Giurma *et al.*, 2010 and Ciaglic, 2010), we aim at contributing as much as possible to determining the specificity of the development of river-ice formations that pose questions, the causes leading to the occurrence of such phenomena, e.g., those during the winter of 1972-1973 on the Bistrița River, namely of an ice jam considered “unique” in Romania and even in Europe, and their evolution over the following years. To this purpose, and having considered that there have been no surveys of both rivers for the same time interval, during the winter of 2011-2012, we conducted visits to

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various sectors of the River Bistrița and its tributary Bistricioara, in order to take measurements of air temperature, water temperature in the river and to map the existing ice-formations.



Fig. 1 Measurements conducted on Bistricioara and Bistrița Rivers, March and November 2012

The need to conduct measurements and observations at the same time was a prerequisite as Ciaglic V. (2008) had noticed that the development of the freezing phenomena on both rivers was almost identical. The same author (Ciaglic, 2008, 2009) appreciated that Bistricioara River could be considered a natural “laboratory” where solutions and procedures could be identified that, if applied to the River Bistrița, may positively influence the development of ice jams while preventing their development. Practically, the procedures proposed modify the river-flow regime and, consequently, riverbed ice-formations as well as the massive frazil slush flow may be reduced significantly. Such flows constitute the main factor that causes ice jam formation at the ‘tail’ of the Izvoru Muntelui – Bicaz Reservoir.

The Area under Study

The River Bistrița, originating in the Rodna Mountains (the North Group of the Oriental Carpathians), has the longest mountain sector (the Carpathians) of the rivers in Romania, i.e., 216 km, or two thirds of its total length. The sector undergoing analysis between its border on the Suceava County (downstream Broșteni, i.e., Borca) and the ‘tail’ (end) of the Izvoru Muntelui – Bicaz Reservoir.

The River Bistricioara, the main right tributary of the Moldavian Bistrița River, crosses a medium-high mountain area belonging to the central group of the Oriental Carpathians. The river sector under study is limited on the upper side by the location called Capul Corbului (downstream the confluence with the Muncelul

Mare Creek, Harghita County), and on the lower side by the Izvoru Muntelui – Bicaz Reservoir.

Genesis of Ice Formations

Every winter, various ice formations develop on these rivers both on the surface and in mid- stream, depending on the physical, geographic, and weather-related factors. A brief presentation of the first hypotheses regarding the development of ice crystals or needles, river-bottom ice and frazil slush is to be found in *Hidrologia*, a book published by Constantinescu *et al.* (1956), which contains a presentation given below:

Gay Lussac, who formulated one of the first hypotheses, claimed that the development of *ice crystals* is possible only on the surface of water and then they are carried away into the entire liquid mass. When the ice crystals reach the river bottom, they are retained in the irregularities thereon and, due to successive gathering, they create crystallising nuclei around which the *bottom ice* develops. When the volume of the bottom ice reaches the limit at which its ascending force exceeds, the cohesion between the ice and the sub-layer it developed on, it detaches and rises to the surface of the water forming *frazil slush* ('zai' or 'inie' = 'floating ice') (Figure 2).

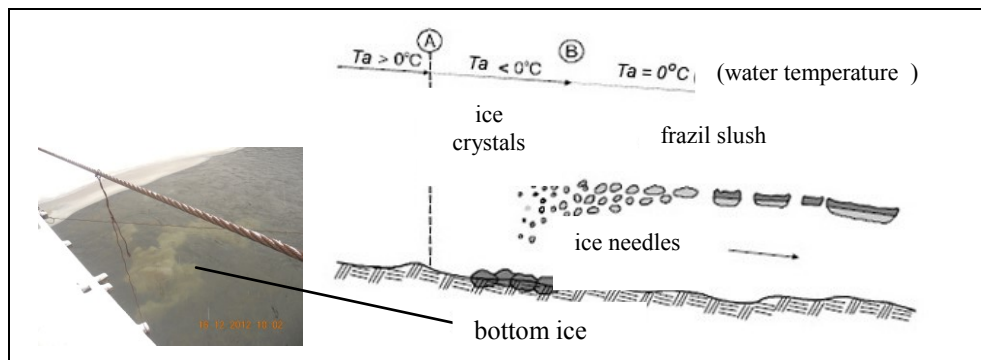


Figure 2 Various types of river ice formations (Beltaos et al., 2000).

Argo, Makaveev, and Altberg claim that the decisive factor causing the formation of various types of ice is the supercooling of water. In N. A. Zillerman's opinion, bottom ice can develop equally in the entire water mass.

While synthesising the hypotheses of the researchers cited above, Ciaglic *et al.* (2009) reaches the following conclusions:

- the supercooling of water is not sufficient enough to form the ice needles; for such needles to form, there is a need for freezing nuclei in the water mass and

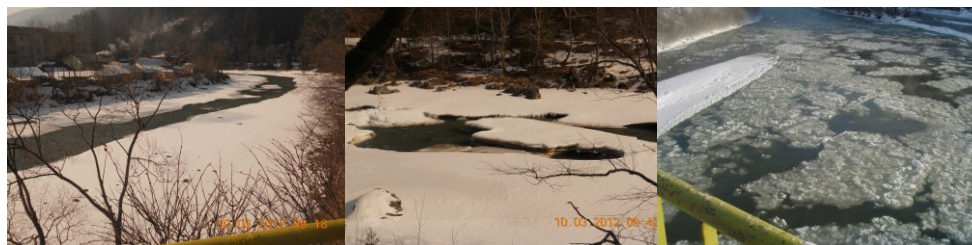
low flow velocity (at the limit), as turbulence prevents the water temperature from dropping sharply;

- water supercooling occurs at very small readings below 0°C, i.e., hundredths of degrees, as demonstrated by the Altberg's experiment;
- in the case of river bottom ice formation, there should be a low water flow velocity, and the area, within a turbulent stream where water flows very slowly, should be on the bottom of the river;
- the very weak low velocity wind, as opposed to strong ones, favours the supercooling water process.

The same author considers that supercooling of water on the river bottom is due to the fact that the first ice needle formations, which are carried to the river bottom by turbulence, melt once they reach the slightly positive-temperature water mass. This process develops similarly to evaporation with heat consumption. The ice needles reaching this area later no longer melt but they accumulate and form river bottom ice.

Moreover, Ștefănaș D. (2007), in the study on the “development of some hazardous hydrological phenomena,” and Victor Sorocovschi, in *Hidrologia uscatului* (2010), present the development of the first ice formations, including shore ice, frazil pans, and ice cover (Figure 3):

- *shore ice* involves an advanced freezing process, which favours the development of a thin ice sheet in the low-velocity sectors. Shore ice looks like an ice sheet developed along either bank or both;



Shore ice, downstream the bridge Ice covers with eyes, some 8 km from Chiril, Suceava county Frazil slush drifting on the Bistrița River upstream Holda, Suceava county

Fig. 3 Ice formations, covered with snow on the Bistrița River, in winter 2011 – 2012

- *frazil pans* represent pieces of ice of various sizes and shapes that drift on the surface of water. In spring, the pans develop from the fragmentation of the ice cover when there is an raise of air temperature;
- *ice cover* is the steadiest formation of all winter phenomenon on rivers. The ice cover can develop both due to the advance of the shore ice along the banks

and to the frazil pans that get jammed where the riverbed narrows or in areas where the gradient varies. In case of very low air temperatures, on some low debit rivers, the river can freeze completely. Hydrometric units record this formation as *full freeze*;

- *discontinue ice cover or with 'eyes'* is encountered on high-velocity river sectors (rapids, meanders etc), having rich underground sources.

From the wide range of freeze-up phenomena that appear on rivers, “**ice jams**” are considered the most dangerous as they cause severe destruction and even claim casualties. This is why Ashton (1986) defines it as “*the most hazardous winter phenomenon on rivers*” – quoted in Maria Rădoane *et al.* (2008). The Romanian term “*zăpor*” (i.e., *ice jam*, English; *zator*, Russian; *embâcle*, Frech; *eisbarre*, German), defines the ice jams developing on rivers during winter. The blockage on the flow sector causes a fall of the water level downstream and a rise of the water level “behind” the ice jam (upstream). Energy builds up and acts in the body of the ice jam; hence, in case of rapid melting, the phenomenon can cause severe damages downstream.

Types of ice jams and their development

Depending on the time of the year when the phenomenon develops, two types of ice jams are distinguished, i.e., freeze-up and meltdown ones.

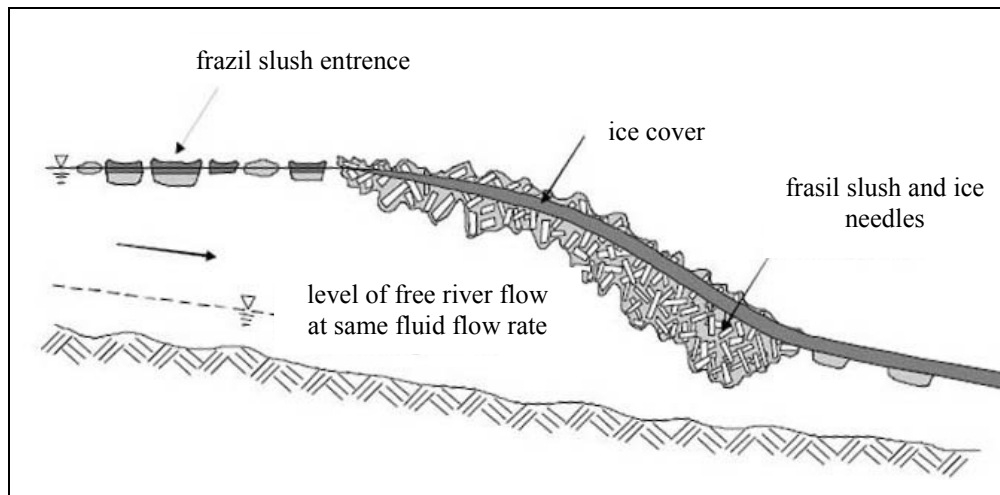


Fig. 4 Longitudinal cross section of a developing ice jam. The high level of the river water should be noted which was caused by the roughness and thickness of the ice jam (Beltaos *et al.*, 2000).

Freeze-up ice jams develop during the occurrence and development of river freezing phenomena (beginning of winter). They are caused by frazil slush

gathering under the ice cover. The evolution and development of the ice jam can be seen in Figure 4.

Meltdown ice jams are caused by ice pans gathered in certain sectors because of a fragmenting ice jam whenever air temperature rises sharply. In the Bistrița basin (upstream of Izvoru Muntelui – Bicăz Reservoir), the phenomenon is highly frequent on the upper sector (Depresiunea Dornelor down to Zugreni) and it has a lower frequency in the Zugreni – Crucea sector (Ștefăneche, 2003, 2007; Surdeanu *et al.*, 2005; Rădoane M. *et al.*, 2009; Giurma and Ștefăneche D., 2010). In the Crucea – Borca sector, these types of ice jams display a very low frequency, and downstream Borca there have been no records of such types of ice jams.

Ice jam upstream the ‘tail’ of Izvoru Muntelui – Bicăz Reservoir

After the development of the Izvoru Muntelui – Bicăz Reservoir, in downstream Borca sector a special type of ice jams began to develop. This type blocks the riverbed over long distances; sometimes exceeding 20 km, the frazil slush accumulations reach between 1 – 8 m thickness (Figure 5 a and b)).

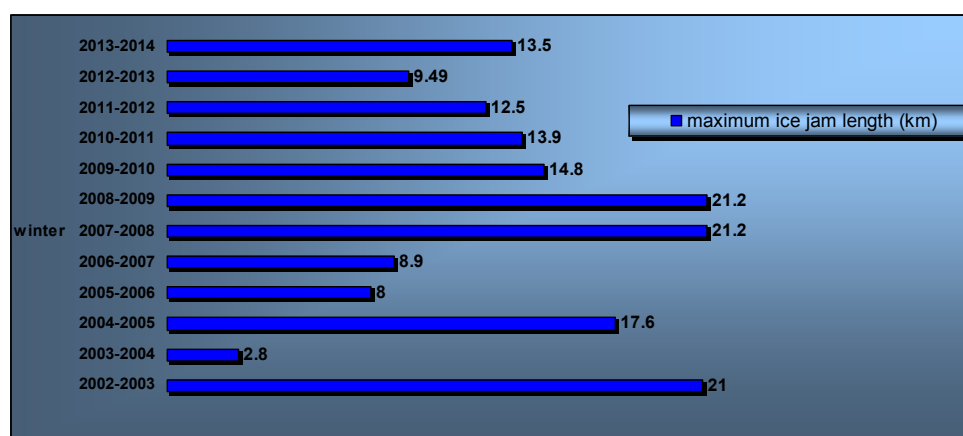


Figure 5 a) Variation of maximum length of the ice jam on the Bistrița River (sector: ‘tail’ of the Izvoru Muntelui - Bicăz Reservoir up to the border on Suceava county), between 2002 – 2014 (Source: data processed by Neamt County Water Management System)

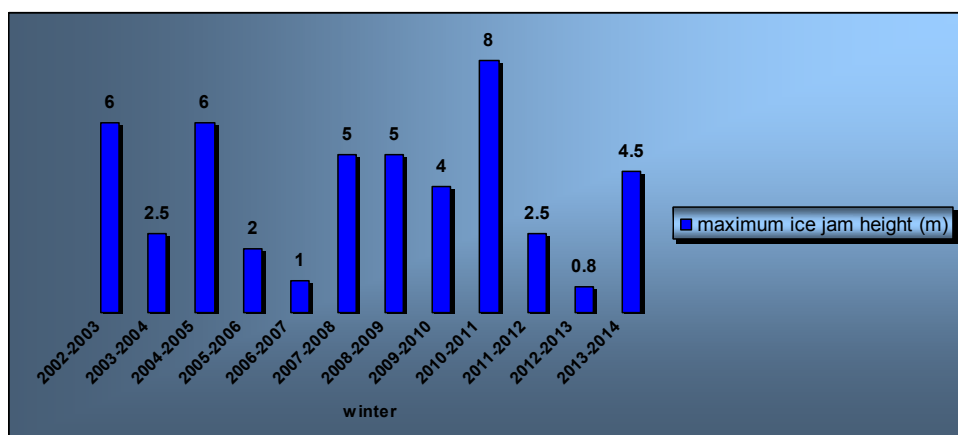


Figure 5. b) Variation of maximum thickness (height) of frazil slush (ice jam) on the Bistrița River (sector: 'tail' of the Izvoru Muntelui – Bicaz Reservoir up to the border on Suceava county), between 2002-2014 (Source: data processed by Neamt County Water Management System)

The duration of the phenomenon ranged between 24 days (winter 1992 – 1993) and 110 days (winter 1995 – 1996) for the time interval 1972 – 2002, and for the interval 2002 – 2014, between 38 and 124 days (Figure 6).

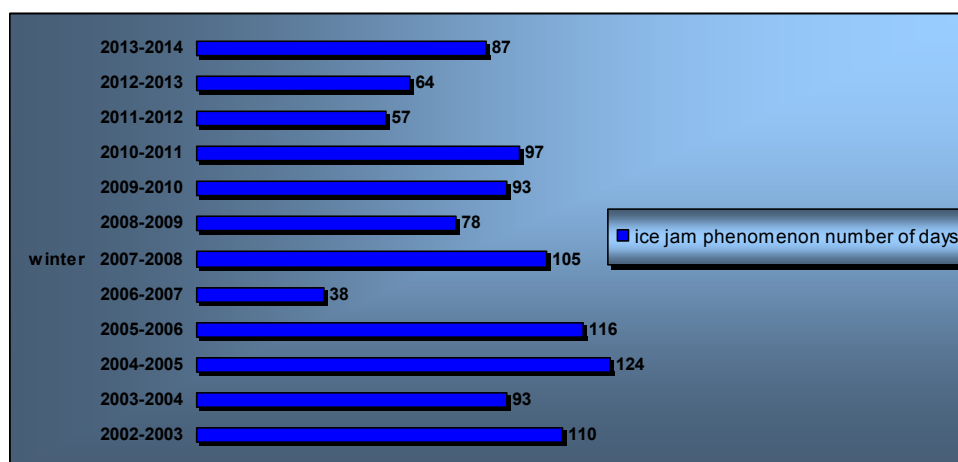


Figure 6. Evolution of the ice jam phenomenon on the Bistrița River (sector: 'tail' of the Izvoru Muntelui – Bicaz Reservoir up to the border on Suceava county), between 2002 – 2014 (Source: data processed by Neamt County Water Management System)

As shown in the bar chart, over the last twelve years, the period when the ice jam phenomenon appeared displayed an uneven distribution depending on the weather conditions specific to each year. The average number of days for the period between 2002 and 2014 when ice jams were recorded was of 88 days.

An analysis of the three previous bar charts allows us to notice that the phenomena was more intense during winters when ice jams developed at short time intervals and exceeding the 88-day average. Hence, the maximum length of the ice jam on Bistrița River upstream of the ‘tail’ of Izvoru Muntelui – Bicaz Reservoir exceeded the Frumosu hydrometric gauging unit, namely 12 km, and the maximum thickness of ice agglomerations was over 4.5 m. Exceptionally, during the winters of 2003 – 2004 and 2005 – 2006, the ice jam phenomenon was manifest for over 88 days, but with a relatively lower intensity.

This type of ice jam was noticed for the first time by Ciaglic *et al.* (1975). The authors state that the phenomenon undergoes two stages, i.e., the first stage *submersed*, when frazil slush carried by the river subducts the ice cover on the river for some distance. Therefore, the sector becomes obstructed due to the deposit of frazil slush on the bottom of the former riverbed inside the reservoir cuvette (Călugăreni area) and not by “juxtaposition” to the lower base of the ice layer (as it happens on rivers), wherefrom it extends gradually upstream through the riverbed, filling it and, quite often, bursting onto the banks as well – the *emersed stage* (Figure 7).



Figure 7. Manifestation of ice jam phenomenon on the Bistrița River (emersed stage), in 2008, 2009

The hypotheses of the authors cited regarding the fact that the first blockage (ice jam) is generated from within the reservoir underneath the ice cover and gradually extends upstream were confirmed by personal observations conducted in March –April 2012. Once the ice cover melted at the ‘tail’ of the reservoir, we noticed that on the entire length of the Bistrița River course, from Călugăreni to the Poiana Teiului viaduct, the riverbed was full of frazil slush containing sediments

and covered with some 8 – 14 cm-thick layer of mud, on top of which there were also pieces of ice (Figure 8).



Figure 8. Modified flow of the Bistrița River in the Izvoru Muntelui – Bicăz Reservoir basin following the obstruction of the former river bed with frazil slush (submerged stage), March and April 2012.

Evolution of the ice jam phenomenon in the winter of 2011 - 2012

During the winter of 2011 – 2012, the first frazil slush agglomerations on Bistrița River developed on the 21st November 2011, covering a length of 2.50 km, in the Topolicești – Poiana Teiului reservoir sector, some 600 m upstream the Ruseni bridge, village of Galu, commune Poiana Teiului. The conditions favouring the occurrence of the ice jam phenomenon were as follows: flow of frazil slush since 18th November 2011 on some 30 – 40 % of the water surface, air temperature recorded at the Frumosu hydrometric gauging unit of – 6.5° C and ice cover upstream the Topolicești dam. Ever since 2003, when the Topolicești reservoir was put to service, a new base level on the Bistrița River was created. The phenomenon manifested for two days, i.e., until the 23rd November, when on the sector between the Topolicești dam and 700 m upstream Ruseni bridge, namely on a 2.50 km-length, the Bistrița River displayed only 0.30-to-1.00m-thick shore ice. The air temperature recorded at the Frumosu hydrologic gauging unit was 0°C. At the ‘tail’ of Izvoru Muntelui – Bicăz reservoir, the first frazil slush agglomerations gathered on 27th January 2012. The hydrologic conditions were as follows:

- from the Poiana Largului viaduct until 200 m upstream Poiana Teiului ACH footbridge, on a 3.6 km-length, the Bistrița river displayed frazil slush

agglomerations with a thickness ranging between 0.15 and 0.80 m, with eyes and melted canal on some 10 % of the sector length;

- there was shore ice at the Frumosu hydrologic gauging unit and frazil slush was floating on 60 % of the water surface (the level of Bistrița river measured 53 cm, the debit – 7.05 mc/s, air temperature was -12.2°C and there was a 7 cm-thick snow layer;

- the water level in the reservoir measured 487.11 m (Ceahlău hydrologic gauging unit).

As shown in the *Level variation graph – Izvoru Muntelui Reservoir, 2012*, the date of the development of the ice cover on the reservoir (Ceahlău hydrologic gauging unit) coincides with the date the ice jam was developed at the ‘tail’ thereof (Figure 9).

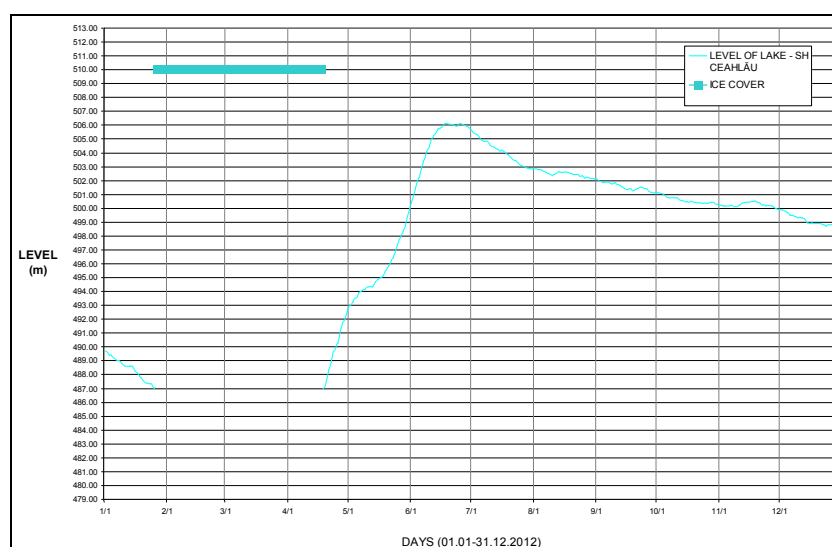


Figure 9. Variation of the level in the Izvoru Muntelui – Bicăz Reservoir, 01/01 – 31/12/2012 (Source: data processed by the Hydrological Unit Piatra Neamț)

The Frumosu hydrologic gauging unit, located downstream the Frumosu bridge (at some 12.8 km from the Poiana Largului viaduct) the frazil slush agglomerations (ice jam) were present for 36 days, since 4th February to 10th March 2012 (Figure 10. a) and b)).

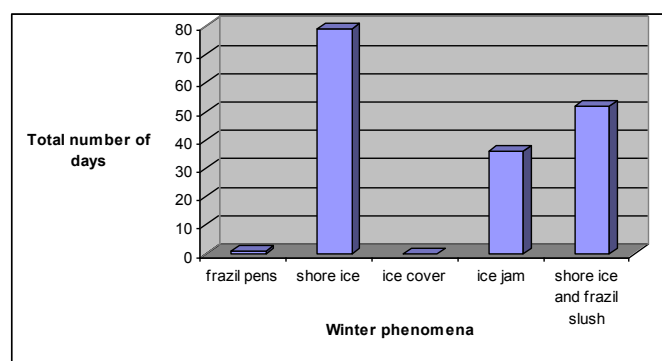


Figure 10. a) Quantitative evolution of winter phenomena on the Bistrița River – Frumosu sector, 17/11/2011 – 24/03/2012 (Source: data processed by the Hydrological Unit Piatra Neamț)

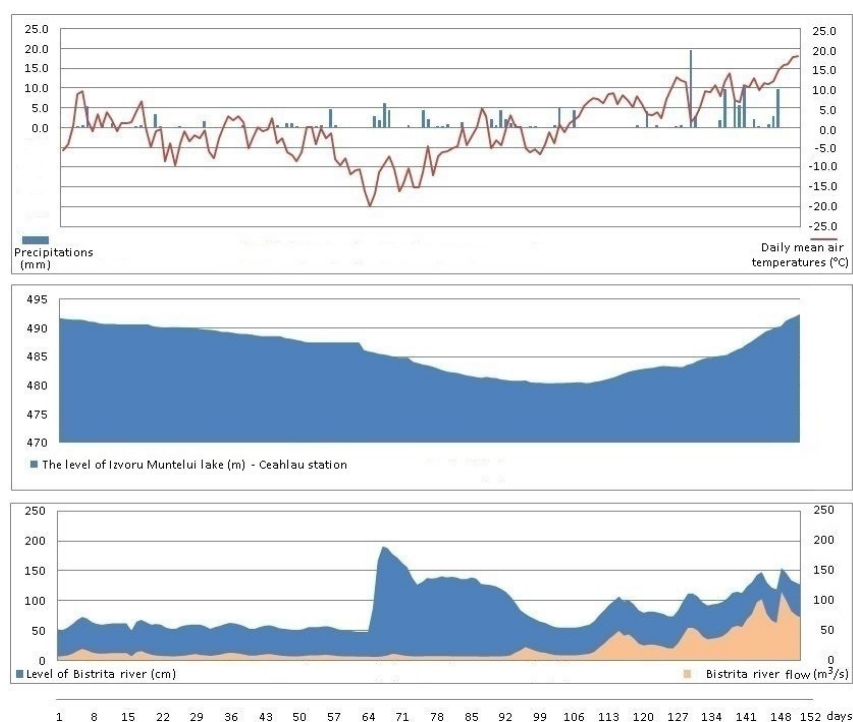


Figure 10. b) Variation of hydro-meteorological factors that influenced the ice jam at the Frumosu hydrometric unit – Bistrița River, 1 December 2011 – 30 April 2012 (Source: data processed by the Hydrological Unit Piatra Neamț)

Owing to the jam formed by frazil slush agglomeration, the daily level of the Bistriței River – Frumosu sector – raised from 48 cm (02/02/2012) to 87 cm (03/02/2012), 167 cm (04/02/2012), and 191 cm (05/02/2012). Meanwhile, the debit of the river remained steady. At 07:00 a.m., on 5th February 2012, the hydrological status on the Bistrița River, upstream the Izvoru Muntelui reservoir was as presented below:

- on the sector contained between the Poiana Largului viaduct and 0.2 km downstream the Ruseni bridge, on a 6.8-km-length, the river displayed frazil slush agglomerations whose thickness measured between 0.2 and 2.5 m;
- on the sector contained between the Săvinești bridge and 0.4 km upstream the Frumosu bridge, on a 4.4-km-length, the river displayed frazil slush agglomerations whose thickness measured between 0.2 m and 1.0 m, with alternating eyes and a 1m-to-3m-wide melted canal on some 30 – 35 % of the sector length;
- from upstream. there was frazil slush floating on some 40% of the water surface; air temperature at Frumosu hydrologic gauging unit, Commune Farcașa, measured -10.5.

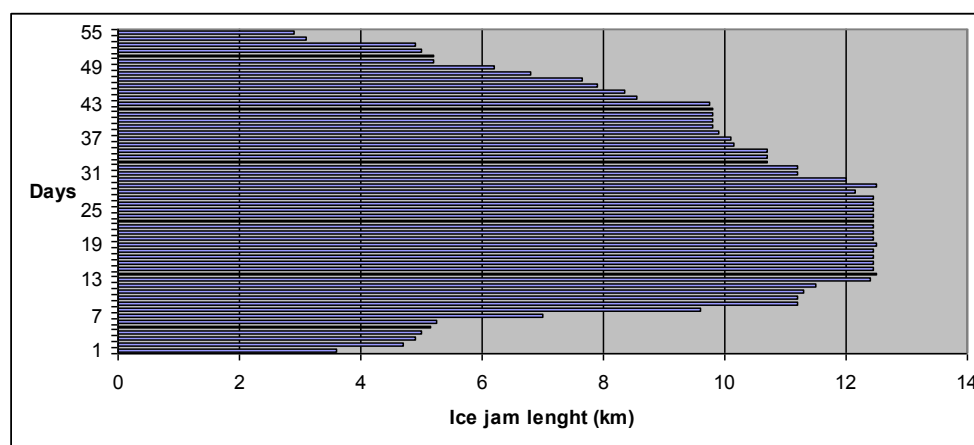


Figure 11. a) Variation of the length of frazil slush agglomerations (ice jam), upstream the ‘tail’ of Izvoru Muntelui – Bicaz Reservoir, between 27 January and 21 March 2012 (Source: data processed by the Hydrological Unit Piatra Neamț)

Depending on the number of days and the intensity of the frazil slush flow (10% - 70% of the water surface), on lengths ranging between 3.60 km (27/01/2012) and 12.50 km (09, 14, and 24 February 2012), on the River Bistrița, upstream the Izvoru Muntelui – Bicaz Reservoir, frazil slush agglomerations (ice

jam) developed alternating with eyes ranging between 0.15 and 2.50 m and a 1-to-5m-wide melted canal on 10 – 40 % of the sector length (Figure 11. a, b and c). Air temperature at Frumosu hydrometric unit was steadily below 0°C, except for 25 February, 19 and 20 March 2012, when positive readings were recorded (Figure 12).



Figure 11. b) Snow-covered frazil slush agglomerations on the Bistrița River, upstream and downstream ('tail' of Topolicești Reservoir) the Săvinești – Poiana Teiului Bridge, on 16/02/2012



Figure 11. c) Snow-covered frazil slush agglomerations on the Bistrița River, downstream Topolicești Dam - commune Poiana Teiului, on 10/03/2012

Starting with 22nd March 2012, no ice jam phenomenon was recorded on the River Bistrița, upstream the Izvoru Muntelui – Bicaz Reservoir, as there were no

more frazil slush flows, and air temperature was on the rise. Thus, in the winter of 2011 – 2012, the phenomenon was reported for a number of 57 days (2 days between 21st and 22nd November 2011 and 55 from 27th January to 21st March 2012).

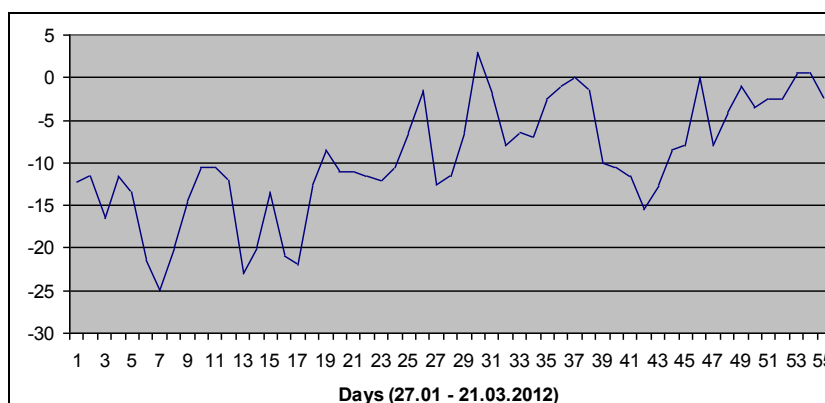


Figure 12. Air temperature variation at Frumosu hydrometric unit (daily measurements at 06.00 a.m.) (Source: data processed by the Hydrological Unit Piatra Neamț)

Following the analysis of the air temperature variation graph at the Frumosu hydrometric unit, we can conclude that significant fluctuations of air temperature were recorded between 27th January and 21st March 2012, which influenced the development and the steadiness of frazil slush agglomerations (ice jams) on the River Bistrița, upstream the Izvoru Muntelui – Bicaz Reservoir.

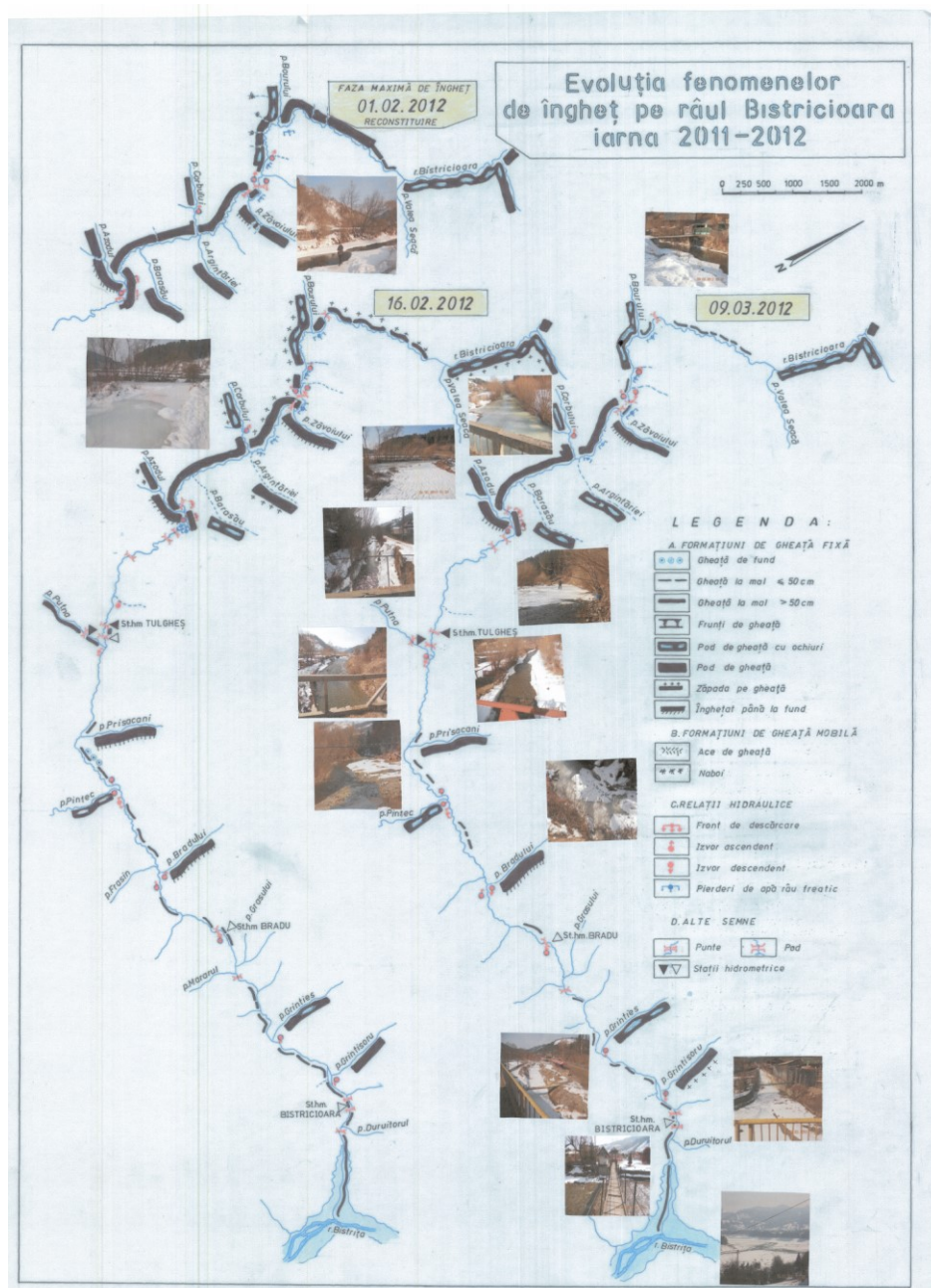


Figure 13. Freezing phenomena mapping on the Bistricioara River, winter 2011 - 2012

Conclusions

The causes of the ice jam development on the River Bistrița, upstream the ‘tail’ of Izvoru Muntelui – Bicaz Reservoir, ice jams that significantly affect human settlements, defence works, infrastructure, farming areas, etc., are both *natural* (e.g., air temperature, wind, as well as the characteristics of the water flow in the river – turbulent or apparently laminar) and *antropic* (before the development of the Izvoru Muntelui – Bicaz Reservoir, there was no ice jam phenomenon recorded, although severe frazil slush and ice cover flow were frequently reported). Moreover, Ciaglic (1985) considers ice jam to be *atypical* as the frazil slush accumulation carried by the River Bistrița develops on the bottom of the Izvorul Muntelui – Bicaz Reservoir and not by ‘fusion’ with the surface ice cover. A particular situation is encountered when the locks of the Topolicești Dam – commune Poiana Teiului, are closed (the Poiana Teiului hydropower station is operating), and frazil slush gathers under the ice cover on the reservoir.

Notwithstanding, the occurrence on the Bistrița and Bistricioara Rivers, under identical climatic conditions, of some sectors with well-developed ice formations as well as some river sectors in the immediate vicinity with poorly-developed or no ice formations proves that there are also some other generating factors, besides the meteorological and hydrological ones, that may strongly influence the development of freezing-up phenomena. The hydraulic relationships between the rivers and the areas they cross play an important role, hence the phenomena display a specific development sometimes manifested by a complete lack of ice due to the underground source.

This theory launched by Ciaglic (1965) was also confirmed by our personal observations conducted in the winter of 2011-2012, when measurements of water temperature were conducted in various areas and the phenomenon was mapped. Despite identical climatic, geological, and morphological conditions, in the small area covered by the Bistricioara River basin, the 35-to-40cm-thick ice cover spread over almost the entire surface of the river in the upper sector of the basin, upstream the confluence with Azod Creek. By comparison, downstream, the ice cover disappeared suddenly despite identical air temperature readings (Figure 14. a), b) and *Freezing phenomena mapping on the Bistricioara River, winter 2011 - 2012*).

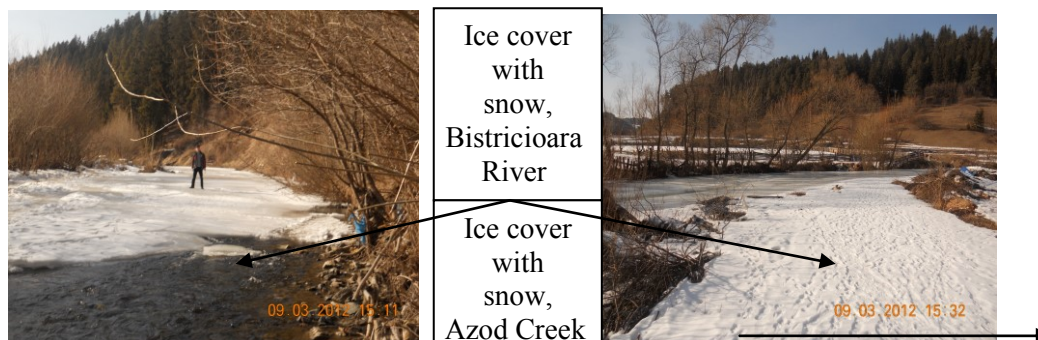


Figure 14. a) Bistricioara downstream its confluence Azod Creek, March 2012

Fig. 14. b) The Azod Creek at the confluence with Bistricioara, March 2012

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