DOI 10.1515/pesd-2015-0037 PESD, VOL. 9, no. 2, 2015

THE INFLUENCE OF THE HYDRAULIC EXCHANGE RELATIONS IN THE EVOLUTION OF ICE JAM PHENOMENA ON BISTRIŢA RIVER IN THE AREA BETWEEN DORNA ARINI (SUCEAVA COUNTY) AND BORCA (NEAMŢ COUNTY)

Gaman Claudiu[1]

Key words: Bistriţa River, frazil slush, ice jam, hydraulic exchange relations

Abstract. The presence on Bistriţa River, in identical climatic conditions, of sectors with well-developed ice formations in the immediate vicinity of river sectors lacking or with weakly developed such formations demonstrates the existence of other factors beside the meteorological and hydrological ones that may influence the evolution of freezing processes and implicitly of ice jams. A special role is held by *the hydraulic exchange relations* established between the river and the aquifers (Ciaglic, 1965; Ciaglic and Vornicu, 1973), the mentioned phenomena having a characteristic evolution, sometimes manifested through the total lack of ice due to underground input (Gaman, 2014). River alimentation from underground waters takes place in two situations: a) nearby well-developed alluvial fans close to floodplain or terraces; b) in areas where the river suddenly changes direction from flowing along one of the banks to an almost perpendicular position towards the valley, or where it meanders in the floodplain. The sectors of the river with areas of free water are those generating ice crystals and river-bottom ice and finally frazil slush. In the areas where the river loses water through infiltration in the floodplain, ice formations are much stronger according to the volume of water losses, and total freezing can be recorded. Field observations and measurements conducted in the winters of 2011-2012, 2012-2013, regarding the evolution of freeze phenomena, respectively ice jam formation, on Bistriţa River confirm the mentioned theory.

Introduction

After the emplacement of Izvoru Muntelui-Bicaz dam lake, in the river sector downstream Borca was produced a special type of ice jam, which may occur 2-3 times in a single winter (Romanescu, 2005; Romanescu and Bounegru, 2012;

[1] „Alexandru Ioan Cuza" University of Iasi, Romania, Faculty of Geography and Geology
gaman_claudiu@yahoo.com

Surdeanu et al., 2005), blocking the river floodplain on lengths of more than 20 km, frazil slush accumulation reaching depths of 1-8 m (fig. 1).

This type of ice jam has been first mentioned by Ciaglic et al. (1975). The authors mention that the phenomenon includes two phases, the first one being *submerged*, in which frazil slush brought by the river enters below the ice cover on a certain distance. The damming of the section is made by the frazil slush which sinks to the bottom of the old floodplain inside the lake (Călugăreni area) and not by gradually attaching to the lower base of the ice layer (as it happens on rivers). From here it gradually extends upstream in the floodplain, filling it and in many cases passing over the river banks (the *emerged* phase*)* (fig. 2 A, B).

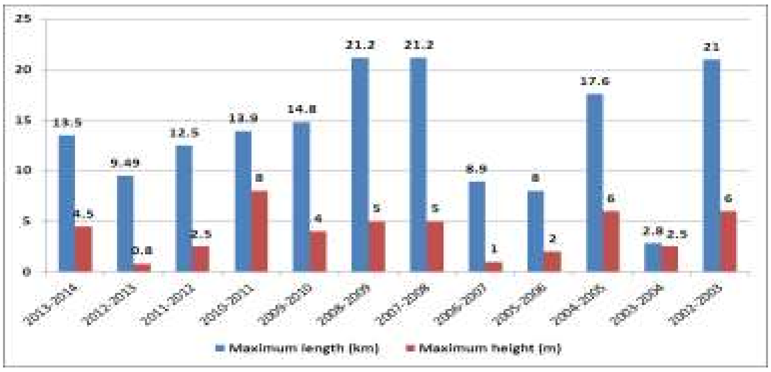

Fig. 1. Variations of the ice jam maximum lengths and heights on Bistriţa River (sector between Izvoru Muntelui-Bicaz dam lake and the limit with Suceava County) during 2002-2014 (Gaman, 2014)

A B

Fig. 2. Ice jams on Bistriţa River: A. on the entire river surface, downstream Frumosu hydrometric station, 28.01.2014; B. with thawed channel, upstream Topoliceni dam, 01.02.2014

The purpose of this study has been of identifying some solutions to reduce the intensity of the frazil slush flows and implicitly of the ice jams, having in view that Ciaglic (2008, 2009) considers that for the substantial diminishment of the effects of the phenomenon it is necessary to act against the causes.

Geographic position and limits

Bistriţa River, the most important tributary of Siret with an length of 278.8 km (Cojoc et al., 2014; Ujvari, 1972), is on more than two thirds a mountainous, Carpathian river. From its spring area (Rodna Massif) and up to Piatra Neamţ, Bistriţa valley, with a NNW-SSE direction, drains mountainous massifs that belong to two large units of the Eastern Carpathians, respectively the Northern (Maramureş and Bucovinei Mts.) and the Central Unit (the Moldo-Transylvanian Carpathians) (Velcea and Savu, 1982).

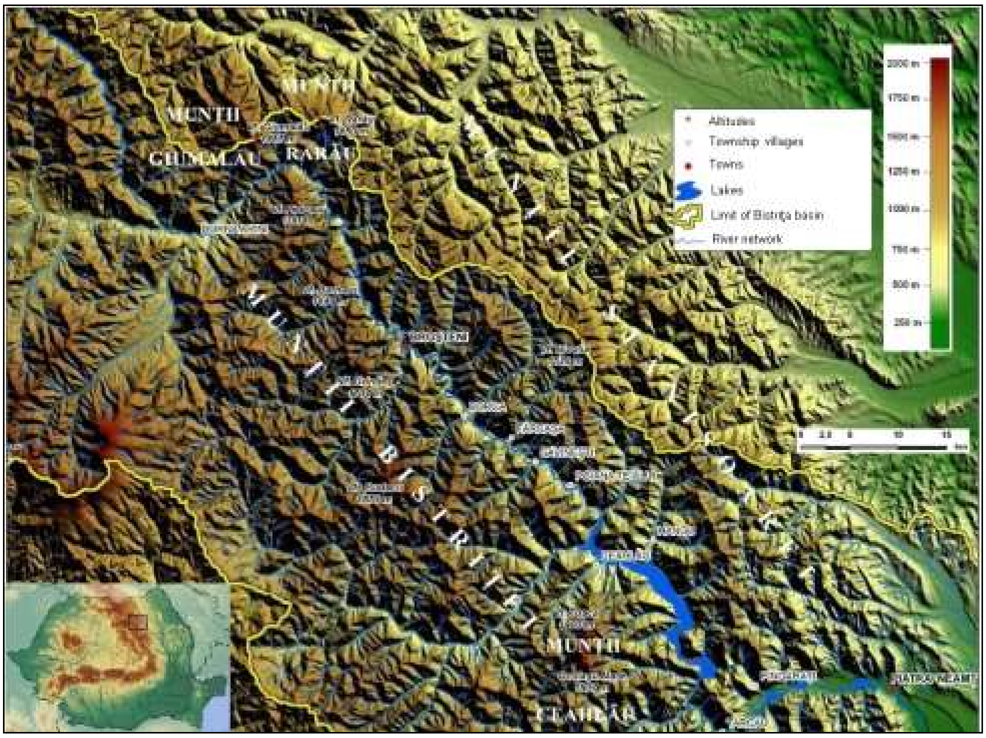

Fig. 3. Geographic position of Bistriţa basin in the study area (RMD CONSULT, 2009)

We have extended the researches in Suceava County, from Dorna Arini village (at the confluence with Neagra Şarului), up to Borca town (Neamţ County), having in view that the source of ice formations (ice packs and frazil slush) that reach the entrance into Izvoru Muntelui-Bicaz lake come from this area. Ciaglic, cited by Rădoane *et al.* (2009), mentions that in the Rusca-Crucea-Cotârgaşi area (fig. 3) occur the strongest and longest as duration frazil slush flows, due to the morphological characteristics of Bistriţa's floodplain, which in cross-section presents alternations of riffle and pools (laminar flow which favors the formation of ice crystals) and slope breaks (with high roughness and turbulent flow that favor the formation of river-bottom ice), essential conditions for the occurrence of frazil slush flows.

Results and discussions

According to the evolution of freeze processes, respectively ice jams, along Bistriţa River, three sectors have been delimited during the field observations from the 2011-2012 and 2012-2013 winters.

The first river sector occupies the entire depression of Dorna up the southern (downstream) limit of Rusca village (the confluence with Osoi brook). The ice jam is the formation with the largest occurrence, spread, duration and thickness. Ice presents an obvious stratification: an upper thin layer (2-3 cm) formed of frozen snow; a medium layer of crystalline ice with thicknesses of 20- 40 cm and a lower layer formed of frazil slush deposited at the lower part of the crystalline ice jam, with a variable depth and undulated lower surface (at the contact with the water) (fig. 4).

Fig. 4. Massive ice fragments brought from Ortoaia (upstream Zugreni dam) that have passed over the shuttle, remaining on land at its base (ice thickness and stratification can be observed), 01.04.2012

In this sector ice jams occur periodically both on Bistriţa and its larger tributaries. The ice jams during the freeze period are less dangerous, because in many situations they do not end in river blocking and floods, and frazil slush accumulation (fig. 5) under the ice bridge is slow.

It is a new (beginning) stage in which are found the conditions for the formation of a new, intermediary type of ice jam (Ciaglic, 2008). It is the most dangerous type of ice jam (in what regards the damages inflicted), reaching impressive dimensions both as surface occupied and depth, being formed in the middle of the winter, in January-February (fig. 6 A, B, C).

Fig.5. Frazil ice flows on Bistriţa, 2011-2012 winter

Fig. 6 A. Settlements flooded during ice jam formation upstream Vatra Dornei (photo Hociung C.)

Fig.6 B. Works of removing ice jams from the Bistriţa floodplain, (photo Gavril Petrică)

Fig.6 C. Evacuation of ice packs reaching DN 17B national road, Suceava County (photo Gavril Petrică)

The ***main*** cause for the occurrence of this ice jam type is the invasion of more humid and warmer Atlantic air masses through the Bârgae-Dorna Couloir in the Dorna Depression (Surdeanu *et al.*, 2005). In this way ice packs resulting from the fragmentation of the ice bridge are overimposed on the frazil slush agglomerations.

The second sector starts downstream Rusca (north, the confluence with Osoi brook), and ends downstream the confluence with Căpriţa brook. Along this sector are distinguished three almost equal compartments: at north between the confluence of Osoi and Chiril brooks, Zugreni Gorges; in the central part, between Chiril and Crucea brooks, a depression basin; downstream, between Crucea and Căpriţa brooks, the Toancele Gorges, the narrowest and deepest valley sector.

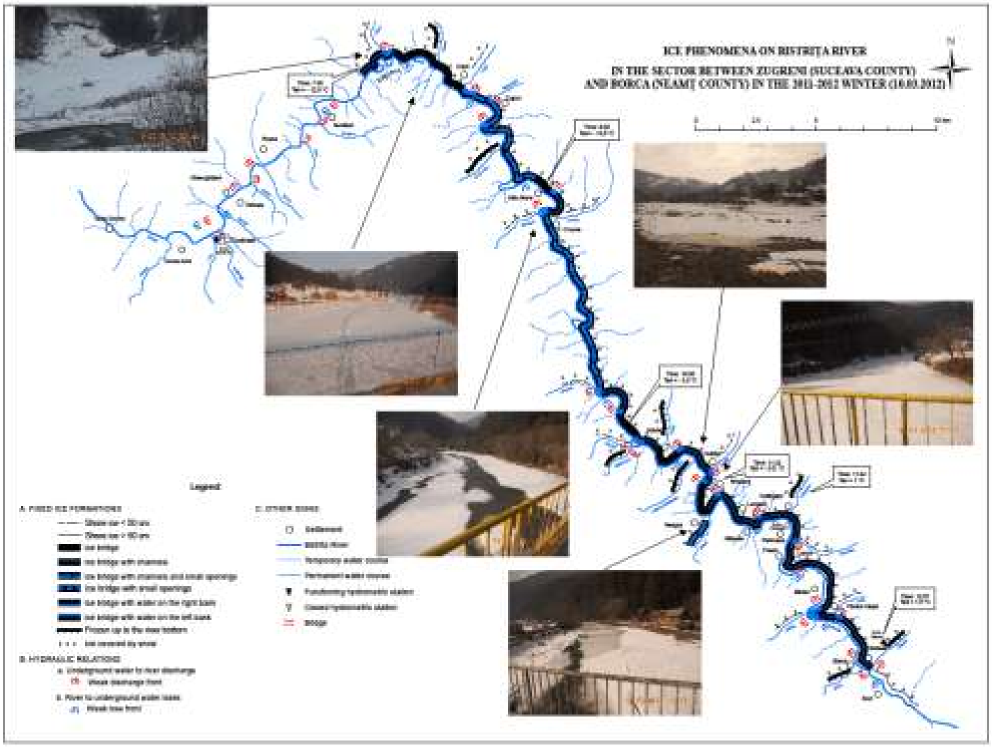

Fig.7. Map of ice jam formations along Bistriţa in the Zugreni (Suceava County) - Borca (Neamţ County) sector (10.03.2012), (Gaman, C., Ciaglic, V.)

A general characteristic of the evolution of ice jam formations on the entire Bistriţa valley downstream Osoi brook (the southern limit of Dorna depression) and up to Izvoru Muntelui Lake is represented by their alternation (fig. 7): shore ice, different types of ice bridges (with spaces, channels or complete). The occurrence of these ice formations is relatively sudden on the entire mentioned river length, but the ice bridges disappear fast enough (a few days) even if air temperature is maintained relatively low or decreases easily. Only the shore ice, with variable widths, remains. At the same time, in the erosion basins, at the upstream part of the floodplain terraces, occurs a patch of free water along the banks. This is the area through which underground water from the floodplain deposits (gravel, boulders) enters the river. The same phenomenon can be seen at the downstream part of the alluvial cones neighboring the high floodplain.

In what regards the freeze ice jams (dams), they occur very rarely, being normally small, just like the thaw ones. In the last case, the ice floes flows of low intensity do not lead to blockings of the river section, because the thaw occurs beginning from the southern lower area and slowly propagates towards the higher north spring area, the floodplain being cleaned from the floes downstream.

In this sector the most dangerous are also the ice floes occurring after the sudden release of intermediary type ice jams from the Dorna Depression. These are conditioned by the transport capacity of the river floodplain in the moment when ice jams in the southern part of Dorna Depression are broken. In the case when the floodplain transport capacity is reduced, a part of the floes remain on the banks and another are retained in the area of the previous dam from Zugreni (fig. 8). In the case when the floodplain transport capacity is high (large liquid discharge) the ice floes overcome the Zugreni dam locks (fig. 9) and can reach downstream the Frumosu village. They can even connect with the atypical ice jam formed almost exclusively out of frazil slush accumulations which is propagated from Izvoru Muntelui-Bicaz Lake upstream. In this type of situation have been registered the largest losses, including human lives, in January 2003 (fig. 10).


Fig. 8 Ice floes deposited upstream the ex-dam of Zugreni on the river banks (01.04.2012, photo Gaman C.) and in the previous lake area (March 2008, photo Rădoane M.)

The most powerful ice jams occur in the compartment from the central Chiril-Crucea area. The most affected points are the following: in the meander of Bistriţa just downstream of Cojoci village; in the tight curve downstream Satul Mare village; upstream Dâmbul Colacului village (the largest ice jams) and immediately upstream the confluence with Crucea village. As the ice floes flows go downstream, they lose intensity and a large part of them are retained on the river banks in the area of the ice dams from upstream.

Fig. 9 Ice floes deposited 1 km upstream Zugreni dam and downstream Crucea township, 01.04.2012

Fig. 10 Properties affected by ice jams in Farcaşa village, January 2003

The last compartment of the second river sector, between Crucea village and Căpriţei brooks, corresponds to Toancelor Gorges, where the floodplain is narrow and presents many sectors with almost vertical walls. On this river sector freeze and thaw ice jams are small and of short duration (in case they occur), without

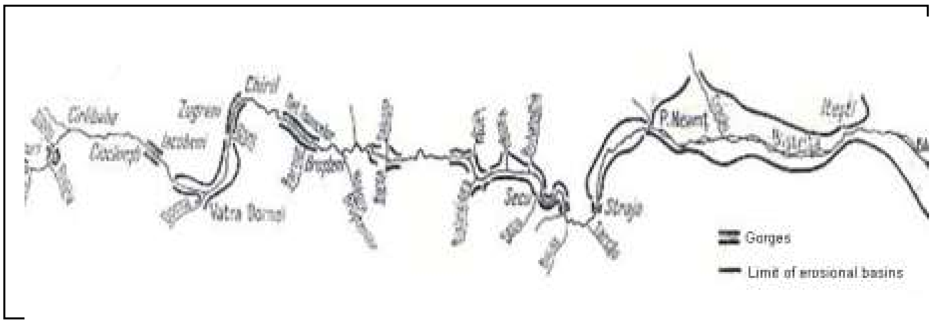

Fig. 11. Gorges and depression basins along Bistriţa (Donisa, 1968)

Ice bridge with small holes at about 8 km from Holda

Bistriţa river – thawing along the banks and ice bridge with snow at Holda

Ice bridge with snow, upstream the bridge, Broşteni

Ice bridge with channel downstream bridge at Lunca (downstream the confluence with Cotârgaşi brook)

Fig. 12. Ice formations on Bistriţa, Suceava County, March 2012

dangerous effects. The intermediary ice jams are also weakly manifested in this area, because most of the ice floes have been retained upstream in the Chiril-Crucea erosion basin.

The third sector, Căpriţei brook up to Izvoru Muntelui-Bicaz Lake, is characterized by a widening of the valley downstream, with narrow sectors between those of the erosion depression basin types. From the north part of the sector, these are the erosion basin of Holda-Broşteni, the narrowing from Cotârgaşi-Pietroasa, the depression basin of Lunca-Mădei-Sabasa-Pârâul Pântei, the narrowing from Piciorul Comorii, Stejaru-Farcaşa basin, a short narrowing at Buşmei, Popeşti-Galu basin, the narrowing immediately downstream from Galu brook, after which the valley widens more and more up to the Izvoru Muntelui-Bicaz Lake (fig. 11). Winter phenomena in this last sector of Bistriţa river are the same as in the second (Osoi-Căpriţei brook) and their evolution is similar (fig. 12). The dangerous ice jams (dams) are also those of intermediary type. The large distance from the area of origin of the massive ice floes flows (Dorna Depression) attenuates their effect as they move downstream. The most exposed areas for this type of ice jams are: upstream Holda, upstream Holdiţa, upstream the Neagra-Broşteni confluence and upstream Pietroasa brook. Yet, in some years ice floes have reached Frumosu hydrometric station, uniting with the massive frazil agglomerations of the „atypical-anthropic" ice jam from the entrance into Izvoru Muntelui-Bicaz Lake.

We have insisted on following the evolution of the freeze phenomena on Bistriţa River with the purpose of identifying a solution that would reduce the intensity of frazil slush flows.

In this regard, during the winter of 2012-2013 have been studied on field the areas with hydraulic exchange (fig. 13), conducting measurements of the river water (longitudinal thermal profile) and of that from the aquifers from Bistriţa's terraces (fig. 14 A, B, 15, 16 and 17). Unfortunately on Bistriţa haven't been conducted discharge measurements for the establishment of a hydric balance for the analyzed sectors. Still the theory regarding **hydraulic exchange** has been confirmed for Bistricioara river by Ciaglic and Vornicu (1965, 1973) after measurements conducted in 1963-1965 (the loses through infiltration varying in certain areas between 19.5 % and 71.4 % and the underground input reaching in some cases 49.5 %).

Upstream the fountain in figure 14 a, Bistriţa (water temperature = 4.4°C) loses water in underground by infiltration (in the area of Crucea mayors), after going downstream through the left bank terrace deposits the water reaching 11°C. In the discharge area (photo bridge with cable) river water temperature has increased by 0.6°C.

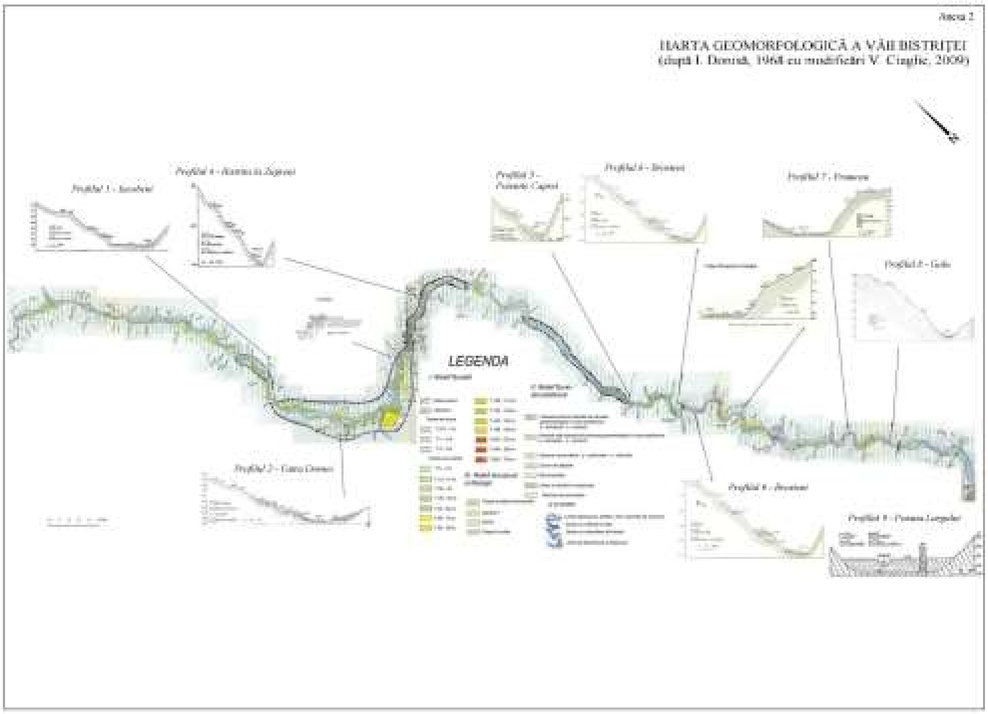

Fig. 13 Geomorphological map of Bistriţa valley upstream Poiana Largului
(Ciaglic - RMD CONSULT, 2009)

A. Fountain downstream Crucea (Poiana Şarpelui) mayors. Level difference between Bistriţa's level and the fountain is of about 4.5 m, fountain water depth = 1 m, Fountain water temperature = 11˚C, river water temperature = 5 ˚ C
B. Fountain at Holda, upstream Broşteni. Level difference between Bistriţa's level and the fountain is of about 5 m, fountain water depth = 1.5 m, Fountain water temperature = 11˚ C, river water temperature = 5.3˚ C.

Fig. 14. Determination of underground water temperature (terrace on the left bank of Bistriţa) in the Crucea – Broşteni sector, 05.10.2012

Bistriţa river, about 150 m downstream the confluence with Arşiţei brook, water temperature = 3.4 ˚C (left); Fountain on the right bank at Rusca, water depth = 1 m, water temperature = 10˚C (center); Bistriţa river near the fountain (water temperature = 4 ˚ C), (right).

Fig. 15. Temperature input (0.6˚ C) from the underground water of the right-side terrace of Bistriţa at Rusca, Suceava County, 11.11.2012 (air temperature = 2˚ C at 11.44 hours).

Rusca brook at the confluence with Bistriţa, water temperature = 5.5℃ (left); Discharge from the right bank terrace, water temperature = 8.9℃, (center); Bistriţa river, downstream the confluence with Rusca, water temperature = 4.3˚C (right)

Fig. 16. Thermal input (0.3˚ C) coming from tributaries and aquifers of the right-bank terrace downstream the confluence with Rusca 11.11.2012 (air temperature = 4˚ C).

Fountain at the entrance in Chiril Fountain at Cojoci

Fig. 17. Measurements of water temperature from the aquifers of alluvial fans from the left side of Bistriţa. Water depth = 1 m, water temperature = 9˚ C, air temperature = 7˚ C, 11.11.2012

Downstream the confluence with Chiril water temperature in Bistriţa rose from 4˚C (downstream the fountain) to 5˚C (thermal input of 1˚C coming from the brook's alluvial fan). Water temperature remained stable up to Satu Mare village, where it increased up to 5.5˚ C (thermal input from the aquifer of the alluvial fan from Bistriţa's left side, downstream Colacului).

In the sector downstream the confluence with Crucea (water temperature = 6 ˚C) and downstream the confluence with Holda (upstream Broşteni village) river water temperature increased by 1.5 ˚C. Air temperature at 15.50 was of 8.5˚C.

Conclusions

The presence on Bistriţa River, in identical climatic conditions, of sectors with well-developed ice formations in the immediate vicinity of river sectors lacking or with weakly developed such formations demonstrates the existence of other factors beside the meteorological and hydrologic ones that may influence the evolution of freezing processes and implicitly of ice jams (Gaman, 2014b). The areas with free water surfaces are "generators" of ice crystals and river-bottom ice, and in consequence of ice jams.

A very important role is held by the thermal input due to the **hydraulic exchange** between Bistriţa and its tributaries (*in one direction*) and the underground waters (in *both directions simultaneously*) from the homogeneous strata formed of gravel, boulders and sands (alluvial deposits from the floodplain of Bistriţa and its terraces, of the main tributaries and the proluvio-coluvial deposits of the alluvial fans and glacises from the footslopes).

Area of aquifer downstream discharge — Ice bridge covered by snow upstream

Fig. 18. Influence of hydraulic exchange on the evolution of freeze processes on Bistriţa (12.01.2013) downstream Crucea (down- and upstream the fountain where the measurements were taken in 05.10.2012)

We meet hydraulic exchange *in a single direction* in the area of Rusca. Here the aquifers from the terraces above the floodplain are permanently discharging their waters into the river, as it can be seen from the transversal hydrogeological profile in the Bistriţa Valley in this section (*Geomorphological map of Bistriţa Valley*, after Donisă, modified by Ciaglic, 2009). Another important aspect that is observed is that the thermal input is small, because the discharge rates from the aquifers are reduced. To solve this problem, Ciaglic (2008 and RMD CONSULT, 2009) propose that in the numerous points where Bistriţa river has loses to be built small submerged transversal steps, with heights of 0.40 – 0.50 m. In this way would occur a level increase upstream, leading to an increase in the discharge lost through infiltration. The effect would be an increase in discharge and a substantial increase in water temperatures in the areas downstream, where the aquifers would return the water to the river. This would contribute to diminishing the production of ice crystals, river-bottom ice and frazil slush.

During the winter period with low temperatures it was witnessed that the thermal regime of the river is more strongly influenced (higher differences between river and aquifer water temperatures) in comparison to other seasons (in October when air temperature is of 2℃, water temperature in the area with aquifer input increased by only 0.6˚C), thus influencing *the evolution of freeze phenomena*. The influence of the caloric input on the freeze phenomena can be seen in figure 18, where downstream the bridge occur small thaw areas, while upstream, where there are water loses, Bistriţa presents an ice bridge on its entire surface.

River alimentation from underground waters takes place in two situations: a) nearby well-developed alluvial fans close to the floodplain or terraces; b) in areas where the river suddenly changes direction from flowing along one of the slopes to an almost perpendicular position towards the valley, or where it meanders in the floodplain.

References:

Ciaglic V. (1965), *Evoluţia fenomenului de îngheţ pe râul pe râul Bistricioara, în iarna 1963 - 1964*, Revista Hidrotehnica, nr. 10. 2.

Ciaglic V., Vornicu P. (1973), *Observaţii asupra schimbului de apă dintre râul Bistricioara şi stratul acvifer freatic din albia majoră*, Studii de hidrogeologie, I.M.H. Bucureşti.

Ciaglic V., Rudnic I., Timofte V., Vornicu P. (1975), *Contribuţii la cunoaşterea fenomenului de colmatare a lacului de acumulare Izvoru Muntelui*, IMH, Studii de hidrologie, XLIV, 235-261.

Ciaglic V. (2008), *Soluţii pentru eliminarea gheţurilor de pe valea Bistriţei*, Monitorul de Neamţ, 02 februarie.

Ciaglic V. (2009), *Metodă „brevetată" de natură pentru înlăturarea zăporului de pe Bistriţa*, România Liberă, 02 martie.

Cojoc M.G., Romanescu G., Tirnovan A. (2014), *The degree of silting and the impact on alluvial deposits in the beds of Bistriţa river basin*, Air and water components of the environment, 86-93.

Donisă I. (1968), *Geomorfologia văii Bistriţei*, Editura Academiei, Bucureşti.

Gaman C. (2014), *Considerations on recent freezing phenomena on Bistriţa and Bistricioara River,* Present Environment and Sustainable Development, vol. 8, nr.2, Editura Universităţii „Alexandru Ioan Cuza", Iaşi.

Gaman C., Apostol L. (2013/2014), *Extreme hydrological and meteorological phenomena in the middle Bistriţa valley, Romania,* Croatian Meteorological Journal, Vol. 48/49, Zagreb.

Rădoane Maria, Ciaglic V., Rădoane N. (2009), *Hydropower impact on the ice jam formation on the upper Bistriţa River*, Romania, Cold Regions Science and Technology Jurnal , vol. 60, Issue 3.

Romanescu G. (2005), *Riscul inundaţiilor în amonte de lacul Izvorul Muntelui şi efectul imediat asupra trăsăturilor geomorfologice ale albiei*, Riscuri şi catastrofe, 4(2),117-124.

Romanescu G., Bounegru O. (2012), *Ice dams and backwaters as hydrological risk phenomena – case study: the Bistrita River upstream of the Izvorul Muntelui Lake (Romania)*, WIT Transactions on Ecology and the Environment, 159,167-178.

Surdeanu V., Berindean N., Olariu P. (2005), *Factori naturali şi antropici care determină formarea zăpoarelor în bazinul superior al râului Bistriţa*, Riscuri şi catastrofe, IV, 2, Cluj-Napoca.

Ujvari I. (1972), *Geografia apelor României*, Editura ştiinţifică, Bucureşti.

Velcea Valeria, Savu A. (1982), *Geografia Carpaţilor şi a Subcarpaţilor Româneşti*, Editura Didactică şi pedagogică, Bucureşti

* * * **(2009), RMD CONSULT BUCUREŞTI,** *Analiza în timp a fenomenului de îngheţ pe râul Bistriţa,amonte de acumularea Topoliceni, Impactul asupra exploatării A.H.E.Poiana Teiului si propuneri de lucrări cu rol de atenuarea fenomenului* (mss).