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DETERMINING THE POTENTIAL HYDROLOGICAL RISK ASSOCIATED TO MAXIMUM FLOW IN SMALL HYDROLOGICAL SUB-BASINS WITH TORRENTIAL CHARACTER OF THE RIVER BAHLUI

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Key words: flood zones; hydrological risk; maximum flow; probability of exceeding.

Abstract. Taken together, the Bahlui basin held a high potential hydrological risk, as attested by the numerous floods that have occurred over time, even in the recent history, such as the events which occurred here in 1932, when a part of the city of Iasi was under waters. After the extensive projects of hydrological development, the hydrological activity of the river was monitored continuously and thus under control. Today, thanks to these efforts to stop water threats, and after designing a comprehensive program of hydrological development, the Bahlui basin is 70-75% anthropic, being a model for the entire country and beyond. However, despite the high degree of river planning and development, there are areas where hydrological threat is still present, especially in small tributaries that have a hydrological system obsolete or missing. Thus, the applicability of formulas for determining maximum flows with different occurrence probabilities have found purpose by identifying the potential hydrological risk in case of very small pools and areas with a more torrential character. The existence of a digital database of the land related with debts results revealed a fact apparently known only by the affected population, namely that the negative events associated with the maximum flow occur and threat human society, agricultural land, households, and annexes. Therefore, on the assumption that flooding and high water runoffs should not get to a catastrophic level in order to start planning; it should be enough that there are sites under direct hydrological threat (bridges, roads, houses, agricultural land, etc.), the present analysis aims to constitute an evaluation model for better management and planning.

Introduction

The term *risk* (It. *risco*, with an uncertain origin) is defined as "the product between the probability for a phenomenon to occur and the negative consequence it may have," or as "mathematic expectancy of possible damage." It corresponds to the probabilistic concept developed in the 1950s (Stângă*,* 2007). The hydrological risks are included in the same definition, having as origin various causing phenomena:

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extreme hydric phenomena; stationary hydrodynamic or hydric phenomena and processes; processes and phenomena related to hydric interfaces, etc. Depending on the way they occur, they may be classified into several research fields. The most important, by far, is the risk of high waters and floods (associated to maximum runoff).

Floods represent the sudden and short-term increase in the flow of a river, exceeding the normal value. In this case, the surrounding land is temporarily or permanently covered by water, a phenomenon also known as high water or overflow. Among all the hydrological hazard phenomena, they are the most dynamic and dangerous, often far more serious than other induced natural hazard phenomena (Romanescu, 2009; Romanescu and Nistor, 2011; Romanescu et al., 2011a,b).

The analysis of the extreme hydrological events is based upon the determining factors. The risk of high waters and floods, in case of the basins analyzed, was evaluated depending on the following: the rain pattern; the typology and dynamics of water runoff; the physico-geographical conditions of the hydrographical basin (specific to the hydrographical network and to the riverbed) etc.

In hydrology, critical situations may occur when the databases used in the statistical processing – to obtain hydrological elements – are missing, erroneous, or incomplete. This is the case of most torrential small basins or of those characterized by a reduced water runoff, where the observations made at the hydrometric stations were either interrupted several times or totally missing.

The floods on the Romanian territory, for small and large basins, have been studied in detail by various researchers: Diaconu, 1988, 1999; Drobot, 2007; Filotti, 1980; Minea and Romanescu, 2007; Minea, 2009; Mustatea, 2005; Pandi and Mika, 2003; Romanescu, 2003, 2006, 2009; Sorocovschi, 2002; Tufescu, 1935, etc.

As consequence, in order to determine the hydrological hazard potential associated to the maximum runoff within the hydrographical basin of Bahlui, three calculation methods were used to determine the maximum flows, with various probabilities of exceeding, using hydrographical basins characterized by different physico-geographical and hydro-morphologic characteristics.

The assessment of hydrological risks by calculating the maximum flows with different probabilities, using the morphometric and morphologic parameters extracted form the numerical field model was limited to certain sub-basins presenting a risk potential associated to maximum runoff. This approach is in concordance with the methodology chosen and it aims to meet the specific parameters for each formula: the standard catchment surface of each method used (the method of the rational, reduction, and volumetric formulas); the risk potential due to the hydro-geomorphologic configurations; the presence of the threatened socio-human component, etc.

This study focused upon certain basins with various surfaces and morphometric and morphologic characteristics: the Băiceni-Cucuteni basin; the Hoiseşti and Velniţei basin. They are included in the hydrographical basin of Bahlui, being situated on the middle stream, in the Tg. Frumos – Podul Iloaiei sector (Fig. 1).

Their identification was based on a preliminary research, starting with the analysis of the hydro-physical characteristics within a field application. The character and risk potential were corroborated with direct measurements in the riverbed sectors, with the study of hydro-technical facilities and their quality (bridges, arches, etc.), and with registering the anthropic interventions (regularizations; bank alterations; floodplain occupation degree, etc.).

An important component in the identification of study areas was also the inventory of the households directly affected by the hydrological events. This way, we obtained valuable data regarding the following: event periodicity; the high water and maximum flows manner of spreading; the frequently affected surfaces; the intensity and violence of high waters; the damage and material losses; the possible causes (heavy rains; bridge blocking; change in the land use, etc.).

After the direct research and that with the help of the numerical field model (the TNTMips program), we have determined the main morphometric characteristics regarding the hydrological risk potential, the landform predisposition to extreme phenomena associated to maximum runoff, the probable modelling, and the dynamics of high water waves, etc.

1. Geographical localisation

The hydrographical basin of Bahlui is situated in the north-eastern part of Romania. It occupies the southern part of the Moldavian Plain, component of the Moldavian Plateau. From the hydrological perspective, it is included in the Prut hydrographical system, being a right-sided tributary of Jijia (Fig. 1).

Mathematically speaking, the 47°32’56” parallel marks the most northern point of the basin in Perişorului Hill (376.0 m), and the 47°00’01” parallel indicates the most southern point of the basin, situated in the area of the Floroaia forest (369.2 m). The western extremity is delimited by the 26°41’49” meridian, on the Tudora Hill (586.0 m), and the eastern extremity is given by the 27°44’17” meridian, in the runoff point of Bahlui in the Jijia River, at an absolute altitude of 35 m.

It has a 2,023 km² surface. The length of the hydrographical network exceeds 3,100 km, of which 119 km are included in the main river. The most important tributaries are the following: Buhalnița Măgura, Bahluieaț, Voineşti on the right; Gurguiata, Totoeşti, Bogonos, Cacaina, Ciric, Chirița, on the left.

From the administrative-territorial perspective, the whole surface of the hydrographical basin of Bahlui belongs to the department of Iaşi, except for its north-western extremity (Minea, 2009).

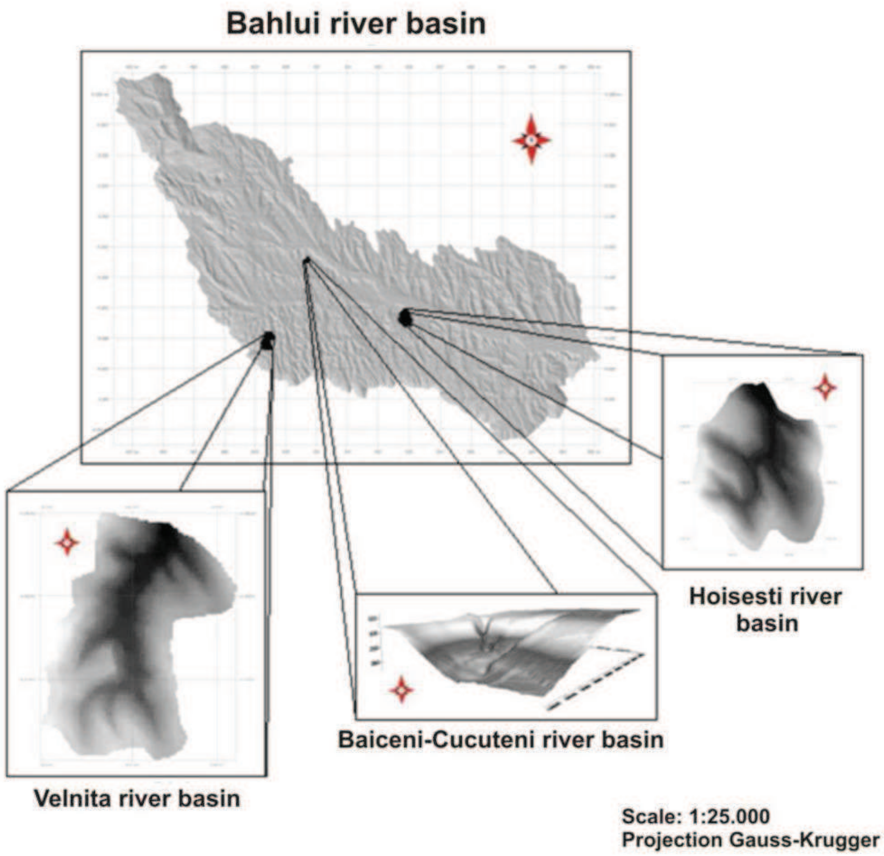

Fig. 1 – Positions of the Băiceni-Cucuteni, Hoiseşti, and Velnița sub-basins within the hydrographical basin of Bahlui

2. Research methods

The assessment of the risk induced by the possible high waters and floods within the hydrographical basin of Bahlui is based on the calculations of the maximum floods with different probabilities in order to determine the hydrological elements defining the extreme phenomena. The determination of maximum flows is made on the basis of certain calculation methods using specific formulas depending on the surface. We used three calculation methods: the rational formula, the reduction formula, and the volumetric formula (Minea and Romanescu, 2007).

The calculations of maximum flows using the rational formula will be applied for the Băiceni-Cucuteni sub-basin, to which the smallest surface within the basins analyzed corresponds, using the following relation:

$$Q_{1\%} = K \cdot \alpha \cdot i_{1\%} \cdot F,$$

where: K = 1.67, being a coefficient of transforming the rain intensity from mm/min into m^3/s and of the surface, from km^2 into m^2; α = the runoff coefficient; $i_{1\%}$ = average intensity of the calculation rain with the 1% probability of exceeding; F = basin surface in km^2.

For the Hoiseşti sub-basin, the calculation of maximum flows was done through the reduction formula, determined by the following relation:

$$Q_{1\%} = \frac{K \cdot \alpha \cdot I_{60.1\%} \cdot F}{(F+1)^m},$$

where: K = 0.28, being a coefficient of transforming the rain intensity from mm/hour into m^3/s and of the surface, from km^2 into m^2; α = a global runoff coefficient; $I_{60,1\%}$ = maximum hourly rain intensity c with the 1% probability of exceeding; F = basin surface in km^2.

The calculation of maximum flows, through the volumetric formula, is used for the hydrographical sub-basin of Velnița, which includes the most important factors of maximum runoff: maximum precipitations and the runoff coefficient (data with a certain probability).

The calculation relation is the following:

$$Q_{\max p\%} = \frac{0.28(H_p - H_0)\alpha_p \lambda \cdot F}{t_1},$$

where: $Q_{\max\ p\%}$ = maximum flow with the p% probability to be calculated [m^3/s]; H_p = height of the precipitations with a p%[mm] probability; H_0 = height of the initial losses [mm]; α_p = runoff coefficient with the p% probability; F = surface of the hydrographical basin corresponding to the basin for which the maximum flow is calculated [km^2]; t_1 = duration of the high water increase [hours]; 0,28 = coefficient of size transformation; λ = parameter of the high water shape determined by the following relation:

$$\lambda = \frac{(m+1)(n+1)}{n+1+k(m+1)},$$

where: m, n = exponents of the two parabolas forming the high water hydrograph; k = the ratio between the decrease duration and the increase duration of the high water; for the summer high water we consider k=2.5, m=2, n=3, and for the spring high waters k=m=n=2.

The expedient methods, which also include the rational, reduction, and volumetric formulas, became a necessity in order to determine the hydrological elements, leading to solutions which were influenced by smaller or bigger approximations, depending on the existing documentary material, on the personal experience in the field, etc.

The graphic material and the data obtained through the mathematic model aim to find the possible extreme phenomena associated to maximum runoff.

3. Results and discussions

By applying the calculation formulas we managed to determine certain maximum flows with different probabilities of occurrence. They are meant to forecast, in a relatively efficient manner, the possible negative events related to water runoff. The results are applicable in case of certain interventions on riverbeds, of projecting hydro-technical facilities or in order to generate risk maps for an effective management of catchment basins.

3.1. The Băiceni-Cucuteni sub-basin. The hydrographical sub-basin of the Băiceni-Cucuteni brook is situated in the upper sector of the Bahluieț. The main stream has a NW-SE direction, starting from the territory of the Todireşti commune. It crosses the Băiceni village, positioned downstream, trough its eastern part. It has a 4.7 ha surface and a 0.21 type ratio (Tab. 1).

The hydrographical basin is characterized by a weak hydrological activity, but with frequent outflows of the precipitation waters. The underground supply is relatively rich, with numerous springs at the basis of slopes. This fact influences the configuration of the minor riverbed, which presents relatively high depths for a disproportionate catchment surface. As we are talking about a very small basin, we used the reduction formula to determine the maximum flows with the $Q_{1\%}$ probability. Being almost entirely covered by pastures and degraded fields, with an average soil texture, the probable maximum flow is the following:

$$Q_{1\%} = K \cdot \alpha \cdot i_{1\%} \cdot F,$$

$$Q_{1\%} = 1.67.\ 0.43.\ 2.6.\ 0.047 = 0.88\ m^3/s.$$

On the basis of this flow – with a $Q_{1\%}$, probability of exceeding – we calculated the maximum flows with different probabilities (Tab. 2).

Tab. 1 – The main morphometric elements of the Băiceni-Cucuteni sub-basin

No.	Morphometric elements	Value	Measurement unit
1	Surface	4.7	ha
2	Length	0.24	km
3	Width	0.19	km
4	Maximum basin length	0.81	km
5	Riverbed length	0.56	km
6	Perimeter	1.9	km
7	Minimum level	243.8	m
8	Maximum level	325.3	m
9	Spring altitude	306.8	m
10	Asymmetry coefficient	0.46	-
11	Shape factor	0.04	-
12	Circularity ratio	0.14	-
13	Extension ratio	0.74	-
14	Watershed development coefficient	1.25	-
15	Shape ratio	0.21	-

Tab. 2 – Maximum flows with different probabilities of exceeding in the Băiceni-Cucuteni sub-basin

p%	0.01	0.05	0.1	0.2	0.3	0.5	1	2	3	5	10	20
Q m^3/s	2.8	1.95	1.66	1.45	1.24	1.08	0.88	0.70	0.56	0.49	0.36	0.25

The Băiceni-Cucuteni hydrographical sub-basin is characterized by a weak hydrological activity during the entire year. Even though it has a small catchment surface, heavy rains cause a hydrological risk potential associated to maximum runoff. The main elements threatened in case of a $Q_{1\%}$ flow are the agricultural lands, two bridges over the brook, and a series of buildings and household annexes.

3.2. The Hoiseşti sub-basin. The Hoiseşti basin crosses the locality with the same name through the north; the locality is situated at approximately 3-4 km downstream from the Podul Iloaiei dam, close to the confluence between Bahlui and Bahluieț. It has a general W-E orientation. The main supply source is that of heavy rains and the series of coastal springs maintaining the permanent character of the surface runoff. The brook bed is irregular, with thresholds. There is an alternation of small depth sectors (30 cm) and abrupt sections. We underline the torrential activity, problematic for the safety of the houses downstream. It is mandatory to build a trapezoid-shape concrete waterway, to be placed at the mouth, where households can be affected, as well as to change the destination of the access road.

The whole surface of the basin is used as pasture and hay field. In the upper sector there are small spots of shrubs, on an area once forested. The morphometric elements are specific to the hills. It has a 45.3 ha surface and a 0.28 type ratio (Tab. 3).

Tab. 3 – Main morphometric elements of the Hoiseşti sub-basin

No.	**Morphometric elements**	**Value**	**Measurement unit**
1	Surface	45.3	ha
2	Length	1.26	km
3	Width	0.5	km
4	Maximum basin length	1.3	km
5	Riverbed length	1.1	km
6	Perimeter	2.9	km
7	Minimum level	50	m
8	Maximum level	145	m
9	Spring altitude	130	m
10	Asymmetry coefficient	1.59	-
11	Shape factor	0.26	-
12	Circularity ratio	0.68	-
13	Extension ratio	0.56	-
14	Watershed development coefficient	1.25	-
15	Shape ratio	0.28	-

In order to estimate the maximum flow with a 1% probability, we preferred the reduction formula:

$$Q_{1\%} = \frac{K \cdot \alpha \cdot I_{60.1\%} \cdot F}{(F+1)^m}.$$

The result is the following:

$$Q_{1\%} = \frac{0.28 \cdot 0.3 \cdot 125 \cdot 0.453}{(0.453+1)^{0.50}} = 3.94 m^3/s.$$

$$Q_{1\%} = 3.94 m^3 s$$

The Hoişeşti has different values of the maximum flow with different probabilities of exceeding (Tab. 4).

Tab. 4 – Maximum flow with different probabilities of exceeding within hydrographical sub-basin of Hoiseşti

p%	0.01	0.05	0.1	0.2	0.3	0.5	1	2	3	5	10	20
Q m^3/s	12.54	8.76	7.43	6.50	5.57	4.84	3.94	3.13	2.51	2.22	1.64	1.13

After analyzing the hydrological risk potential associated to the maximum runoff within the hydrographical basin of Hoiseşti, we can state that $Q_{1\%}$ = 3.94 m^3/s. the value is very high, indicating an increased vulnerability regarding extreme weather-climatic events. The fact is also demonstrated by the high circularity ratio (Rc = 0.68), facilitating a short time of the water runoff on the main stream of the valley.

3.3. The Velnița sub-basin. The hydrographical sub-basin of Velnița is a tributary of the Găneşti brook. It is situated on the right side of Bahluieț. The general runoff direction is on the S-N alignemnt. It has a 411.2 ha surface and a 0.76 shape ratio (Tab. 5).

Tab. 5 – Morphometric elements of the Velnița sub-basin

No.	**Morphometric elements**	**Value**	**Measurement unit**
1	Surface	411.2	ha
2	Length	2.95	km
3	Width	1.88	km
4	Maximum basin length	3.47	km
5	Riverbed length	2.25	km
6	Perimeter	9.25	km
7	Minimum level	105	m
8	Maximum level	198.5	m
9	Spring altitude	167	m
10	Asymmetry coefficient	0.38	-
11	Shape factor	0.34	-
12	Circularity ratio	0.60	-
13	Extension ratio	0.69	-
14	Watershed development coefficient	1.04	-
15	Shape ratio	0.76	-

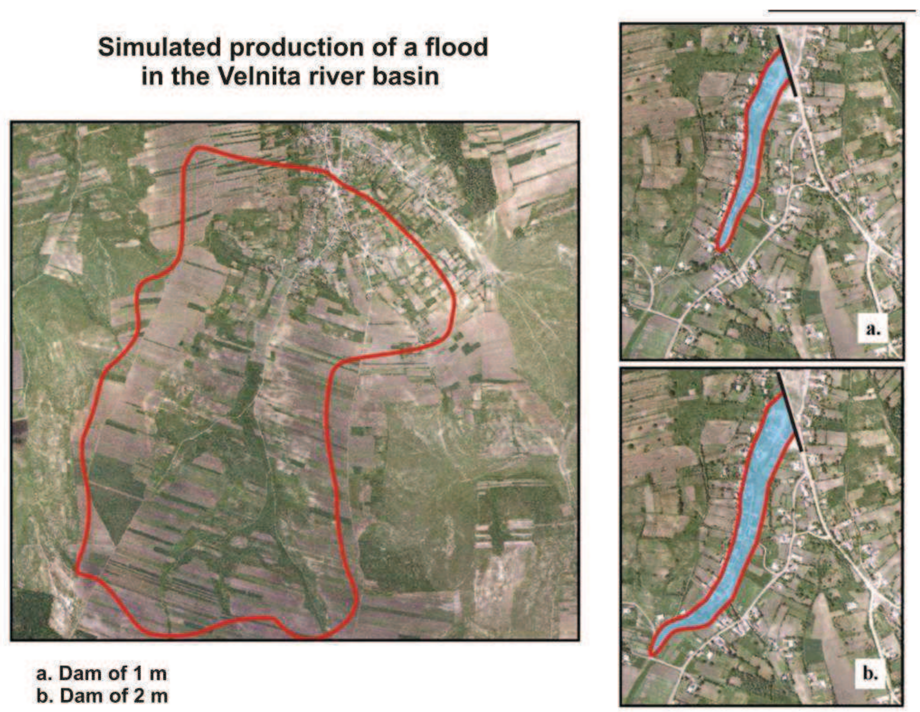

Fig. 2 – Flood simulation in the hydrographical basin of Velnița. Hypothesis of occurrence: a. 1 m dam; b. 2 m dam

The hydrological regime is given by the permanent character, even though the flows have low values. In exchange, the extreme events associated to maximum runoff, such as high waters and outflows, occur during heavy rains. We determined the maximum flows with different occurrence probabilities through the volumetric formula:

$$Q_{1\%} = \frac{0.28(H_p - H_0)\alpha_p \lambda \cdot F}{t_1}.$$

The result is the following:

$$Q_{1\%} = \frac{0.28(54.95 - 15)0.3 \cdot 1.04 \cdot 4.1}{3.03}$$

$$Q_{1\%} = 4.72 m^3 / s.$$

The Velnița has different values of the maximum flow with different probabilities of exceeding (Table 6).

Tab. 6 - Maximum flow with different probabilities of exceeding within hydrographical sub-basin of Velnița

p%	0.01	0.05	0.1	0.2	0.3	0.5	1	2	3	5	10	20
Q m^3/s	15.02	10.49	8.90	7.79	6.68	5.80	4.72	3.75	3.01	2.66	1.97	1.36

Given the large surface of the basin, we were able to simulate a flood, having as determining factor the damming of a bridge placed on the main stream (Fig. 2). The application was elaborated with the TNTmips v. 6.9 program, using the Flood Zones command. Thus, we underlined the importance of the numerical field model, not only in the analysis of hydrological risks.

The first working hypothesis admits the creation of a 1 m dam. Because of the emplacements on the brook floodplain, around 7 households would be affected by floods because of a temporary lake created behind the temporary dam. The second version admits the creation of a 2 m dam, which would lead to flooding 20 households, as well as agricultural areas.

Conclusions

The big water floods and outflows cannot be catastrophic in the three basins as the surfaces are relatively small. Nevertheless, hydro-technical planning is necessary in order to prevent the destruction of local objectives (houses, bridges roads, agricultural fields, etc.).

The flows obtained after applying the calculation formula showed that the reduced catchment surface of the Băiceni-Cucuteni basin is not an indicator of the total lack of hydrological risk potential. Such an event could threaten the households and a big part of the agricultural land. The Hoiseşti basin, larger, demonstrates the existence of possible important floods, affecting a part of the village. The Velnița brook has the most important hydrological risk parameters, constituting a real danger for the local community.

The flood simulation, having as working hypothesis the damming of a bridge, is the clearest example of the damage produced by such a negative hydrological event, associated to maximum runoff.

After assessing the hydrological risks associated to maximum runoff within the hydrographical basin of Bahlui, with applicability on the sub-basins, we may conclude that this field has become more and more practical, with great results in preventing unfortunate situations for human society.

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